

The American Association for Thoracic Surgery (AATS) 2025 Expert Consensus Document: Surgical management of mitral annular calcification



Ahmed El-Eshmawi, MD,^a Monika Halas, MD,^b Brian T. Bethea, MD,^c Tirone E. David, MD,^d Eugene A. Grossi, MD,^e Mayra Guerrero, MD,^f Samir R. Kapadia, MD,^g Serguei Melnitchouk, MD,^h Stephanie L. Mick, MD,ⁱ Eduard Quintana, MD,^j Matthew A. Romano, MD,^k Gilbert H. L. Tang, MD, MSc, MBA,^l Shinya Unai, MD,^m Ravi K. Ghanta, MD,^{b,n} and AATS Volunteer Leadership

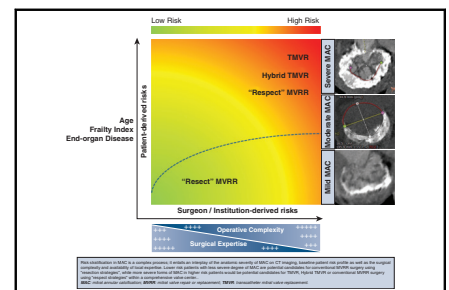
ABSTRACT

Objective: Surgery for mitral valve disease in patients with mitral annular calcification (MAC) remains challenging. There is no consensus on the ideal management strategy or patient selection, and perioperative and periprocedural morbidity and mortality rates remain high. The recent surge of patients presenting with MAC has been accompanied by increased interest in MAC surgery and interventions. This expert consensus document is meant to provide a simplified outline for managing MAC, including patient selection, imaging, and surgical and transcatheter therapeutic options, with a particular focus on conventional surgical techniques and hybrid approaches.

Methods: The American Association for Thoracic Surgery Clinical Practice Standards Committee assembled an international panel of cardiac surgeons and structural heart interventionalists with established expertise in the field of MAC. A comprehensive literature review was performed by the panel and a medical librarian. Clinical recommendations were developed utilizing a modified Delphi method.

Results: Expert consensus was reached on 33 recommendations, with class of recommendation and level of evidence, for each of 5 main topics: (1) preoperative evaluation for patients with MAC, patient selection, and indications for intervention; (2) standard surgical techniques in MAC; (3) hybrid procedures in MAC; (4) transcatheter MAC interventions; and (5) complications and bailout of MAC surgery and interventions.

Conclusions: Despite the complexity and heterogeneity of patients presenting with MAC, consensus on several key recommendations was reached by this American Association for Thoracic Surgery expert panel. These recommendations provide guidance for cardiac surgeons and structural heart interventionalists in treating most patients who present with MAC. (J Thorac Cardiovasc Surg 2025;170:502-22)



Risk stratification involves MAC severity, patient risk profile, and surgical complexity.

CENTRAL MESSAGE

For mitral valve disease related to annular calcification, an expert panel formulated recommendations regarding its evaluation and management, including surgical, transcatheter, and hybrid strategies.

PERSPECTIVE

Mitral annular calcification (MAC) is increasingly common and poses substantial perioperative risks. We discuss the diagnosis and treatment of MAC, including MAC imaging, the role of comprehensive valve centers, patient selection, risk stratification, and therapeutic options including surgical, transcatheter, and hybrid procedures, and bailout for perioperative or periprocedural complications.

From the ^aDepartment of Cardiovascular Surgery, Icahn School of Medicine at Mount Sinai, New York, NY; ^bDivision of Cardiothoracic Surgery, Michael E. DeBakey Department of Surgery, Baylor College of Medicine, Houston, Tex; ^cDivision of Cardiac Surgery, MedStar Union Memorial Hospital, Baltimore, Md; ^dDivision of Cardiovascular Surgery of the Peter Munk Cardiac Centre, Toronto General Hospital and University of Toronto, Toronto, Ontario, Canada; ^eDepartment of Cardiothoracic Surgery, NYU Langone Health, New York, NY; ^fDepartment of Cardiovascular Medicine, Mayo Clinic, Rochester, Minn; Departments of ^gCardiology and ^hThoracic and Cardiovascular Surgery, Heart, Vascular, and Thoracic Institute, Cleveland Clinic, Cleveland, Ohio; ⁱDivision of Cardiac Surgery,

Massachusetts General Hospital and Harvard Medical School, Boston, Mass; ^jDepartment of Cardiothoracic Surgery, New York Presbyterian Weill Cornell Medicine, New York, NY; ^kDepartment of Cardiovascular Surgery, Hospital Clínic de Barcelona, University of Barcelona, Barcelona, Spain; ^lDepartment of Cardiac Surgery, Michigan Medicine, University of Michigan, Ann Arbor, Mich; ^mDepartment of Cardiovascular Surgery, Mount Sinai Health System, New York, NY; and ⁿDepartment of Cardiovascular Surgery, The Texas Heart Institute, Houston, Tex. Financial support was provided by The American Association for Thoracic Surgery.

Abbreviations and Acronyms

AATS = American Association of Thoracic Surgery

AVG = atrioventricular groove

C-EO = class of recommendation—expert opinion

C-LD = class of recommendation—limited data

C-NR = class of recommendation—non-randomized

CT = computed tomography

GDMT = guideline-directed medical therapy

HTMVR = hybrid transcatheter mitral valve replacement

LV = left ventricle

LVOT = left ventricular outflow tract

MAC = mitral annular calcification

MDCT = multidetector computed tomography

MR = mitral regurgitation

MS = mitral stenosis

MV = mitral valve

MVR = mitral valve replacement

PVL = paravalvular leak

STS = Society of Thoracic Surgeons

TEE = transesophageal echocardiography

TEER = transcatheter edge-to-edge repair

TMVR = transcatheter mitral valve replacement



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Mitral annular calcification (MAC) poses anatomical challenges for mitral valve (MV) interventions that affect clinical and surgical decision-making. Although the prevalence of MAC is increasing,¹ MAC has existed since ancient times, having been observed through computed tomographic analysis in 6% of Egyptian mummies with intact hearts/heart remnants from 1981 BC to 364 AD (Figure 1).² Atrioventricular groove (AVG) disruption after annular decalcification during mitral valve replacement

(MVR) was recognized in early postmortem studies and remains the primary concern for surgical approaches in MAC.³

In 1979, Miller and colleagues⁴ described 3 different types of AVG disruption after MVR (annular separation [type 1], posterior ventricular rupture [type 2], and midventricular tear [type 3]), with the notable finding that chordal preservation was protective. In the 1980s, Carpentier and colleagues⁵ described the technique of en bloc annular decalcification and reconstruction by sliding atrioventriculoplasty in 68 patients, who had excellent early and late outcomes. At the 75th Annual American Association of Thoracic Surgery (AATS) meeting in Boston in April 1995, Feindel and colleagues⁶ described a pericardial patch technique for AVG reconstruction, another common approach.

Since these seminal reports were made, numerous approaches have been developed to address MAC during mitral surgery, including working around the MAC with limited or no resection, a more conservative partial debridement (using mechanical or ultrasonic decalcification), complete resection of MAC with patch reconstruction, and transatrial hybrid transcatheter mitral valve replacement (HTMVR).⁷ Which technique is most appropriate depends on the risk-benefit assessment of the patient’s age, frailty, and comorbidities, tissue quality, degree of MAC, and surgeon experience. These various options allow the clinician to address the increasing pool of high-risk patients requiring surgery. In addition, with the recent advances in cardiac imaging and transcatheter technologies, transcatheter MV interventions for MAC have been developed as an alternative to surgery, particularly for high-risk patients. A major limitation of transcatheter therapy stems from anatomic and physiologic challenges related to the MV apparatus, which have thus far limited its applicability. Hybrid approaches have emerged as a valid alternative for patients in whom surgical or transcatheter therapies might be considered unsuitable, as these approaches combine the advantages and versatility of both open-access surgery and available balloon-expandable devices. These devices have been deployed off-label, primarily at comprehensive valve centers of excellence.^{8,9}

Because MAC represents a complex disease entity whose diagnosis and treatment requires an armamentarium of tools, the purpose of this expert consensus document is to provide the cardiac surgical and structural heart interventional community with a practical guide to the management of

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Address for reprints: Ahmed El-Eshmawi, MD, Department of Cardiovascular Surgery, Icahn School of Medicine at Mount Sinai, 1190 Fifth Ave, GP2W, Box 1028, New York, NY 10029 (E-mail: ahmed.el-eshmawi@mountsinai.org).

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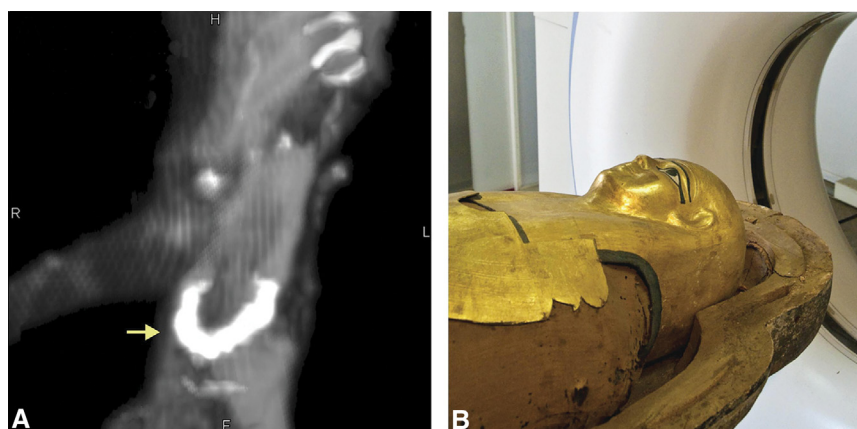


FIGURE 1. Mitral annular calcification visualized on computed tomography (A) in ancient Egyptian mummies (arrow) (B) in the Horus study. Reprinted with permission from Allam and colleagues.²

symptomatic MV disease in patients with MAC. We present 33 recommendations, divided into preoperative evaluation and decision-making process (Tables 1-3),^{5-8,10-39} surgical considerations (Table 4),^{5,6,15-28,35-59} hybrid options (Table 5),^{7,8,26,60-65} transcatheter interventions (Table 6),⁶⁶⁻⁷⁴ and management of complications (Table 7).^{26,75-91} A review of all percutaneous transcatheter technologies is beyond the scope of this document. Because more patients with MAC now face the need for MV interventions, we discuss best practices to address surgical and interventional complications to help bailout of these complex situations.

METHODS

We followed the AATS/Society of Thoracic Surgeons (STS) guidelines for developing clinical practice documents. An expert consensus document pathway was created, involving a 15-member expert panel of cardiothoracic surgeons and cardiologists.^{92,93} The panel developed consensus statements and rated them by class of recommendation and level of evidence. The class of recommendation indicates the strength of each recommendation, considering the estimated benefit-risk ratio, whereas the level of evidence reflects the quality of evidence from clinical trials and other sources that supports each recommendation, graded by data type, quantity, and consistency (Figure 2).⁹⁴

Expert consensus statements were developed for each of 5 main topics dealing with MV disease in patients with MAC: (1) preoperative evaluation, patient selection, and indications for intervention; (2) standard surgical techniques; (3) hybrid procedures; (4) transcatheter interventions; and (5) complications and bailout of surgical and interventional treatment.

A scholarly communications librarian conducted literature searches via PubMed, reviewing all publications since 2000 as well as significant earlier

studies, as determined by the expert panel. The writing committee reviewed literature, and recommendations were developed through discussions. Consensus was reached on 33 statements. Each recommendation required 80% participation and 75% consensus for approval, ensuring voting validity. This process was repeated for each document section, and controversies were addressed through regular online meetings and voting based on the Delphi Method.^{10,95,96}

Each author contributed to writing the document's sections, which were finalized by the committee chairs. The writing committee and the AATS Adult Cardiac Clinical Practice Standards Committee were given the chance to review, comment on, and approve the document before it was submitted for final approval to the AATS Board of Directors and submitted for publication.

