



Echocardiographic Imaging for Transcatheter Tricuspid Edge-to-Edge Repair

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The tricuspid valve has an intricate configuration, with its function dependent on the synchronized coordination of its various components.¹ The occurrence of functional tricuspid regurgitation (TR) in association with and without heart disease is linked with dismal clinical outcomes.^{2,3} Nevertheless, current management generally leans toward a “wait and see” approach because of elevated morbidity and mortality linked with isolated surgical tricuspid intervention.⁴ The rapid emergence of transcatheter procedures, which are generally lower up-front risk, can potentially alter treatment paradigms and provide additional pathways in the management of tricuspid valve disease.⁵

Several transcatheter devices are currently undergoing investigation for severe TR in a number of clinical trials.^{4–6} Although not yet approved by the US Food and Drug Administration, tricuspid edge-to-edge repair devices have demonstrated promising results in treating leaflet malcoaptation in severe or torrential TR.⁷ A set of standardized and reproducible imaging algorithms that can be used to image the anatomical and functional nature of the tricuspid valve, as well as for intraprocedural device navigation, will be necessary as transcatheter treatment of TR continues to expand.⁸ Furthermore, a comprehensive multimodality imaging approach consisting of computed tomography, echocardiography with transthoracic (TTE) and transesophageal (TEE) approaches and fluoroscopy will be paramount to help standardize the procedure for echocardiographers and interventionalists. In this context,

we will provide a step-by-step primer for pre- and intraprocedural echocardiographic imaging of tricuspid valve edge-to-edge repair.

Etiology

The causes of TR can be broadly divided into primary and secondary causes. Primary TR accounts for only about a quarter of the total cases.⁹ Etiologies for primary TR include rheumatic, neoplastic, traumatic, infective endocarditis, iatrogenic (after right ventricular biopsy, device lead tethering, etc), and congenital heart disease. Secondary (or functional) TR commonly occurs because of left-sided heart disease, atrial arrhythmias, and pulmonary hypertension.

Tricuspid Valve Anatomy

The tricuspid valve is a complex structure, requiring a fundamental understanding of the underlying anatomy.^{10,11} Structural or morphological alterations can alter the tricuspid valve framework, resulting in incompetent valve closure and TR.¹ The tricuspid apparatus is made of 3 leaflets, chordae tendinae, and 2 to 3 papillary muscles.^{12,13} The 3 leaflets are anterior, posterior, and septal and are not identical in size or distribution.⁴ The anterior leaflet is quadrangular in shape and is the largest, while the generally semicircular septal leaflet has the smallest radial length. The posterior leaflet is triangular and has multiple scallops and the smallest annular circumference. There have also been reports of 4 leaflets on the tricuspid valve, caused by incomplete formation of the anterior leaflet, and therefore a lateral leaflet remains.¹³

There are 2 to 3 papillary muscles, and the anterior papillary muscle is particularly vital, as it supplies chordae to the anterior and posterior leaflets. The posterior papillary muscle provides chordae to the posterior and septal leaflets, and the septal papillary muscle may be absent in almost 20% of patients.¹⁴ Chordae to the anterior and septal leaflets may also arise from the septal wall.

