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STATE-OF-THE-ART REVIEW

Emerging Approaches to Management of Left Ventricular Outflow Obstruction Risk in Transcatheter Mitral Valve Replacement

Mackram F. Eleid, MD,[a] Jeremy D. Collins, MD,[b] Paul Mahoney, MD,[c] Eric E. Williamson, MD,[b] Ammar M. Killu, MBBS,[a] Brian K. Whisenant, MD,[d] Charanjit S. Rihal, MD, MBA,[a] Mayra E. Guerrero, MD[a]

ABSTRACT

An increasing number of patients with mitral valve disease are high risk for surgery and in need of less invasive treatments including transcatheter mitral valve replacement (TMVR). Left ventricular outflow tract (LVOT) obstruction is a predictor of poor outcome after TMVR, and its risk can be accurately predicted using cardiac computed tomography analysis. Novel treatment strategies that have shown efficacy in reducing risk of LVOT obstruction after TMVR include pre-emptive alcohol septal ablation, radiofrequency ablation, and anterior leaflet electrosurgical laceration. This review describes recent advances in the management of LVOT obstruction risk after TMVR, provides a new management algorithm, and explores forthcoming studies that will further advance the field. (J Am Coll Cardiol Intv 2023;16:885–895) © 2023 by the American College of Cardiology Foundation.

Mitral valve disease, one of the most common forms of valvular heart disease, is increasing in prevalence with the aging population.[1] Given the increasing number of patients considered high risk for conventional surgery in need of alternative treatment options, transcatheter mitral valve replacement (TMVR) has garnered great interest, with a wide range of devices currently under investigation. A major obstacle to TMVR is the risk of left ventricular outflow tract (LVOT) obstruction, which occurs due to displacement of the anterior mitral leaflet toward the LVOT by the transcatheter valve. The risk of LVOT obstruction is proportional to the degree of left ventricular hypertrophy with associated narrowing of the LVOT and is more likely to be present in patients with severe mitral annular calcification (MAC) owing to shared predisposing factors.[2] Significant LVOT obstruction causing hemodynamic compromise is a predictor of 1-year mortality in patients with severe MAC undergoing TMVR.[3] Risk of LVOT obstruction is a common reason for ineligibility for TMVR after computed tomography (CT) analysis.[4] Despite careful screening and efforts to mitigate LVOT obstruction risk in the prospective MITRAL (Mitral Implantation of Transcatheter Valves) trial, LVOT obstruction with hemodynamic compromise still occurred in 9% of patients.[5] Risk of LVOT obstruction can be accurately predicted by gated cardiac CT analysis using virtual prosthesis modeling to measure the neoLVOT area, with a cutpoint of <189 mm^2 measured at end-systole predictive of significant LVOT obstruction.[6] Several novel

From the [a]Department of Cardiovascular Medicine, Mayo Clinic, Rochester, Minnesota, USA; [b]Department of Radiology, Mayo Clinic, Rochester, Minnesota, USA; [c]Sentara Heart Hospital, Norfolk, Virginia, USA; and the [d]Division of Cardiology, Intermountain Heart Institute, Salt Lake City, Utah, USA.

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ABBREVIATIONS AND ACRONYMS

ASA = alcohol septal ablation

CT = computed tomography

HCM = hypertrophic cardiomyopathy

LAMPOON = anterior leaflet electrosurgical laceration

LVOT = left ventricular outflow tract

MAC = mitral annular calcification

RFSA = radiofrequency septal ablation

THV = transcatheter heart valve

TMVR = transcatheter mitral valve replacement

and effective strategies to mitigate the risk of LVOT obstruction have been developed including pre-emptive alcohol septal ablation (ASA),[7] pre-emptive radiofrequency ablation of the septum,[8,9] and anterior mitral leaflet laceration using catheter-based electrocautery techniques.[10-12] Accordingly, we sought to develop an algorithm employing these recently developed innovative techniques for the optimal management of LVOT obstruction risk before TMVR.

ASSESSMENT OF LVOT OBSTRUCTION RISK BEFORE TMVR

The gold standard method for assessment of the LVOT anatomy and procedural TMVR planning is gated cardiac CT angiography, which provides excellent spatial resolution and clear definition of left ventricular structure. All patients being considered for TMVR require a gated cardiac CT assessment for determination of procedural candidacy. An exception to this is patients who have a degenerated mitral bioprosthesis being considered for mitral valve-in-valve therapy, in which case CT may be unnecessary if echocardiography imaging does not show evidence of significant LVOT narrowing or obstruction at baseline. Preprocedure predictive 3-dimensional modeling using computer-aided design to simulate the neoLVOT has been validated in patients undergoing balloon-expandable TMVR (mitral valve-in-valve, valve-in-ring, or valve-in-MAC),[13] with a cutpoint of 189 mm^2 or less, having 100% sensitivity and 97% specificity for predicting an increase in the LVOT gradient of 10 mm Hg or more after TMVR.[6] Using dedicated software, the mitral valve annulus is defined and baseline LVOT area is measured (**Figure 1**). Given the changing geometry of the LVOT during the cardiac cycle, it is important to measure the LVOT area during systole when the cavity size is the smallest. The specific timing of smallest LVOT area may vary depending on conduction delay and other factors. Subsequently, a virtual valve is overlaid into the desired mitral annular position, which allows for measurement of the neoLVOT area.[14] An additional measurement of the skirt neoLVOT can also be measured, which predicts the LVOT area if the anterior mitral leaflet does not cover the open cells of the transcatheter valve stent frame.[15] Notably, the neoLVOT area will vary with different TMVR devices, and the fixed cutpoints discussed in this review are conservative in order to minimize risk of LVOT obstruction. Additionally, neoLVOT prediction algorithms have limitations including interobserver variability in positioning of the transcatheter heart valve (THV) and measuring landmarks. Further work to achieve better standardization and automation, as well as external validation, of neoLVOT prediction algorithms is needed. Additionally, forthcoming advances in software technology may enable a more "active" virtual implantation that may be superior to the current "passive" method, which does not take into account prosthesis tilting and surrounding tissue characteristics.

