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Review

Anesthesia Considerations for Transcatheter Tricuspid Valve Repair and Replacement

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Abstract

Tricuspid regurgitation is a highly prevalent disease associated with significant morbidity and mortality. Historically, many patients went untreated due to the lack of effective surgical options, high operative risks, and the presence of multiple comorbidities. The emergence of transcatheter valve technologies has transformed this landscape, driving rapid advancements in transcatheter tricuspid valve interventions. Early data indicate promising short- and medium-term outcomes for several devices, though many are still in the early stages of clinical testing. As these interventions become more widely accessible, a thorough understanding of the devices, anesthesia considerations, and potential complications is essential for delivering optimal patient care. This manuscript will present 3 cases of transcatheter tricuspid interventions and review tricuspid valve regurgitation, current techniques for transcatheter tricuspid repair and replacement and the anesthesia considerations for these procedures.

Keywords

transcatheter tricuspid valve repair; transcatheter tricuspid valve replacement; tricuspid regurgitation; tricuspid valve

Introduction

Tricuspid regurgitation (TR) is a common condition associated with significant morbidity and mortality, yet it has remained undertreated for decades [1]. Surgical treatment is recommended only in select cases, and the mortality rate for tricuspid valve surgery is higher than for any other valve surgery [2]. Over the past decade, transcatheter tricuspid valve interventions have emerged as a transformative treatment option, with their use expanding significantly. Currently, two devices—TriClip and the EVOQUE valve—are Food and Drug Administration (FDA) -approved, and numerous others are undergoing clinical trials. This manuscript presents three cases of successful transcatheter tricuspid interventions. It also provides a comprehensive review of tricuspid valve anatomy, the pathophysiology of TR, current techniques and evidence supporting transcatheter tricuspid valve repair and replacement, and key anesthesia considerations for these procedures.

Case Presentations

Patient 1

A 75-year-old male presented with a history of chronic lymphocytic leukemia, atrial fibrillation, coronary artery disease, hypertension, severe secondary TR, and associated right heart failure (NYHA III) presented for evaluation. His condition was further complicated by cirrhosis and chronic kidney disease. Transesophageal echocardiography (TEE) revealed a normal left ventricular size and function, mild right ventricular dilation with mildly decreased function, and torrential TR due to leaflet restriction due to annular dilation (Fig. 1). Given his poor surgical candidacy—owing to prior revascularization and multiple comorbidities—he was referred to our institution for transcatheter tricuspid valve repair. The patient was admitted for transcatheter tricuspid valve repair using the Precision Transcatheter Valve Repair System (PASCAL) device. A left radial arterial line was placed before anesthesia induction. General anesthesia was administered with midazolam, fentanyl, propofol, and rocuronium. TEE and fluoroscopy guided the procedure. Bilateral femoral vein access was established using surface ultrasound, heparin bolus was administered. The tricuspid steerable guide catheter was positioned in the right atrium and the PASCAL system was advanced. The tricuspid leaflets were successfully grasped, and the clip was

