

Echocardiographic Imaging in Transcatheter Mitral and Tricuspid Valve Therapies

Essential tips, challenges, and future perspectives in imaging for transcatheter valve therapies.

BY OSAMA SOLIMAN, MD, PhD, FACC, FESC; CHUN CHIN CHANG, MD;
AND THOMAS MODINE, MD, PhD, MBA

Functional moderate and severe mitral regurgitation (MR) and tricuspid regurgitation (TR) have been associated with increased mortality.¹ Over the past decade, transcatheter valve therapy (TVT) for patients with MR and, more recently, TR has increasingly gained importance as an alternative to more invasive and relatively higher-risk surgeries. TVT is complex and requires intense imaging preparation and guidance, so there is an increasing demand for comprehensive imaging to optimize success. Echocardiography is versatile, readily available, and easily repeated at bedside. Therefore, it plays a key role for TVT in preplanning,

intraprocedural guidance, and postprocedural follow-up. In this article, we aim to highlight the general as well as tailored use of echocardiography for transcatheter mitral valve (TMV) and transcatheter tricuspid valve (TTV) therapy (see the *Summary of Key Concepts in TVT Imaging* sidebar).

THE NEED FOR ECHOCARDIOGRAPHY IN TVT

The mitral and tricuspid valves are three-dimensional (3D) apparatuses with complex geometry surrounded by important anatomic structures (Figure 1). The mitral annulus and tricuspid annulus are dynamic 3D structures. Three-dimensional

transesophageal echocardiography (TEE) can provide better images of the annuli, but the reproducibility of multislice CT (MSCT) is higher. MSCT can be applied to evaluate the coronary artery, coronary sinus, and inferior vena cava, and it simulates neo-left ventricular outflow tract for TMV replacement.

A comprehensive imaging assessment is important for the treatment approach. Most TMV and TTV therapies replicate surgical procedures

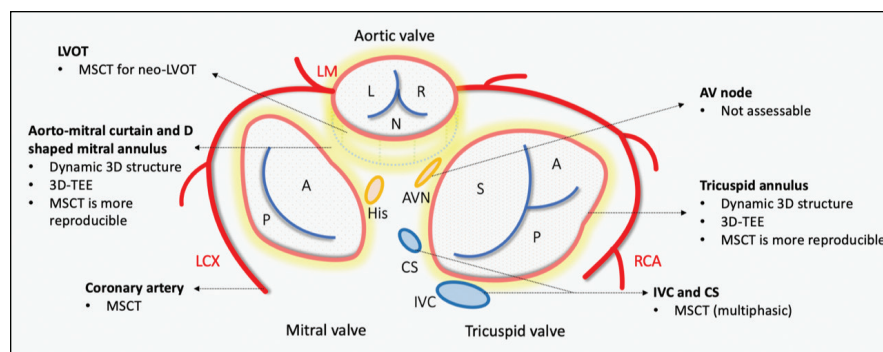


Figure 1. Imaging modalities for anatomic assessment of the mitral and tricuspid valves. A, anterior leaflet; AVN, atrioventricular node; CS, coronary sinus; IVC, inferior vena cava; L, left leaflet; LCX, left circumflex artery; LM, left main artery; LVOT, left ventricular outflow tract; N, noncoronary leaflet; P, posterior leaflet; R, right leaflet; RCA, right coronary artery; S, septal leaflet.

SUMMARY OF KEY CONCEPTS IN TVT IMAGING

- There is currently no stand-alone imaging modality that can fulfill all requirements for a safe, successful procedure. Echocardiography, CT, and fluoroscopy are to be optimally combined.
- Imaging is paramount in patient selection, mainly through confirming disease severity, anatomic eligibility for specific devices, device success, and assessment of complications.
- In terms of echocardiography, 3D echocardiography is superior to 2D echocardiography. If the latter is used, biplane and simultaneous multiplane 2D imaging are essential.
- TEE is the main echocardiography modality used during procedural guidance.
- Intracardiac echocardiography (ICE) is utilized in some centers as an alternative to TEE. However, ICE is limited by high cost, the need for significant training, a limited scan sector, and the absence of 3D capabilities in most commercially available probes.
- Knowledge of anatomy, device components, and implantation process is a must for sonographers.
- Assessment of complex nonplanner mitral or tricuspid annulus should preferably be performed on 3D dynamic images over the entire cardiac cycle. Annulus disjunction is an important caveat when measuring annulus size and preplanning for device implantation.
- Ensuring coaxiality of the device to the landing zone is a key step for a successful procedure.
- Leaflet characterization includes size, morphology, calcification, coaptation distance, and coaptation length.
- Subvalvular apparatus characterization includes extra or secondary chordae and papillary muscle heads.
- Local remodeling is an important determinant of procedural success.
- Valve replacement is the only procedure that could eliminate regurgitation.
- Echocardiographic endpoints of device and procedural success, as well as optimal regurgitation reduction, are yet to be clearly defined. Future definitions should include prosthesis, leaflet, and stent/frame structural changes on follow-up.

for valve repair.^{2,3} Valve repair can be performed at the level of the annulus (with annuloplasty), leaflets (with edge-to-edge repair), or subvalvular apparatus (neo-chordae implantation). If repair is not feasible, a nondedicated device, such as one built for the aortic position, or a device built for TMV or TTV replacement can be used.