Section 1: MAC Definition, Risk Factors, and Classification

MAC is defined as a chronic, degenerative condition characterized by the progressive deposition of dystrophic calcium in the fibrous annulus of the MV apparatus, which impairs its function.⁹³ Although the pathogenesis of MAC is not fully understood, annular hemodynamic-related stress injury and endothelial dysfunction are thought to contribute to the degenerative process that correlates with increasing patient age. This process involves calcium formation in the posterior annulus at the mid-hinge point, with anterior extension toward the trigones and vertical extension into the left ventricle (LV). This process is distinct from that of rheumatic mitral disease, which primarily affects the commissure and leaflet free edge. This petrification of the annulus leads to upward deformity of the leaflets, typically causing mitral stenosis (MS), regurgitation (MR), or both.^{92,93}

Data from a recent nuclear imaging study suggest that patients with MAC have elevated local calcific and inflammatory activity that is also associated with disease progression.⁹⁷ These data confirm the clinical observation of progressive MAC severity on repeated computed

TABLE 1. MAC grading and anatomic classification

Recommendations	COR	LOE	References
1. Severity of MAC should be assessed preoperatively according to annular circumferential extension, depth, thickness, and trigonal and subvalvular involvement.	I	B-NR	5,7,8,10,11
2. It is reasonable to refer a patient with moderate or greater MAC in the setting of mitral valve disease to an experienced and comprehensive mitral valve center.	IIa	B-NR	12,13

The color shadings indicate comparable classes of recommendation and levels of evidence. MAC, Mitral annular calcification; COR, class of recommendation; LOE, level of evidence; B-NR, nonrandomized.

TABLE 2. Classification of mitral annulus calcification

Stage	Circumferential involvement	Thickness, mm	Leaflet, trigonal, or subvalvular involvement
Mild	<180° of the annulus	<5	No trigonal, leaflet, or subvalvular extension
Moderate	180-270° of the annulus	5-10	One leaflet, or posterior trigonal involvement without subvalvular extension
Severe	>270° of the annulus	>10	Both leaflets, anterior commissure, or subvalvular extension

tomography (CT) imaging in patients with MAC who present for multiple cardiovascular interventions.

The prevalence of MAC is approximately 10% in postmortem investigations and 2.8% according to echocardiographic findings from the Framingham study.^{10,92} MAC most often arises in older patients, women, and those with hypertension, hyperlipidemia, diabetes, degenerative mitral disease (eg, Barlow MV disease, fibroelastic deficiency), end-stage renal disease, aortic stenosis, and hypertrophic cardiomyopathy.^{95,98} The use of warfarin in patients with atrial fibrillation may also be a risk factor for MAC, as it was associated with higher incidences of aortic and mitral valvular calcification in a retrospective observational study⁹⁹; whether this is a causal relationship is unknown. The presumed mechanism is inhibition of vitamin K2 mediated by matrix Gla protein. Other, rarer causes of MAC include metabolic disorders caused by calcium-phosphorus homeostasis imbalance, other syndromes such as Marfan syndrome and Hurler disease, and other rheumatologic processes.⁹² Mediastinal radiation is also an increasingly recognized cause of a more extensive form of MAC that is commonly seen in long-term cancer survivors who have received mantle field radiation.

MAC has been associated with cardiovascular disease, including arrhythmias (particularly conduction defects and atrial fibrillation), coronary artery disease, peripheral vascular disease, diastolic dysfunction, and heart

failure with preserved ejection fraction. MAC has been also independently associated with mortality, acute myocardial infarction, stroke, and atrial fibrillation.^{10,95,98,100-103} In a natural history study of patients with MAC, 1-year survival was 72% and was worse in patients with a mean MV gradient >8 mm Hg or pulmonary artery systolic pressure >50 mm Hg.¹ Hence, MAC presents one of the most challenging and morbid pathologies in the arena of cardiovascular medicine and surgery. MAC is also associated with endocarditis; *Staphylococcus aureus* is the predominant pathogen. Vegetations (which attach preferentially to calcific deposits) are frequently thrombogenic. Limited data suggest a very high mortality rate (29%) among patients with MAC who undergo surgery for infective endocarditis.¹⁰⁴

Statement 1. Severity of MAC should be assessed preoperatively according to annular circumferential extension, depth, thickness, and trigonal and subvalvular involvement. (I, B-nonrandomized [NR])

Because anatomic features are critical to determining surgical risk and management options, the presence and degree of MAC should be evaluated. Different grading and classification systems of MAC have been increasingly put forth recently in concert with the expansion of transcatheter therapy in mitral disease. The Framingham Heart Study (N01-HC-25195 and 5R01-NS-17950) showed that MAC is independently associated with cardiovascular disease, cardiovascular death, and all-cause death. The

TABLE 3. Preoperative evaluation for patients with mitral annular calcification and indications for intervention

Recommendations	COR	LOE	References
3. In patients with MAC who are undergoing mitral valve intervention, The STS predicted risk of mortality and morbidity does not fully capture the risk of surgery or intervention; therefore, evaluation by a multidisciplinary heart team is essential.	I	C-EO	5,14,15
4. All cases of moderate and severe MAC in high-risk patients with MV disease should be evaluated by a multispecialty heart valve team that includes (and is not limited to) a cardiac surgeon and a structural heart cardiologist.	I	C-LD	5,14,15
5. Preoperative TEE can be considered in select MAC patients to provide high-quality assessment of mitral valve.	IIa	B-NR	15,16
6. Preoperative TEE should be performed in all patients who are being considered for a transcatheter or hybrid intervention.	I	C-EO	15,16
7. In addition to echocardiography, CT imaging should be performed in all MAC patients to adequately assess MAC extent and distribution for operative planning.	I	C-EO	6,17-27
8. Diagnostic right heart cardiac catheterization for hemodynamic and risk assessment is reasonable for patients with MAC in the setting of mitral valve disease.	IIa	C-EO	7,28-34
9. In asymptomatic or mildly symptomatic patients (New York Heart Association class I or II) with significant mitral valve disease and severe MAC, the risk of mitral intervention may be carefully weighed against watchful waiting and GDMT.	IIb	C-LD	7,28,35-39
10. TMVR and HTMVR techniques with a multidisciplinary heart team approach are reasonable in selected high-risk patients with severe MAC.	IIa	B-NR	7,28,35-37
11. In patients with a limited life expectancy due to non-cardiac pathologies, marked frailty or those who are unlikely to see symptomatic benefit, mitral valve intervention may be futile.	IIb	B-NR	7,28,35-37

The color shadings indicate comparable classes of recommendation and levels of evidence. COR, Class of recommendation; LOE, level of evidence; MAC, mitral annular calcification; STS, Society of Thoracic Surgeons; C-EO, class of recommendation—expert opinion; MV, mitral valve; C-LD, class of recommendation—limited data; TEE, transesophageal echocardiography; B-NR, nonrandomized; CT, computed tomography; GDMT, guideline-directed medical therapy; TMVR, transcatheter mitral valve replacement; HTMVR, hybrid transcatheter mitral valve replacement.

TABLE 4. Surgical considerations for mitral valve repair or replacement in mitral annular calcification

Recommendations	COR	LOE	References
12. Both en bloc annular decalcification “Resect” strategies and no-resection or limited-resection “Respect” surgical strategies are reasonable in select patients with MAC.	IIa	C-LD	5,6,16-19,21-25
13. Mitral valve repair is reasonable in nonextensive MAC in selected patients with repairable anatomy.	IIa	C-EO	5,6,15-17,20,26,27
14. MVR should be considered over repair in patients with extensive MAC, infected MAC, or severe mitral stenosis.	IIa	C-EO	6,7,19,23,25,28,35,36,40
15. In surgical MVR, the extent of decalcification should be tailored to the patient’s risk profile and surgical expertise to ensure that an adequately sized prosthesis is implanted.	I	C-EO	6,7,19,23,25,28,35,36,40
16. Ultrasonic debridement may be a useful adjunctive tool in surgical valve repair or replacement in patients with MAC to facilitate suture placement and seating of the prosthesis.	IIb	C-LD	25,37-39,41
17. Chordal sparing MVR techniques should be implemented with attention given to avoid interference with prosthetic valve function.	I	B-NR	16,19,42-50
18. Heavy involvement of the aortomitral curtain, as seen in radiation-induced MAC with trigonal involvement or circumferential MAC, may often require aortomitral curtain reconstruction and a concomitant aortic valve replacement or aortic root procedure.	IIa	C-EO	51-56
19. A felt strip layer may be used with the bioprosthetic valve to help reduce paravalvular leak.	IIb	C-EO	19,38,57-59

The color shadings indicate comparable classes of recommendation and levels of evidence. *COR*, Class of recommendation; *LOE*, level of evidence; *MAC*, mitral annular calcification; *C-LD*, class of recommendation—limited data; *C-EO*, class of recommendation—expert opinion; *MVR*, mitral valve replacement; *B-NR*, nonrandomized.

frequency of these outcomes was associated with MAC severity in a dose-responsive linear manner; for each 1-mm increase in MAC thickness, the risk increased by 10%.¹⁰ Hence, the degree of MAC affects the disease’s natural history, along with the clinical outcomes of any cardiovascular procedures for MAC, and should be graded accurately. Historically, in Carpentier and colleagues’ landmark paper⁵ on MAC, extensive MAC was defined as involving at least one third of the annulus; cases involving less than one third of the annulus were excluded from the analysis.

Several MAC classifications have been proposed, most of which are determined by echocardiographic and CT findings. The purpose of these classifications is primarily to estimate the feasibility of transcatheter mitral valve replacement (TMVR) with balloon-expandable valves and associated risks, particularly left ventricular outflow tract (LVOT) obstruction, embolization, and paravalvular leak (PVL).^{7,8} Although these classification schemes are mandated in screening patients being considered for transcatheter and hybrid intervention, their utility in surgical patients is yet to be proven; however, understanding the anatomical extension of MAC can

help with surgical planning, predicting the feasibility of standard valve replacement and the extent of decalcification.

We proposed a simplified classification (Table 2) on the basis of CT imaging that focuses primarily on circumferential extension, thickness of the calcium bar, leaflet and trigonal extension, and subvalvular involvement, as these are the main determinants of successful repair or replacement of the MV by standard surgical techniques. As a surrogate measure of calcium volume, quantified calcium score of the MV annulus obtained from the gated CT scan and expressed in Agatston units is also useful in determining MAC severity.¹¹

Statement 2. It is reasonable to refer a patient with moderate or greater MAC in the setting of MV disease to an experienced and comprehensive MV center. (IIa, B-NR)

Moderate or severe MAC requires expertise with advanced surgical techniques for successful and durable valve repair or replacement and to minimize perioperative mortality and morbidity. This was shown in a New York State–wide multicenter analysis that suggested that for

TABLE 5. Hybrid transatrial transcatheter balloon-expandable devices in mitral annular calcification

Recommendations	COR	LOE	References
20. To determine the feasibility of HTMVR, MDCT analysis should include mitral annular dimensions and geometry, MAC severity on the basis of the MAC score, MAC bar width and height, septal thickness, neo-LVOT area, and skirt neo-LVOT area.	I	B-NR	60-62
21. In severe MAC, it is reasonable to consider HTMVR instead of standard MVR if sutures cannot be placed safely around the annulus for conventional surgical prosthesis implantation.	IIa	C-EO	61,63
22. Anterior mitral leaflet resection with or without septal myectomy should be considered to reduce the risk of LVOT obstruction.	IIa	B-NR	26,60,62,64
23. A felt strip layer should be used with the balloon-expandable transcatheter valve to help reduce paravalvular leak.	I	C-EO	—
24. To reduce PVL, balloon postdilation, atrial plication sutures, or both may be useful.	IIb	C-EO	26,64,65
25. MDCT after HTMVR can be useful to evaluate post-implant anatomy.	IIa	C-EO	7,8

The color shadings indicate comparable classes of recommendation and levels of evidence. *COR*, Class of recommendation; *LOE*, level of evidence; *HTMVR*, hybrid transcatheter mitral valve replacement; *MDCT*, multidetector computed tomography; *MAC*, mitral annular calcification; *LVOT*, left ventricular outflow tract; *B-NR*, nonrandomized; *MVR*, mitral valve replacement; *C-EO*, class of recommendation—expert opinion; *PVL*, paravalvular leak.

