

Tricuspid Valve: Anatomical Basis and Patient Selection Criteria for Transcatheter Structural Interventions

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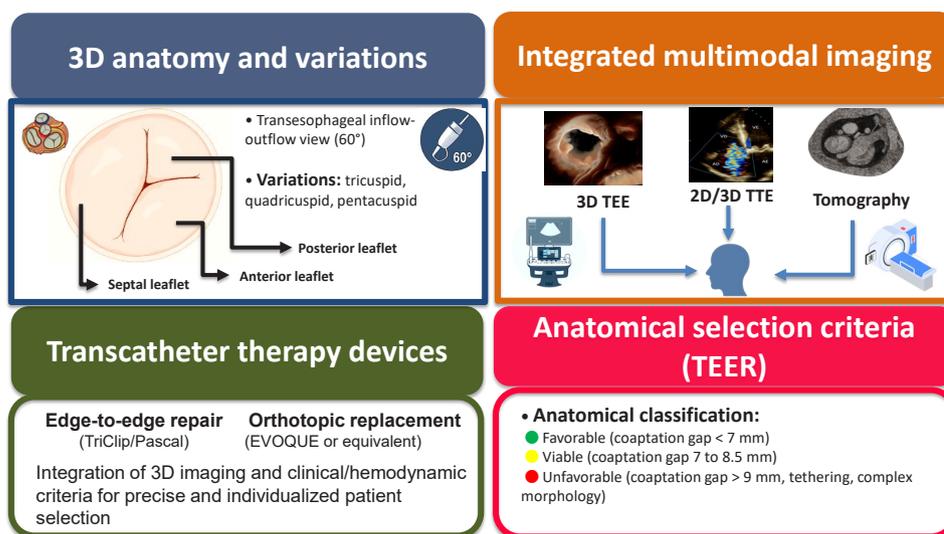
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Central Illustration: Tricuspid Valve: Anatomical Basis and Patient Selection Criteria for Transcatheter Structural Interventions



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TEE: transesophageal echocardiography; TEER: transcatheter edge-to-edge repair; TTE: transthoracic echocardiography; 2D: two-dimensional; 3D: three-dimensional.

Abstract

Tricuspid regurgitation has been recognized as a relevant clinical entity, with a direct impact on morbidity and mortality. Recent advances in multimodal cardiovascular imaging have promoted more detailed anatomical and functional

Keywords

Tricuspid Valve; Tricuspid Valve Insufficiency; Three-Dimensional Echocardiography; Transesophageal Echocardiography

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assessment of the tricuspid apparatus, guiding the indication and planning of transcatheter interventions. To provide a review of the anatomical basis of the tricuspid valve and discuss echocardiographic and clinical criteria for selecting candidates for transcatheter therapies. This narrative review of the anatomical variability of the tricuspid valve and its subvalvular apparatus incorporates recent recommendations from echocardiography societies and clinical evidence. Special emphasis has been given to three-dimensional echocardiography, transesophageal echocardiography, and computed tomography for morphological and functional characterization of tricuspid regurgitation. Contemporary evidence has demonstrated that up to 45% of patients present with non-classical morphologies (quadricuspid or pentacuspid valves), which impact the viability and outcomes of edge-to-edge repair. The integration of three-dimensional echocardiography enhances accuracy in grading regurgitation severity, enables precise measurement of the vena contracta area, and assists in device selection. Clinical factors including

right ventricular function, pulmonary artery systolic pressure, and the presence of intracardiac devices also influence patient selection. Appropriate selection of candidates for transcatheter tricuspid valve therapies requires a systematic approach with integrated application of imaging methods and clinical parameters. Detailed echocardiographic characterization of leaflet morphology, coaptation gap, and annulus geometry is crucial for planning the procedure, selecting the device, and predicting outcomes.

Introduction

The tricuspid valve is an anatomical and functional complex that plays a fundamental role in adequate cardiac mechanics, influencing hemodynamics of both ventricles. The term “tricuspid” derives from the traditional anatomical description, composed of the anterior, septal, and posterior cusps, although we know that, in up to 45% of cases, the valve may be bicuspid or even have more than three cusps, with considerable anatomical variability.¹ Normal tricuspid valve area ranges from 7 to 9 cm²; anatomically speaking, it is the most inferior valve in the heart. The more apical position in relation to the mitral valve, associated with the saddle-shaped, elliptical geometry of the valve annulus and the proximity of structures such as the coronary sinus and bundle of His, pose particular challenges to transcatheter structural procedures, making imaging-based definition extremely important. In addition to the tricuspid valve, the tricuspid complex is composed of the fibromuscular annulus and subvalvular apparatus (chordae tendineae and papillary muscles), whose dynamic interaction ensures correct valve coaptation during the cardiac cycle. Three-dimensional (3D) reconstruction studies, by means of 3D transthoracic or transesophageal echocardiography or even computed tomography, allow for more detailed visualization of the cusps (en face view on 3D echocardiography) and precise measurement of valve dimensions, reducing the subjectivity inherent to two-dimensional approaches.^{1,2}

As a complement to anatomical visualization, functional assessment of the tricuspid valve is essential for determining the mechanism of dysfunction and planning the best therapeutic option. For this purpose, 3D echocardiography has emerged as a useful tool that allows for real-time volumetric imaging, using specific techniques to quantify valve annulus measurements and function. Furthermore, it enables rendered and realistic analysis of cardiac structures, allowing free navigation throughout the dataset, obtaining anatomical slices that show the relationship between the valve, the subvalvular apparatus, and other adjacent structures.³ Direct measurement of the vena contracta area using 3D echocardiography increases the accuracy of tricuspid regurgitation (TR) quantification, overcoming technical limitations and measurement errors of two-dimensional methods, as it is able to capture the irregular geometry of the valve regurgitant orifice and reduce the need for geometric assumptions.³ The integration of 3D Doppler also allows for more accurate estimation of regurgitant volume using techniques such as 3D proximal isovelocity surface area (PISA) radius and assessment of dynamic flow changes throughout the cardiac cycle, providing greater consistency in reflux grading and, consequently, supporting more accurate therapeutic decisions.⁴

Cardiovascular imaging specialists must have an integrated understanding of the following three fundamental pillars when selecting candidates for percutaneous tricuspid valve interventions:

1. Valve morphology: Anatomical variations that deviate from the classic “tricuspid” pattern can directly influence the choice of edge-to-edge devices, annuloplasty techniques, or prostheses.
2. Accurate quantification of regurgitation severity currently benefits from 3D methods to measure vena contracta area and regurgitant volume and to assess jet dynamics and multiple jets, thus avoiding underestimations that could delay treatment.
3. A patient’s clinical and functional profile includes assessment of the right ventricle (RV), pulmonary artery systolic pressure, presence of intracardiac devices, and comorbidities that may alter the risk-benefit ratio.