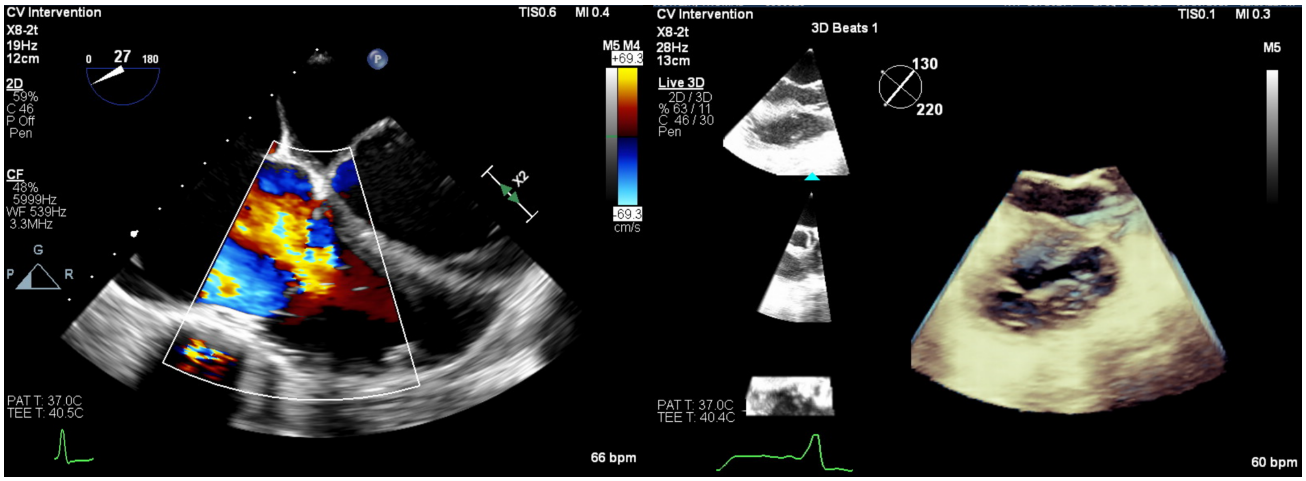

Fig. 1. Pre-procedure transesophageal echocardiography (TEE). (a) Mid esophageal four-chamber view showing torrential Tricuspid Regurgitation (TR) and dilated right atrium (RA). (b) End systole frame of 3D TEE demonstrating wide coaptation gap.

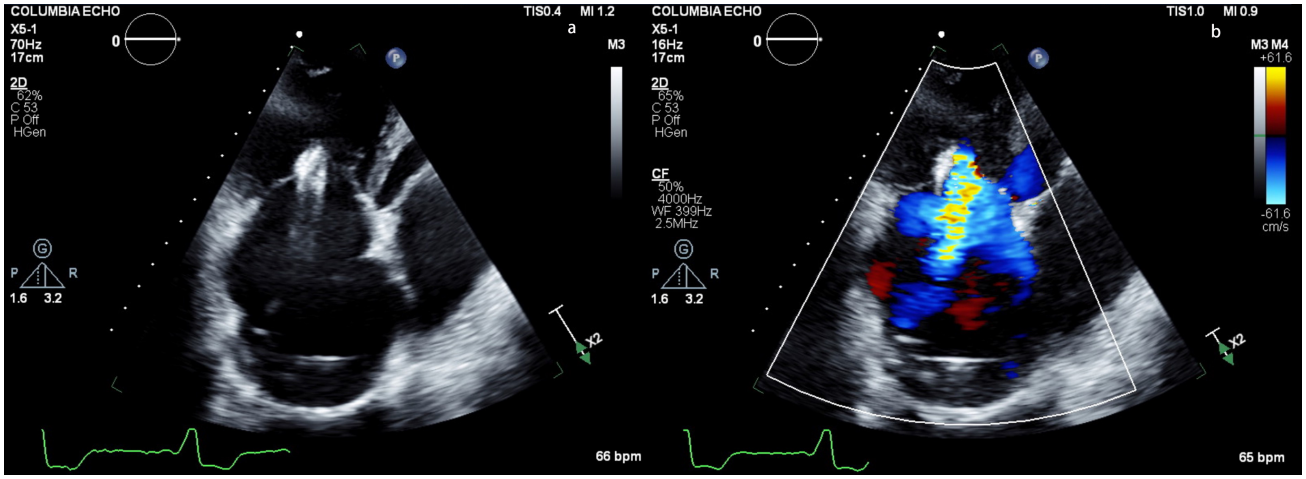

Fig. 2. Post-procedure apical four-chamber TTE view demonstrating (a) PASCAL device and (b) Residual mild to moderate tricuspid regurgitation (TR).

deployed, reducing the regurgitation to mild/moderate TR (Fig. 2). The procedure was uneventful. The patient was monitored overnight and discharged home the following day. At three-month follow-up he reported significant improvement in shortness of breath, with the TR remaining graded as mild/moderate.

Patient 2

A 69-year-old male with a medical history of hypertension, prior Type A aortic dissection repair, atrial fibrillation, mitral and TR, and right-sided heart failure with moderately reduced right ventricular function (NYHA Class III) presented for evaluation. Three years prior, he had undergone mitral and tricuspid clip placements but continued to experience severe TR due to significant leaflet tethering, primary leaflet degeneration, and posterior leaflet flail (Fig. 3). During the procedure, a right radial arterial line was placed for monitoring, and general anesthesia was induced using midazolam, fentanyl, propofol, and rocuronium. Access to the left and right femoral veins was established, and an Evoque 52 mm valve was successfully deployed under fluoroscopic and TEE guidance. The patient experienced a significant improvement in blood pressure with no evidence of conduction abnormalities or bleeding. Post-procedure echocardiography confirmed stable biventricular function with the valve securely positioned, showing only mild paravalvular regurgitation and trace central regurgitation (Fig. 4). The patient was monitored for 72 hours on the regular nursing floor, with an uneventful recovery.