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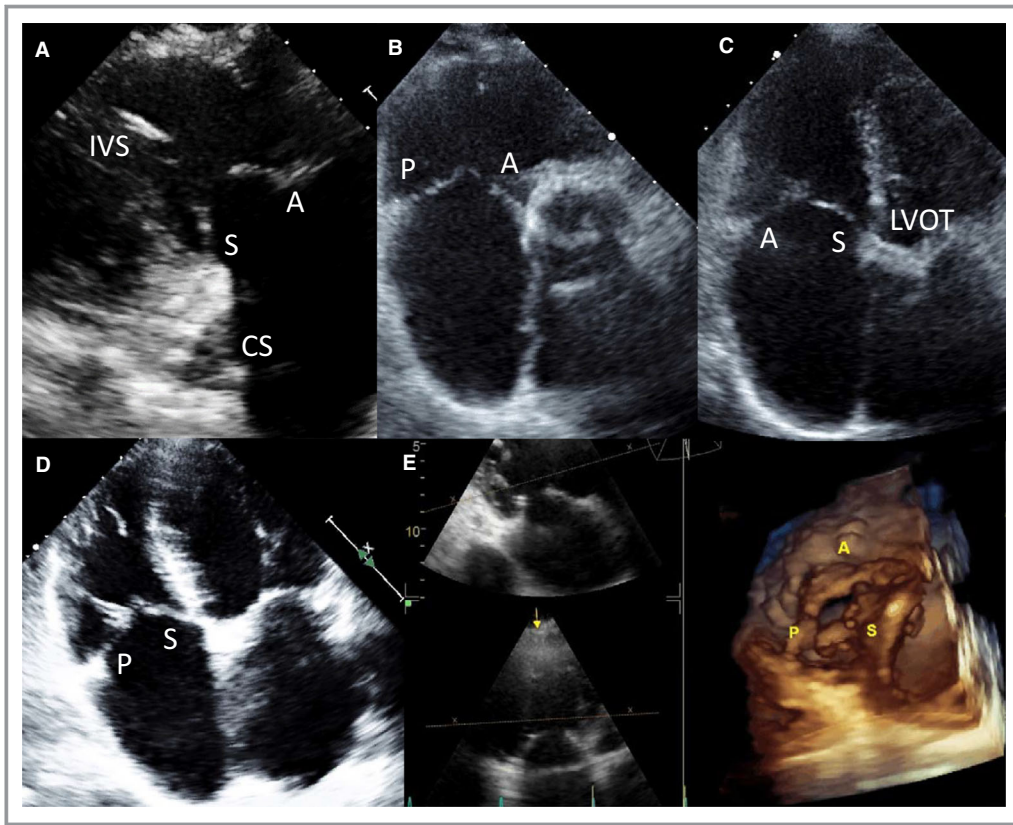


Figure 1. A, Transthoracic echocardiography demonstrating the right ventricular inflow view. The interventricular septum (IVS) is visualized, so the leaflets likely seen are septal (S) and anterior (A). In addition, the coronary sinus (CS) ostium is seen. B, The short-axis view at the level of the aortic valve on TTE shows the posterior (P) and anterior (A) leaflets. C, In the TTE apical 4-chamber with the probe anteriorly angulated to reveal the left ventricular outflow tract (LVOT), the anterior (A) and septal (S) leaflets are visualized. D, Probe angulation posteriorly allows visualization of the posterior (P) and septal (S) leaflets. E, A 3D TTE image can be used to clearly delineate the leaflets. 3D indicates 3-dimensional; TTE, transthoracic echocardiography.

Preprocedural Imaging

Transthoracic Echocardiography

A comprehensive TTE evaluation of the tricuspid valve and right heart chambers is recommended by the American Society of Echocardiography. Preprocedural imaging of the tricuspid valve is initially performed using TTE to evaluate systolic function and size of the right and left ventricles, the subvalvular apparatus, and grading the severity and mechanism of regurgitation. The complex nature of the valve makes it increasingly difficult to visualize all 3 leaflets in a single 2-dimensional (2D) plane, although progressive annular dilatation can result in a more circular and planar tricuspid configuration. Multiple transthoracic windows facilitate visualization of the tricuspid valve and identification of specific pathology^{4,5} with the help of certain anatomic landmarks. The commissure between the anterior and septal leaflets is generally close in proximity to the noncoronary cusp of the aortic valve, and the coronary sinus is near the commissure

between the septal and posterior leaflet. We first visualize the tricuspid valve in the parasternal right ventricular inflow view, where it is necessary to visualize the anterior and posterior walls to visualize the anterior and posterior leaflets.⁴ Visualization of the interventricular septum in this view reveals the septal and anterior leaflets (Figure 1A). Rotation of the transducer about 90° from the parasternal long-axis view will yield the short-axis view, where the anterior tricuspid valve leaflet is generally seen. However, the anterior and posterior leaflets may be seen with the aforementioned dilatation of the tricuspid annulus (Figure 1B). The next step is acquiring the 4-chamber view, where we can observe the septal and posterior leaflets. With slight anterior angulation, we can image the septal and anterior leaflets (Figure 1C and 1D). Despite these multiple views that can be obtained by the sonographer, the orientation of the ultrasound scanning plane will determine the leaflets ultimately visualized. This concept accounts for the possible deviation in the actual leaflets seen compared with the expected leaflets in each view. Therefore, the use of