Thus, the sonographer should have adequate step-by-step knowledge of the procedure and the appropriate devices, wires, and catheters. Before the procedure, the sonographer must confirm disease severity, patient eligibility, and appropriate device sizing. During the procedure, the sonographer must properly identify the device, wire, and catheter positions and properly communicate with the operator. Furthermore, anticipation and timely detection of procedural complications on echocardiography is a crucial role of sonographers. Both two-dimensional (2D) and 3D transthoracic echocardiography (TTE) and TEE have critical roles in the planning, guidance, and follow-up of TVT, and 3D TEE is indispensable for procedural guidance in current practice.

A GLOBAL APPROACH TO ECHOCARDIOGRAPHY IN TVT

Our clinical routine is to follow a stepwise approach when using echocardiography for patients with suspected or established functional MR or TR. We begin with comprehensive 2D and 3D echocardiography to assess valve regurgitation, morphology (annulus dilatation, leaflet coaptation, tethering), and the mechanism and etiology of regurgitation. Second, we confirm regurgitation severity via a semiquantitative approach including, at least, regurgitant jet vena contracta, proximal isovelocity surface area radius, effective regurgitant orifice area (EROA), and regurgitation fraction. Third, we assess the hemodynamic impact regarding volume and coexisting pressure overload. Fourth, we identify the presence and severity of other-sided valvular disease. Fifth, we assess the presence and severity of left- and right-sided heart chamber remodeling. Finally, we combine these data to allow for an optimal heart team decision.

ECHOCARDIOGRAPHY FOR TMV THERAPY

MitraClip (Abbott Structural Heart) is the only FDA-approved device for the treatment of native and, recently, functional MR.³ More than 80,000 MitraClips have been implanted worldwide,⁴ and thus, this article mainly focuses on the use of echocardiography during a MitraClip procedure. The first task is a comprehen-

TABLE 1. PREPROCEDURAL ASSESSMENT FOR THE MITRACLIP PROCEDURE FOR MR

Area of Assessment	Key Role of Echocardiographic Guidance	Preferred Echocardiography Modality
Diagnosis and disease severity	Assess MR severity using an integrated approach including MR jet VC, PISA radius, EROA, and RF—at minimum; the MR jet VC and PISA radius should preferably be measured and averaged from two orthogonal views to account for the frequently elliptic MR jet	2D TTE, 2D TEE, 3D TEE
Annulus	Assess the mitral annulus—a dynamic, complex, saddle-shaped structure with its highest level in the septal-lateral level	3D TEE is mandatory, allowing for full dynamic imaging of the 3D annulus over the entire cardiac cycle; MSCT is a good alternative to 3D TEE
Leaflets	- Assess the leaflet motion to provide the Carpentier type I, II, or III classification, as well as the localization of leaflet(s) pathology - Measure the CL, CD, tenting depth, systolic TA, and tenting volume as important markers of the patient's eligibility for MitraClip repair	2D TTE, 2D TEE, 3D TEE
Subvalvular apparatus	Assess the chordae tendinae, papillary muscle insertion, and IPD	2D TTE, 2D TEE, 3D TEE
Global LV remodeling	Assess LV end-diastolic and end-systolic dimensions, LV volume, and LV SI (calculated as $SI = 1/4 L/d$, where L is the major axis and d is the minor axis)	2D TTE, 3D TEE
Local LV remodeling	Assess apical displacement of posteromedial papillary muscle, second order cords, and IPD	2D TTE, 3D TEE
Mitral valve deformation	Assess systolic TA, CD, and PLA	2D TTE, 3D TEE
Anatomic suitability	Assess annular size (3D dynamic), annular calcification (severity), TA and tenting volume, CL, CD, PLA, presence of ring or prosthesis (for "valve-in-ring" or "valve-in-valve" procedures), and left atrial and LV size	2D TTE, 3D TEE

Abbreviations: CD, coaptation distance; CL, coaptation length; EROA, effective regurgitant orifice area; IPD, interpapillary muscle distance; LV, left ventricle; MR, mitral regurgitation; MSCT, multislice CT; PISA, proximal isovelocity area; PLA, posterolateral angle; RF, regurgitation fraction; SI, sphericity index; TA, tenting area; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography; VC, vena contracta.

sive preprocedural assessment, which involves establishing the diagnosis, MR severity, and anatomic suitability for MitraClip repair (Table 1). Then, sonographers should follow mandatory steps to provide echocardiographic guidance during the procedure. The main steps for the MitraClip procedure include: (1) perform trans-septal puncture; (2) introduce the guide catheter and clip delivery system into the left atrium (LA); (3) position the MitraClip above the mitral valve; (4) advance the MitraClip into the left ventricle (LV); and (5) grasp the mitral leaflet and deploy the MitraClip. The role of echocardiographic guidance for each step is presented in Table 2 and Figure 2.