TABLE 6. Transcatheter mitral valve interventions

Recommendations	COR	LOE	References
26. Patients with MAC and mitral stenosis who remain symptomatic despite medical management, and who are inoperable or at prohibitive anatomical surgical risk should be considered for TMVR.	IIa	B-NR	66-71
27. Symptomatic patients with MAC and severe mitral regurgitation who have acceptable MV area but are at high surgical risk may be considered for TEER.	IIb	C-LD	68,72-74
28. Symptomatic patients with MAC and severe mitral regurgitation who are high surgical risk and are likely to develop severe mitral stenosis with TEER can be considered for TMVR.	IIa	C-LD	68,72-74

The color shadings indicate comparable classes of recommendation and levels of evidence. *COR*, Class of recommendation; *LOE*, level of evidence; *MAC*, mitral annular calcification; *TMVR*, transcatheter mitral valve replacement; *B-NR*, nonrandomized; *MV*, mitral valve; *TEER*, transcatheter edge-to-edge repair; *C-LD*, class of recommendation—limited data.

individual surgeons, greater MV case volume was associated with better early- and long-term outcomes after MV surgery for patients with degenerative MV disease.¹² Likewise, in a large, nationally representative MVR study that used the STS Adult Cardiac Surgery Database and that included 9551 patients with MAC, patients with MAC treated at centers with low MV case volumes were found to have worse outcomes after MVR.¹³ Interestingly, in both of these large population studies, a volume of fewer than 50 MV cases/year was associated with worse outcomes. Therefore, to optimize outcomes, patients with moderate or severe MAC should be referred to a comprehensive valve center with expertise in MAC surgery and intervention, advanced cardiac imaging modalities, and transcatheter therapies.

Section 2: Preoperative Evaluation, Risk Stratification, and Indications for Interventions for Patients With MAC

Statement 3. In patients with MAC who are undergoing MV intervention, The STS predicted risk of mortality and morbidity does not fully capture the risks associated with surgery or intervention; therefore, evaluation by a multidisciplinary heart team is essential. (I, class of recommendation—expert opinion [C-EO])

Statement 4. All cases of moderate and severe MAC in high-risk patients with MV disease should be evaluated by a multispecialty heart valve team that includes (and not limited to) a cardiac surgeon and a structural heart cardiologist. (I, class of recommendation—limited data [C-LD])

Estimating perioperative or periprocedural risk in MAC is a complex process. Several types of risk factors need to be accounted for, including anatomic risk factors at the MV level; the general risk related to burden of

associated cardiovascular disease or other, extracardiac comorbidities; procedure-related risks unique to a particular intervention; and the availability of surgical and interventional expertise. The STS risk model commonly used to estimate the likelihood of complications or mortality for an index cardiac surgical procedure is based on various patient factors, such as age, comorbidities, and procedural details. The STS risk score does not incorporate MAC as an independent risk variable and thus underestimates perioperative morbidity and mortality risk in patients who undergo surgery for MAC.¹⁴ In addition, it has been shown that 1-year survival after MAC intervention may be compromised even if the patient survives the index hospitalization. This longer-term risk is thought to be primarily due to the burden of comorbidities, but it is also attributable to valve-related complications, particularly with the expansion of off-label use of transcatheter devices in the mitral position in HTMVR and TMVR procedures.⁵

Given these risk factors, all high-risk patients and patients with moderate or greater degrees of MAC should be evaluated by a multidisciplinary heart team to estimate the risk an intervention would pose. This team should include a cardiac surgeon with experience in MAC surgery, an interventional cardiologist, and an imaging specialist with expertise in structural heart interventions. Depending on the extent of systemic comorbidities, involving clinicians from other disciplines may be indicated, with a focus on screening out patients with prohibitive risk factors for surgery, such as chronic liver disease with a high Model for End-Stage Liver Disease score, chronic lung disease causing severely reduced lung function, marked frailty, and poor functional and nutritional status. After a thorough multidisciplinary evaluation, decisions are made regarding surgical or interventional candidacy and the choice of surgical, hybrid, or transcatheter intervention or medical

TABLE 7. Complications of MAC interventions and surgery

Recommendations	COR	LOE	References
29. In patients with bleeding from AVG disruption after MVR, it is generally recommended to remove the previously implanted mitral prosthesis and reconstruct the AVG with a patch to cover the area of tear and/or disruption (ie, internal repair).	I	C-EO	26,75-79
30. In the setting of ongoing bleeding, despite previous maneuvers, it is reasonable to place the patient on VA-ECMO support, to decompress the LV, and to temporize the situation with packing to control the bleeding.	IIa	C-EO	80
31. In cases of circumflex arterial injury, while grafting the lateral wall is preferred, the surgeon must balance the impact/complications of the ischemia and risk of injury to the mitral annulus or treat the ischemia with a transcatheter approach or medically.	IIa	C-EO	81-84
32. Surgical MVR can be considered in patients with LVOT obstruction after TMVR.	IIa	C-EO	85-88
33. In case of PVL after mitral replacement in the setting of MAC, transcatheter procedure can be effective.	IIa	C-LD	89-91

The color shadings indicate comparable classes of recommendation and levels of evidence. *MAC*, Mitral annular calcification; *COR*, class of recommendation; *LOE*, level of evidence; *AVG*, atrioventricular groove; *MVR*, mitral valve replacement; *C-EO*, class of recommendation—expert opinion; *VA-ECMO*, venoarterial extracorporeal oxygenation; *LV*, left ventricle; *LVOT*, left ventricular outflow tract; *TMVR*, transcatheter mitral valve replacement; *PVL*, paravalvular leak; *C-LD*, class of recommendation—limited data.

Class of Recommendation

Class of Recommendation		Suggested phrases for writing recommendations
I	Strong recommendation Benefit >>> risk	- Is recommended - Is indicated
IIa	Moderate recommendation Benefit >> risk	- Should be considered - Is reasonable - Can be useful/effective/beneficial
IIb	Weak recommendation Benefit ≥ risk	- May/might be reasonable - May/might be considered
III	Moderate recommendation No benefit: risk = benefit Strong recommendation Harm: risk > benefit	- Is not recommended - Is contraindicated - Should not be performed/administrated

Level of Evidence

A	High-quality evidence from more than one RCT with no concern for high risk of bias, or meta-analyses of high-quality RCTs with no concerns for significant bias.	
B	Randomized (B-R):	Moderate-quality evidence from 1 or more RCT or meta-analysis of RCTs.
	Non-Randomized (B-NR):	Moderate-quality evidence from 1 or more well-designed, well-executed nonrandomized studies, observational studies, or registry studies or meta-analyses or such studies.
C	Limited data (C-LD):	Studies with limitations of design or execution, meta-analyses of such studies, case series, or physiological or mechanistic studies in human subjects.
	Expert opinion (C-EO):	Consensus of expert opinion based on clinical experience.

AATS, American Association for Thoracic Surgery; EACTS, European Association for Cardio-Thoracic Surgery; ESTS, European Society of Thoracic Surgeons; STS, Society of Thoracic Surgeons; RCT, randomized controlled trial.

FIGURE 2. Adopted definitions of classes of recommendation and levels of evidence. *RCT*, Randomized controlled trial. From: Milojevic and colleagues.⁹⁴

optimization; perioperative or periprocedural risks are estimated; and potential bailout options are selected.¹⁵

Statement 5. Preoperative transesophageal echocardiography (TEE) can be considered in select patients with MAC to provide high-quality assessment of the MV. (IIa, B-NR)

Statement 6. Preoperative TEE should be performed in all patients who are being considered for transcatheter or hybrid intervention. (I, C-EO)

Statement 7. In addition to echocardiography, CT imaging should be performed in all patients with MAC to adequately assess MAC extent and distribution for operative planning. (I, C-EO)

Transthoracic echocardiography remains the first-line modality in diagnosing MAC-related MV dysfunction as it provides information regarding biventricular function, pulmonary artery pressure, LVOT anatomy, and other associated valve lesions. However, transthoracic echocardiography has several limitations with respect to MAC, including its limited ability

to quantify the severity of MAC; for instance, its limited ability to differentiate between fibrosis and calcification may lead to an overestimation of MAC severity. In contrast, TEE offers high-quality evaluation of MV anatomy and function in patients with MAC. Three-dimensional TEE provides an especially detailed anatomic assessment of annular dimensions and of leaflet and segmental involvement, as well as circumferential and commissural distribution of MAC, LVOT anatomy, basal septal thickness, and anterior leaflet height. Hence, preoperative TEE should be performed in all patients being considered for transcatheter or hybrid intervention for MAC.^{15,16}

CT imaging, particularly multidetector computed tomography (MDCT), is considered the imaging modality of choice for MAC. It is a versatile, noninvasive modality that provides complementary data to that from echocardiography. In particular, the high spatial resolution of CT allows fibrosis to be distinguished from calcification, enabling a more accurate estimation of MAC severity. Anatomic analysis with MDCT involves several anatomic variables that inform treatment strategy and determine the feasibility of TMVR or HTMVR in patients with MAC (Figure 3). These variables include intercommissural and anterior-posterior dimensions, aortomitral angle, degree of circumferential involvement, maximum calcium thickness, and height. The MDCT assessment of potential LVOT obstruction uses the concept of neo-LVOT area and “skirt” neo-LVOT and is crucial to predicting the likelihood of LVOT obstruction with hemodynamic compromise, along with the level of risk of prosthetic embolization and PVL. Extensive aortic calcification (“porcelain aorta”), an important anatomic finding for determining the feasibility and risk of cardiopulmonary bypass use, can also be accurately evaluated with CT

imaging. For these reasons, MDCT is critical to determining the feasibility and risks of transcatheter and hybrid interventions.^{6,17-25}

MDCT evidence of involvement of the aortomitral curtain, anterior annulus, and anterior commissure may be particularly helpful in predicting the need for more complex procedures such as reconstruction of the intervalvular fibrosa in patients with radiation-induced MAC, which would warrant referral to a center with surgical expertise.^{26,27} The few limitations of CT imaging include radiation exposure, the adverse effects of contrast agents (particularly in patients with renal dysfunction), and inability to quantify hemodynamics, which can be assessed with other imaging modalities.

Statement 8. Diagnostic right heart cardiac catheterization for hemodynamic and risk assessment is reasonable for patients with MAC in the setting of MV disease. (IIa, C-EO)

Invasive hemodynamic evaluation should be part of preoperative assessment of patients with MAC, particularly those with suspected pulmonary hypertension, ventricular dysfunction, multivalvular disease, intrinsic pulmonary disease as in chronic obstructive pulmonary disorders, and frailty, and patients in a decompensated state. In such cases, medical optimization can be initiated and maintained by the heart team, with a focus on optimizing volume status, pulmonary artery pressure, and cardiac output to minimize perioperative and periprocedural risk. Right heart catheterization with direct measurement of pulmonary artery pressure, pulmonary vascular resistance, and pulmonary arterial reactivity to vasodilators can differentiate precapillary from postcapillary pulmonary hypertension and identify other important hemodynamic abnormalities, such as severe diastolic dysfunction, that might not be expected to improve with a high-risk MV