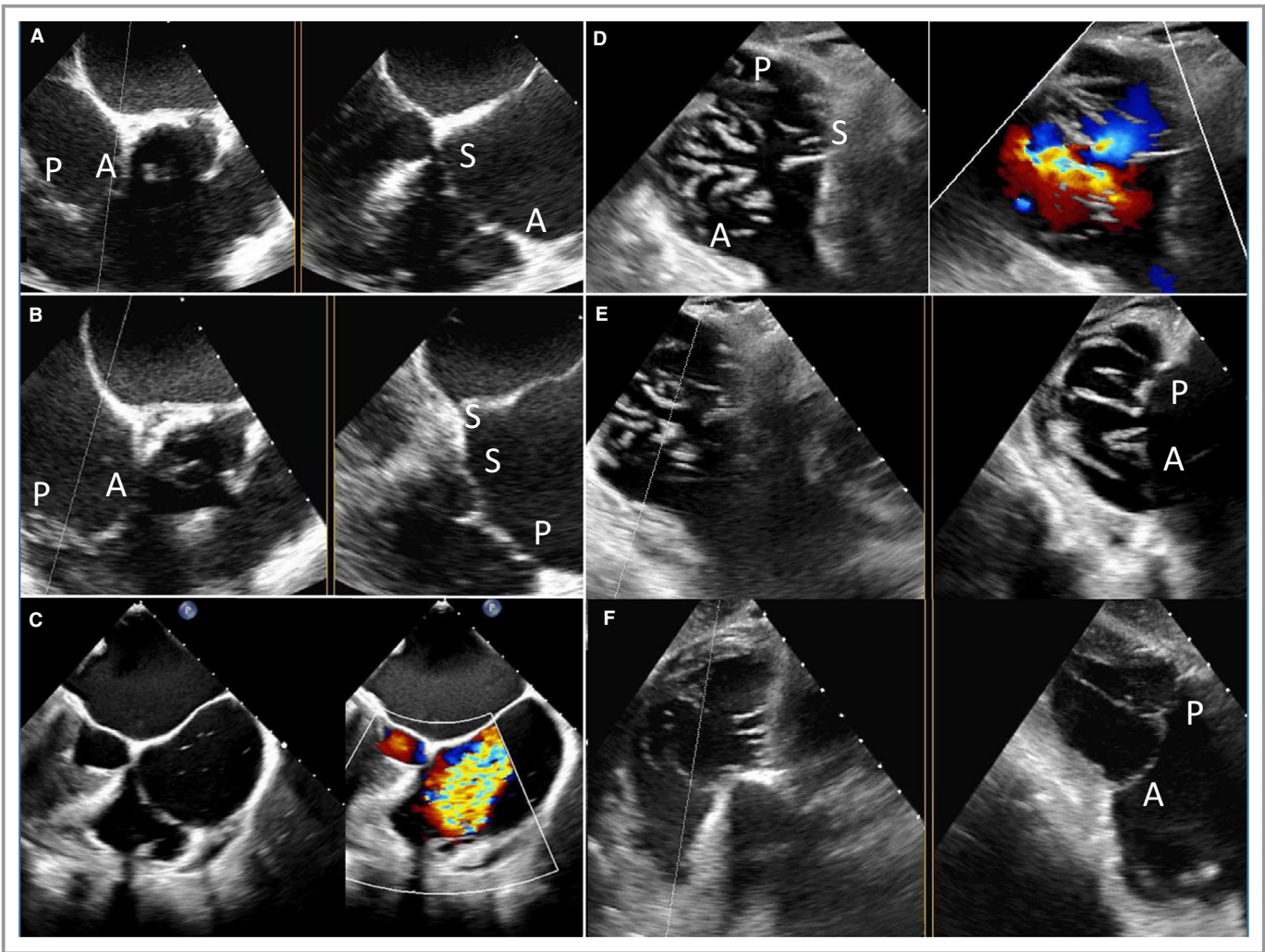


Figure 2. **A**, TEE in the midesophageal short-axis view of the aortic valve. The anterior (A) and posterior (P) leaflets are seen, and biplane imaging can be used to visualize one of those selected leaflets with the septal (S) leaflet in the right sided panel. **B**, The biplane cursor is directed over the posterior leaflet, so the septal (S) and posterior (P) leaflets are noted on the right. **C**, In the single 2D TEE view increased to 180°, the tricuspid leaflets can be seen with corresponding color flow Doppler. **D**, In TEE, the probe is advanced to the stomach. The 3 leaflets (A, anterior; P, posterior; S, septal) are labeled with color Doppler on the right-hand panel. **E**, Biplane imaging can once again be used to visualize specific leaflets. There is a coaptation gap between the anterior (A) and posterior (P) leaflets. **F**, In a different patient, prolapse of the anterior leaflet is seen. 2D indicates 2-dimensional; TEE, transesophageal echocardiography.

3-dimensional (3D) echocardiography in these cases can be helpful to confirm the leaflets actually seen; in addition, as the right-sided structures are anteriorly situated, 3D TTE may be superior to 3D TEE.¹⁵ Three-dimensional TTE can be performed in the parasternal, subcostal, and apical windows, as detailed in the prior section. The acoustic window with the best visualization of the tricuspid valve in 2D TTE is used to obtain the 3D data set for the valve. In these views, a full-volume image of the right heart and color Doppler image of the tricuspid valve should be obtained. The ideal 3D TTE acquisition can be obtained in the apical window because of the close position of the heart and tricuspid valve to the chest. The foreshortened 4-chamber view can be used in the

apical window to capture the entire tricuspid valve. Though the parasternal approach can achieve a higher spatial resolution, the overall quality is higher with the apical approach.

To achieve good 3D TTE acquisition, it is imperative that the 2D TTE image of the tricuspid valve provides clear demarcation of the tricuspid valve. The pyramidal imaging volume should be the smallest possible to maximize volume rate and spatial resolution but is adjusted accordingly to enable complete visualization of the entire valve and its neighboring anatomic landmarks to identify all 3 leaflets (Figure 1E). Temporal resolution can be increased by increasing the number of acquisition beats but can be limited by