Patient 3

A 77-year-old female with a medical history significant for coronary artery disease with prior Coronary Artery Bypass Graft Surgery (CABG), hypertension, obstructive sleep apnea, chronic obstructive pulmonary dis-

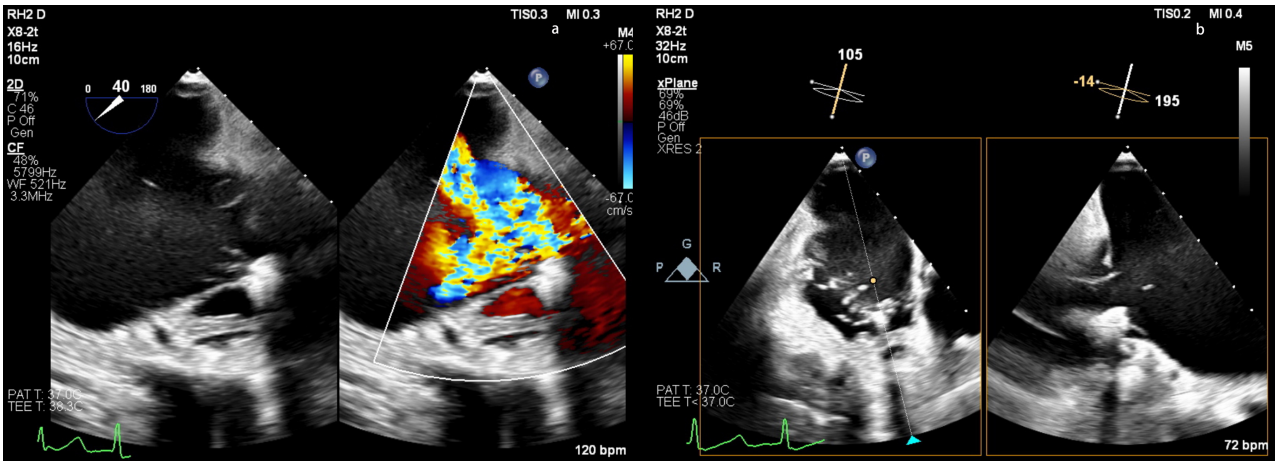

Fig. 3. Pre-procedure TEE showing (a) mid esophageal four chamber view zoomed into tricuspid valve showing prior tricuspid valve clip and torrential TR and (b) End systole transgastric two-chamber right ventricle (RV) view with wide copatation gap and tricuspid clip.

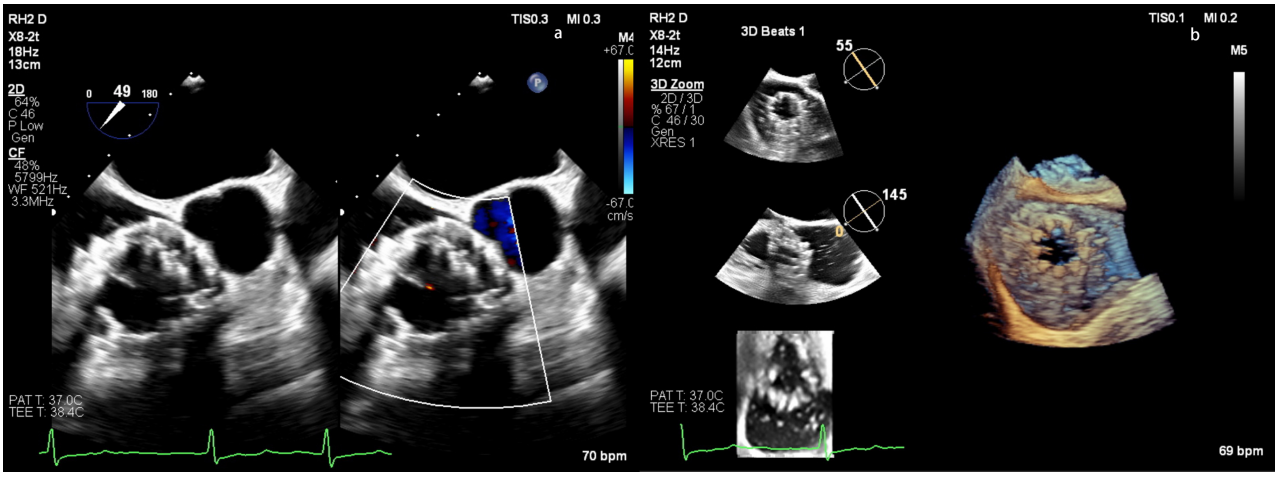

Fig. 4. Post-procedure TEE showing EVOQUE valve in (a) mid esophageal right ventricle (RV) inflow outflow view with trace TR and (b) A 3D view that shows a well-seated valve.