Criteria for MitraClip Procedure Success

After MitraClip implantation, and in the absence of complication criteria on echocardiography, procedural success is characterized by reduction of MR by two

or more grades in comparison to baseline, a residual mitral effective orifice area $\geq 1.5 \text{ cm}^2$, and a mean transmitral gradient $< 5 \text{ mm Hg}$. Additionally, residual MR jets are characterized by spraying nature and multiplicity after implantation. The 3D TEE planimetry of MitraClip EROA after implantation correlates well with cardiac magnetic resonance.⁵ Therefore, the use of 3D TEE is superior to 2D TEE and to quantitative Doppler interrogation of the residual MR, and it is preferred for planimetry of the mitral valve area.⁶

ECHOCARDIOGRAPHY FOR TTV THERAPY

Similar to TMV repair, transcatheter treatments of TR include techniques that replicate surgical repair procedures at the annulus, leaflet, and/or subvalvular levels. These TTVs are most often replicates of suture annuloplasty or ring annuloplasty. Currently, the most widely used technique in the tricuspid valve position is the off-

TABLE 2. INTRAPROCEDURAL GUIDANCE FOR THE MITRACLIP PROCEDURE FOR MR

Step	Key Role of Echocardiographic Guidance	Views	Preferred Echocardiography Modality
1. Cross the interatrial septum	Confirm location: midposterior/posterosuperior	- ME bicaval view (90°–110° angle) for midposterior/posterosuperior location - ME short-axis view to visualize tenting point	2D TEE, 3D TEE
2. Advance guide catheter into the LA	Confirm distance: 4 cm above the mitral annulus	ME four-chamber view for measurement of the distance between septal tenting and mitral annulus	2D TEE, 3D TEE
3. Advance the MitraClip delivery system into the LA	Visualize the clip system exiting the guide catheter to ensure no injury to surrounding anatomy	2D TEE, beginning in the ME bicaval view and turning the TEE probe	2D TEE
4. Position and align MitraClip in the LA	- Adjust the open clip perpendicular to the commissure in the LA - Visualize the clip position over location of MR jet	3D TEE en face surgical view to ensure visualization of the guide catheter tip, which is sometimes out of the 2D plane 2D TEE ME using color Doppler in the commissural view on biplane imaging to verify mediolateral and anteroposterior clip location relative to MR jet	3D TEE, 2D biplane imaging
5. Open the MitraClip arms in the LA	Visualize opening the clip arms in the LA and then orient the clip perpendicular to the mitral orifice at the intended grasping location	3D TEE surgical en face view	3D TEE
6. Precisely position the MitraClip system to straddle the mitral leaflets	Guide the clip delivery system to straddle the mitral valve in a precise position, confirmed in the mediolateral and anteroposterior position	3D TEE en face surgical view to ensure visualization of the guide catheter tip, which is sometimes out of the 2D plane	3D TEE
7. Position MitraClip in the LV below the mitral leaflets	- Visualize the transition from the LA to the LV - Immediately communicate changes from the expected trajectory with the primary operator	ME 2D commissural view with biplane imaging	2D TEE biplane imaging
8. Grasp the leaflets	Verify optimal grasp of both anterior and posterior mitral leaflets as the clip is withdrawn from the LV toward the leaflets	2D TEE commissural view or the three-chamber view with biplane imaging of grasping for verification of both leaflets in gripper arms 3D surgical view to visualize tissue bridge across leaflets	2D biplane imaging, 3D TEE
9. Verify reduction of MR	When clip arms are closed, verify MR reduction	2D color Doppler, using multiple views where MR reduction is best visualized	2D biplane imaging, 3D TEE
10. Procedural success	- Assess residual mitral valve area(s) - Assess transvalvular mitral gradient - Withdraw clip delivery system and guide catheter - Assess flow across the interatrial septum	2D color Doppler and 3D color Doppler planimetry of EROA from ME views - Pulsed-wave Doppler for pulmonary vein flow reversal - Continuous-wave Doppler for peak/mean transmitral gradients - Planimetry of mitral valve neo-orifices using 3D multiplanar reconstruction of ME views	2D biplane imaging, 3D TEE
11. Repeat the process with a second clip if needed	Position the second clip relative to the first clip	—	—

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; EROA, effective regurgitant orifice area; LA, left atrium; LV, left ventricle; ME, midesophageal; MR, mitral regurgitation; TEE, transesophageal echocardiography.

label use of edge-to-edge repair with the MitraClip device.^{7,8} In general, most steps for mitral valve repair using the MitraClip device also apply to tricuspid valve repair, except for atrial-septal crossing.