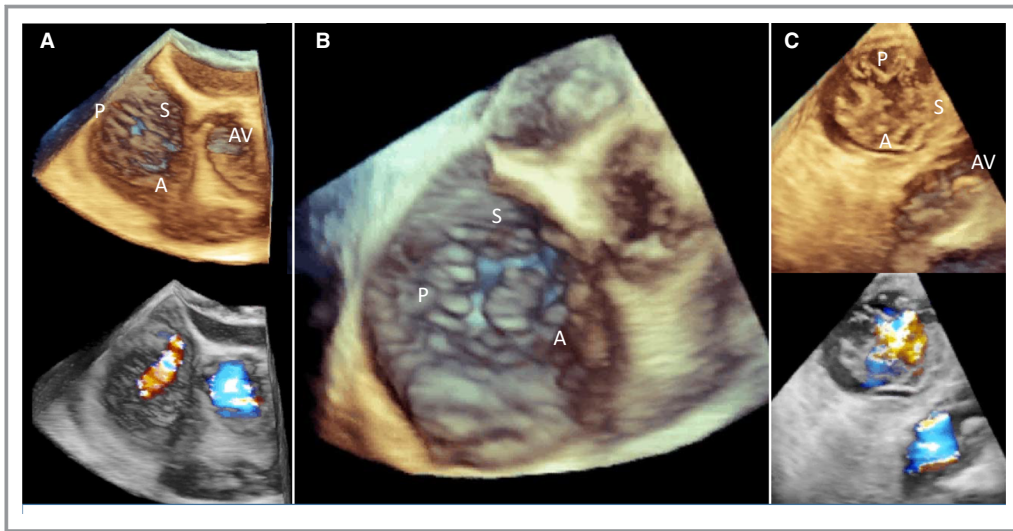


Figure 3. A, TEE with full-volume imaging from the midesophageal bicaval view with corresponding color Doppler below. B, This 3D TEE view at the same location is once again noted with leaflet identification using surrounding anatomical landmarks (Video S1). C, In a 3D image from the transgastric view on TEE, the 3 leaflets can again be clearly identified including the aortic valve (AV). Corresponding color Doppler below shows the tricuspid regurgitant jet, as well as aortic outflow (Videos S2 and S3). 3D indicates 3-dimensional; TEE, transesophageal echocardiography.

patient or sonographer motion, leading to stitch artifact.¹⁶ The subcostal view can be used to measure the wall thickness of the right ventricle and evaluate the inferior vena cava. Color Doppler should be used in all of these views to evaluate the TR jet and its possible etiology, and any view where the regurgitant jet can be aligned parallel to the ultrasound beam should be interrogated with continuous-wave Doppler for estimation of the right ventricular systolic pressure.

Transesophageal Echocardiography

Similarly, newer American Society of Echocardiography guidelines underscore the importance of performing a comprehensive TEE for the tricuspid valve.¹⁷ It must be emphasized that at each and every level, we must examine multiple planes for complete and clear assessment of the tricuspid valve as pathology has been initially identified during the transthoracic study. This will allow us to appreciate the complexity of the leaflet anatomy, as there is considerable variation in the anatomy of each patient, and begin to consider therapeutic options. Both single plane and, more importantly in our opinion, simultaneous biplane images should be acquired through the entire exam. Systematic interrogation of the tricuspid valve using color Doppler with a Nyquist limit >50 cm/s and continuous-wave Doppler is paramount. Imaging begins at the midesophageal level, with focus given to the tricuspid valve and ideally adequate visualization of the right ventricular apex. The anterior and septal leaflet can be seen at the 4-chamber view, which can

be confirmed using biplane imaging, and as we increase the transducer angle to 30° with retroflexion, the posterior leaflet may be seen. We then proceed to about 60 to 70° , which yields a “commissural” view where the anteroseptal and posteroseptal commissures can be imaged using biplane imaging (Figure 2A and 2B). At 90° , we can observe the anterior and posterior leaflets, and biplane imaging can be again used here to visualize either leaflet with the septal leaflet. The 180° view is also useful as the tricuspid valve can be seen through the left atrium, and mitral annular shadowing is usually below the tricuspid leaflets (Figure 2C). With slow advancement of the probe into the distal esophagus, we can visualize the right-sided anatomy, particularly the tricuspid valve, without interference of the left heart structures. At 0° in the distal esophageal view, the anterior and posterior leaflets can be visualized, and the septal leaflet is noted at 90° (with the anterior leaflet). Progressive increase in transducer angle with biplane imaging and color Doppler all add to understanding the nature of the regurgitant jet and valvular anatomy. By advancing the TEE probe into the stomach, we can enter the transgastric view. Right flexion and ante flexion at 0° can allow us to see anterior and posterior leaflets. All 3 leaflets can be visualized by increasing to about 30° . The septal leaflet is near the septum and the anterior leaflet can be seen in the far field, while the posterior leaflet is in the near field (Figure 2D through 2F). With careful advancement, then rightward and anterior flexion of the probe, we can create the deep transgastric view, which is similar to the TTE apical 4-chamber view. A potential benefit of this view is that