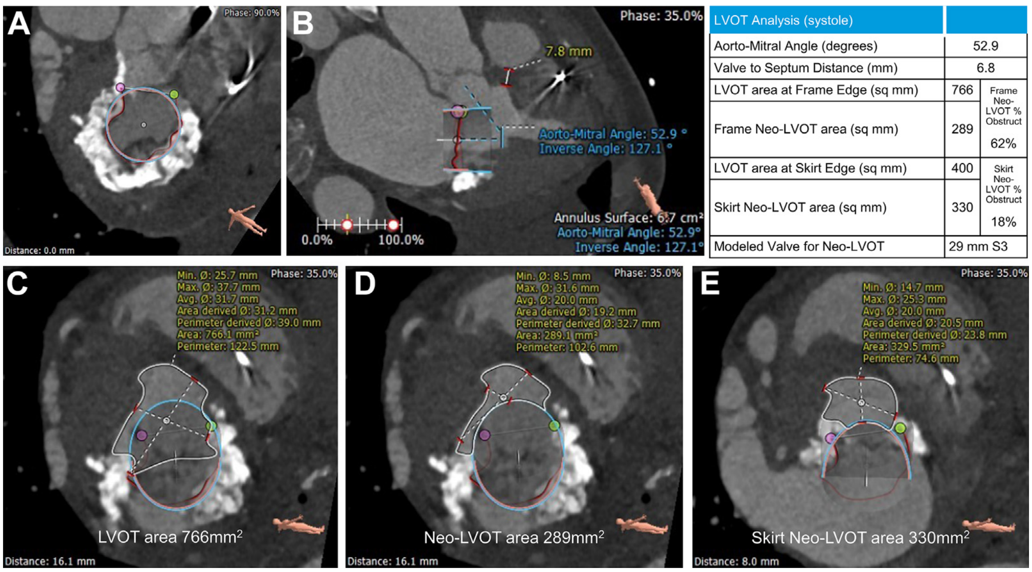
HIGHLIGHTS

- LVOT obstruction is a predictor of poor outcome after transcatheter mitral valve replacement (TMVR) and is a common reason for exclusion from TMVR therapy.
- Several novel therapeutic strategies have shown efficacy at reducing risk of LVOT obstruction to facilitate TMVR. This review introduces a new algorithm for approach to avoidance of LVOT obstruction before TMVR with septal reduction strategies that include alcohol septal ablation and radiofrequency ablation, as well as anterior mitral leaflet electrosurgical laceration.
- Several forthcoming therapies under study will further characterize the optimal management of LVOT obstruction risk before TMVR, including novel techniques to reduce septal thickness, dedicated anterior leaflet modification devices, and dedicated TMVR devices designed to prevent anterior leaflet displacement toward the LVOT.

IMPACT OF TMVR DESIGN ON LVOT OBSTRUCTION RISK

The self-expanding double-framed nitinol Tendyne device (Abbott) has a tapered shape in the left ventricular cavity that allows for less protrusion into the LVOT compared with cylindrical-shaped devices.[16] The Intrepid device (Medtronic) similarly has a low profile with minimal protrusion into the LVOT, thus lowering LVOT obstruction risk. As a result, the neoLVOT for Tendyne or Intrepid in a given patient

FIGURE 1 **Assessment of LVOT Obstruction Risk Using Cardiac Computed Tomography**



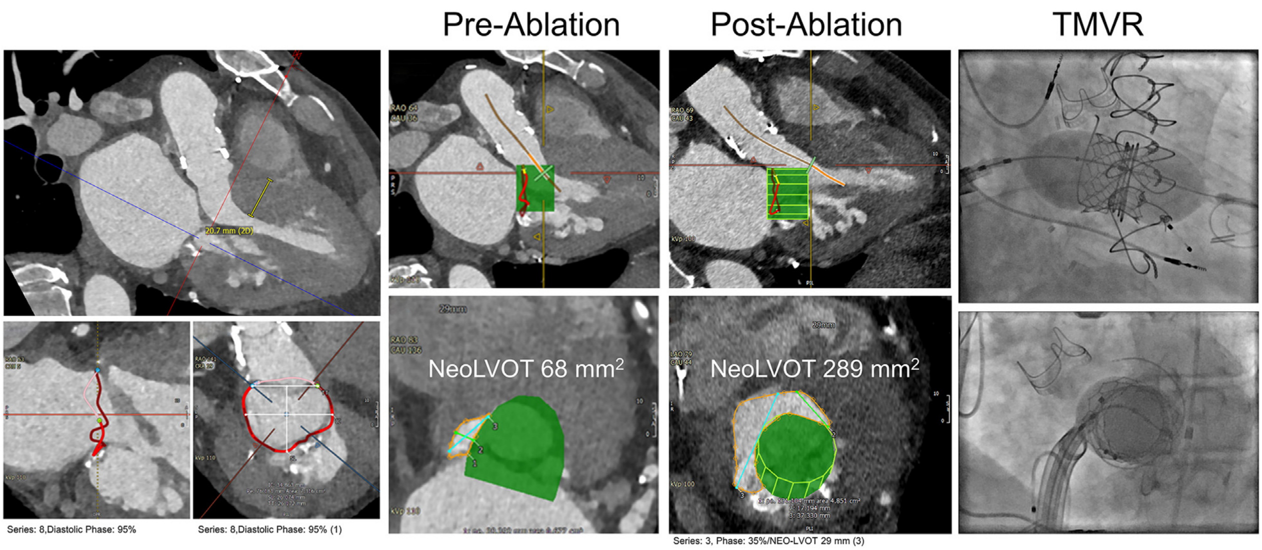
(A) A virtual transcatheter valve is overlaid on the intended site of implantation in the mitral annulus. **(B)** In the long-axis view, the septal thickness and virtual valve frame-to-septum distance are measured along with the aortomitral angle. **(C)** The left ventricular outflow tract (LVOT) area is measured. **(D and E)** The neoLVOT area and skirt neoLVOT areas are then measured.