Essential Differences: Tricuspid Versus Mitral Valve Imaging

Imaging of the tricuspid valve is more challenging than in patients with MR. The tricuspid valve is an anterior structure, and it lies in the field far from the TEE probe insonation beam. Therefore, TTE is more appropriate than TEE for imaging of the tricuspid valve. Consequently, TTE is important in preprocedural assessment of the tricuspid valve. Essential imaging concepts for patients with TR on echocardiography are listed in Table 3.⁹ TR severity is confirmed on multiple 2D TTE views using 2D with Doppler imaging of TR jet(s). Then, 3D dynamic measurements of the tricuspid valve annulus are performed, ideally on 3D TEE¹⁰ or simultaneous, multiplane, 2D imaging.¹¹ The three leaflets of the tricuspid valve are difficult to simultaneously visualize on 2D echocardiography¹²; therefore, 3D echocardiography or a transgastric view is mandatory during procedural guidance, and a deep esophageal view with the TEE probe inferior to the LA and more directly behind the right atrium is more appropriate for tricuspid valve leaflet visualization.

Furthermore, standard transgastric and deep transgastric views are commonly used to guide tricuspid valve leaflet repair.¹³ These views are essential for the assessment of leaflet morphology, coaptation gap, device landing zone, and location of the main TR jet.^{13,14} Additionally, quantitative assessment of TR severity before and after TTV therapy has less established cut-off values in comparison with MR severity assessment,^{6,15} although a new TR severity grading scheme that differs from MR has been proposed to include massive and torrential TR.¹⁶

Anatomic Considerations

TTV procedures are more challenging than TMV procedures because patients with significant TR have several anatomic and pathophysiologic constraints. Most patients undergoing early TTV repair/replacement device feasibility studies have extensive right heart remodeling with loss of anatomic landmarks, which complicates catheter navigation

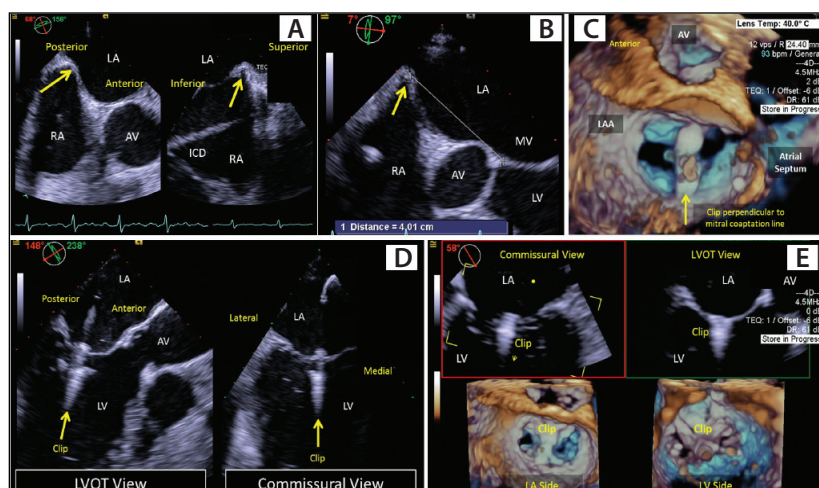


Figure 2. Stepwise intraprocedural imaging of the MitraClip procedure for MR. TEE guidance of transeptal puncture in the superior and posterior aspect of the interatrial septum (A, B). Biplane 3D TEE image with septal tenting (A). Measurement of septal tenting from the plane of the mitral annulus (B). Three-dimensional TEE guidance of clip orientation perpendicular to the mitral coaptation line on the atrial side of the valve (C). Three-dimensional TEE biplane guidance of leaflet grasping by the clip on the ventricular side of the valve (D). The final result with a single clip deployed across the A2-P2 coaptation line (E). Reproduced with permission from the American College of Cardiology. Alter E, Jilaihawi H, Williams M, Saric M. Imaging in MV Interventions: MitraClip and Beyond... <http://www.acc.org>. Aug 06, 2018. Accessed May 14, 2019. <https://www.acc.org/latest-in-cardiology/articles/2018/08/06/13/25/imaging-in-mv-interventions>.

and interferes with proper positioning of repair/replacement devices. The sonographer has to identify preexisting device leads that might interfere with device delivery and deployment. Furthermore, imaging views and quality will depend on numerous patient characteristics (eg, mechanical valves in place, chest deformation, esophageal anatomy/pathologies) but also on the device used for repair.