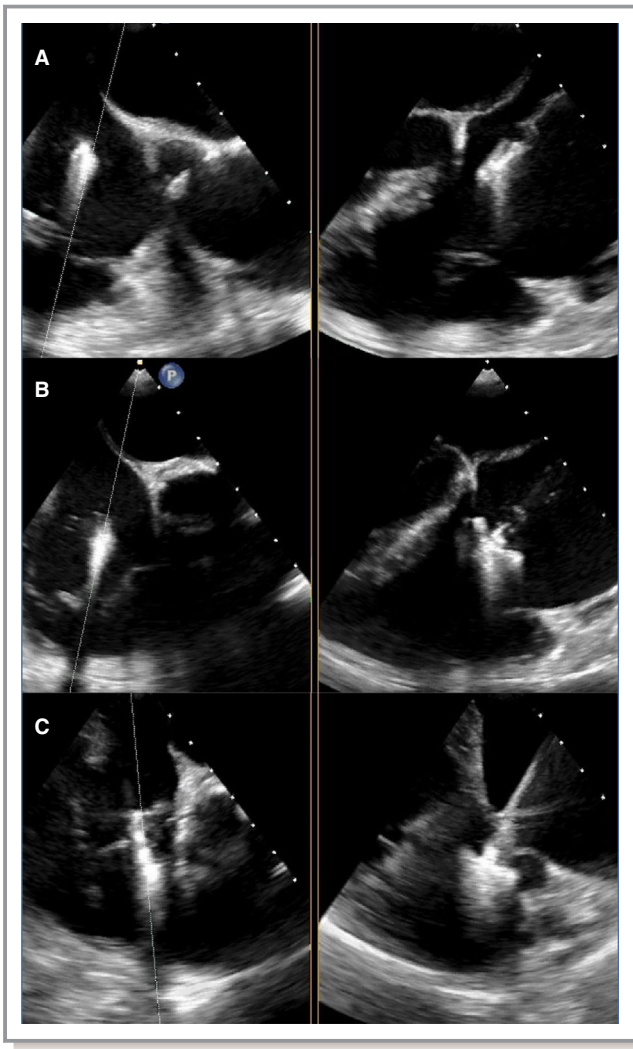


Figure 4. **A**, TEE images where the clip is directed toward the tricuspid leaflets in the closed position. **B**, The device is now opened and just below the level of the tricuspid annulus. **C**, The target leaflets can be seen for adequate grasping when the device is open. TEE indicates transesophageal echocardiography.

it facilitates spectral Doppler assessment of the TR jet, if this was not assessed previously with higher transducer angulation of the midesophageal and distal esophageal views.

It is frequently necessary to collect several 3D TEE data sets from multiple probe positions to completely evaluate the valve and annulus, as long as the 2D images are of sufficient quality. In our experience, the bicaval view in full-volume mode is particularly useful to view the tricuspid valve en-face in relation to the interatrial septum and aortic valve, which aids in the identification of the leaflets (Figure 3A and 3B; Video S1). If there is limited visualization of the valves or subvalvular apparatus in the midesophageal and lower esophageal views, the probe must be advanced to the transgastric and deep transgastric views for further attempts at 3D imaging (Figure 3C; Videos S2 and S3). Concurrent