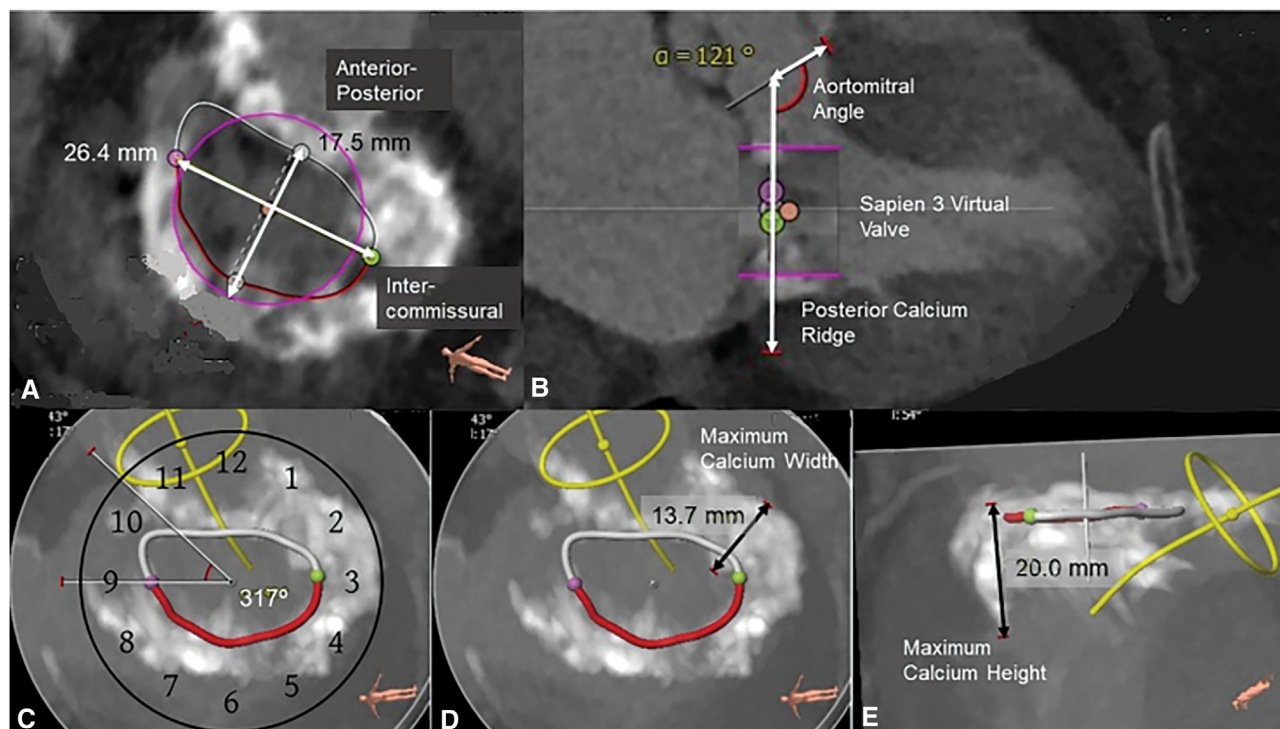


FIGURE 3. Anatomic analysis by multidetector CT of MAC and feasibility of transcatheter valve placement. Clockwise from top left: A, Intercommissural and anterior-posterior dimensions are determined. B, Aortomitral angle is measured and a virtual transcatheter valve (SAPIEN 3; Edwards Lifesciences, LLC) is placed to assess the fit inside the MAC and LVOT obstruction risk. C, Severity of MAC is determined, using a clockface orientation, with 270° to 300° deemed horseshoe and more than 300° circumferential. D and E, Maximum calcium thickness and height of MAC are calculated to determine the extent of anchoring with the transcatheter valve. CT, Computed tomography; MAC, mitral annular calcification; LVOT, left ventricular outflow tract. Reprinted from El-Eshmawi and colleagues.¹⁹

intervention. In addition, less-symptomatic patients with good hemodynamic parameters on guideline-directed medical therapy (GDMT) could benefit more from a watchful waiting strategy than from a high-risk intervention.^{7,28}

Historically, pulmonary hypertension has been reported as a risk factor for worse early and late outcomes in MV surgery.²⁹⁻³¹ The 30-day mortality risk effect of pulmonary hypertension has been also included in the European System for Cardiac Operative Risk Evaluation.³² However, given the recent introduction of new pulmonary vasodilators for perioperative management of pulmonary hypertension, contemporary data suggest that MV surgery can be performed with acceptable perioperative mortality risk in patients with MS and severe pulmonary hypertension. Therefore, pulmonary hypertension in patients with MAC should not be considered an absolute contraindication to surgical or transcatheter MV intervention. However, it should warrant careful preoperative evaluation and perioperative management.^{33,34}

Statement 9. In asymptomatic or mildly symptomatic patients (New York Heart Association class I or II) with significant MV disease and severe MAC, the risks of mitral intervention may be carefully weighed against those of watchful waiting and GDMT. (IIB, C-LD)

Statement 10. TMVR and HTMVR techniques with a multidisciplinary heart team approach is reasonable in selected high-risk patients with severe MAC. (IIB, B-NR)

Statement 11. In patients with a limited life expectancy attributable to noncardiac pathologies, marked frailty or those who are unlikely to see symptomatic benefit, MV intervention may be futile. (IIB, B-NR)

Several factors should be considered in decision-making regarding the best therapeutic modality in patients who present with significant MAC, including patient quality of life, life expectancy, and functional status. These factors should be interpreted in the context of anatomic risk factors, the risk associated with the patient's comorbid conditions, and the availability of local expertise and access to comprehensive reference centers.

In patients with mild symptoms, the risk of mitral intervention must be carefully weighed against watchful waiting and GDMT. No specific medical therapy exists to prevent progression of MAC; instead, treatment should be directed toward controlling other cardiovascular risk factors. This is also suggested by the current guidelines, which state that intervention should be delayed for high-risk patients until their symptoms become limiting and not manageable with guideline-driven medical therapy.⁷ At a reference center with experienced multidisciplinary teams, referral to a heart failure cardiologist or electrophysiologist could help to guide therapy.

In addition, high-risk or futile interventions should be avoided, especially in patients with limited life expectancy, end-stage organ dysfunction (eg, chronic lung disease), chronic liver disease with a high Model for End-Stage Liver Disease score, or marked frailty, as well as patients with poor social support or poor functional and nutritional status.^{7,28,35-37} MAC should always be interpreted as a cardiac presentation of a systemic disease, the burden of which ultimately determines long-term outcome in terms of survival or quality of life regardless of any anatomic repair made at the MV level. This has been illustrated in the TMVR trials showing poor midterm outcomes in addition to high periprocedural mortality rates; some reported in-hospital mortality rates are as high as 20%. In 126 patients in a multicenter study with longer-term follow-up, investigators observed an in-hospital mortality rate of 10% and a 1-year survival rate of 69%.^{38,39}

Section 3: Surgical Considerations for MV Repair or Replacement in MAC

Statement 12. Both en bloc surgical annular decalcification “Resect” strategies and no-resection or limited-resection “Respect” strategies are reasonable in select patients with MAC. (IIa, C-LD)

Over the past few decades, 2 major surgical concepts in dealing with the calcified mitral annulus have emerged: en bloc annular decalcification by Resect strategies and by no-resection or limited-resection Respect strategies.

Resect strategy. An en bloc resection of MAC (Figure 4) provides the most curative procedure by eliminating the disfiguration of the annulus and providing a smooth substrate for subsequent repair or replacement. This may allow for a durable repair or replacement with less risk of PVL or device dehiscence. This approach also facilitates the insertion of an adequately sized prosthesis to avoid patient-prosthesis mismatch and functional MS. Initially reported by Carpentier and colleagues,⁵ this technique, with variations, has been successfully reproduced by experienced groups.^{6,16-18,21,22,25} Outcomes are good after en bloc resection and MV repair or replacement: Survival exceeds 75% to 85% at 5 years.^{6,17} The extent of the decalcification process is variable and may or may not include the ventricular free wall. Reconstructive techniques after removal of the entire calcium bar along with its capsule range from sliding atrioventriculoplasty to patch reconstruction of the AVG (Figure 4).

Respect strategy. Respect is a more conservative technique that involves limited or no resection, with the goals of reducing operative complexity and, potentially, the risk for AVG disruption or circumflex artery injury. However, the Respect strategy requires the surgeon to work around residual calcium, which can potentially limit valve prosthesis size and increase risk for PVL. This strategy may be most suitable for high-risk patients, patients with extensive calcification (eg, ventricular extension of calcium), and patients at elevated risk for AVG disruption, including elderly and frail patients, patients with poor endomyocardial tissue quality, and patients with multiple comorbidities who would not tolerate the long bypass run that a more complex operation would require.

Both Resect and Respect techniques allow mitral repair when sufficient disease-free leaflet tissue exists, as well as prosthetic valve replacement. Aggressive use of both techniques has resulted in rates of freedom from mitral reintervention exceeding 95% at 8 years.²⁴ More conservative use of the Respect strategy has also achieved satisfactory results in high-risk patients.^{19,23} Both surgical techniques (en bloc total resection and no or limited resection) carry the risk of embolization and AVG disruption. Thus, surgical techniques must be selected according to the surgeon's own experience, the patient's anatomy, and consideration of the risks and benefits of AVG disruption, patient-prosthesis mismatch, and PVL.

Statement 13. MV repair is reasonable in non-extensive MAC in selected patients with repairable anatomy. (IIa, C-EO)

As in patients with no MAC, MV repair has been shown to provide superior early and late outcomes over MVR in terms of perioperative mortality and morbidity, survival, and ventricular function in patients with MAC and repairable anatomy.^{6,15,20} Anatomic features that favor repair include



FIGURE 4. En bloc annular decalcification showing the completely excised calcium bar.

calcification limited to the annulus, preserved leaflet pliability and mobility, limited leaflet extension, and extension into a resectable segment of the leaflet where excess tissue allows annular approximation without tension. Thus, the feasibility of repair is determined by both the extent of calcification and the amount of healthy leaflet tissue available for reconstruction. For example, Barlow anatomy would be repairable in the majority of patients, even those with extensive calcification, as opposed to fibroelastic deficiency.

For repair techniques using the Resect strategy, the posterior leaflet can be completely detached from the calcium bar spanning commissure to commissure. The calcium bar is excised (Figure 4) circumferentially by a combination of sharp dissection and diathermy or other energy-based techniques to allow en bloc dissection of the calcium bar along with its fibrous capsule without causing fragmentation. The AVG is reconstructed with either a pericardial patch or a sliding atrioventriculoplasty, wherein figure-of-eight mattress sutures are used to reattach the atrial flap to the ventricular endocardium (Figure 5). The rest of the leaflet and chordal pathology can be treated with standard surgical techniques before the annuloplasty device is implanted.¹⁵

In Carpentier and colleagues⁵ series of mitral repairs in patients with extensive MAC, no incidents of AVG disruption or circumflex injury were observed, and long-term outcomes were excellent. This group's use of viable vascularized atrial and ventricular tissue to reconstruct the annulus probably translated into better healing of the prosthesis and may have contributed to favorable long-term outcomes. In addition, the sliding atrioventriculoplasty component of the procedure would tend to evert the coronary vessels away from the groove, possibly accounting for the low rate of circumflex coronary artery injury.

Valve repair is also feasible using Respect strategies such as partial decalcification. Limiting the decalcification to the area of repair can reportedly restore good leaflet mobility and annular approximation without compromising the long-term durability of the repair.²⁰

Other Respect techniques include an "oversized annuloplasty" wherein annular sutures are placed behind the calcium bar, while the sliding plasty is done at the leaflet level (Figures 6 and 7).^{16,17} Another technique, "unconventional annuloplasty," involves modifying the shape of the annuloplasty to fit the pliable parts of the annulus. These Respect techniques in

repair might be considered palliative valve procedures because annular decalcification is the preferred surgical technique, particularly in young patients (Videos 1-3).^{15,26}

Other palliative repair techniques include the edge-to-edge technique to correct leaflet pathology. However, this technique produced suboptimal results in MAC patients, particularly when an annuloplasty device was not used.²⁷

Statement 14. MVR should be considered over repair in patients with extensive MAC, infected MAC, or severe mitral stenosis. (IIa, C-EO)

Statement 15. In surgical MVR, the extent of decalcification should be tailored to the patient's risk profile and surgical expertise to ensure that an adequately sized prosthesis is implanted. (I, C-EO)

Although MV repair remains the treatment of choice for most MV disease, its superiority over MVR is less clear in patients with MAC and severely fibrotic, calcific, and immobile leaflets; MS or mixed disease; endocarditis; extensive or circumferential calcifications with commissural involvement; or radiation-related MAC. In those high-risk patients, replacing the MV by using one of several reproducible techniques is considered an excellent and safe surgical alternative.