will typically be slightly larger than with a cylindrical-shaped valve such as SAPIEN 3 (Edwards Lifesciences). However, patients with severe left ventricular hypertrophy and small cavity often still have a small predicted neoLVOT <200 mm^2 even with these devices. Dedicated valve systems such as SAPIEN M3 3 (Edwards Lifesciences)[17] and other forthcoming devices under early feasibility investigation such as Innovalve (Innovalve Biomedical)[18] actively secure or "wrap" the anterior leaflet away from the LVOT and allow for yet lower LVOT obstruction risk. Despite these features, additional LVOT obstruction mitigation may still be required. Figure 2 shows a patient with mixed mitral stenosis and regurgitation with mild annular calcification who ultimately became a candidate for TMVR with SAPIEN M3 as a result of LVOT enlargement with septal ablation.

TECHNIQUES TO REDUCE RISK OF LVOT OBSTRUCTION

ALCOHOL SEPTAL ABLATION. Alcohol septal ablation was originally developed for treatment of hypertrophic cardiomyopathy (HCM) in the 1980s[19] and is recommended as a Class I indication for treatment of severely symptomatic LVOT obstruction refractory to medical therapy.[20] The technique involves percutaneous cannulation of the coronary artery in the cardiac catheterization laboratory using a guiding catheter, advancing a 0.014-inch wire and over-the-wire balloon into the septal perforator branch supplying the basal anterior septum. Appropriate vessel location is confirmed with multiple angiographic cinefluoroscopic views, and the balloon is inflated to occlude blood flow to the septal perforator (Figure 3). Once septal artery occlusion is confirmed, selective angiography through the lumen of the balloon is performed to confirm appropriate location, lack of collateral flow, and lack of flow back into the left anterior descendent artery. Microbubble contrast is also injected with simultaneous transthoracic echo to confirm opacification of the interventricular septum in the desired location with no opacification of papillary muscles or other undesired structures. Once confirmed, 0.5 to 1 mL of 98% dehydrated ethanol is slowly infused over a period of 5 to 10 minutes. Occasionally, larger amounts up to 1 to 2 mL are used, depending on the degree of hypertrophy, size of vessels, and number of vessels treating.[21] In general, a smaller volume of ethanol has been used to date (<1 mL) when preparing the septum for TMVR, compared with treatment of obstructive HCM (typically >1 mL). A temporary pacemaker is placed before the procedure due to

FIGURE 2 **LVOT Enlargement to Facilitate TMVR**

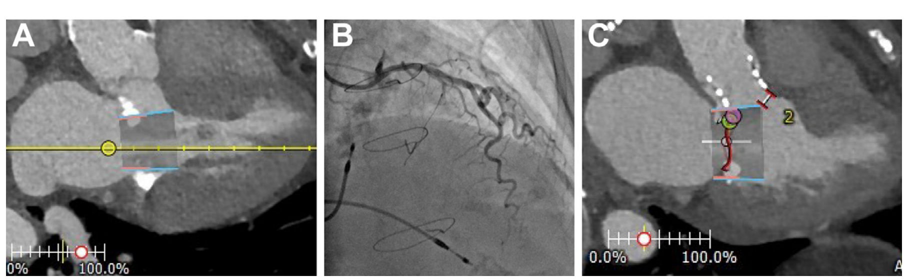


A patient with mixed mitral stenosis and regurgitation with only mild annular calcification who ultimately became a candidate for transcatheter mitral valve replacement (TMVR) with SAPIEN M3 as a result of left ventricular outflow tract (LVOT) enlargement with septal ablation is shown.

risk of atrioventricular block during and after the procedure. Akinesis of the septum is confirmed with echocardiography, and final angiography is used to confirm lack of flow in the septal perforator. If needed, additional alcohol to achieve septal obliteration or an additional septal perforator can be treated sequentially during the same procedure. Risks of alcohol septal ablation include conduction system disease (right bundle branch block occurs in up to 50% of patients, and high-grade atrioventricular block in 24%).[22] Other risks include mortality, stroke, major vascular complications, and pericardial effusion in 1% to 2%, and 30-day survival is 98% at experienced centers.[22]