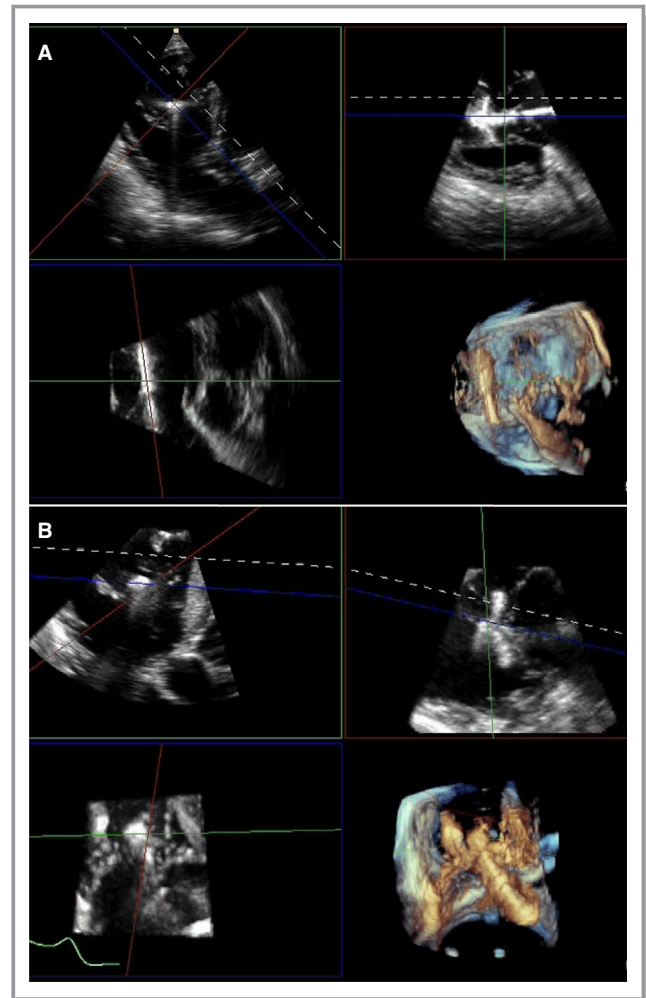


Figure 5. **A**, Multiplane imaging during TEE in the transgastric view facilitates positioning of the device between the target leaflets into the right ventricle (Video S4). **B**, The clip system is pulled back closer to the anterior and septal leaflets, where both are assessed for adequate grasping. TEE indicates transesophageal echocardiography.

color. Doppler imaging in 3D views may assist in grading the severity of regurgitation and pathologic mechanism. The dimensions of a coaptation defect can be measured, as a defect >20 mm was set forth as part of the exclusion criteria in a study of tricuspid edge-to-edge repair.¹⁸ However, a coaptation gap >7.2 mm was associated with increased procedural failure.¹⁹ Other eligibility criteria to consider that precludes tricuspid edge-to-edge repair include severe leaflet thickening, noncentral or eccentric jets originating from the anteroposterior commissure, lead-induced TR, or advanced right ventricular failure.²⁰

If there is suboptimal visualization despite the use of multiple imaging planes attributable to shadowing from adjacent structures or challenging patient anatomy, the use of intracardiac echocardiography can be considered. Leaflet

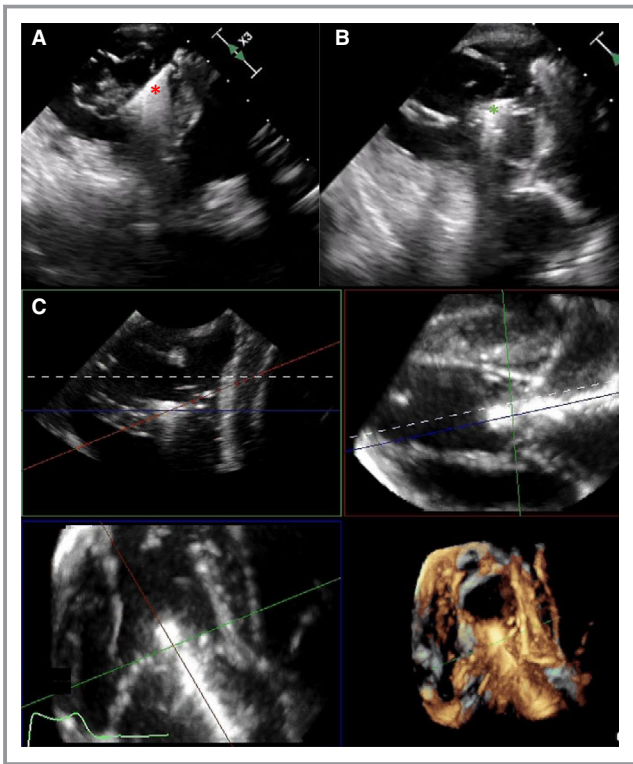


Figure 6. **A**, The transgastric views in TEE are used to confirm grasping of the intended target leaflets. The device is open (red asterisk) between the anterior and septal leaflets. **B**, The device is now closed with both leaflets successfully grasped, and the 2 orifices are noted. **C**, Multiplane imaging can also be used to confirm leaflet grasping when the clip is closed before eventual deployment (Video S5). TEE indicates transesophageal echocardiography.

imaging and confirmation of grasping can be enhanced by positioning the intracardiac probe in the right atrium above the tricuspid valve.²¹