Patient Selection

Data from TTV therapy studies are scarce. Most patients enrolled are currently inoperable or at “high surgical risk” with chronic functional TR. Due to the fact that patients with TR who are in need of intervention represent a very heterogeneous population, the role of imaging in patient selection is paramount to optimize clinical results and the effectiveness of TTV therapy. In general, key concepts include characterization of the annulus and leaflets (including coaptation distance and tethering), local and global right heart remodeling, and hemodynamic assessment of right-sided volumes and pressures.¹⁷

Echocardiography for Proper Sizing

The most important step in device sizing for TTV repair or replacement is the proper quantification of the

TABLE 3. ESSENTIAL IMAGING CONCEPTS FOR PATIENTS WITH TR UNDERGOING TTV THERAPY

Area of Assessment	Views	Preferred Echocardiography Modality
TR severity	On multiple TTE views and confirmed on TEE during the procedure: • 2D TTE apical four-chamber view • 2D TTE RV inflow • 2D TTE parasternal short-axis view • 2D TEE subcostal short- and long-axis views	2D grayscale, color Doppler, spectral Doppler
Annulus measurements	On multiple TTE or TEE views: • 2D TTE apical four-chamber view • 2D TTE RV inflow • 2D TTE parasternal short-axis view	3D TEE (ideally) or simultaneous multiplane 2D; confirm on MSCT
Leaflet visualization and measurement	On multiple TTE or TEE views: • 2D TTE apical four-chamber view • 2D TTE RV inflow • 2D TTE parasternal short-axis view • 2D TEE subcostal short- and long-axis views	Subcostal 2D TTE, transgastric 2D TEE, 3D TEE
RA and RV volume	On multiple TTE views or 3D full-volume acquisition	2D TTE or 3D full-volume acquisition
RV function	M-mode for TAPSE: • 2D TTE for RV global longitudinal strain • 2D TTE for fractional area change • 3D TTE for RVEF (less validated)	2D TTE
Estimated RV systolic pressure and pulmonary artery pressure	Based on TR jet velocity measurements from at least three views: • 2D TTE apical four-chamber view • 2D TTE RV inflow • 2D TTE parasternal short-axis view Inferior vena cava diameter and inspiratory collapse from subcostal 2D TTE views	2D TTE plus Doppler
Abbreviations: 2D, two-dimensional; 3D, three-dimensional; MSCT, multislice CT; RA, right atrium; RV, right ventricle; RVEF, right ventricular ejection fraction; TAPSE, tricuspid annular plane systolic excursion; TEE, transesophageal echocardiography; TR, tricuspid regurgitation; TTE, transthoracic echocardiography; TTV, tricuspid valve therapy.		

tricuspid valve annulus. This step is challenging because the tricuspid valve annulus diameter is significantly larger than other valves and is highly influenced by volume status, which might preclude appropriate sizing and device selection. In addition, the landing zone that includes the tricuspid valve annulus and surrounding myocardium is more fragile. Therefore, TTV devices are at increased risk of dehiscence. There is also a risk of injuring adjacent structures. Multimodality imaging—including echocardiography, CT, and fluoroscopy—is needed for proper device implantation and to avoid devastating complications such as cardiac tamponade or injury to the right coronary artery or atrioventricular node.

Echocardiographic Guidance of the MitraClip Procedure for TR Repair

Similar to MR repair, the most frequently used device to repair TR is the off-label use of the MitraClip device.

Two-dimensional TEE is a mandatory imaging modality for evaluating the suitability for TR edge-to-edge repair. Two-dimensional TEE biplane imaging with the primary view displaying the right ventricular inflow-outflow view is paramount to identify the tricuspid leaflets and visualize the coaptation of the septal-anterior and septal-posterior commissure with the secondary perpendicular plane.¹⁷ A stepwise approach for TR edge-to-edge repair is summarized in Table 4 and Figure 3.