In conjunction, these elements, obtained through conventional or 3D echocardiography, tomography, magnetic resonance imaging, and hemodynamic correlations, guide the definition of the optimal moment, the most appropriate strategy, and prognosis for each patient, supporting safe interventional practices focused on individualization.

Severity classification and correlation with candidate selection

It can be difficult to quantify TR for several reasons, including multiple regurgitant jets, respiratory-related changes, or blood volume. Characterization of TR severity depends on an integrative assessment of multiple parameters.

Current recommendations from the European Association for Cardiovascular Imaging (EACVI) and the American Society of Echocardiography (ASE) suggest using qualitative, semi-quantitative, and quantitative parameters to classify TR severity into three grades.

Important TR is defined as follows:

- Qualitative parameters: Leaflets with a large coaptation gap; on continuous Doppler, dense signal, often triangular with an early peak
- Semiquantitative parameters: Systolic flow reversal pattern in the hepatic vein; dominant E wave (≥ 1 m/s); PISA radius > 9 mm; vena contracta width > 7 mm
- Quantitative parameters: Effective regurgitant orifice area (EROA) ≥ 40 mm²; regurgitant volume ≥ 45 ml or regurgitant fraction $\geq 50\%$.

More recently, a five-grade classification system was proposed by Hahn et al., including massive and torrential TR patterns, defined as follows: massive TR (vena contracta width: 14 to 20 mm, EROA: 60 to 79 mm², 3D vena contracta area 95 to 114 mm²) and torrential TR (vena contracta width: ≥ 21 mm, EROA ≥ 80 mm², 3D vena contracta area ≥ 115 mm²). This classification has demonstrated better risk stratification of patients with TR before and after percutaneous tricuspid valve intervention^{5,6} (Table 1).

Transesophageal echocardiography (TEE) has also become an integral part of the assessment of candidates for transcatheter tricuspid valve therapy, complementing the

Table 1 – Echocardiography criteria for grading tricuspid insufficiency

	Mild	Moderate	Severe	Massive	Torrential
2D assessment (Semiquantitative)					
Vena contracta width, mm	< 3	3 to 6.9	7 to 13.9	14 to 20.9	≥ 21
PISA radius, mm	≤ 5.4	5.5 to 8.9	≥ 9	≥ 9	≥ 9
Hepatic vein flow	Systolic dominant	Systolic blunting	Systolic flow reversal	Systolic flow reversal	Systolic flow reversal
Tricuspid inflow	A-wave dominant	Variable	E-wave dominant (velocity ≥ 1 m/s)	E-wave dominant (velocity ≥ 1 m/s)	E-wave dominant (velocity ≥ 1 m/s)
2D assessment (Quantitative)					
EROA, mm ²	< 20	20 to 39	40 to 59	60 to 79	≥ 80
Regurgitant volume, mL	< 30	30 to 44	45 to 59	60 to 74	≥ 75
Regurgitant fraction	< 15%	16% to 49%	≥ 50%	≥ 50%	≥ 50%
Quantitative Doppler EROA, mm ²	–	–	75 to 94.9	95 to 114.9	≥ 115
3D assessment					
Vena contracta area, mm ²	–	–	75 to 94.9	95 to 114.9	≥ 115

Adapted from Badano et al.⁵ EROA: effective regurgitant orifice area; PISA: proximal isovelocity surface area; 2D: two-dimensional; 3D: three-dimensional.

information provided by transthoracic echocardiography (TTE). Whereas TTE allows for initial quantification of the degree of regurgitation and measurement of functional parameters, TEE, especially the 3D version, offers much higher spatial resolution, which allows for precise characterization of both the etiology (primary, functional, or device-related) and the morphology of leaflets and commissures. This more detailed anatomical definition facilitates confirmation of the severity of regurgitation, especially in situations involving multiple jets or hemodynamic variability related to volume and respiration. By means of TEE, it is also possible to accurately measure valve failure and assess the tricuspid valve's relationship with adjacent structures, especially cardiac implantable electronic device (CIED) leads. This information is crucial for selecting the transcatheter device (edge-to-edge clip versus orthotopic prosthesis) and defining appropriate positioning and diameter. Furthermore, by providing real-time images during procedure planning and execution, TEE guides the precise alignment of the clip arms or prosthesis seating, contributing to reduced mechanical complications and improved intervention efficacy. Thus, incorporating TEE into a heart team's assessment protocol significantly improves the safety, accuracy, and clinical success of transcatheter tricuspid valve therapies.

Three-dimensional TEE enhances anatomical and functional assessment of the tricuspid valve, enabling volumetric reconstructions of the valve apparatus and real-time visualization of its dynamics throughout the cardiac cycle. This 3D precision guides the choice of the optimal point of capture during the edge-to-edge procedure and

helps determine the appropriate orthotopic prosthesis size, reducing the risk of oversizing. Additionally, 3D TEE facilitates intraprocedural monitoring of device positioning, allowing immediate adjustments to angulation and implantation depth, which result in greater efficacy and reduced periprocedural complications.

Anatomy and relationships of the tricuspid valve complex

Recent 3D TEE studies have proposed a morphological classification system that is capable of reflecting the true variability of the tricuspid leaflets and guiding interventional planning. Hahn et al. identified six distinct valve configurations (Figure 1), ranging from the classic three-leaflet pattern (type I) to quadricuspid variants with additional anterior (IIIA), posterior (IIIB), or septal (IIIC) leaflets, also including bicuspid (type II) and even pentacuspid (type IV) forms. They demonstrated that under 55% of patients exhibited the usual tricuspid form, and type IIIB (two posterior leaflets) was the most prevalent quadricuspid subtype. This standardized nomenclature not only facilitates communication between imaging teams and interventionalists but also highlights the need for dedicated 3D protocols for en face mapping and accurate assessment of valve morphology before attempting any transcatheter intervention.⁶

In this context, the description of the morphological subtype ceases to be a taxonomic exercise and begins to have a direct operational impact on the strategy of tricuspid transcatheter edge-to-edge repair (T-TEER). The greater