If en bloc annular decalcification is chosen, annular reconstruction can be performed with a strip of autologous or bovine pericardium as described by Feindel and colleagues.⁶ To reconstruct the AVG, the pericardial strip is sutured to the endocardium of the LV. The valve sutures are then passed through the strip at a level that corresponds to the mitral annulus posteriorly and to the intervalvular fibrous body superiorly. Before a prosthetic valve is implanted, the proximal part of the patch is secured to the left atrium (Figure 8, Video 4).⁴⁰

There are several clinical scenarios in which en bloc resection may not be considered appropriate due to patient condition or lack of local expertise, and Respect techniques would be more appropriate. Those techniques entail limited decalcification or enough debridement to allow safe placement of an adequately sized prosthesis without compromising the integrity of the AVG, placing sutures around or through the calcium bar if needles can be passed without calcium fragmentation, and intraleaflet implantation of the prosthesis by incorporating the pliable posterior leaflet into the suture line, or by building a new annulus. The use of these techniques must be balanced against the risk of an undersized prosthesis, PVL, "toothpaste"

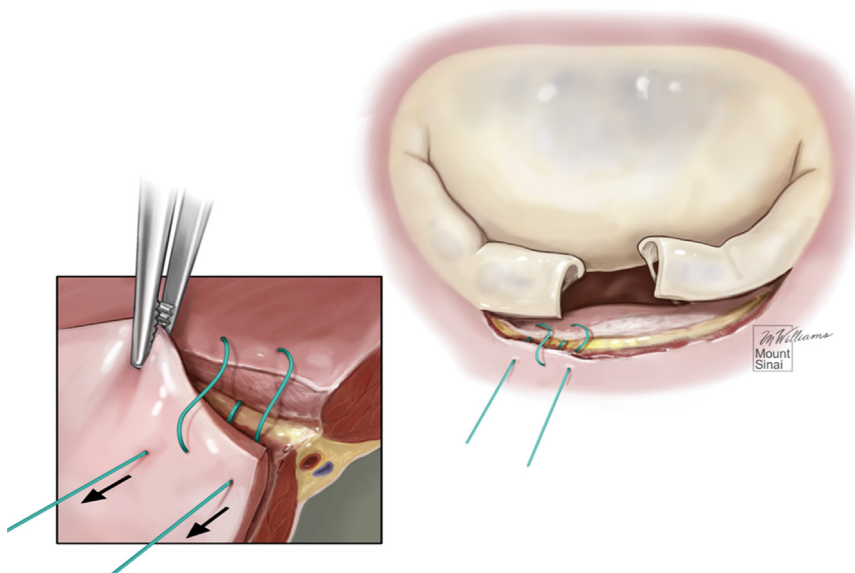


FIGURE 5. Sliding atrioventriculoplasty using nonpledgeted vertical figure-of-eight-mattress sutures. Reprinted with permission from Carpentier and colleagues.¹⁵

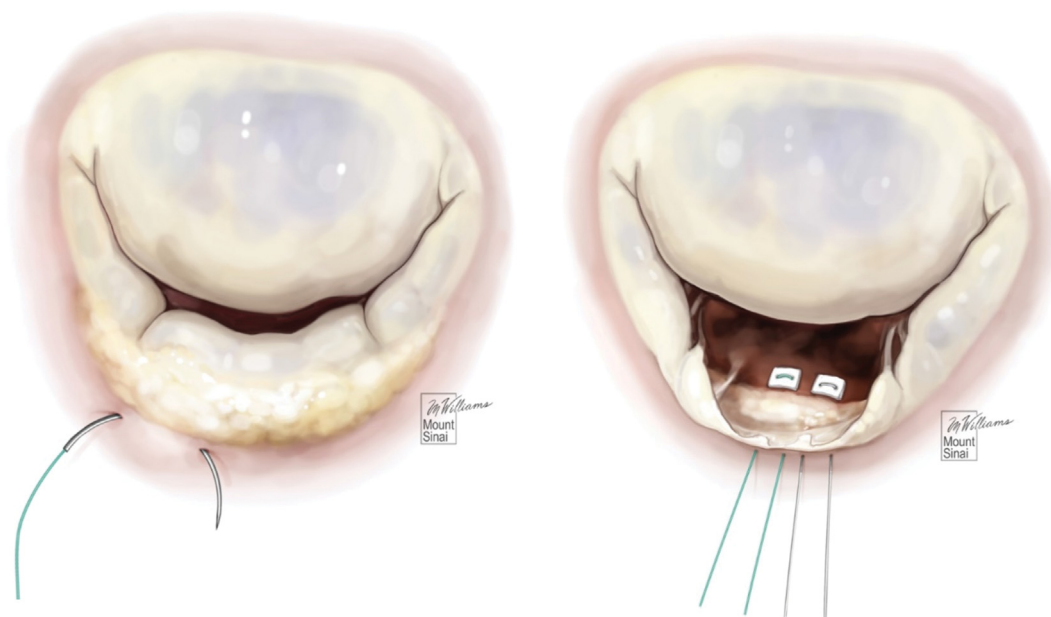


FIGURE 6. Annuloplasty suture placement for mitral repair using Respect techniques. *Left:* Sutures are placed behind the calcium bar. *Right:* Pledged noneverting sutures are placed from the ventricle up to the atrium with a small half-circle needle.

caseous calcium embolization, and the risk of circumflex coronary artery injury (Video 5).^{7,19,23,28,35,36}

Occasionally, in cases of extensive MAC involving the medial commissure, valve sutures can be placed from the right atrial side of the interatrial septum anterior to the coronary sinus to avoid the conduction system.²³

However, techniques that entail intra-atrial or supra-annular implantation of a prosthetic MV should be avoided in patients with extensive MAC to avoid the risk of transferring high LV pressure into the left atrium with resultant increased risk of bleeding, valve dehiscence, or aneurysm formation.²⁵

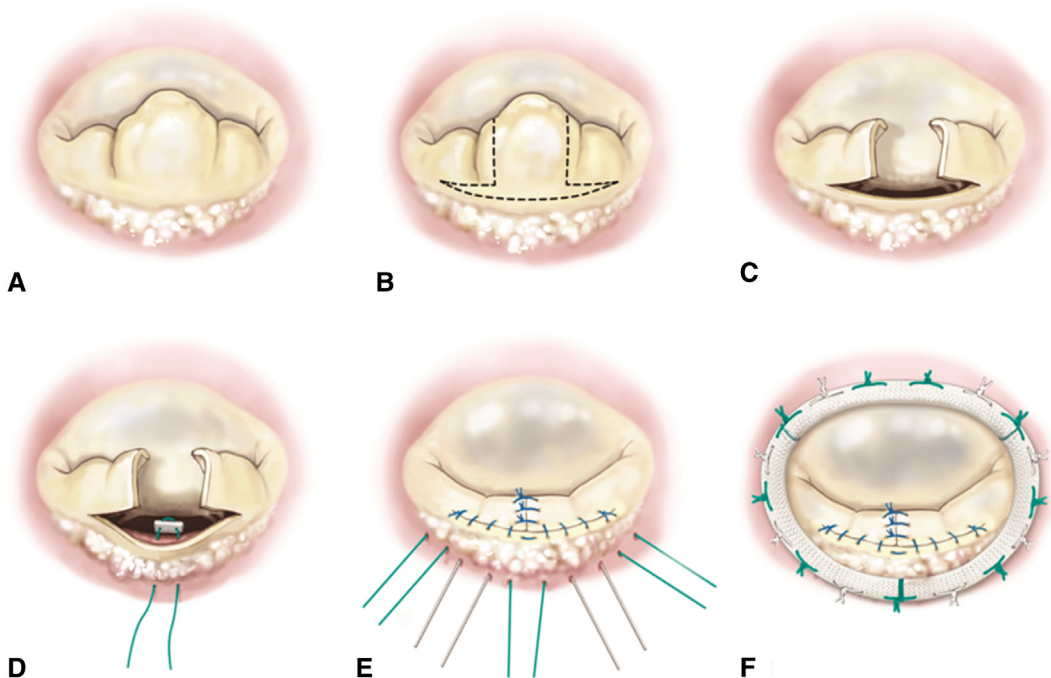
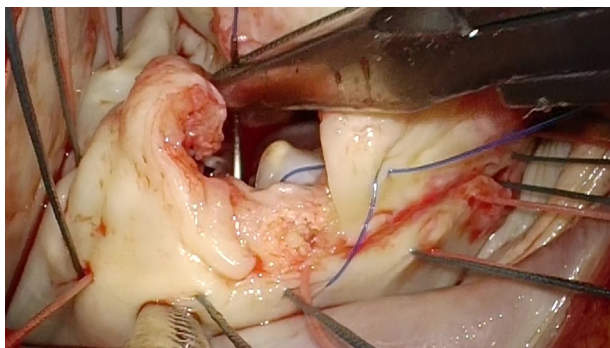


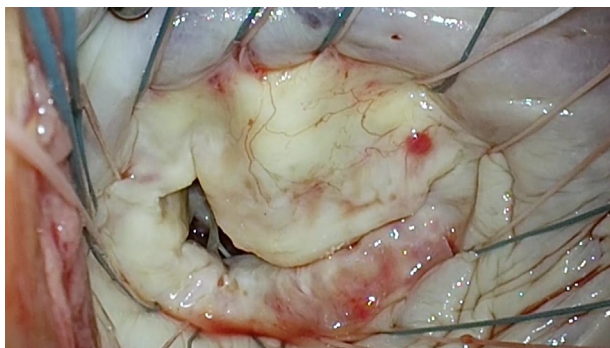
FIGURE 7. Mitral valve reconstruction using Respect oversized annuloplasty technique. A, Calcified Barlow valve. B and C, Quadrangular resection. D, Annuloplasty sutures. E, Leaflet sliding plasty in front of the calcium bar. F, Oversized annuloplasty behind the calcium bar.



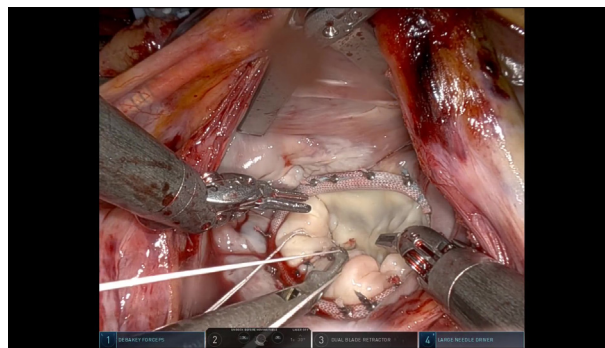
VIDEO 1. Mitral valve repair using Respect technique. The patient had degenerative MAC with ventricular extension treated with limited leaflet and calcium resection, as well as neochordoplasty, with oversized partial annuloplasty. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).

Statement 16. Ultrasonic debridement may be a useful adjunctive tool in surgical valve repair or replacement in patients with MAC to facilitate suture placement and seating of the prosthesis. (IIb, C-LD)

Ultrasonic energy is a safe and attractive alternative to manual debridement of the calcified mitral annulus during MV repair or replacement. It is increasingly being adopted in MAC operative procedures to mitigate some of the technical challenges and risk of surgical complications associated with this challenging disease.^{25,37-39,41} Unlike manual debridement with a rongeur or scissors, this technique uses ultrasound to emulsify the calcified matter. The devices currently available are the Sonopet Ultrasonic Aspirator (Stryker Corp) and the Cavitron Ultrasonic Surgical Aspirator (CUSA) device (Integra LifeSciences). Either of these devices can be used for the focused debridement of calcium. This technique can be used to achieve controlled complete decalcification, although this is often unnecessary, and it mitigates the risk of needing extensive reconstruction of the LV-mitral annulus complex with a pericardial patch. Alternatively, it is advisable to pursue a limited-resection approach to MAC with sufficient remodeling of the annulus to safely seat a prosthetic valve or annuloplasty device. This remodeling approach using ultrasonic emulsification and aspiration of the calcified annulus provides a method of controlled and purposeful debridement of the annulus.^{38,39,41} Ultrasonic debridement facilitates preservation of the ventricular aspect of the MAC's capsule and avoids the excessive torque of the calcium bar that may occur during blunt or sharp



VIDEO 2. Mitral valve repair in a 73-year-old female patient with congestive heart failure and reduced ejection fraction with severe MR and severe TR due to type I dysfunction with extensive posterior MAC. Repair was done using the Respect technique with oversized annuloplasty. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).



VIDEO 3. Mitral valve repair in MAC using the Respect technique. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).

debridement, thereby potentially decreasing the risk of AVG disruption due to uncontrolled fracture of the calcified annulus. Not infrequently, emulsification of MAC will soften the annulus, which facilitates suture placement. In a recent retrospective study that compared ultrasonic emulsification with manual debridement, there were no AVG disruptions, operative mortality, or stroke after ultrasonic emulsification.⁴¹ This finding shows that this technique is potentially safe and reduces the operation's technical complexity (Videos 6 and 7).

Statement 17. Chordal sparing MVR techniques should be implemented with attention given to avoid interference with prosthetic valve function. (I, B-NR)

Maintaining the ventricular annular continuity in MVR has been shown to minimize the risks of perioperative AVG disruption and to maintain long-term ventricular function.⁴²⁻⁴⁹

The anterior leaflet flip technique originally described by Casselman and colleagues⁵⁰ is an attractive alternative wherein the anterior leaflet is used to reconstruct the decalcified posterior annulus. This technique has been modified to allow total valve-sparing MV replacement in patients with MAC (Video 8).^{16,19}

However, these techniques have many limitations, such as using smaller prostheses with higher transvalvular gradients, although the clinical impact of patient-prosthesis mismatch in the mitral position remains to be clarified. Mechanical valves theoretically offer a better effective orifice area but necessitate lifelong anticoagulation, and implanting them in patients with MAC could be challenging. Currently available low-profile tissue valves, however, provide a safe alternative, particularly in high-risk patients. Regardless of the prosthesis choice, care should be taken to remove any excess subvalvular apparatus that would interact with prosthetic valve leaflets and predispose the prosthetic valve to dysfunction or early failure. Finally, patients with MS and a small LV can develop subvalvular gradients. In these patients, particularly those with diastolic dysfunction, sacrificing the subvalvular apparatus might be needed to create more open inflow and avoid subvalvular gradients.