The success of ASA critically depends upon the colocalization of coronary perfusion and septal hypertrophy. Typically, the most proximal septal perforator branch or sub-branch is the vessel supplying the basal anterior septum, which is usually the desired region of ablation to enlarge the LVOT. It is imperative to confirm in multiple angiographic views (both right and left anterior oblique) that the target vessel is indeed a septal perforator rather than a diagonal branch, as well as to confirm with

FIGURE 3 **Alcohol Septal Ablation to Facilitate TMVR in Mitral Annular Calcification**



(A) A patient with aortic stenosis, mitral stenosis and severe left ventricular hypertrophy has a small neoLVOT and prominent basal septal hypertrophy. **(B)** Alcohol septal ablation is performed using 1 mL of dehydrated alcohol in the first septal perforator. **(C)** 4 weeks following septal ablation, the basal septal hypertrophy is decreased with a resulting increase in the virtual valve-to-septum distance. Additionally, interval transcatheter aortic valve replacement has also been performed. Abbreviations as in Figure 2.

simultaneous contrast echocardiography imaging before performing ablation.

Recently, ASA has been employed for TMVR-related LVOT obstruction, initially as a bailout strategy,[23] followed by implementation of ASA as a pre-emptive tactic[7] to avoid acute LVOT obstruction after TMVR in patients who did not have resting LVOT obstruction. In the initial experience of pre-emptive ASA before TMVR in 30 patients included in a multicenter registry, the mean amount of alcohol injected was 1.6 $\pm$ 0.7 mL, and the median increase in neo-LVOT surface area post-ASA was 111.2 mm^2 (IQR: 71.4 to 193.1 mm^2).[7] Five patients (16.7%) required pacemaker implantation post-ASA, and 30-day mortality was 6.7% (2/30 patients). After ASA, TMVR was performed successfully in 100% of attempted cases.

An updated single-center experience of ASA before TMVR in 22 patients was recently published and compared outcomes to patients undergoing ASA for HCM during the same time period.[24] Mean total volume of alcohol injected was higher in the HCM group (1.4 $\pm$ 0.49 mL vs 0.8 $\pm$ 0.2 mL; $P < 0.001$). Mean LVOT area increased significantly after ASA in the patients undergoing TMVR (135 $\pm$ 89 mm^2 vs 233 $\pm$ 111 mm^2; $P < 0.001$). The incidence of post-ASA complete heart block requiring a permanent pacemaker tended to be higher in the TMVR group (35% vs 21%; $P = 0.195$). No patients in either group had ventricular arrhythmia or stroke. Major bleeding complications were 4% in the HCM group and 0 in the TMVR group. The 30-day mortality was 4% in the HCM group and 0 in the TMVR group; however, 1 patient died at 37 days in the TMVR group, presumably from late heart block. This study importantly demonstrated that safety of ASA before TMVR is comparable to that of the established indication for patients with HCM.

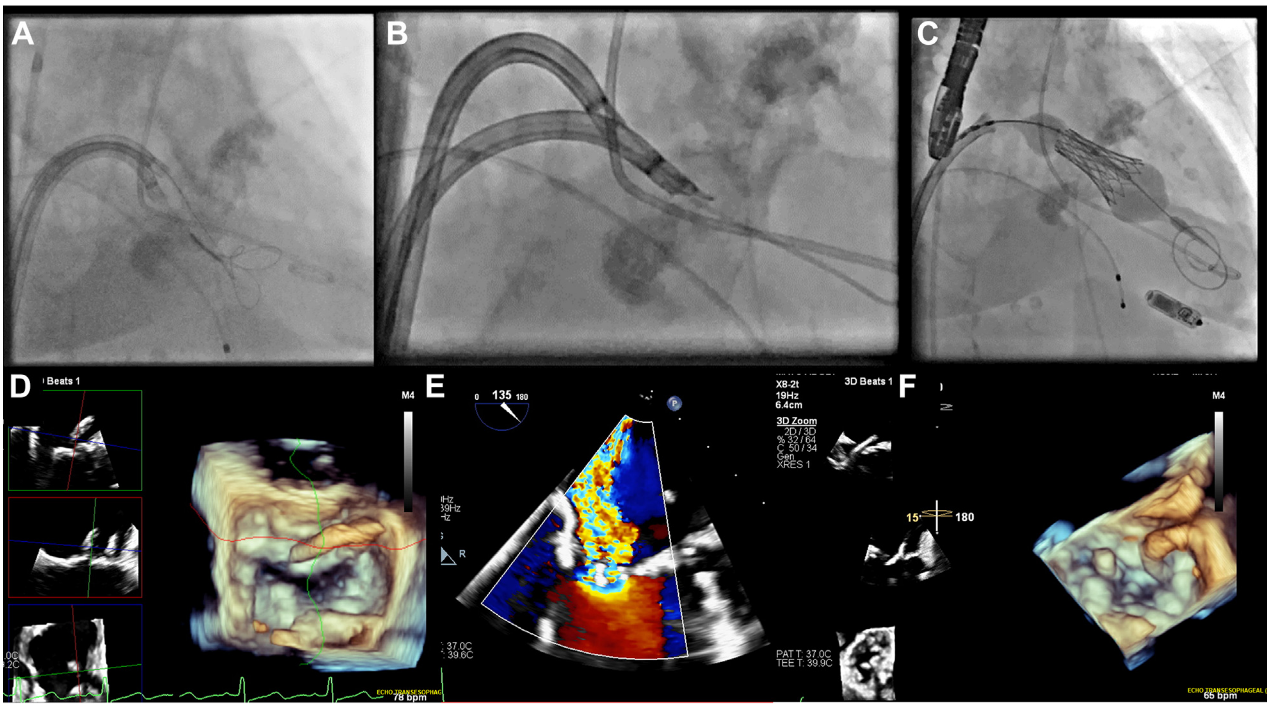
RADIOFREQUENCY SEPTAL ABLATION. Radiofrequency septal ablation (RFSA) is a newer procedure that has emerged as a strategy to reduce septal thickness in preparation for TMVR.[8,9] The first cases have been recently reported in patients in whom ASA was inadequate to reduce the neoLVOT and in patients in whom other techniques were not viable options.[21]