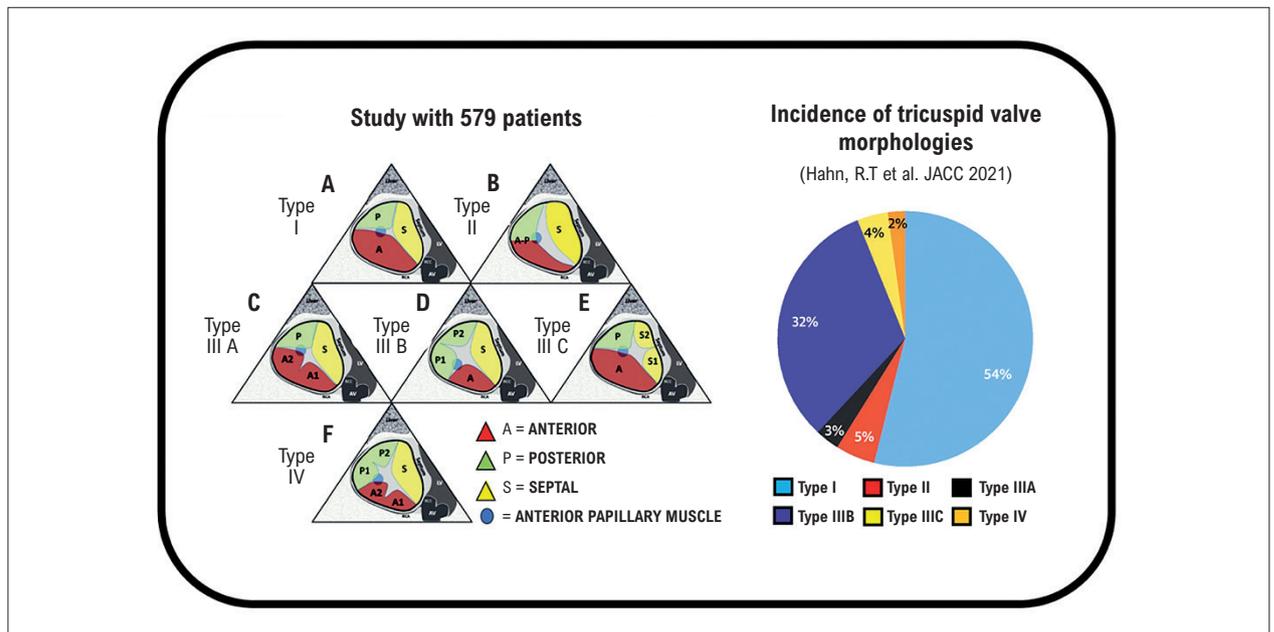


Figure 1 – Standardized echocardiographic nomenclature of tricuspid valve leaflets. Adapted from Hahn RT et al.⁶

the anatomical complexity, especially in quadricuspid and pentacuspid valves, where incisions longer than 10 mm define true commissures, and duplicate leaflets may be present in critical positions, the more difficult it becomes to align the clip arms, ensure adequate coaptation, and avoid significant residual regurgitation. Multicenter studies indicate that valves with four or more leaflets exhibit greater residual TR after the procedure, because the choice of safe clipping points, the number of clips required, and the risk of uneven leaflet tensioning vary according to the morphological pattern. Thus, the recently proposed morphological classification guides tactical decisions, from candidate selection to planning the catheter path and the number of clips to be used, increasing the likelihood of technically successful T-TEER.⁶⁻⁸

Retrospective multicenter data reinforce this relationship between anatomy and T-TEER efficacy. In a cohort of 145 patients undergoing T-TEER, Sugiura et al. identified a four-leaflet configuration in 29% of cases and demonstrated that this morphology increased the likelihood of \geq moderate residual TR ($\geq 3+$) by 2.6, even after adjusting for baseline severity, coaptation gap width, and jet location. Furthermore, the presence of TR $\geq 3+$ at 30 days doubled the combined risk of mortality or heart failure hospitalization at 1 year (56.1% versus 27.7%), demonstrating that reducing regurgitation below moderate is crucial to prognosis. The study also proposed a sequential evaluation combining morphology, coaptation gap > 7 mm, and noncentral jets, identifying subgroups with up to 45% of residual TR \geq moderate at 30 days, a marker of adverse clinical outcome. These findings complement the classification proposed by Hahn by providing clear prognostic data, supporting careful patient selection and, when necessary, consideration of alternative approaches such as annuloplasty or valve replacement, in cases with more complex morphologies.^{6,8}

Imaging techniques for selecting candidates and planning percutaneous tricuspid valve interventions

Echocardiographic assessment should include the transgastric short-axis view, acquired in the deep transgastric plane with a rotation of approximately 30° to 50°. In this view, the tricuspid valve is visualized en face, and the aorta is located at 5 o'clock, providing interventionalists with a direct anatomical reference to inspect the coaptation line, estimate tethering, classify morphology, and identify commissures.⁶

For 3D volumetric study, two 3D reconstructions are particularly useful. The surgeon's view (aorta at 11 o'clock) is derived from a midesophageal acquisition, and it uses the interatrial septum and aorta as anatomical landmarks. The interventionalist's view, generated from the same 3D acquisition, with the aorta rotated to 5 o'clock, reproduces the orientation of the transgastric window and, therefore, matches the fluoroscopic perspective in the catheterization laboratory. The equivalence between the transgastric and interventionalist views standardizes the clockwise and counterclockwise orientation of the leaflets, reducing intraprocedural orientation errors and errors in the anatomical assessment of candidates for dedicated devices (Figure 2).

Three-dimensional reconstruction of the tricuspid annulus, complemented by cardiac tomography, makes it possible to confirm annulus diameters, area, and perimeter; assess the relationship with the right coronary artery; and define optimal fluoroscopic projections, completing the multimodal imaging-guided selection and planning cycle.

Complementing the transgastric views and the surgeon and interventionalist 3D reconstructions described above, the RV inflow-outflow echocardiographic window, acquired in the mid-esophagus at approximately 60°, with progressive anteriorization of the probe until simultaneously encompassing