Statement 18. Heavy involvement of the aortomitral curtain, as seen in circumferential MAC and in radiation-induced MAC with trigonal involvement, may often require aortomitral curtain reconstruction and concomitant aortic valve replacement or an aortic root procedure. (IIa, C-EO)

Radiation can cause fibrosis, scarring, and calcification. Calcification often extends from the aortic root or annulus toward the aortomitral curtain and anterior mitral leaflet. In addition, the fibrosis and scarring may themselves limit the size of the prosthesis, even after thorough debridement. In these scenarios, after the decalcification, there may not be adequate healthy tissue to place the sutures. Dividing the aortomitral curtain can improve exposure; reconstructing it may allow placement of a larger prosthesis and adequate sealing of the valve. These operations require extensive experience (Figure 9 and Videos 9 and 10).⁵¹⁻⁵⁶

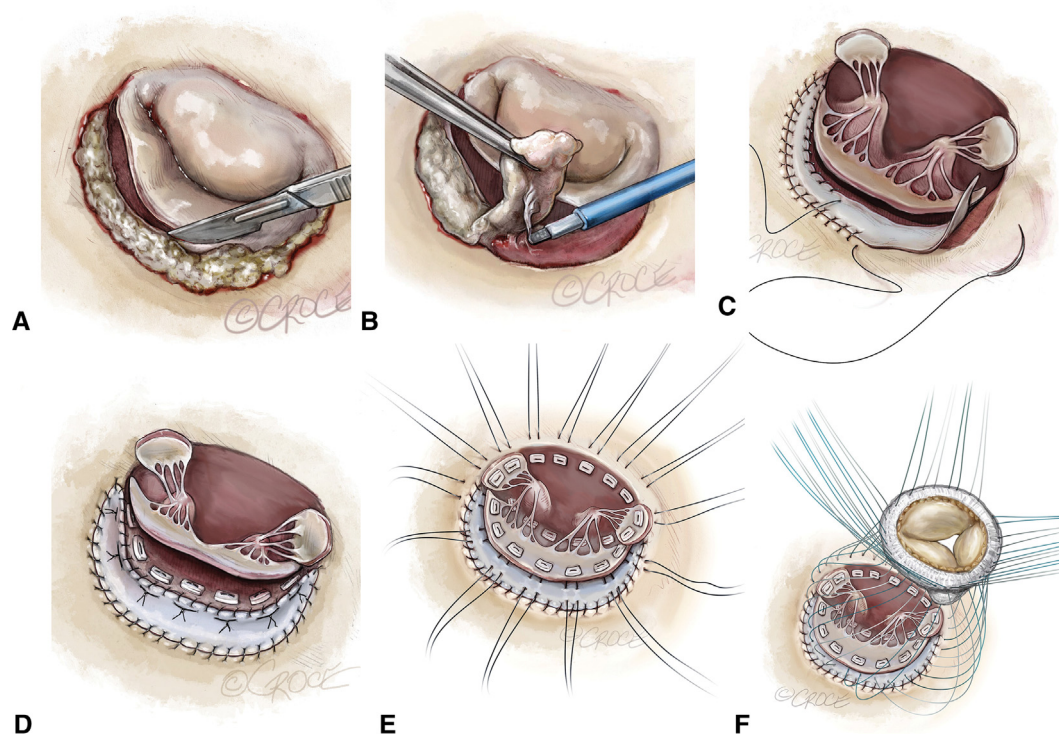


FIGURE 8. Pericardial patch reconstruction of the atrioventricular groove. A, The base of the posterior leaflet of the mitral valve is incised and detached from the mitral annulus. B, The calcium bar is excised. C, A piece of pericardium is fashioned and used to patch the defect with continuous polypropylene (Prolene, Ethicon) suture. D, The patch is reinforced on the left ventricular side with multiple pledgeted sutures. E, Valve sutures are then placed. F, A prosthetic mitral valve is then parachuted and secured in standard fashion. Reprinted with permission from Shi and colleagues.⁴⁰

Statement 19. A felt strip layer may be used with bioprosthetic valve to help reduce paravalvular leak. (Iib, C-EO)

Postoperative PVL is a known complication of MVR for MAC and has been associated with worse clinical outcomes.⁵⁷ The irregularity and bulk of the calcified annulus can interfere with seating the valve prosthesis, leading to an incomplete seal between the annulus and the sewing cuff of the valve; this incomplete seal may persist even after debriement of MAC. To mitigate this risk, a circumferential polytetrafluoroethylene felt strip or “skirt” may be placed between the annulus and prosthetic valve to

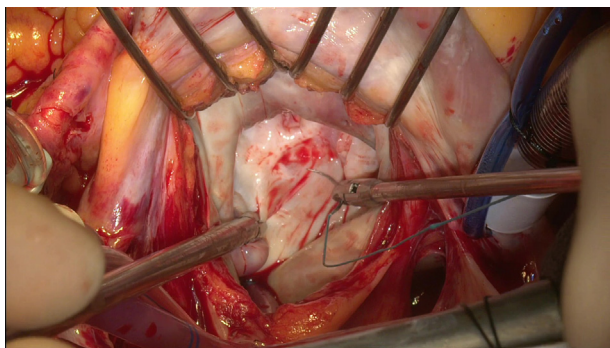
improve sealing against the MAC and reduce the risk of PVL. The felt is cut in a “doughnut” shape to match the size of the sewing cuff of the valve. Pledgeted valve sutures are placed, and the suture is passed through the felt skirt and then through the sewing cuff and tied, thereby providing a layer of insulation between the valve and the MAC.^{38,58} Felt strips are routinely used in the hybrid transcatheter open transatrial MVR procedure. The felt is secured around the inflow portion of a transcatheter heart valve before implantation and balloon expansion to reduce the risk of PVL.^{19,59} An additional advantage of using felt with a standard surgical



VIDEO 4. Pericardial patch reconstruction of the atrioventricular groove after en bloc annular decalcification in a patient with extensive posterior MAC. The mitral valve was accessed via an inflow/outflow approach (Comando procedure). Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).



VIDEO 5. Mitral valve replacement using Respect technique of periannular suture placement. Noneverting pledgeted sutures are passed behind the calcium bar without decalcification, and the prosthetic valve is implanted in a supra-annular position. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).



VIDEO 6. Controlled decalcification of the calcium bar with the Sonopet device and subsequent mitral valve repair. Complete decalcification is not necessary. Sutures are placed above the calcium bar as needed. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).

prosthetic valve may be the incremental atrialization of the prosthesis, which may further reduce the interference of the prosthetic valve apparatus with the LVOT. Atrializing the prosthetic valve may be of value in patients with a small and hyperdynamic LV, which is occasionally encountered in cases of MS (Video 11).

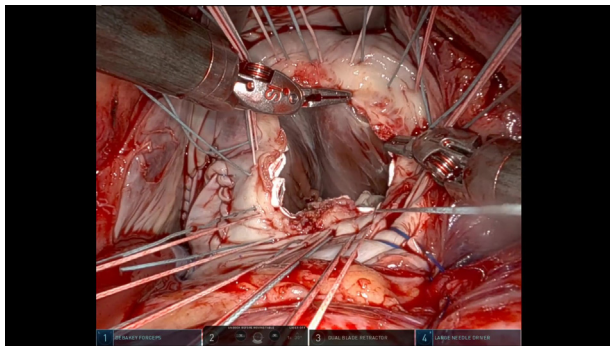
Section 4: Hybrid Transatrial Transcatheter Balloon-Expandable Devices (ie, HTMVR) in Patients With MAC

Statement 20. To determine the feasibility of HTMVR, MDCT analysis should include mitral annular dimensions and geometry, MAC severity determined on the basis of the MAC score, MAC bar width and height, septal thickness, neo-LVOT area, and skirt neo-LVOT area. (I, B-NR)

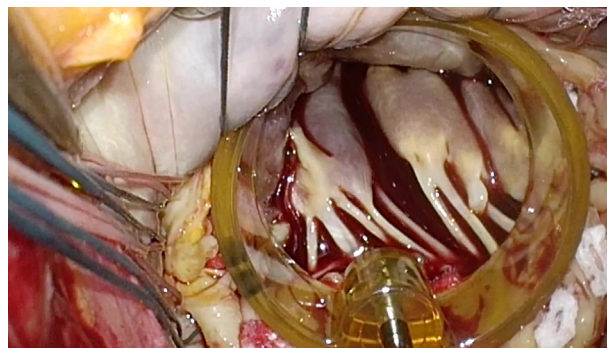
Surgical patients with severe MAC and mitral disease who require MVR can be considered either for conventional surgery or HTMVR. MDCT should be used to determine the MAC's severity, location, distribution, width, height, and eccentricity; percentage of over- or undersizing with balloon-expandable valves; and neo-LVOT area to assess LVOT obstruction risk with HTMVR.⁶⁰⁻⁶² Performing MDCT is therefore essential to determining the optimal approach to MVR.

Statement 21. In severe MAC, it is reasonable to consider HTMVR instead of standard MVR if sutures cannot be placed safely around the annulus for conventional surgical prosthesis implantation. (IIa, C-EO)

Although HTMVR may be a simpler operation than conventional MVR in patients with severe MAC, implanting the device for this purpose is



VIDEO 7. Mitral valve replacement using CUSA for annular decalcification. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).



VIDEO 8. Modified anterior leaflet flip technique. The anterior leaflet is disinserted and rotated toward the posterior leaflet, preserving the whole subvalvular apparatus and creating a “neo-annulus” in front of the calcium bar. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).

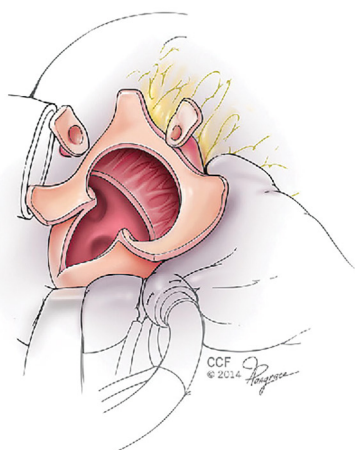
considered off-label, and depending on the degree of over- or undersizing and the number of sutures placed around the annulus, there remains a risk of device migration or embolization. Although periannular sutures can be placed to help fixate the balloon-expandable valve, MDCT-based MAC scoring to predict the risk of PVL, device migration, or embolization is helpful in HTMVR.⁶¹ Similarly, the risk of LVOT obstruction may be high despite surgical resection of the anterior leaflet. Hence, intraoperative valve analysis is always implemented to confirm preoperative imaging findings, with preference for standard surgical valve implantation over a hybrid technique. A recent multicenter study of HTMVR showed high 30-day and 1-year mortality rates of 9% and 18%, respectively; hence, this approach should always be considered a bailout for high-risk patients.⁶³

Statement 22. Anterior mitral leaflet resection with or without septal myectomy should be considered to reduce the risk of LVOT obstruction. (IIa, B-NR)

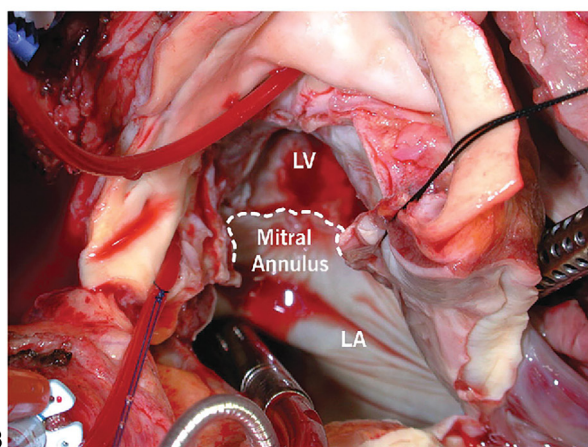
The anterior mitral leaflet is responsible for LVOT obstruction in percutaneous TMVR, but in HTMVR it should be resected such that only the skirt neo-LVOT must be evaluated to determine LVOT obstruction risk.^{26,60,62,64} A rim of native anterior leaflet can be left in situ to facilitate annular suture placements to help secure the balloon-expandable valve, particularly if the MAC is noncircumferential. No threshold for septal thickness has been established to determine whether septal myectomy is needed. Given that the anterior mitral leaflet is removed in HTMVR, the risk posed by a thick septum is more about the contact or interaction of the balloon-expandable valve with the endocardium in the LVOT during systole. Such interaction potentially increases the risk of atrial migration of the device, especially when no periannular sutures are placed against the valve. The pros and cons of septal myectomy in this situation should be carefully assessed in terms of increasing procedural complexity and risking potential complications from the septal myectomy (eg, heart block, ventricular septal defect, aortic valve injury, longer bypass run).