The RFSA is typically performed under general anesthesia using femoral access and is facilitated using a 3-dimensional electroanatomical mapping system and intracardiac echocardiography. Either transseptal or retroaortic approaches can be used for left-sided septal ablation. Left atrial transseptal access is obtained using a large-curl Agilis sheath (Abbott Cardiovascular) via the right femoral vein under intracardiac echocardiography and fluoroscopic guidance, and therapeutic anticoagulation is administered. An externally irrigated, navigation-enabled ablation catheter is advanced to the area of septal thickening. The proximal left ventricular conduction system is tagged and ablation at each site performed for 60 to 90 seconds with up to 50 W power using 0.9% saline and, on occasion, 0.45% saline and D5W solution, at an irrigation rate of 17 to 30 mL/min. Ablation is continued until the local electrogram is diminutive, which often correlates with extensive lesion formation on intracardiac echocardiography. Loss of myocardial capture with high-output pacing (up to 20 mA at 9-ms pulse width) is determined before moving to a new site.

In the initial case series of 4 patients undergoing RFSA before balloon-expandable TMVR for severe MAC, 3 patients had previously undergone ASA and had inadequate reduction in the neoLVOT area, and 1 did not have anatomy suitable for alcohol septal ablation due to the septal perforator supplying an anomalous chord to the papillary muscle.[25] Three patients developed complete heart block and underwent pacemaker implantation, whereas 1 had a pre-existing pacemaker. RFSA resulted in an 11% to 30% reduction in end-diastolic septal thickness compared with baseline (neoLVOT area increased, ranging from 30 to 80 mm^2) and allowed for TMVR to be performed in all 4 patients, 2 of whom had concomitant laceration of the anterior mitral leaflet to further augment the neoLVOT during TMVR.

ELECTROPORATION. Pulsed electric field ablation, also known as electroporation, is an established treatment modality for solid tumors, an emerging therapy for the treatment of cardiac arrhythmias, but is also being applied experimentally in animal studies to thin the myocardium as a potential alternative therapy to septal ablation.[26] Electroporation uses electric fields applied in the form of short direct current pulses that result in increased cell membrane permeability to ions and molecules. This increase in membrane permeability then leads to cellular apoptosis and/or necrosis depending on the electric field, thus achieving tissue ablation. Potential advantages of electroporation include avoidance of thermal injury risks associated with radiofrequency ablation such as coronary artery injury, atrioventricular conduction block, and thrombogenicity. The current experience is limited to animal studies, with 1 recent study in 8 canines demonstrating consistent transmural lesions indicating efficacy in ablation.[27] Observed complications include ventricular arrhythmias and evidence of myocardial edema that can be modified by reducing pulse intervals.

FIGURE 4 **Anterior Mitral Leaflet Laceration to Facilitate TMVR**



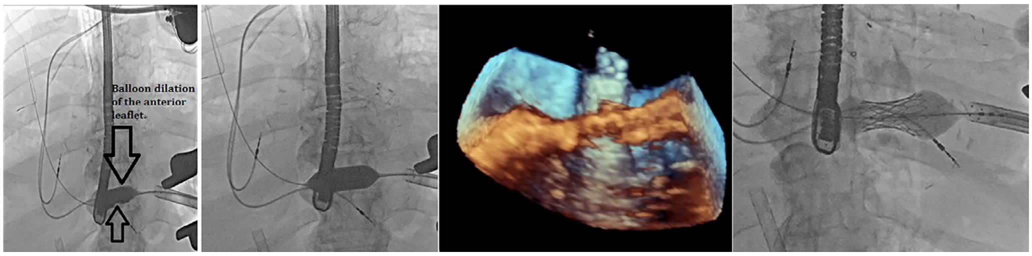
The simplified transseptal LAMPOON (percutaneous laceration of the anterior mitral leaflet to prevent left ventricular outflow tract obstruction) approach involves anterior leaflet perforation with wire followed by wire snaring **(A)**, anterior leaflet laceration with balloon pump support **(B)** to facilitate balloon expandable transcatheter mitral valve replacement (TMVR) **(C)**. Transesophageal echocardiography guidance is used to confirm appropriate catheter positioning **(D)**, and following laceration, there is an increase in mitral regurgitation **(E)** and evidence of anterior leaflet splitting on 3-dimensional imaging **(F)**.

Further studies are needed to fully define the safety and role of this technique.