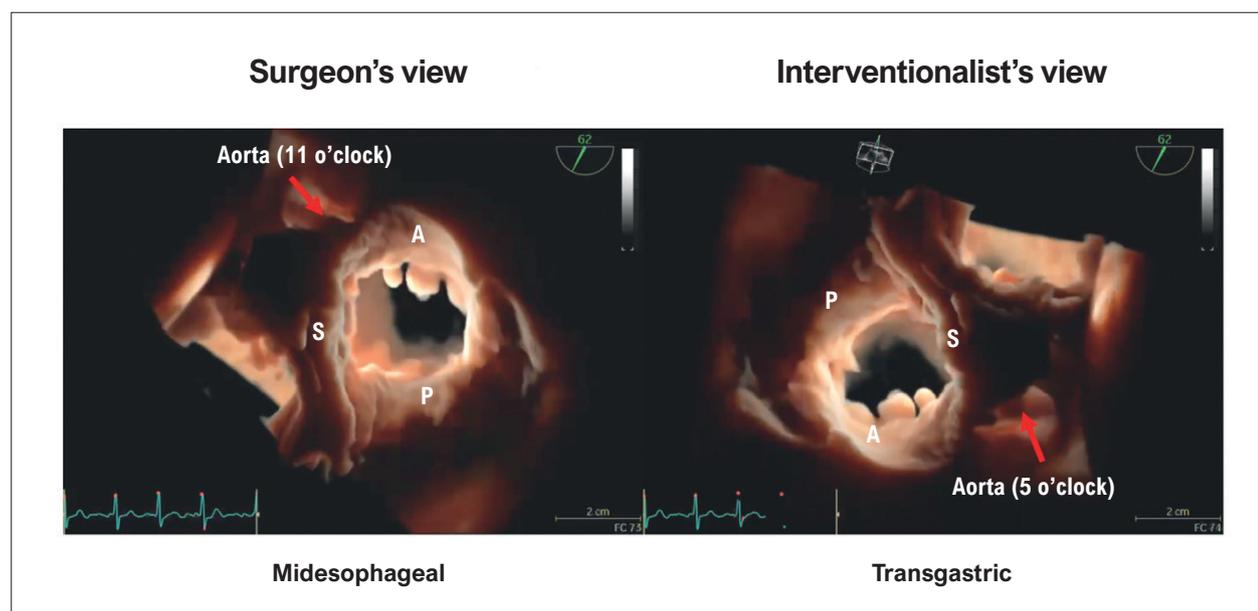


Figure 2 – Three-dimensional reconstructions of the tricuspid valve applying transillumination in three-dimensional transesophageal echocardiography, highlighting two complementary orientations. On the left, the surgeon's view shows the valve en face with the aorta positioned at 11 o'clock, replicating the operative perspective. On the right, the interventionalist's view results from the rotation of the three-dimensional volume to position the aorta at 5 o'clock, corresponding to fluoroscopic view in the catheterization laboratory. The anterior, posterior, and septal cusps are delimited in both projections. A: anterior; P: posterior; S: septal.

the inflow tract (septal and anterior leaflets) and the outflow tract (RV outflow tract and pulmonary valve), provides a relevant longitudinal view for selecting candidates for transcatheter tricuspid valve intervention. In this projection, it is possible to measure the angle between the tricuspid annulus and the catheter path, estimating the coaxiality of T-TEER systems; to assess the degree of tethering of the anterior leaflet, which is a decisive parameter for eligibility without overlapping the posterior leaflet; and to delineate the course of the right coronary artery, as well as the position of intracavitary electrodes in relation to the annulus, reducing the risk of conflict with implanted devices. During the procedure, the same view acts as a dynamic guide for interventionalists, allowing fine adjustments to the rotation of the clip or orthotopic replacement system, monitoring leaflet coaptation in real time and confirming that the device does not invade the RV outflow tract or distort the pulmonary valve. Thus, the inflow-outflow projection connects pre-procedure anatomical characterization with intra-procedure feedback, increasing precision in navigation, anchoring, and immediate verification of hemodynamic results.

For illustrative purposes contributing to a better understanding of the inflow-outflow echocardiographic window in the mid-esophagus at 60° and its related slice planes, the anterior cusp is represented in purple, the septal cusp in green, and the posterior cusp in yellow. In this window, the anterior cusp is presented in the position closest to the aortic valve, with the posterior cusp in the opposite position. By adding biplane technology such as X-plane (Philips) or Multi-D (GE), it is possible to acquire an orthogonal slice with the analysis plane directed toward both the anterior and

posterior cusps. Figure 3 displays the biplane slice from the anterior cusp, with the formation of a simultaneous image corresponding to the inverted apical four-chamber window with the RV on the left, and the left ventricle on the right. If the coronary sinus ostium or the interventricular septum are visualized, the adjacent leaflet is most likely the septal leaflet. On the biplane image, the anterior leaflet will appear in a more distal position in relation to the transducer.

Figure 4 displays the biplane view, but from the posterior leaflet. In this case, the septal leaflet will be closer to the coronary sinus, and the posterior leaflet will be more distal to the transducer.

In Figure 5, adding a 3D analysis plane with the tricuspid valve in open and closed positions, with the biplane view orthogonal to the anterior leaflet clearly and precisely shows the correlation between the echocardiographic planes, thus providing correct spatial understanding of the analyzed leaflets without the need to memorize or infer the position of each tricuspid valve component, which is not always successful.

The transgastric window provides a short-axis view that integrates the tricuspid valve plane with its septal, anterior, and posterior leaflets and the RV cavity, making it possible to measure the gap between leaflets, characterize morphology, and quantify tethering without geometric assumptions. This perspective also facilitates the identification of residual clefts, providing essential information for planning a transcatheter strategy, as demonstrated in Figure 6.

With this anatomical basis, in candidates for T-TEER, the transgastric window displays all leaflets en face, guiding the