Intraprocedural Imaging

Multiplane TEE imaging is vital for assessment of the functional anatomy of the leaflets, location of TR jets, and visualization of the leaflet grasping. This bears repeating, which is that the valve should be evaluated in a systematic manner as detailed previously in the midesophageal, distal esophageal, transgastric, and deep transgastric views with deliberate increase in transducer angulation. Similarly, concurrent 3D imaging is imperative to perform transcatheter edge-to-edge repair safely. If adequate visibility of the tricuspid valve cannot be achieved even with optimal positioning during the screening study before the planned procedure, edge-to-edge repair is not feasible these patients. The 2 leaflets that will ultimately be clipped, whether it be the anterior and septal or posterior and septal

leaflets, and the targeted TR jet needs to be initially localized by utilizing a biplane and 3D approach. The grasping view should be created by using biplane imaging to create orthogonal planes that are exactly aligned with the device arms with clear target leaflet identification to facilitate leaflet grasping (Figure 4). However, there may be instances where the grasping views are difficult to obtain. Intracardiac echocardiography may be useful for leaflet identification and grasping to confirm optimal leaflet insertion before device closure if transesophageal images are unable to do so.

Navigating the clip delivery system to the tricuspid valve is the first step. A bicaval view during TEE guides this process, where the device should be moving toward the tricuspid valve along the right atrial wall. One of the most important aspects of this process is to avoid damage to the interatrial septum and possible perforation.^{4,5} Multiplane imaging in the bicaval view should be able to determine if the steerable guide catheter is positioned too inferiorly at the inferior vena cava. The intercommissural view or distal esophageal view at 60 to 80° is used to direct the clip delivery system toward the tricuspid valve. In this view, multiplane imaging can be obtained to locate the tricuspid annulus in relation to the aorta. Another key feature of multiplane imaging is that it identifies the location of the TR jet and guides initial adjustment of clip rotation.

The transgastric short-axis view at 10 to 40° is the optimal approach for visualizing all the leaflets and site of coaptation. Most importantly, this view enables the navigation of the clip to the right ventricle and allows continuous monitoring of clip rotation (Figure 5; Video S4). Multiplane imaging will be needed if the coaptation zone cannot be shown in a single plane. The optimal position of the clip can additionally be confirmed with 3D TEE.

Leaflet Grasping and Clip Deployment

Multiplane views will be needed to visualize both arms of the clip during grasping of the two target leaflets. This is especially important given the limitation of 2D biplane view of the transgastric short-axis image, where the biplane beam direction may not necessarily be perpendicular to the 2 leaflets targeted for grasping. Multiplane imaging enables custom positioning of the orthogonal planes to match the device orientation to optimize leaflet grasping (Figure 6; Video S5). Once the leaflets are adequately grasped, the insertion of leaflets must be confirmed by using all available views, including the formation of a tissue bridge with clip stability. Three-dimensional TEE can once again be used for confirmation. An acceptable mean tricuspid gradient following clip insertion is considered to be <4 mm Hg, and the severity of

TR is reassessed in multiple views as done previously. The vena contracta area can be measured by 3D color Doppler planimetry to quantify the reduction in TR. In our experience, the role of TTE is generally limited during the procedure. It may assist if there is a concern for an intraprocedural complication such as pericardial effusion that may be better visualized by TTE. However, after the procedure, a transthoracic echocardiogram must be repeated to reevaluate the degree of regurgitation, measure the mean gradient, assess clip stability, and reveal any possible complications such as pericardial effusion.

Conclusions

Severe TR is a serious clinical entity with relatively few treatment options available. The prognosis in untreated severe TR is poor, and surgical intervention of the tricuspid valve is associated with elevated morbidity and mortality.⁹ Percutaneous catheter-based devices have emerged as a minimally invasive alternative treatment option in high-risk patients. A number of cases have been performed worldwide with promising results.⁷ Comprehensive imaging algorithms, consisting of step-by-step approaches to preprocedural and intraprocedural echocardiographic imaging, are absolutely essential to procedural success.

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Disclosures

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