ELECTROSURGICAL ANTERIOR MITRAL LEAFLET LACERATION. Percutaneous laceration of the anterior mitral leaflet to prevent left ventricular outflow tract obstruction (LAMPOON) was first described in 2017 to avoid LVOT obstruction and facilitate TMVR in patients with prior annuloplasty or severe MAC.[28] With this technique, longitudinal splitting of the anterior leaflet is achieved, which allows the anterior leaflet to splay when the transcatheter valve stent frame is expanded. As the anterior mitral leaflet is displaced toward the LVOT, the laceration results in spreading apart of the 2 halves of the leaflet such that the LVOT is not obstructed by the leaflet. The initial technique was more complex with use of both antegrade and retrograde entry into the left ventricle along with an arteriovenous rail. In the original technique, 2 retroaortic catheters were positioned (1 in the LVOT and another retrograde across the mitral valve, stabilized using a transseptal arteriovenous rail). Subsequent iterations have been developed to allow the laceration to be accomplished all through an antegrade transseptal approach (Figure 4).

The antegrade LAMPOON technique is complex and involves obtaining transfemoral transseptal access with 2 steerable guiding catheters containing 2 coronary guiding catheters (typically a 6-F JR4 and 6-F MP), 1 of which (MP) is used to direct an electrified guidewire (Astato wire, Asahi Intecc) in an insulated Piggyback Wire Converter (Teleflex Medical) across the center and base of the anterior mitral leaflet. The JR4 catheter is positioned in the left ventricle and contains a snare that is used to capture the end of the electrified guidewire. This wire is externalized to create a guidewire loop that is then electrified to lacerate the anterior mitral leaflet along the centerline from base to tip. Because this typically results in worsening or development of severe mitral regurgitation, an intra-aortic balloon pump can be used during the procedure for left ventricular unloading and maintaining stable hemodynamics.

FIGURE 5 Balloon-Assisted Anterior Leaflet Translocation



Two-dimensional and 3-dimensional transesophageal echocardiographic view of the balloon dilation of the anterior leaflet. Valve position under the fluoroscopy image used with permission from Helmy et al.[29]

Following the laceration, the TMVR procedure is then performed with expansion of the transcatheter valve within the mitral annulus.

In the initial experience of the LAMPOON procedure, 15 patients with severe MAC and 15 patients with prior annuloplasty underwent LAMPOON-facilitated TMVR.[10] In this study, all patients underwent successful laceration of the anterior leaflet and TMVR, although 10% of patients still experienced significant LVOT obstruction with a gradient >30 mm Hg despite anterior leaflet laceration. Thirty-day survival was 93%. In the initial experience of the simplified antegrade LAMPOON technique in 9 patients undergoing TMVR, laceration of the anterior leaflet was achieved with considerably shorter procedure times compared with the initial technique, and no patients developed LVOT obstruction although there was 1 procedural mortality (11%) related to ventricular wire perforation.[12] An additional version of the LAMPOON that lacerates from tip to base has also been developed for patients with an anterior mitral annuloplasty ring or a bioprosthesis that protects the aortomitral curtain.[11]

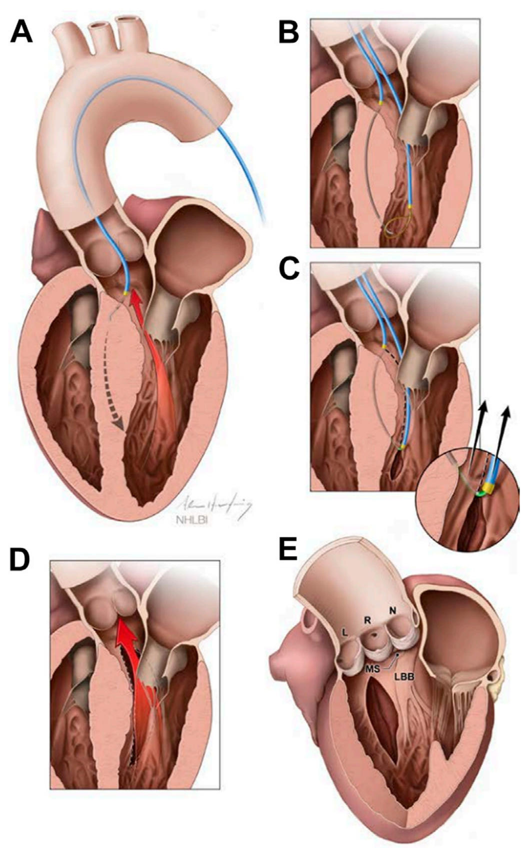
OTHER NOVEL EMERGING TECHNIQUES. In small series, other techniques to reduce LVOT obstruction before TMVR have been performed with evidence of feasibility. BATMAN (Balloon-Assisted Translocation of the Mitral ANnterior leaflet) involves insertion of a needle via a transapical approach, and advancing the needle "through," perforating the anterior mitral leaflet, through which a wire is placed in the left atrium (Figure 5). Over the wire, a 20-mm valvuloplasty balloon was positioned "within" the anterior leaflet and inflated, leading to translocation of the anterior mitral leaflet. TMVR was then performed via a transapical approach with the transcatheter valve placed at the perforation of anterior leaflet, translocating it to the posterior aspect of the annulus. This technique was achieved in 3 patients.[29] Work is ongoing to translate this technique to a transseptal approach.

Another new technique termed SESAME (SEptal Scoring Along the Midline Endocardium) has been devised to "score" the septum via a retroaortic approach (Figure 6). In this technique, the basal septum is engaged between the native right-left commissure and the nadir of the right coronary sinus with a 6-F HS guiding catheter and tip-amputated guidewire followed by a microcatheter. A chronic total occlusion guidewire is then exchanged and passed through the intended course of the basal septum, snared in the left ventricle with a second retroaortic guide, a flying V is created on the guidewire, and electrocautery is applied with traction on both guiding catheters, thereby lacerating/scoring the basal septum. This technique has so far been reported in 1 patient before TMVR.[30] The feasibility and efficacy in terms of magnitude of septal thickness reduction with this technique is still under study. A summary of different approaches to LVOT obstruction risk reduction following TMVR is summarized in the Central Illustration.