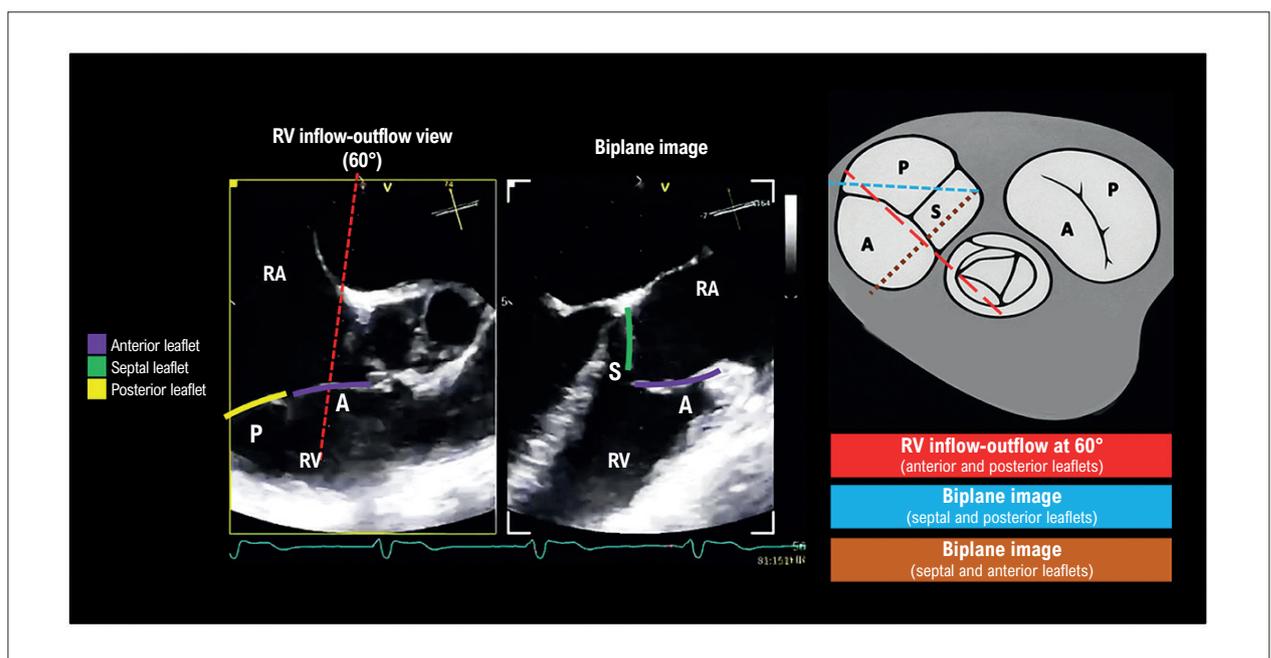


Figure 3 – Echocardiographic representation of the tricuspid valve in the transesophageal right ventricular inflow-outflow window, complemented by biplane mode. On the left, the image obtained at 60° shows the anterior and posterior leaflets, useful in selecting candidates for transcatheter therapies. In the center, biplane mode allows simultaneous assessment of the orthogonal plane, identifying the septal leaflet in combination with the anterior leaflet. On the right, a schematic diagram relating the echocardiographic slice planes to the corresponding leaflets, indicating different pairs of leaflets visualized according to the angle and orientation of the transducer. A: anterior; P: posterior; RA: right atrium; RV: right ventricle; S: septal.

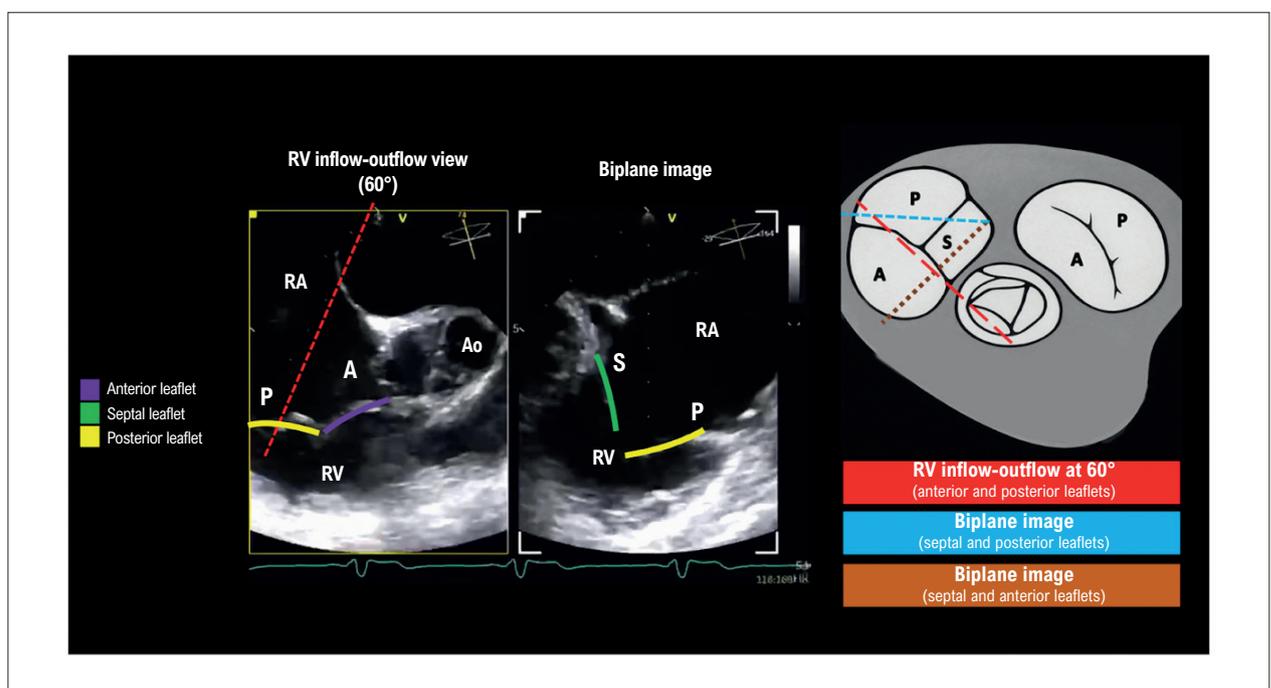


Figure 4 – Image of the right ventricular inflow-outflow tract in the 60° plane, with the orthogonal section from the posterior leaflet, concomitant image of the anterior and posterior leaflets, and in parallel the septal and posterior leaflets, allowing for better anatomical detailing of the tricuspid valve. A: anterior; Ao: aorta; P: posterior; RA: right atrium; RV: right ventricle; S: septal.