Statement 23. A felt strip layer should be used with the balloon-expandable transcatheter valve to reduce paravalvular leak. (I, C-EO)

Placing a layer of Teflon felt strip (approximately 1 cm in width) all around the balloon-expandable valve (secured with a continuous 5-0 PRO-LENE suture at the inflow), or placing a felt pillow circumferentially around the mitral annulus before the balloon-expandable valve implantation (“felt-pillow technique”), helps to reduce PVL; improve sealing against the annulus, particularly when the device is undersized to the annulus; and potentially avoid AVG injury due to direct trauma from the metallic stent frame of the balloon-expandable valve (Figure 10, Videos 12 and 13).



A



B

FIGURE 9. A, The divided intervalvular fibrosa converts the aortic and mitral orifices into a single big opening into the left ventricle. Note that the planes of the mitral and aortic annuli are at right angles to each other. B, Operative photograph from an actual Commando operation after removal of the aortic and mitral valves. The dotted line shows the posterior mitral annulus. The picture shows that the human and pig heart anatomy look the same. LA, Left atrium; LV, left ventricle. Reprinted from Pettersson and colleagues.⁵⁶

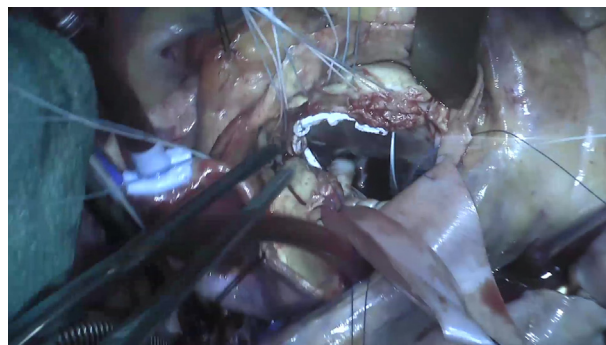
Statement 24. To reduce PVL, balloon postdilation, atrial plication sutures, or both may be useful. (IIb, C-EO)

If PVL is seen after the saline injection test, balloon postdilation with added inflation volume may be performed to attempt to optimize valve frame expansion to reduce the leak. The decision should be based on the MAC anatomy, eccentricity, and the degree of valve over- or undersizing and weighed against the risk of AVG injury. In areas in which periannular sutures cannot be placed and PVL is suspected or visualized, pledgeted sutures can be placed from the left atrial wall to the atrial inflow of the balloon-expandable valve to reduce potential PVL while also reducing the risk of atrial migration of the device.^{26,64}

Rarely, vascular plug devices can be used under direct vision if the PVL persists with saline testing. However, this procedure requires preplanning with the structural heart team in case bailout becomes necessary.⁶⁵

Statement 25. MDCT after HTMVR can be useful to evaluate postimplant anatomy. (IIa, C-EO)

Although the 5-year reintervention rate of percutaneous TMVR in MAC remained low (in a cohort with 67.9% all-cause mortality), the durability of



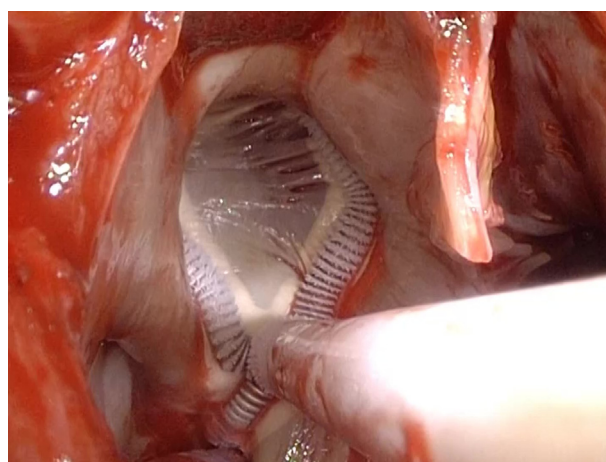
VIDEO 9. Radiation-induced MAC with anomalous coronary artery treated with a Commando procedure and coronary reimplantation. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).

HTMVR currently remains unknown.^{7,8} Therefore, it would be beneficial to obtain postprocedural MDCT imaging to evaluate prosthesis geometry, orientation, and neo-LVOT area. Leaflet thickening or valve thrombosis can also be detected.

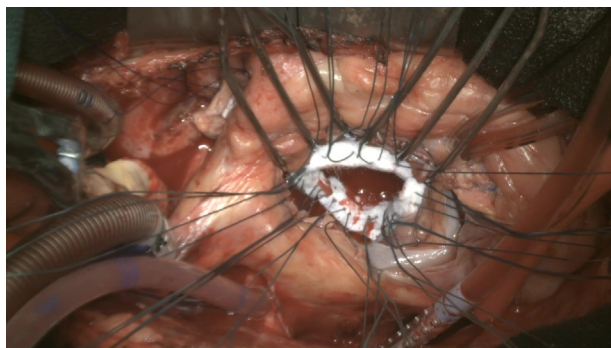
Section 5: Transcatheter MV Intervention

Statement 26. Patients with MAC and mitral stenosis who remain symptomatic despite medical management, and who are inoperable or are at prohibitive anatomical surgical risk, should be considered for TMVR. (IIa, B-NR)

Patients with MAC and MS have few medical therapy options. Conventional surgical MVR has been the default treatment strategy, but many of these patients have prohibitive risk factors including advanced age, multi-organ dysfunction, severe pulmonary hypertension, and frailty. In these instances, patients should be evaluated for TMVR. However, current investigational TMVR devices all suffer from limitations of anatomic suitability and risk of LVOT obstruction.



VIDEO 10. Commando procedure: intervalvular fibrosa reconstruction using a bovine pericardial patch in a patient with previous TAVR, as well as extensive MAC. The mitral valve was replaced by the Respect technique, wherein periannular sutures were passed behind the calcium bar by using an SH needle. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).



VIDEO 11. Mitral valve replacement using CUSA decalcification and Teflon felt. The Sonopet device, an ultrasonic aspirator, was used to partially decalcify the calcium bar to the extent that a prosthesis would fit in the annulus and to soften the calcium to facilitate suture placement. Complete removal of the calcium bar is not required. Unconventional suture placement, such as on the left atrial wall above the annulus, was also used. A felt skirt was placed between the annulus and the sewing cuff to further reduce the risk of paravalvular regurgitation. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).

LVOT obstruction risk can be reduced with anterior mitral leaflet laceration (LAMPOON) or deploying the valve through the anterior mitral leaflet.⁶⁶⁻⁶⁸ Studies of investigational devices in relatively small numbers of patients have reported promising results.⁶⁹⁻⁷¹

Statement 27. Symptomatic patients with MAC and severe mitral regurgitation who have acceptable MV area but are at high surgical risk may be considered for transcatheter edge-to-edge repair (TEER). (Iib, C-LD)

Statement 28. Symptomatic patients with MAC and severe mitral regurgitation who are high surgical risk and are likely to develop severe mitral stenosis with TEER can be considered for TMVR. (Iia, C-LD)

With MR in patients with MAC having highly heterogeneous anatomies, a tailored approach is required in high-risk patients to determine whether TEER or TMVR would have a more durable result.

Given that anatomic factors—primarily LVOT obstruction—can make TMVR infeasible in patients with MAC and severe MR, complex TEER may be considered provided that the risk of MS is low. This risk can be determined by measuring the MV area and baseline MV mean gradient on TEE. Other factors to consider are leaflet calcification and restricted mobility, which could also increase the risk of elevated mitral gradient.

Although procedural success rates can be high with TEER in MAC, 1-year outcomes have been mixed in terms of sustained MR reduction, suggesting that this strategy may not be durable in certain patients.⁷²⁻⁷⁴

Given the high risk of MS after TEER in MAC patients, TMVR can be considered a more definitive treatment option. However, in patients with MAC, procedural complications may be more likely with TMVR, as evidenced by these patients' nontrivial 2-year mortality rate of nearly 40%.⁶⁸ Therefore, a heart team approach should be followed in determining the ideal treatment option in these patients, including medical management.

Section 6: Complications of MAC Interventions and Surgery

Statement 29. In bleeding from AVG disruption after MVR, it is generally recommended to remove the previously implanted mitral prosthesis and reconstruct the AVG with a patch to cover the area of tear and/or disruption (ie, internal repair). (I, C-EO)

Although rare, AVG disruption is the most lethal complication of MV surgery, particularly in patients with MAC. The risk is even greater in elderly patients, who generally have a disproportionate degree of friable tissue and less reserve to tolerate prolonged cardiopulmonary bypass. The most commonly recommended approach is “internal repair,” which consists of explanting the prosthesis, completely reconstructing the AVG with a patch, and reimplanting the prosthesis. This strategy has been advocated by most surgeons; however, it is a massive undertaking that is still associated with a mortality rate approaching 90%.^{26,75-77} In contrast, some authors have advocated reinstituting cardiopulmonary bypass and performing external suture repair with or without felt, pericardial patches, and bioadhesive.^{26,78} Yet there are scattered reports of such repairs made solely with bioadhesives and patch material.⁷⁹

Although any of these techniques can be applied in these dire situations, a high success rate is not guaranteed. Hence, decisions should be individualized on the basis of surgeon experience, patient risk profile, and anatomic factors. Younger patients, who are more likely able to tolerate an additional, prolonged cardiopulmonary bypass run, may benefit from the more complex internal repair. In contrast, the “external repair” approach represents an alternative for use in elderly patients and patients with fragile endomyocardial tissues. As the volume of elderly patients with MAC who require MV surgery increases, the mitral surgeon should become familiar with surgical techniques to salvage this complication.

Statement 30. In the setting of ongoing bleeding, despite previous maneuvers, it is reasonable to place the patient on venoarterial extracorporeal oxygenation support, to decompress the LV, and to temporize the situation with packing to control the bleeding. (Iia, C-EO)

Recently, some surgeons have advocated the use of mechanical assistance, including central or peripheral venoarterial extracorporeal oxygenation with adequate LV decompression, after ventricular repair. This strategy provides hemodynamic support, decompresses the LV, and may limit bleeding.⁸⁰ However, it should be reserved for refractory cases of AVG rupture. Meticulous surgical techniques should be implemented to avoid air entrapment in the circuit.

Preemptive decompression with an LV assist device may also be considered in select patients, particularly those with severe ventricular dysfunction for whom AVG repair would pose high risk due to poor myocardial integrity.

Statement 31. In cases of circumflex arterial injury, while grafting the lateral wall is preferred, the surgeon must balance the impact/complications of the ischemia and risk of injury to the mitral annulus or treat the ischemia with a transcatheter approach or medically. (Iia, C-EO)

In patients with MAC who are undergoing MVR, direct suture injury or tissue distortion can cause circumflex artery injury. This injury's clinical presentation in the operating room is variable and can include wall motion abnormalities, electrocardiographic changes, malignant arrhythmias, inability to wean from bypass, and cardiogenic shock. However, some patients may be asymptomatic in the operating room and have these findings postoperatively.

If circumflex artery injury is diagnosed in the operating room, coronary artery bypass grafting or, in some cases, revision of valve sutures and prosthesis can be considered if technically feasible.^{81,82} In choosing among these options, important considerations include the technical difficulty and complexity of the MVR, the amount and distribution of MAC left in place, the presence or absence of an annular patch, the patient's underlying coronary anatomy, and the availability of a bypass conduit.