Echocardiographic Determinants of Successful Repair

Ideally, success of TTV repair should be defined on echocardiography in the immediate postoperative period as reduction to mild or less regurgitation severity, associated with significant reduction of valve annulus diameter if previously dilated. Long-term success is reflected by reverse ventricular remodeling as well as reduction of ventricular afterload. Successful TTV repair

TABLE 4. INTRAPROCEDURAL GUIDANCE FOR EDGE-TO-EDGE REPAIR USING THE CLIP PROCEDURE FOR TR

Step	Key Role of Echocardiographic Guidance	Views	Preferred Echocardiography Modality
1. Position the guide catheter in the RA	Confirm location: the guide catheter should be positioned in the mid RA on 3D TEE	3D en face view from the RA perspective	3D TEE
2. Advance the guide catheter into the RA	Confirm distance: 2 to 3 cm above tricuspid leaflets	ME four-chamber view for measurement of the distance between the guide catheter and tricuspid leaflets; allow a distance that is sufficient to allow the clip to be advanced forward out of the guide catheter	2D TEE, 3D TEE
3. Advance the delivery system into the RA	Visualize the clip system exiting the guide catheter toward the leaflet(s) of choice	3D TEE en face surgical view in the transgastric position to ensure visualization of the guide catheter tip, which is sometimes out of the 2D plane	2D TEE, 3D TEE
4. Open the clip arms in the RA	Visualize opening the clip arms in the RA and then orient the clip perpendicular to the tricuspid orifice at the intended grasping location	2D biplane transgastric view and 3D-TEE en face view - Positioning and aligning the clip is better appreciated on a 2D biplane imaging	2D TEE, 3D TEE
5. Position clip below the leaflets	Visualize the transition from the RA to the RV	2D biplane transgastric view	2D TEE, 3D TEE
6. Grasp the leaflets	- Ensure coaxial "perpendicularity" by clip rotation, remove "septal-huggers" - Cross the leaflets for grasping - Reassess and correct for coaxiality "perpendicularity" in a transgastric view after leaflet crossing - Grasp leaflets and evaluate for adequate grasp	- ME RV inflow view: the most important view for aligning and grasping the anterior-septal and the posterior-septal commissure - Inverted four-chamber "grasping" view (ME 180°) as the primary plane in the biplane mode - Secondary (orthogonal) plane to display either the septal-anterior or septal-posterior leaflets (90°) - If anterior-posterior: use ME bicaval view	2D TEE, 3D TEE
7. Verify reduction of TR	When clip arms are closed, verify reduction of TR	- Transgastric short-axis view of the tricuspid valve 2D color Doppler, using multiple views where TR reduction is best visualized	2D TEE, 3D TEE
8. Procedural success	- Assess residual tricuspid valve area(s) - Assess transvalvular tricuspid gradient - Withdraw the delivery system and guide catheter	- Transgastric view short-axis of the tricuspid valve 2D color Doppler and 3D color Doppler planimetry of EROA from ME views - Pulsed-wave Doppler for hepatic vein flow reversal - Continuous-wave Doppler for peak/mean transtricuspid gradients - Planimetry of tricuspid valve neo-orifices using 3D multiplanar reconstruction of ME views	2D TEE, 3D TEE, and final TTE as baseline for follow-up
9. Repeat the process with a second clip if needed	Position the second clip relative to the first clip	—	—

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; EROA, effective regurgitant orifice area; ME, midesophageal; RA, right atrium; RV, right ventricle; TEE, transesophageal echocardiography; TR, tricuspid regurgitation; TTE, transthoracic echocardiography.

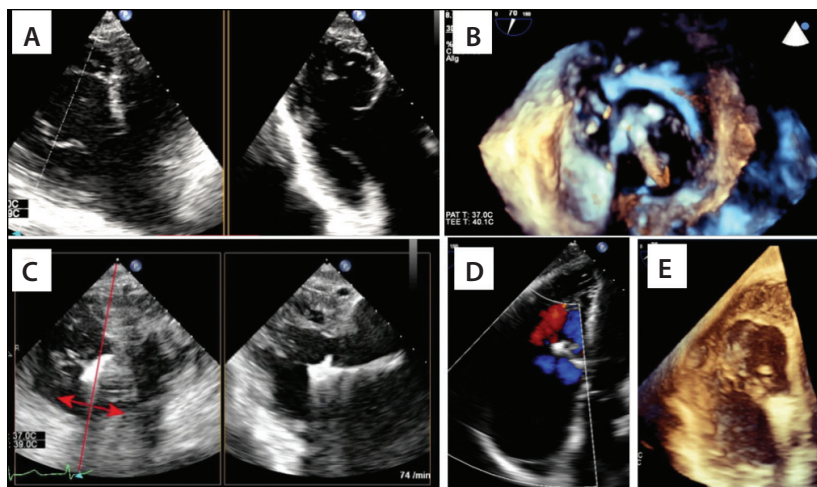


Figure 3. Stepwise intraprocedural imaging of the MitraClip procedure for TR. Biplane TEE transgastric view (A). Three-dimensional TEE image of clip positioning; the clip is positioned perpendicular to the closure line between the anterior and septal leaflet (B). Biplane TEE transgastric view guidance of clip positioning; continuous slight movement of the biplane beam from left to right in order to visualize both arms of the clip (C). TEE transgastric view (D). The final result after clipping (E).

is often coupled with patients' symptomatic and functional improvement. In contrast, device failure could be reflected as patient death or a need for reintervention. Currently, most candidates for TVT repair are patients with advanced TR, which is often associated with right ventricular dysfunction. Most of these patients are beyond the point of complete repair. The definition of successful repair is yet to be determined.