ease (COPD), Stage C NYHA III right-sided heart failure, severe TR, cirrhosis, and chronic kidney disease was admitted to the Intensive Care Unit (ICU) for decompensated heart failure. After medical stabilization, she underwent transcatheter tricuspid valve repair. Pre-procedure echocardiography showed a normal left ventricular size and function, a severely dilated right ventricle with mildly reduced function, and torrential TR due to a wide coaptation gap and marked leaflet tethering (Fig. 5). A right radial arterial line was placed prior to induction. General anesthesia was administered using midazolam, fentanyl, propofol, and rocuronium, and a right internal jugular central venous catheter was placed after induction. Following surgical cutdown of the femoral vein, the delivery system was advanced into the right atrium and de-aired. The #48 mm Intrepid device was introduced and guided into the right ventricle using TEE and fluoroscopy. Rapid pacing at 140 beats per minute was performed, and the valve was positioned with the fixation ring 1 mm above the annular plane. The ventricular end of the valve was deployed, and the atrial brim suture was carefully removed under TEE guidance. The procedure was completed without complications, and the patient maintained with stable hemodynamics. Post-procedure echocardiography confirmed stable valve positioning, trace central TR, and no stenosis (Fig. 6). Biventricular function remained unchanged. She was transferred back to the ICU and discharged home a week later without complications. At her one-year follow-up, the patient reported significant symptom improvement and had no progression of TR.

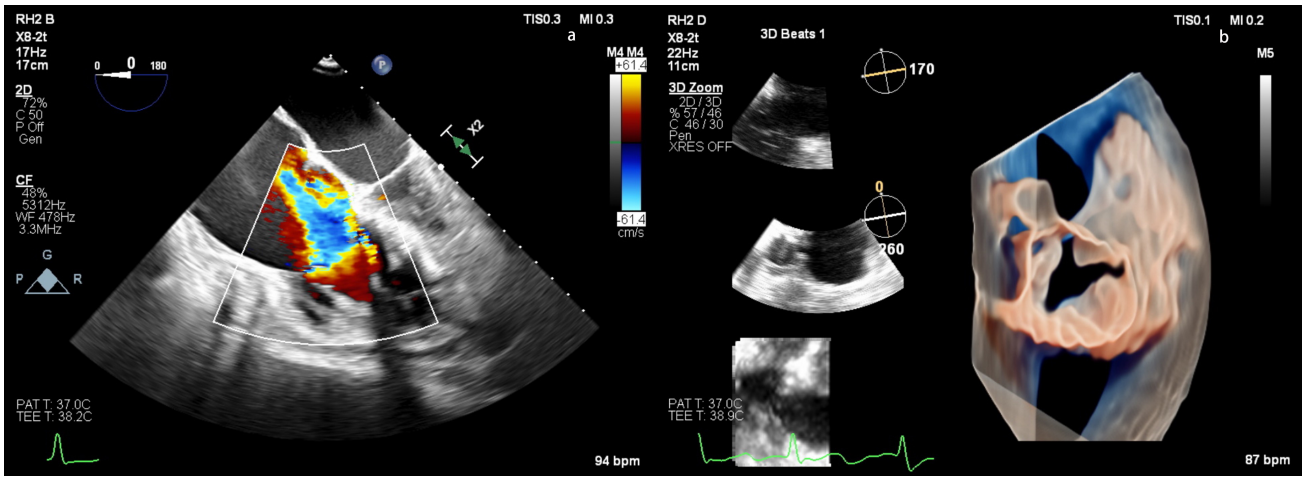

Fig. 5. Pre-procedure TEE. (a) Mid esophageal four-chamber view showing torrential TR and dilated right atrium (RA). (b) The end systole frame of 3D TEE demonstrates tethered leaflets and wide coaptation gap.