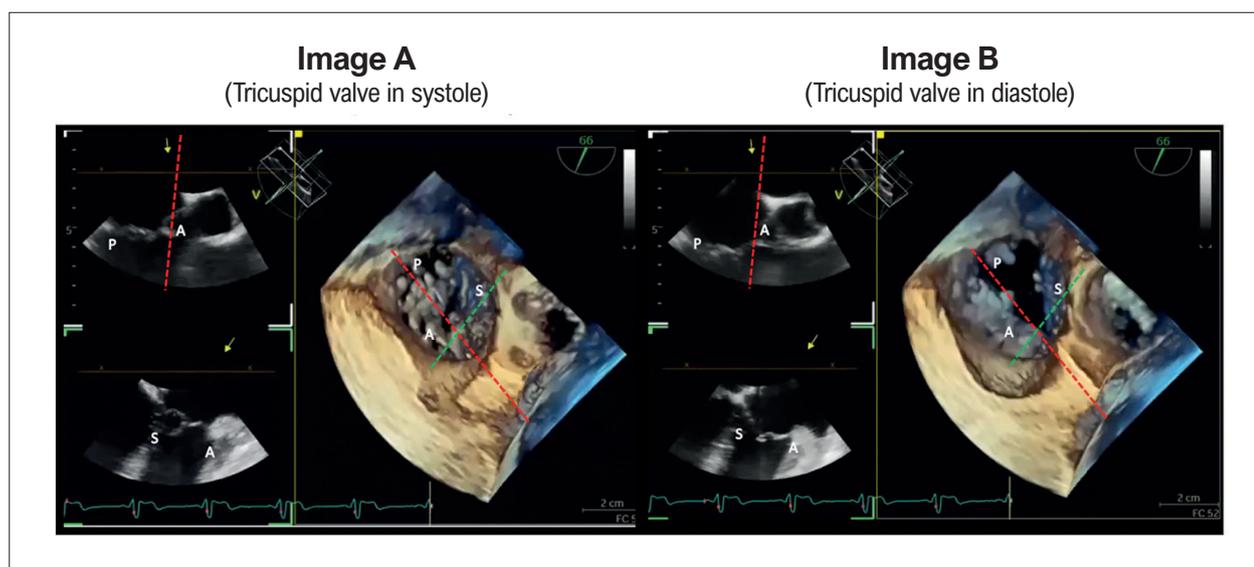


Figure 5 – Three-dimensional transesophageal echocardiogram. Assessment of the tricuspid valve with biplane reconstruction in the systole (Image A) and diastole (Image B) phases, oriented according to the interventionalist's view, with the aorta positioned at 5 o'clock. The central images present volumetric reconstruction, displaying the valve en face. The dashed lines indicate the orthogonal planes used for multiplanar analysis. On the left of each block, the two-dimensional sections correspond to the inflow-outflow plane (top), highlighting the anterior and posterior leaflets, and the orthogonal plane (bottom), showing the anterior leaflet in relation to the septal leaflet. Comparison between the phases of the cardiac cycle allows for the assessment of the dynamics of leaflet opening and coaptation. A: anterior; P: posterior; S: septal.

point of optimal grasping and ensuring clip coaxiality in relation to the interventricular septum. This perpendicular orientation in relation to the coaptation plane maximizes the coaptation area and reduces leaflet tension; the clip is only released after confirmation of adequate edge capture, which contributes to technical reproducibility and procedural success.

For orthotopic prosthesis implantation, the transgastric window allows direct measurement of tricuspid annulus diameter, guiding selection of appropriate prosthesis size and alignment along the aorta-tricuspid axis. During the procedure, real-time monitoring enables precise adjustments of device angulation and depth, reducing the risk of unwanted contact with adjacent structures and ensuring stable prosthesis positioning.

Eligibility criteria for transcatheter intervention

The most recent publication of the Tricuspid Valve Academic Research Consortium (TVARC) defines the criteria required for transcatheter device implantation to be considered successful.⁹

- Absence of significant tricuspid stenosis (tricuspid valve area $\geq 1.5 \text{ cm}^2$ or tricuspid valve area index $\geq 0.9 \text{ cm}^2/\text{m}^2$ [≥ 0.75 if body mass index $> 30 \text{ kg}/\text{m}^2$])
- Doppler velocity index < 2.2
- Mean gradient $< 5 \text{ mmHg}$
- Reduction of total TR to levels considered optimal (mild residual TR $\leq 1+$) or acceptable (mild residual TR $\leq 2+$)

Multiple studies have demonstrated worse outcomes in patients with more severe residual TR. According to the current consensus, eligibility for transcatheter repair is classified into the following three anatomical groups: favorable, viable, and unfavorable. This categorization derives from assessments of echocardiographic data that demonstrate greater or lesser likelihood of therapeutic success of the procedure, as displayed in Table 2.¹⁰ With the development of new devices and improvements in their structure, feasibility parameters tend to expand over time.

Tricuspid transcatheter edge-to-edge repair

T-TEER is a catheter-based tricuspid valve repair technique that reduces TR by restoring coaptation by means of leaflet approximation, which indirectly reduces or stabilizes the valve annulus. T-TEER is currently the most commonly applied transcatheter tricuspid valve repair technique. It can be performed with TriClip (Abbott) or Pascal (Edwards Lifesciences), two guided systems that utilize a transvenous transfemoral approach to restore tricuspid valve coaptation with a valve clipping device.

In the majority of studies on T-TEER, procedural success is defined as a reduction in TR to \leq moderate or $2+$. In this context, multiple small studies have identified predictors of success, including the following:

- Jet location
- Coaptation gap size
- Valve morphology (number of leaflets)
- Valve thickness or calcification
- Valve mobility

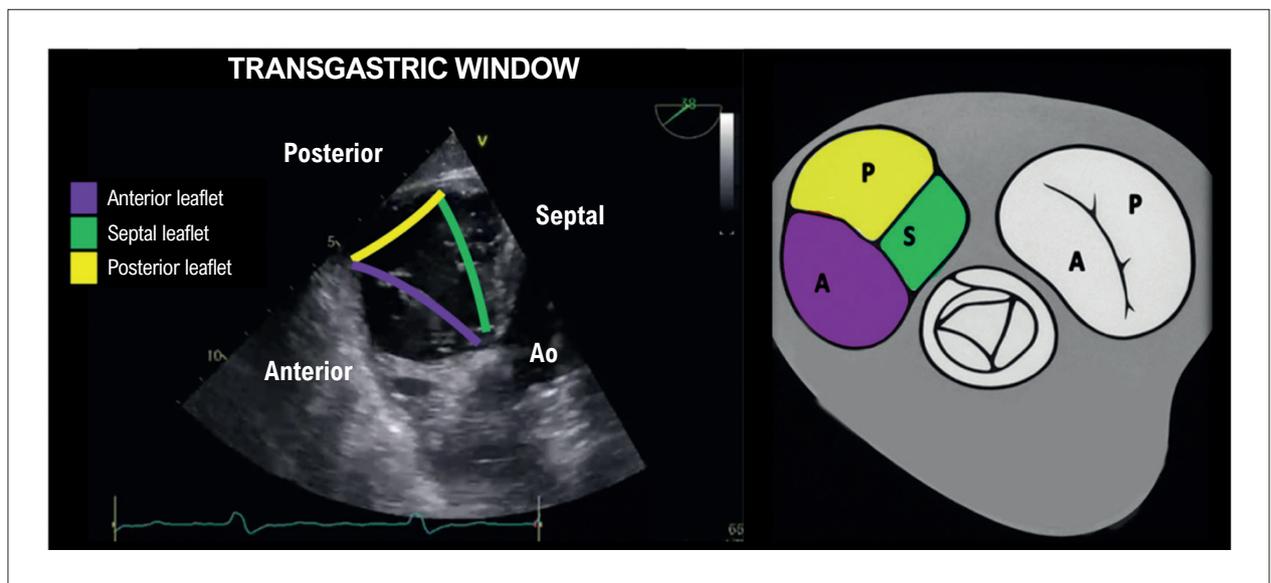


Figure 6 – Two-dimensional transgastric view of transesophageal echocardiography in short-axis view (30° insonation angle), demonstrating the tricuspid valve in an anterior position to the aortic plane. Note the morphology of the tricuspid leaflets, with complete coaptation in diastole, and the contour of the aortic root just above the valve plane. A: anterior; Ao: aorta; P: posterior; S: septal.