According to data on tricuspid valve surgery, a higher grade of pre-operative TR, larger tricuspid valve annuloplasty ring, presence of pacemaker leads through the tricuspid valve, combined mitral valve replacement rather than repair, depressed LV function, and advanced LV remodeling are associated with TR recurrence after surgery.¹⁸ Likewise,

OVERVIEW OF CONTEMPORARY DEVICES FOR MR AND TR

TRANSCATHETER DEVICES FOR MR

Leaflet repair

- MitraClip
- Pascal (Edwards Lifesciences)

Annuloplasty devices

- Cardioband (Edwards Lifesciences)
- Mitralign (Mitralign, Inc.)
- Carillon mitral contour system (Cardiac Dimensions, Inc.)
- Arto (MVRx, Inc.)

Chordal technique

- NeoChord DS1000 (NeoChord, Inc.)
- Harpoon (Edwards Lifesciences)

TMV replacement

- Tendyne (Abbott Structural Heart)
- Tiara (Neovasc, Inc.)

- Intrepid (Medtronic)
- CardiAQ (Edwards Lifesciences)
- Caisson (LivaNova PLC)
- HighLife (HighLife Medical, Inc.)
- Twelve (Medtronic)

TRANSCATHETER DEVICES FOR TR

Annuloplasty devices

- Trialign (Mitralign, Inc.)
- Cardioband
- TriCinch (4Tech Cardio Ltd.)
- Iris transcatheter annuloplasty ring (Boston Scientific Corporation)
- MIA (Micro Interventional Devices, Inc.)
- DaVinci (Cardiac Implants LLC)

Coaptation devices

- Regurgitant orifice occupation: Forma repair system (Edwards Lifesciences)
- Edge-to-edge repair: MitraClip
- Pascal

TTV replacement

- Gate (NaviGate Cardiac Structures, Inc.)
- Lux (Ningbo Jenscare Biotechnology Co., Ltd.)
- Trisol (TriSol Medical)
- TRiCares (TRiCares SAS)

Heterotopic (caval vein)

- TricValve (P&F Products Features GmbH in cooperation with Braile Biomedica)
- Tricento (NVT GmbH)

tethering distance has been associated with recurrent TR after annuloplasty.¹⁹ Patients with significant tricuspid valve leaflet tethering are nonsurgical candidates, and they are typically the first target population for transcatheter devices. On principle, annuloplasty alone will be insufficient in these patients. Thus, TVT devices should ideally also be able to address tethering. The *Overview of Contemporary Devices for MR and TR* sidebar summarizes transcatheter devices that are either currently available or under investigation for TVT.

OTHER COMPLIMENTARY IMAGING MODALITIES

There is no stand-alone imaging modality for TVT. MSCT could aid in preplanning for TVT that mimics surgical annuloplasty, spacer devices, and transcatheter valve replacement. It provides accurate 3D measurement and assessment of the annulus, device landing zone, relationship between the annulus and surrounding left circumflex (for TMV therapy) and right coronary artery (for TTV therapy), and annular tissue quantity and quality, as well as access selection and guidance. A stepwise approach is often used to assess suitability for a certain device, device sizing, vascular access, and the relationship of the tricuspid valve annulus to critical anatomic structures. Cardiac magnetic resonance provides accurate regurgitation fraction and could be used as an alternative to both echocardiography and CT for morphologic and functional assessment. The recent advent of fusion imaging allows superimposition of echocardiographic images to fluoroscopic images, which allows for better understanding of anatomic relationships and facilitates transcatheter procedures.

CONCLUSION

Transcatheter devices evolve rapidly, which could provide therapeutic alternatives to surgery in selected patients with significant MR or TR. Echocardiography plays a fundamental role in patients' screening, selection, procedure guidance, and postprocedural follow-up. Standardized echocardiographic imaging protocols could provide effective communication among the heart team members during the procedure and potentially optimize therapeutic outcomes. ■

echocardiography: comparison with 3D velocity-encoded cardiac magnetic resonance. *JACC Cardiovasc Imaging*. 2009;2:1245-1252.

6. Zoghbi WA, Asch FM, Bruce C, et al. Guidelines for the evaluation of valvular regurgitation after percutaneous valve repair or replacement: a report from the American Society of Echocardiography developed in collaboration with the Society for Cardiovascular Angiography and Interventions, Japanese Society of Echocardiography, and Society for Cardiovascular Magnetic Resonance. *J Am Soc Echocardiogr*. 2019;32:431-475.