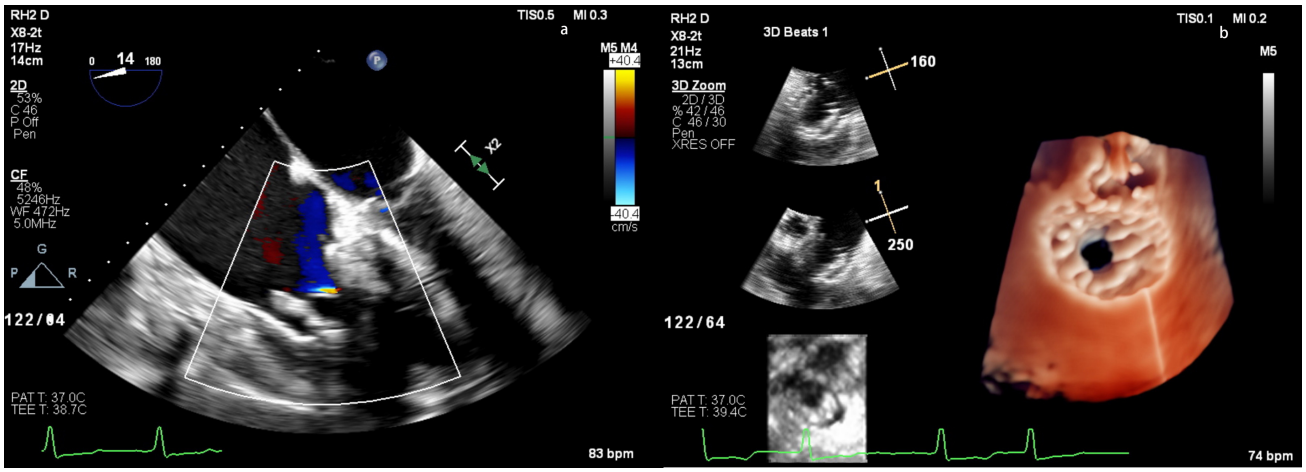

Fig. 6. Post-procedure TEE. (a) Mid esophageal four-chamber view showing Intrepid valve with residual trace TR. (b) The end diastolic frame of 3D TEE shows implanted Intrepid valve.

Discussion

Tricuspid Valve Anatomy, Pathophysiology, and Prognosis

Understanding the anatomy of the tricuspid valve is essential for grasping its complex pathophysiology and the considerations involved in its repair. The tricuspid valve is composed of four key components: leaflets (septal, anterior, and posterior), papillary muscles, chordal attachments, and the annulus. The leaflets are thin and translucent, making them particularly vulnerable to damage during interventional procedures [3]. The annulus has a D-shaped structure, is flat along the septum, and exhibits dynamic changes throughout the cardiac cycle and under varying loading conditions. These dynamic and circumferential variations make the placement of interventional annular devices particularly challenging [3].

Adjacent anatomical structures significantly impact tricuspid valve interventions. The superior and inferior vena cava, which serve as pathways for device insertion, have limitations in terms of diameter and angulation. The large, thin-walled right atrium provides sufficient space for device maneuvering. However, the right coronary artery, which runs in the posterior interventricular sulcus near the inferior annulus, is at risk of perforation by annular anchoring devices. Similarly, the noncoronary sinus of Valsalva, located near the commissure between the anterior and septal leaflets, is susceptible to perforation. Additionally, the atrioventricular (AV) node and the bundle of His, which are close to the septal leaflet and anteroseptal commissure, increase the risk of AV block if disrupted [3].

The classification of TR has been updated to include four main categories: primary TR, ventricular TR, atrial TR, and cardiac implantable electronic device (CIED)-related TR [4] (Table 1, Ref. [4,5]). Primary TR results from structural abnormalities of the valve apparatus. Com-

Table 1. Mechanisms of tricuspid regurgitation.

	Common etiology [4]	Echocardiographic characteristics [4,5]
Primary TR	Degenerative [prolapse, flail] Ebstein's disease Leaflet clefts Rheumatic heart disease Endocarditis Carcinoid disease Tumors Endomyocardial fibrosis Traumatic Iatrogenic [biopsy, drugs, radiation]	-Tricuspid valve tethering with apically displaced septal leaflet and atrialized right ventricle in Ebsteins disease. -Leaflet perforation or rupture in endocarditis. -Leaflet restriction in rheumatic heart disease. -Excessive leaflet motion on myxomatous disease. -Leaflet and chordal rupture or perforation in iatrogenic injury. -Variable RA dilation, TA dilation, RV dilation and RV dysfunction.
Ventricular TR	Right ventricular dilation secondary to: -Pulmonary hypertension -Left-sided valvular disease -Left ventricular dysfunction -Right ventricular infarction -Chronic RV pacing	-Elliptical or spherical RV deformation with RV dilation in mid diameter and base to apex length dimensions (mm). -Possible decreased LV systolic function and increased end diastolic volume. -Left atrial volume increased in left sided cardiac disease and pulmonary hypertension. -Decreased RV function measured with fractional area change (%) and TAPSE (mm). -TA dilation measured at end diastole (mm) (not as significant as in atrial TR). -Increased leaflet tethering measured by tenting height (mm) and tenting area (mm^2) with leaflet restriction in systole.
Atrial TR	Right atrium dilation secondary to: -Atrial fibrillation -Heart failure with normal ejection fraction	-Conical RV deformation -Increased RA indexed area (cm^2/m^2), RA indexed volume (mL/m^2) and RA major and minor axis (cm). -Increased TA annulus measured at end diastole (mm). -No mid RV dilation or base to apex dilation (mm). -Normal RV function measured with fractional area change (%) and normal TAPSE (mm). -Less leaflet tenting compared to ventricular TR measured by tenting height (mm) and tenting area (mm^2). -Normal systolic pulmonary artery pressure (mmHg). -Normal LV size and function (end diastolic and systolic volumes and ejection fraction).
CIED-related TR/CIED associated TR	-CIED-related TR: CIED mechanical interaction with tricuspid apparatus. -CIED-associated TR: no CIED mechanical interaction with tricuspid apparatus.	-Variable RA dilation, TA dilation, RV dilation and RV dysfunction. -Increased leaflet tethering measured by tenting height (mm) and tenting area (mm^2) with leaflet restriction in systole and diastole.