Table 2 – Echocardiographic eligibility criteria for percutaneous edge-to-edge tricuspid valve repair (TriClip)

	Transcatheter device repair (TriClip)		
	Favorable	Feasible/viable	Unfavorable
Valve morphology	3 leaflets	Non-tricuspid morphology	Non-tricuspid morphology with thickened valve and subvalvular complex
Coaptation gap, mm	< 7	7 to 8.5	> 8.5
Leaflets	Normal leaflet length (≥ 7 mm), normal mobility, no flail or tethering	Primary TR with flail gap (< 10 mm), secondary TR with tethering height < 9 mm	Primary TR with flail gap (≥ 10 mm); short (< 7 mm), thickened, or perforated leaflets; secondary TR with tethering height ≥ 9 mm or tenting area > 2.1 cm ²
Jet location	Central and within the anteroseptal commissure	Central but not within the anteroseptal commissure	Massive, torrential, very eccentric, or multiple commissures
PM leads	No leads	Leads that do not participate in TR	Leads that cause impingement
Windows	Excellent transesophageal echocardiographic windows	Adequate windows with transesophageal or intracardiac echocardiography	Inadequate windows
RV remodeling	Normal, mildly dilated, or mildly dysfunctional	Moderate dilation or dysfunction	Severe dilation or dysfunction (LVEF < 45% on 3DE or NMR)
Pulmonary hemodynamics	Normal PASP, normal TPG, TAPSE/PASP > 0.41	PASP ≤ 60 to 65 mmHg, PVR ≤ 4 WU, MPAP ≤ 30 mmHg, TPG ≤ 17 mmHg	PASP > 60 to 65 mmHg, PVR > 4 WU, MPAP > 30 mmHg, TPG > 17 mmHg, TAPSE/PASP ≤ 0.41

Adapted from Hungerford SL et al.¹¹ LVEF: left ventricular ejection fraction; MPAP: mean pulmonary artery pressure; NMR: nuclear magnetic resonance; PASP: pulmonary artery systolic pressure; PM: pacemaker; PVR: pulmonary vascular resistance; TAPSE: tricuspid annular plane systolic excursion; TPG: transpulmonary gradient; TR: tricuspid regurgitation; WU: Wood units; 3DE: three-dimensional echocardiography.

- Complexity of the subvalvular apparatus
- TR severity
- Valve-to-annulus ratio
- Location and extent of CIED-related TR
- Tenting height
- Left atrial appendage volume.

Very large coaptation gaps, torrential TR, markedly thickened or immobile valves, and CIED-related TR in which the device adheres to the leaflets or subvalvular apparatus may be relative contraindications for the use of this technique. Furthermore, correct and adequate visualization of the leaflets during the procedure, through the use of TEE (with or without adjunctive intracardiac echocardiographic imaging), is also an important technical prerequisite for planning the intervention.

Transcatheter tricuspid valve replacement

Transcatheter tricuspid valve replacement (TTVR) involves the insertion of a bioprosthesis through a transvenous transcatheter approach. TTVR can be orthotopic or heterotopic; the latter is often used as a palliative procedure to relieve systemic venous congestion in patients who cannot undergo T-TEER or orthotopic TTVR. The anatomical requirements for TTVR are primarily related to the ability to position the device within the annular plane and the anchoring mechanism. Therefore, different devices will have different anatomical constraints. Initial TTVR implantations were performed through the implantation of a balloon-expandable prosthesis within a surgical valve prosthesis or in a prosthetic annulus. Due to the growing demand for implants in native valve disease, there has been progressive improvement in devices, in addition to optimization of access, which is currently transfemoral or transjugular. Unlike T-TEER devices, large coaptation gaps, torrential TR, complex morphologies, markedly thickened or immobile leaflets, and CIED-related TR are not typically exclusion criteria. For these devices, the main determinants of feasibility are current device sizes, as well as the ability to guide the device to achieve a coaxial implantation trajectory, largely determined by the size of the implant device itself and the available right atrial space. Although also described for T-TEER, acute changes in RV preload and afterload and the occurrence of ventricular decoupling can lead to left ventricular failure after reduction of massive and torrential TR and should be a concern in TTVR, given that \leq mild TR can be achieved in $> 90\%$ of patients.

Table 3 displays the main anatomical and echocardiographic considerations that must be assessed in order to determine whether or not each of these types of implant is appropriate, bearing in mind that these criteria are constantly changing due to the technological evolution of prostheses.

Innovations and future perspectives

The expanding trend in percutaneous tricuspid valve interventions reflects both technological advances and the growing demand for less invasive alternatives in patients with significant regurgitation. This growth is expected to be driven by a reduction in complications associated with conventional surgery, increased familiarity of multidisciplinary teams with valve anatomy, and improved imaging techniques used in pre-procedure assessment.

In this context, appropriate candidate selection requires an integrated analysis of clinical and anatomical profile, considering

factors such as age, comorbidities, degree of RV dysfunction, and tolerance to anticoagulation or contrast media, in addition to the structural characteristics of the valve, including annulus dimensions, degree of tethering, extent of coaptation, and leaflet number and integrity. It is also necessary to take into account the particular characteristics of each device, including compatibility with the tricuspid annulus, the viability of vascular access, and the technical complexity involved in implantation. This systematic approach contributes to defining the most appropriate therapeutic strategy for each clinical and anatomical profile.

During subsequent phases, new transcatheter replacement devices are expected to be introduced and expanded in Brazil, for example, EVOQUE (Edwards Lifesciences), which has already been approved in Europe (CE Mark in October 2023) and recently authorized by the United States Food and Drug Administration in February 2024. With its self-expandable design, multiple sizes, and transfemoral delivery, EVOQUE represents a viable alternative for cases with anatomy that is unfavorable to T-TEER.

Even though the initial results from the pivotal TRISCEND II study indicated a reduction in the degree of TR and functional improvement with implantation of the EVOQUE prosthesis, it will be necessary to monitor the device's performance regarding safety, durability, and clinical outcomes in local populations. The eventual incorporation of this technology into the Brazilian scenario should be accompanied by training programs and structured assessment protocols in order to ensure appropriate application to clinical and institutional realities.¹³

Conclusion

Appropriate selection of candidates for percutaneous tricuspid valve intervention requires a systematic echocardiographic approach, focused on the functional and morphological analysis of the valve complex and its adjacent structures. Characterizing leaflet anatomy, identifying points of effective coaptation, quantifying the degree of tethering, and assessing annulus dimensions are important steps in determining technical viability and expected clinical benefit. The integrated use of multiplanar windows and 3D reconstructions, when available, enhances diagnostic accuracy and contributes to individualized therapeutic planning. Accordingly, echocardiographic assessment has become not only a diagnostic tool but also a relevant step in the decision-making process for transcatheter tricuspid valve therapies.