TMVR PATIENT MANAGEMENT ALGORITHM

The approach we use consists of positioning the virtual transcatheter valve in the anticipated implantation location and measuring the virtual THV frame neoLVOT and skirt neoLVOT (Figure 7). When the frame neoLVOT is <200 mm^2 and the skirt neoLVOT is <200 mm^2, the interventricular septum is assessed to determine whether hypertrophy is present and whether ablation of the basal septum is feasible. We use a diastolic septal thickness cutoff of 10 mm or more to determine whether ablation can be

FIGURE 6 Endocardial Septal Scoring



(A) A stiff guidewire is navigated through the interventricular septum. **(B)** The guidewire with microcatheter support reenters the left ventricular cavity into a snare. **(C)** Traction applied during electrification to create the myotomy. **(D)** Following transcatheter SEptal Scoring Along the Midline Endocardium (SESAME), the muscle splays increasing space in the left ventricular outflow tract, with increased blood flow. **(E)** The SESAME laceration avoids the conduction system. The **arrows** indicated pulling force direction that is applied to achieve the septal scoring. L = left cusp; LBB = left bundle branch; MS = membranous septum; N = noncoronary cusp; R = right cusp. Image used with permission from Khan JM, Bruce CG, Greenbaum AB, et al. Transcatheter myotomy to relieve left ventricular outflow tract obstruction: the septal scoring along the midline endocardium procedure in animals. *Circ Cardiovasc Interv*. 2022;15(6):e011686. https://doi.org/10.1161/CIRCINTERVENTIONS.121.011686

performed. Importantly, by eliminating systolic contraction, ASA may be helpful in preventing LVOT obstruction even when the septum is not abnormally thickened. The coronary anatomy is examined as well to confirm that ablation is possible. After ASA is performed, the CT is repeated 4 weeks later to reassess TMVR candidacy. If ASA is not feasible or does not successfully increase the skirt neoLVOT to >200 mm^2, radiofrequency ablation is considered. The anticipated increase in neoLVOT area with ASA is 100 to 110 mm^2 based on published data.[7,24]

In patients with a frame neoLVOT <200 mm^2, but a skirt neoLVOT >200 mm^2, we assess whether LAMPOON is feasible. Suitable candidates include: 1) patients with a central portion of the anterior leaflet that is free of calcification that can facilitate wire traversal and electrocautery laceration; and 2) patients in whom there is adequate anterior annular calcium or other anterior structures that can anchor the transcatheter valve without the integrity of the body of the anterior leaflet. Importantly, LAMPOON can reduce anterior anchoring stability of the transcatheter valve so care must be taken to avoid lacerating the leaflet too close to the leaflet base. In patients with favorable anatomy, LAMPOON-facilitated TMVR is then performed. The decision to proceed with ASA first vs LAMPOON first in patients with neoLVOT <200 mm^2 may also be influenced by the specific local expertise in each procedure, as well as the procedural risks, with consideration of pacemaker risk with ASA and procedural complexity/other risks associated with LAMPOON.

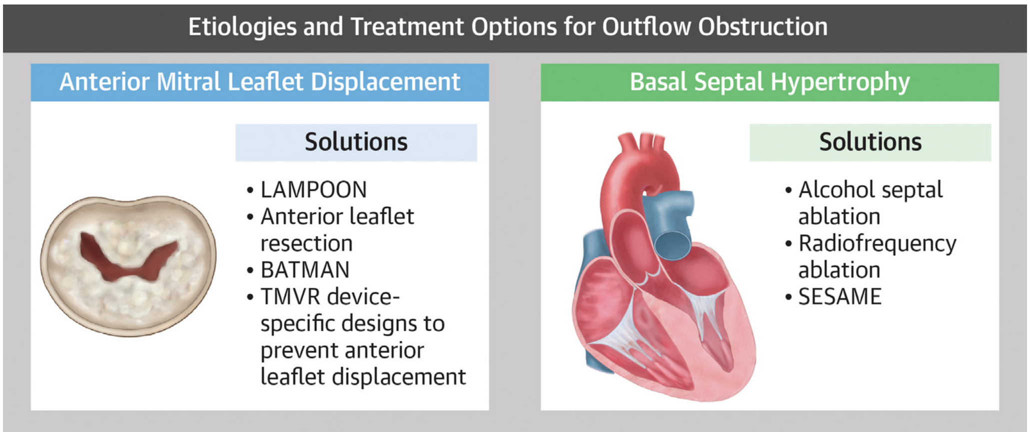
An additional consideration that may affect LVOT modification technique is that valve-in-MAC and valve-in-ring with the SAPIEN 3 valve may be complicated by paravalvular leak when the sealing skirt is atrial to the annular plane. Such leaks can be readily addressed with deployment of a second SAPIEN 3, thereby sealing the stent frame cells with the valve leaflets. LAMPOON division of the anterior leaflet facilitates and demands flow through the open cells of the SAPIEN THV to maintain sufficient flow through the LVOT, and its effect is lost after valve-in-valve deployment due to displacement of the prosthetic valve leaflets. Alcohol septal ablation may be preferable with anatomies prone to PVL below the sealing skirt such as saddle-shaped mitral rings or narrow landing zone annular calcification.