TR, tricuspid regurgitation; RV, right ventricle; RA, right atrium; TA, tricuspid annulus; TV, tricuspid valve; CIED, Cardiac Implantable Electronic Device; lV, left ventricle.

mon causes include degenerative disease, lead-related damage, radiation, rheumatic heart disease, endocarditis, and carcinoid disease. Secondary TR, or functional TR, is more prevalent and subdivided into ventricular and atrial types. Ventricular TR is caused by right ventricular (RV) dilation, which may arise from pulmonary hypertension, left-sided valvular disease, left ventricular dysfunction, RV infarction, or chronic RV pacing. Atrial TR occurs due to atrial dilation, typically from atrial fibrillation or heart failure with preserved ejection fraction. These insights into tricuspid valve anatomy, adjacent structures, and TR classification are critical for guiding effective and safe interventions.

Tricuspid regurgitation is highly prevalent in the United States, with TR-related mortality rising at an average annual rate of 4% over the past decade [1]. Evaluating the clinical impact of TR is complicated by its association with comorbidities and its diverse underlying causes. However, several studies have sought to isolate its effects. For example, in patients with primary TR caused by flail leaflets, significant TR was associated with an annual excess mortality rate of 4.5% compared to matched U.S. population controls [6]. Similarly, patients who develop TR secondary to leaflet damage from a cardiac implantable electronic device (CIED) face higher mortality rates than those without significant TR [7,8].

For the past 20 years, it has been well established that secondary TR is associated with increased mortality [9]. In patients with secondary TR due to left-sided valvular disease, studies have consistently demonstrated elevated mortality rates in those with at least moderate TR undergoing procedures such as mitral valvuloplasty [10], mitral clip implantation [11,12], and aortic valve replacement [13,14]. Additionally, in patients with secondary TR resulting from systolic heart failure, the severity of TR has been independently linked to higher mortality [15]. Even isolated severe TR, in the absence of significant comorbidities, is associated with an increased risk of mortality [16].

Despite growing awareness that TR is independently associated with increased mortality, it remains significantly undertreated [16]. A recent retrospective cohort study revealed that only 4% of patients with severe TR underwent surgical intervention within five years of diagnosis [8]. Current American College of Cardiology and American Heart Association guidelines provide a Class I recommendation for tricuspid valve repair or replacement only when concurrent surgery for a left-sided valve is indicated. For other cases, the recommendations are limited to Class 2a for symptomatic right-sided heart failure and Class 2b for asymptomatic TR with progressive right ventricular (RV) dysfunction [17].

The mortality rate for tricuspid valve repair or replacement reported in national registries is approximately 8–10%, significantly higher than for left-sided valve intervention [2]. Furthermore, many patients with severe TR have complicating factors such as RV dysfunction, pulmonary hypertension, and prior heart surgeries, which make them poor candidates for traditional surgical intervention [18].

Medical therapy for TR remains limited, primarily consisting of diuretics, pulmonary vasodilators, and guideline-directed medical therapy for heart failure [17]. However, emerging transcatheter tricuspid valve (TTV) repair technologies offer new hope for patients who are unsuitable for surgery or receive suboptimal medical therapy. These advancements could address a significant unmet need in the treatment of severe TR.

Anesthesia Considerations

Pre-Procedure Evaluation and Patient Selection

Patients are referred to the valve team from various specialties depending on the underlying cause of TR. For primary TR, referrals typically come from internal medicine, general cardiology, or gastroenterology. Secondary TR patients are usually referred by heart failure specialists, pulmonologists, or cardiac surgeons. Those with TR related to cardiac implantable electronic devices (CIEDs) are most often referred by electrophysiology or heart failure teams [19].

Once referred, patients undergo an evaluation of their surgical risk. Traditional risk assessment models, such as the Society of Thoracic Surgeons (STS) score and the Clinical Risk Score (CRS), were not developed for patients undergoing transcatheter tricuspid interventions. To address this gap, the TRI-SCORE model was introduced in 2021 to predict in-hospital mortality following tricuspid valve surgery [20]. The TRI-SCORE has also demonstrated superior predictive accuracy compared to the STS score for patients undergoing transcatheter edge-to-edge tricuspid valve repair [21]. Key parameters assessed in these calculators include patient age, NYHA classification, presence of a permanent pacemaker or defibrillator, glomerular filtration rate (GFR) <30 mL/min, and the underlying mechanism of TR [20]. Patients deemed to be at low surgical risk are typically referred for open-heart surgery to address their TR.