Author Contributions

Conception and design of the research: Souza AC. Acquisition of data: Souza AC. Analysis and interpretation of the data: Silva H. Writing of the manuscript: Souza AC, Silva H. Critical revision of the manuscript for intellectual content: Felix AS.

Potential conflict of interest

No potential conflict of interest relevant to this article was reported.

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There were no external funding sources for this study.

Table 3 – Anatomical, technical, and clinical considerations for selecting between percutaneous edge-to-edge repair and orthotopic valve replacement strategies in the management of tricuspid regurgitation

	Edge-to-edge repair	Orthotopic replacement
Tricuspid valve anatomic considerations		
Flail or prolapse	Device appropriate	Device appropriate
CIED-related TR	Device not appropriate or use with caution	Device appropriate
No alternative pacing option possible (in cases of pacemaker dysfunction or impossibility of implantation)	Use with caution	Device not appropriate or use with caution
Coaptation gap > 10 mm	Device not appropriate or use with caution	Device appropriate
Tethering > 10 mm	Device not appropriate or use with caution	Device appropriate
> 3 leaflets	Use with caution	Device appropriate
Thick, short, or immobile leaflets	Device not appropriate	Device appropriate
Torrential TR	Use with caution	Device appropriate
Device-specific considerations		
Large valve annulus	Device appropriate	Use with caution
Small RV dimensions	Device appropriate	Use with caution
RV systolic dysfunction	Use with caution	Device not appropriate or use with caution
Suboptimal access or trajectory	Device not appropriate or use with caution	Device not appropriate or use with caution
Other considerations		
Contraindication to anticoagulation or high bleeding risk	Device appropriate	Device not appropriate or use with caution
Inadequate transesophageal echocardiography images	Device not appropriate or use with caution	Use with caution

Adapted from Madhavan et al.¹² CIED: cardiac implantable electronic device; RV: right ventricular; TR: tricuspid regurgitation.

Study association

This study is not associated with any thesis or dissertation work.

Ethics approval and consent to participate

This article does not contain any studies with human participants or animals performed by any of the authors.

Use of Artificial Intelligence

The authors did not use any artificial intelligence tools in the development of this work.

Data Availability

The underlying content of the research text is contained within the manuscript.

References

- Dahou A, Levin D, Reisman M, Hahn RT. Anatomy and Physiology of the Tricuspid Valve. *JACC Cardiovasc Imaging*. 2019;12(3):458-68. doi: 10.1016/j.jcmg.2018.07.032.
- Pena JLB, Vieira MLC, editors. *Ecocardiografia e Imagem Cardiovascular*. Rio de Janeiro: Thieme Revinter; 2021.
- Muraru D, Hahn RT, Soliman OI, Faletta FF, Basso C, Badano LP. 3-Dimensional Echocardiography in Imaging the Tricuspid Valve. *JACC Cardiovasc Imaging*. 2019;12(3):500-15. doi: 10.1016/j.jcmg.2018.10.035.
- Jost ZT, Nooli NP, Ali AE, Jaganathan V, Nanda NC. Three-Dimensional Echocardiography of the Tricuspid Valve. *Front Cardiovasc Med*. 2023;10:1114715. doi: 10.3389/fcvm.2023.1114715.
- Badano LP, Tomaselli M, Muraru D, Gallo X, Li CHP, Marsan NA. Advances in the Assessment of Patients with Tricuspid Regurgitation: A State-of-the-Art Review on the Echocardiographic Evaluation Before and After Tricuspid Valve Interventions. *J Am Soc Echocardiogr*. 2024;37(11):1083-102. doi: 10.1016/j.echo.2024.07.008.

- Hahn RT, Weckbach LT, Noack T, Hamid N, Kitamura M, Bae R, et al. Proposal for a Standard Echocardiographic Tricuspid Valve Nomenclature. *JACC Cardiovasc Imaging*. 2021;14(7):1299-305. doi: 10.1016/j.jcmg.2021.01.012.
- Stankovic I, Daraban AM, Jasaityte R, Neskovic AN, Claus P, Voigt JU. Incremental Value of the en Face View of the Tricuspid Valve by Two-Dimensional and Three-Dimensional Echocardiography for Accurate Identification of Tricuspid Valve Leaflets. *J Am Soc Echocardiogr*. 2014;27(4):376-84. doi: 10.1016/j.echo.2013.12.017.
- Sugiura A, Tanaka T, Kavsar R, Öztürk C, Vogelhuber J, Wilde N, et al. Leaflet Configuration and Residual Tricuspid Regurgitation after Transcatheter Edge-to-Edge Tricuspid Repair. *JACC Cardiovasc Interv*. 2021;14(20):2260-70. doi: 10.1016/j.jcin.2021.07.048.
- Hahn RT, Lawlor MK, Davidson CJ, Badhwar V, Sannino A, Spitzer E, et al. Tricuspid Valve Academic Research Consortium Definitions for Tricuspid Regurgitation and Trial Endpoints. *J Am Coll Cardiol*. 2023;82(17):1711-35. doi: 10.1016/j.jacc.2023.08.008.
- American Society of Echocardiography. Key Echocardiographic Considerations for Transcatheter Edge-to-Edge Repair of the Tricuspid Valve (TriClip): Eligibility Criteria. *J Am Soc Echocardiogr*. 2023;36(11):1090-105. doi:10.1016/j.echo.2023.08.012.
- Hungerford SL, Rye EE, Hansen PS, Bhindi R, Choong C. Key Echocardiographic Considerations for Tricuspid Valve Transcatheter Edge-to-Edge Repair. *J Am Soc Echocardiogr*. 2023;36(4):366-380.e1. doi: 10.1016/j.echo.2023.01.013.
- Madhavan MV, Agarwal V, Hahn RT. Transcatheter Therapy for the Tricuspid Valve: A Focused Review of Edge-to-Edge Repair and Orthotopic Valve Replacement. *Curr Cardiol Rep*. 2024;26(6):459-74. doi: 10.1007/s11886-024-02051-4.
- Hahn RT, Makkar R, Thourani VH, Makar M, Sharma RP, Haefele C, et al. Transcatheter Valve Replacement in Severe Tricuspid Regurgitation. *N Engl J Med*. 2025;392(2):115-26. doi: 10.1056/NEJMoa2401918.



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