7. Nickenig G, Kowalski M, Hausleiter J, et al. Transcatheter treatment of severe tricuspid regurgitation with the edge-to-edge MitraClip technique. *Circulation*. 2017;135:1802-1814.

8. Asmarats L, Puri R, Latib A, et al. Transcatheter tricuspid valve interventions: landscape, challenges, and future directions. *J Am Coll Cardiol*. 2018;71:2935-2956.

9. Soliman OI, McGhie J, Anwar AM, et al. Tricuspid valve disease: imaging using transthoracic echocardiography. In: Soliman OI, ten Cate FJ, eds. *Practical Manual of Tricuspid Valve Diseases*. Cham, Switzerland: Springer International Publishing; 2018:79-115.

10. Muraru D, Hahn RT, Soliman OI, et al. 3-dimensional echocardiography in imaging the tricuspid valve. *JACC Cardiovasc Imaging*. 2019;12:500-515.

11. McGhie JS, Menting ME, Vletter WB, et al. a novel 13-segment standardized model for assessment of right ventricular function using two-dimensional iRotate echocardiography. *Echocardiography*. 2016;33:353-361.

12. Anwar AM, Geleijnse ML, Soliman OI, et al. Assessment of normal tricuspid valve anatomy in adults by real-time three-dimensional echocardiography. *Int J Cardiovasc Imaging*. 2007;23:717-724.

13. Hahn RT. Imaging of the tricuspid valve: transoesophageal echocardiography. In: Soliman OI, ten Cate FJ, eds. *Practical Manual of Tricuspid Valve Diseases*. Cham, Switzerland: Springer International Publishing; 2018:117-126.

14. Hahn RT. State-of-the-art review of echocardiographic imaging in the evaluation and treatment of functional tricuspid regurgitation. *Circ Cardiovasc Imaging*. 2016;9:e005332.

15. Zoghbi WA, Adams D, Bonow RO, et al. Recommendations for noninvasive evaluation of native valvular regurgitation: a report from the American Society of Echocardiography developed in collaboration with the Society for Cardiovascular Magnetic Resonance. *J Am Soc Echocardiogr*. 2017;30:303-371.

16. Hahn RT, Zamorano JL. The need for a new tricuspid regurgitation grading scheme. *Eur Heart J Cardiovasc Imaging*. 2017;18:1342-1343.

17. Hausleiter J, Braun D, Orban M, et al. Patient selection, echocardiographic screening and treatment strategies for interventional tricuspid repair using the edge-to-edge repair technique. *EuroIntervention*. 2018;14:645-653.

18. Navia JL, Nowicki ER, Blackstone EH, et al. Surgical management of secondary tricuspid valve regurgitation: annulus, commissure, or leaflet procedure? *J Thorac Cardiovasc Surg*. 2010;139:1473-1482.e5.

19. Fukuda S, Song JM, Gillinov AM, et al. Tricuspid valve tethering predicts residual tricuspid regurgitation after tricuspid annuloplasty. *Circulation*. 2005;111:975-979.

Osama Soliman, MD, PhD, FACC, FESC

Department of Cardiology
Thoraxcenter, Erasmus University Medical Center
Rotterdam, the Netherlands
The Euro Heart Foundation
Amsterdam, the Netherlands
o.i.soliman@gmail.com
Disclosures: None.

Chun Chin Chang, MD

Division of Cardiology
Department of Medicine
Taipei Veterans General Hospital
Taipei, Taiwan
Disclosures: None.

Thomas Modine, MD, PhD, MBA

Jiao Tong University
Shanghai, China
Heart Valve Center, Institut Coeur Poumon
CHRU Lille
Lille, France
Disclosures: None.

1. Nath J, Foster E, Heidenreich PA. Impact of tricuspid regurgitation on long-term survival. *J Am Coll Cardiol*. 2004;43:405-409.

2. Abdelghani M, Schofer J, Soliman OI. Transcatheter interventions for tricuspid regurgitation: rationale, overview of current technologies, and future perspectives. In: Soliman OI, ten Cate FJ, eds. *Practical Manual of Tricuspid Valve Diseases*. Cham, Switzerland: Springer International Publishing; 2018:353-377.

3. Stone GW, Lindenfeld J, Abraham WT, et al. Transcatheter mitral-valve repair in patients with heart failure. *N Engl J Med*. 2018;379:2307-2318.

4. MitraClip: Transcatheter Mitral Valve Repair website. MitraClip frequently asked questions. <https://mitraclip.com/physician/mitraclip-faq>. Accessed May 21, 2019.

5. Marsan NA, Westenberg JJ, Ypenburg C, et al. Quantification of functional mitral regurgitation by real-time 3D