For patients deemed high risk for surgery, the transcatheter tricuspid intervention pathway is considered, beginning with preoperative testing to stage the disease. This process includes evaluating biomarkers, clinical status, and the severity of TR. Patients with end-stage disease are considered for palliative care, while those with a favorable prognosis undergo more detailed preoperative assessments to guide procedural planning. Key evaluations include transthoracic and TEE to determine the etiology of TR and assess biventricular function, computed tomography (CT) scanning to analyze coronary anatomy, annular size, and vascular access, and magnetic resonance imaging (MRI) to investigate rare causes such as carcinoid syndrome or congenital abnormalities. Right heart catheterization is also performed to characterize heart failure severity and pulmonary hypertension [19].

Additional testing includes an electrocardiogram, complete blood count, comprehensive metabolic panel, kidney function tests, coagulation studies, blood typing with cross-matching, and device checks for those with CIEDs. This comprehensive preoperative workup ensures precise patient selection and effective procedural planning for transcatheter interventions.

When determining the most suitable valve intervention for each patient, anatomy and etiology are critical considerations. In cases of primary TR, transcatheter tricuspid replacement (TTVR) is more appropriate if there is evidence of restricted leaflet motion or insufficient tissue, whereas a transcatheter edge-to-edge repair (TEER) device may be suitable for localized lesions. For patients with TR related to CIEDs, options include TEER, TTVR, or caval valve implantation (CAVI). These patients should also be evaluated by electrophysiology teams for potential device removal or replacement [19].

In atrial TR, TEER is a viable option if the coaptation gap is less than 8.5 mm and the coaptation depth exceeds 10 mm. For cases where these criteria are not met, annuloplasty followed by TEER may be considered. Patients with ventricular TR may qualify for TEER, TTVR, or CAVI, especially in advanced disease stages [19].

The choice between valve repair and replacement also depends on additional factors. Valve repair is generally less invasive, poses a lower or negligible risk of requiring a pacemaker, preserves options for future interventions, and does not necessitate anticoagulation. However, repairs may leave residual TR, carry a risk of single-leaflet device detachment, and are limited by anatomical and imaging constraints. In contrast, valve replacement often eliminates TR entirely and is less dependent on anatomical factors but is more invasive, has a higher pacemaker risk, and requires long-term anticoagulation [22].

Since most of these patients will already be on maximal medical therapy before reaching this stage, their medication regimens must also be factored into pre-anesthetic evaluations. Many will be on diuretics to manage cardiovascular congestion. Patients with associated heart failure symptoms will likely be on guideline-directed medical therapy, including renin-angiotensin-aldosterone system blockers or angiotensin receptor-neprilysin inhibitors (ARNIs), beta-blockers, and sodium-glucose cotransporter 2 (SGLT2) inhibitors. Pulmonary vasodilators are often used for those with pulmonary hypertension, while rhythm control therapies are employed in patients with atrial fibrillation [23].

Additionally, these patients frequently present with extensive comorbidities, including chronic kidney disease, chronic liver disease, diabetes, chronic obstructive pulmonary disease (COPD), peripheral artery disease, coronary artery disease, and implanted cardiac devices (CIEDs) [24]. These factors require careful consideration to optimize both the procedural plan and perioperative management.

Intraprocedure

Transcatheter tricuspid interventions are performed in a hybrid operating room using advanced imaging and monitoring techniques, including fluoroscopy, TEE, intracardiac echocardiography, fusion imaging, and invasive hemodynamic monitoring [19]. Candidates for these procedures are typically high-risk for general anesthesia due to significant cardiac and systemic comorbidities. Blood pressure monitoring is conducted via an arterial line, and central venous access is established through the venous sheath used for the procedure.

Most devices are delivered through the femoral vein; however, certain devices, such as the Lux valve, require a transjugular approach [25]. After the induction of general anesthesia, gentle volume expansion is often necessary to distend the venous system, facilitating device manipulation and placement. This meticulous setup ensures precision and safety during these technically complex interventions.

The choice between sedation and general anesthesia for transcatheter tricuspid interventions is complex and influenced by multiple factors. Since these procedures are relatively new, data on the safety and efficacy of each approach remains limited. Insights from transcatheter mitral valve interventions suggest that conscious sedation and deep sedation can be as safe and effective as general anesthesia [26]. However, unique challenges associated with tricuspid interventions must be considered.