If significant interaction between the transcatheter valve and myocardium is expected (defined as an overlap of 2 mm or more), then ablation to reduce this interaction is considered with repeat CT in 4 weeks. Patients with a frame neoLVOT >200 mm^2 who have otherwise suitable anatomy can proceed to TMVR without any LVOT modifications.

FUTURE DIRECTIONS

The neoLVOT management algorithm proposed in this review is currently being used in the prospective MITRAL 2 (MITRAL II Pivotal Trial [Mitral Implantation of TRAnscatheter vaLves];

CENTRAL ILLUSTRATION **Major Factors and Solutions for Left Ventricular Outflow Tract Obstruction Following Transcatheter Mitral Valve Replacement**



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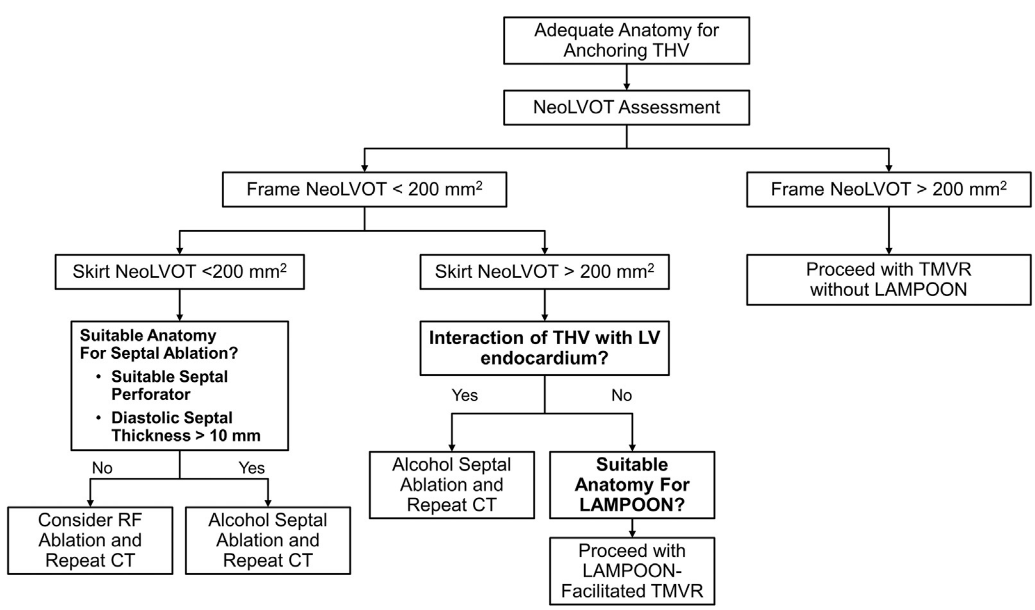
Current strategies are targeted either toward septal reduction or anterior leaflet modification in order to reduce risk of left ventricular outflow tract obstruction after transcatheter mitral valve replacement (TMVR). BATMAN = balloon-assisted anterior leaflet translocation; LAMPOON = percutaneous laceration of the anterior mitral leaflet to prevent left ventricular outflow tract obstruction; SESAME = SEptal Scoring Along the Midline Endocardium.

FIGURE 7 **Algorithm for Management of LVOT Obstruction Risk Before TMVR**



CT = computed tomography; LV = left ventricular; RF = radiofrequency; THV = transcatheter heart valve; other abbreviations as in Figures 2 and 4.

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NCT04408430) and outcomes of this approach will be forthcoming. As experience with LVOT modification techniques in TMVR grows, more data regarding patient selection and efficacy of these approaches will become available. Future study of clinical and anatomical predictors of optimal response to ASA, LAMPOON, and other techniques to facilitate TMVR is needed. Additionally, experience with ASA before implantation of dedicated TMVR devices is growing and will help inform its use for non-balloon-expandable TMVR therapies. Dedicated leaflet laceration devices that overcome the complex techniques required for LAMPOON are also currently under investigation (The ShortCut™ Study Protocol; NCT04952909).

Finally, several dedicated TMVR devices under investigation include design features that inherently avoid LVOT obstruction by actively securing the anterior leaflet away from the LVOT. It is anticipated that more patients will become candidates for TMVR as these devices become available, given that LVOT obstruction risk is a common reason for screen failure at present. The role of these various TMVR devices in treatment of patients with mitral valve disease and risk of LVOT obstruction will be addressed in forthcoming studies.

CONCLUSIONS

Several new and effective techniques are available to help reduce the risk of LVOT obstruction in TMVR.

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Dr Mahoney has served as a consultant for Edwards Lifesciences and Medtronic. Dr Killu has served as a consultant for Boston Scientific; and has received honoraria from Biosense Webster. Dr. Guerrero has received institutional research grant support from Edwards Lifesciences; and has served as consultant for Abbott Structural Heart and Medtronic. All other authors have reported that they have no relationships relevant to the contents of this paper to disclose.

ADDRESS FOR CORRESPONDENCE: Dr Mackram F. Eleid, Mayo Clinic, Department of Cardiovascular Medicine, 200 First Street SW, Rochester, Minnesota 55905, USA. E-mail: Eleid.mackram@mayo.edu. Twitter: @EleidMack, @MayraGuerreroMD.

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KEY WORDS ablation, left ventricular outflow tract obstruction, transcatheter mitral replacement

APPENDIX For an interactive version of the Central Illustration, please see the online version of this paper.