Besides these factors, management decisions will largely rest on the patient's clinical stability. Even in patients with severe MAC, revascularization is mandated in cases of hemodynamic instability despite optimum inotropic or intra-aortic balloon pump support and clear signs of coronary compromise after MVR. Coronary artery bypass grafting, with attention to avoiding lifting the heart excessively to minimize the risk of injury to the

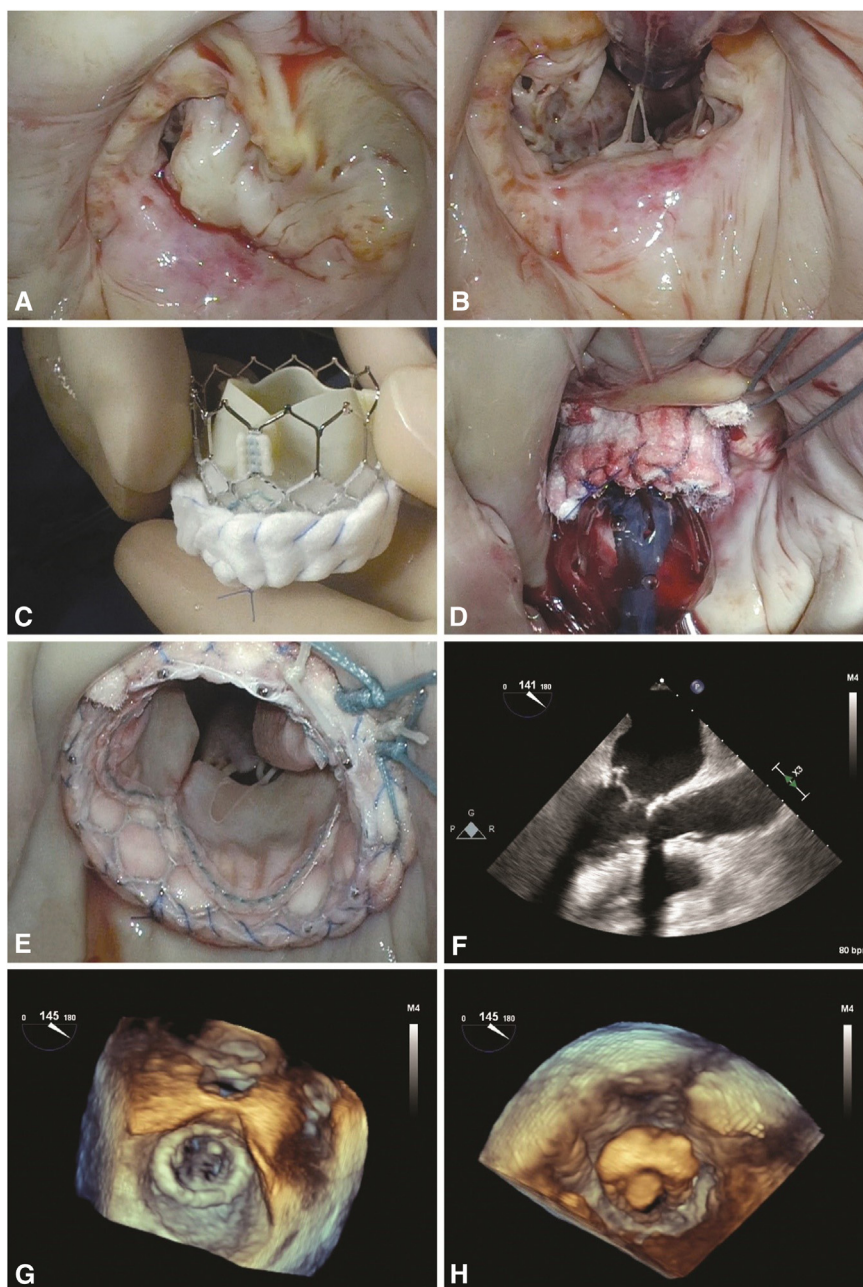
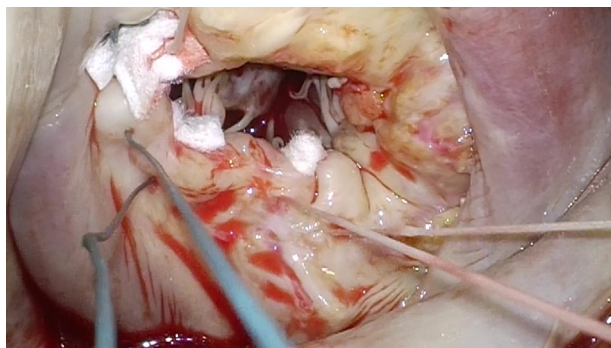


FIGURE 10. HTMVR stepwise technique: Valve analysis showing horseshoe MAC (A), anterior leaflet resection (B), SAPIEN 3 valve wrapped in felt strips (C), valve balloon deployment (D), fully deployed valve (E), and 2-dimensional and 3-dimensional transesophageal echocardiography reconstruction showing the well-seated valve (F-H). HTMVR, Hybrid transcatheter mitral valve replacement; MAC, mitral annular calcification. Reprinted from El-Eshmawi and colleagues.¹⁹

mitral annulus, can be considered. The use of apical suction devices might facilitate safe exposure of a lateral wall target. However, in patients stable enough to transfer to the catheterization laboratory (or, in the ideal scenario, patients whose index case was performed in a hybrid operating room), percutaneous coronary intervention can be an effective and safe solution, especially if there is circumflex kinking.⁸¹⁻⁸⁴ A prompt diagnostic angiogram should always be considered in borderline situations, particularly in lower-risk patients, to avoid the serious risks associated with undiagnosed perioperative ischemia.

Statement 32. Surgical MVR can be considered in patients with LVOT obstruction after TMVR. (IIa, C-EO)

LVOT obstruction is a major risk and complication of TMVR. Of the first 116 patients treated with TMVR in the MAC Global Registry, 11.2% had LVOT obstruction with hemodynamic compromise; these patients had an 85% mortality rate.⁸⁵ Although preoperative planning and using advanced techniques (LAMPOON, SESAME,⁸⁶ septal debulking) can help avoid this complication, it still occurs in roughly 15% of patients.⁸⁷ Because TMVR in patients with MAC is reserved for those at



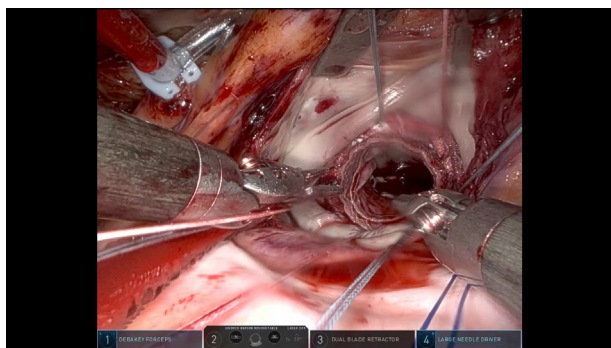
VIDEO 12. Direct-access transatrial implantation of a SAPIEN 3 valve in a patient with circumferential MAC. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).

high or prohibitive risk, additional de novo hemodynamic compromise poses exceptionally high risk in these patients. A clear preprocedural plan that includes a detailed discussion with the patient and family is necessary to know their informed decisions regarding potential surgical intervention should hemodynamic compromise occur. Among highly selected patients, salvage surgery might be lifesaving for some patients with no recognized prohibitive surgical risk and could yield acceptable outcomes. Alcohol septal ablation, balloon dilatation of the neo-LVOT, and transcatheter myotomy are potential treatment options for acute TMVR-induced LVOT obstruction in patients who are at prohibitive risk for surgery.^{86,88}

Statement 33. In case of PVL after mitral replacement in the setting of MAC, transcatheter procedure can be effective. (IIa, C-LD)

Paravalvular leak occurs in 7% to 17% of MVRs, and MAC is an important risk factor for its development.⁸⁹ Late PVL in patients with MAC has been attributed to the gradual resorption of incompletely debrided calcification but may also be related to imperfect prosthesis seating at the time of surgery, or to the gradual shifting of fractured calcification and associated sutures through repeated cardiac cycles.⁹⁰ In patients with PVL, it is imperative to rule out infective endocarditis.

Most PVLs are asymptomatic; however, 2% to 5% are clinically significant. Approximately 90% of patients with symptomatic PVL present with congestive heart failure. The second most common presentation is hemolytic anemia, affecting somewhere between 30% and 75% of symptomatic patients; this anemia can precipitate or worsen heart failure symptoms.



VIDEO 13. HTMVR in a patient with circumferential MAC. The CUSA is used to debride the calcium and provide a smooth landing zone for the balloon-expandable valve. Video available at: [https://www.jtcvs.org/article/S0022-5223\(25\)00292-2/fulltext](https://www.jtcvs.org/article/S0022-5223(25)00292-2/fulltext).

Current guidelines⁹¹ recommend reoperation for symptomatic PVL in patients at low risk for surgery. In patients who are at high risk for surgery, guidelines recommend percutaneous leak closure at a comprehensive valve center because expert operators and high-quality imaging are required for the success of this procedure. Notably, even at experienced centers, the success rate of percutaneous closure ranges from 70% to 77%.⁹¹

Section 7: Future Perspectives, Clinical Trials, and Innovations

There is no question that MAC-related MV disease is an expanding epidemic in the field of cardiovascular medicine and surgery due to the rapid expansion of the aging population and its high prevalence of overlapping comorbid conditions. Although there are dedicated clinical trials of transcatheter therapies, including valve-in-MAC TMVR with the balloon-expandable valve (MITRAL, MITRAL II) and hybrid balloon-expandable valve-in-MAC implantation (SITRAL) with dedicated TMVR devices, few dedicated registries currently exist on the management of MAC.^{105,106}

Creating a prospective multicenter, international registry with standardized MAC classification and coding, as well as reporting outcomes from different therapeutic modalities and interventions—whether surgical, transcatheter, or hybrid—with longitudinal follow-up will help to identify patients in this heterogeneous population who could potentially benefit from a particular intervention.

Using dedicated devices for TMVR with design modifications to overcome limitations in MAC interventions, such as the D-shaped annulus of the Tendyne THV, Intrepid, and Cephea, can potentially mitigate the risk of LVOT obstruction and PVL, resulting in better in situ valve and LVOT hemodynamics. Dedicated substudies are ongoing and will provide further insights into the utility of TMVR devices in treating MAC.¹⁰⁷ However, as the result of current anatomic limitations and challenges related to the application of transcatheter therapy in patients with MAC, standard surgical techniques, as well as the newly adopted hybrid procedures, will remain critical to the treatment of most patients with MAC. Surgical interventions in this challenging population have yielded excellent results at mitral reference centers with the necessary imaging infrastructure and surgical expertise. Consequently, patients with high-risk MAC should be evaluated by dedicated teams with the experience to handle the challenges in clinical decision-making and the unforgiving learning curve of MAC interventions and surgery. Finally, training the next generation of mitral surgeons at valve reference centers in advanced surgical techniques to treat MAC should take priority, given the increasingly complex clinical profiles of MAC patients and the currently limited applicability of transcatheter technology in treating MAC.

Conflict of Interest Statement

Dr Bethea reported consulting fees from Abbott and Edwards Lifesciences. Dr Ghanta reported grants from the National Institutes of Health and American Heart Association (to institution); consulting fees: RBL, LLC (to self); stock options: Sentinel Bio (to self); and expert testimony for various attorneys (payment to institution) unrelated to current work. Dr Grossi reported royalties or licenses, consulting fees, payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events, payment for expert testimony, and participation on a Data Safety Monitoring Board or Advisory Board: Medtronic, Edwards, and Baim. Dr Guerrero reported institutional research grant support from Edwards Lifesciences. Dr Kapadia reported

Transcatheter Tricuspid Valve Replacement NDA writing committee. Dr Mick reported consulting fees from Johnson & Johnson, Artivion, AtriCure, and Medtronic. Dr Quintana reported speakers fees (<5K) from Medtronic and Edwards; support for attending and presenting in 1 conference from Cardiva SL; and European Association for Cardio-Thoracic Surgery (EACTS) Vascular Task Forces, EACTS Clinical Guidelines Committee, European Board of Cardiothoracic Surgery (EBCTS) board member, and EACTS Francis Fontan Board Member. Dr Romano reported consulting fees from Edwards Lifesciences. Dr Tang reported consulting fees and payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing or educational events from Medtronic, Abbott Structural Heart, Boston Scientific, Siemens Healthineers, Shockwave Medical, Peija Medical, Shenqi Medical Technologies, NeoChord, and JenaValve. 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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