The tricuspid valve's anatomical location often necessitates significant TEE probe manipulation for optimal imaging, which is more easily achieved under general anesthesia [27]. Additionally, patients undergoing these procedures are typically older and may present with complicating factors such as right ventricular dysfunction and pulmonary disease. These comorbidities can increase the risks associated with deep sedation and may favor the use of general anesthesia to ensure procedural safety [28]. Ultimately, the decision requires a careful balance of patient-specific risks, procedural complexity, and imaging requirements.

The TriClip has been the most widely used technique for transcatheter tricuspid valve repair (TTVr) to date. A recent study comparing general anesthesia and sedation for this procedure demonstrated equal procedural success, with no conversions to general anesthesia and no differences in total procedure duration. Interestingly, hospital stays were shorter for patients under sedation (six days vs. eight days). In this study, sedation was achieved using midazolam and propofol [29]. Other devices, such as the PASCAL device, have been successfully placed under both deep sedation [30] and general anesthesia [31]. CAVI procedures, on the other hand, are typically performed under local anesthesia

with fluoroscopic guidance [19]. At our institution, TTVR procedures are conducted under general endotracheal anesthesia, with most patients extubated in the operating room. Currently, no published outcome data directly compare sedation to general anesthesia for TTVR procedures.

Intraoperative complications associated with these procedures should be anticipated and include acute bleeding, incomplete TR correction, device embolization or migration, and acute arrhythmias [32]. Each type of intervention also carries specific risks. For TEER procedures, single leaflet detachment is a known complication [28]. The Cardioband device may lead to major bleeding, ventricular arrhythmias, atrioventricular block, or cardiac tamponade caused by anchoring device penetration into the right coronary artery [33].

Heterotopic valve replacement procedures carry risks of device embolization, migration, arrhythmias, and bleeding [34]. Acute correction of TR can also result in acute afterload mismatch and subsequent right ventricular (RV) failure [32]. A thorough understanding of these risks is critical for optimizing patient outcomes and managing complications effectively.

Transcatheter Tricuspid Repair (TTVr)

Over the past two decades, transcatheter valve repair techniques have been successfully developed and utilized for mitral and aortic valve disease. More recently, these technologies have been adapted for use in the tricuspid valve, marking a significant advance in the treatment of TR [35]. The field has expanded rapidly, with numerous devices under investigation. Currently, the FDA has approved two devices specifically for tricuspid valve interventions: the TriClip for tricuspid valve repair [35] and the Evoque for tricuspid valve replacement [36].

In 2021, the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS) valvular heart disease guidelines recommended that interventional treatment for secondary TR may be considered in anatomically eligible patients at experienced valve centers [37].

The primary strategies for treating TR focus on improving leaflet coaptation using TEER devices such as MitraClip, TriClip, and PASCAL; reducing annular size with the Cardioband; addressing vena cava reflux with devices like the TricValve and Sapien Valve; and replacing the valve entirely with implants like the Evoque, Trisol, Sapien, and Melody valves [38].

This review will focus on the most extensively studied tricuspid valve repair and replacement devices (Table 2, Ref. [19,27,28,33–36,39–56]).

Coaptation Enhancement

TEER devices are approved for restoring leaflet coaptation in the tricuspid valve position: the TriClip and PASCAL, with the TriClip also receiving FDA approval. The TriClip consists of a steerable guide catheter and a clip delivery system. The steerable guide catheter is introduced into the right atrium through the femoral vein, while the clip delivery system is positioned above the tricuspid annulus [27]. The delivery system includes a 4 mm-wide metal implant with two polyester-covered arms. TEE is employed to guide clip placement [28].

In functional TR, the regurgitation jet is often central, making the anteroseptal commissure the primary target for clipping. However, compared to the MitraClip, the TriClip can be more challenging to position due to the shorter distance between the inferior vena cava (IVC) and the tricuspid annular plane, as well as the difficulty of achieving high-resolution TEE imaging of the tricuspid valve [28].

Predictors of procedural failure with TEER include leaflet clefts and significant leaflet tethering, both of which complicate achieving effective coaptation. Additionally, TEER rarely eliminates TR completely, and there is a risk of TR recurrence. This recurrence may limit future treatment options, highlighting the importance of careful patient selection and procedural planning [23].

Annuloplasty

The Cardioband device is a transcatheter annuloplasty system designed to reduce the tricuspid annular size, thereby improving leaflet coaptation and mitigating TR [33]. One significant advantage of annuloplasty devices like Cardioband is the preservation of native leaflet anatomy, which allows for the possibility of combining annuloplasty with other interventions, such as TEER, to enhance therapeutic outcomes [33]. However, limitations of this approach include prolonged procedural times and challenges associated with intraprocedural imaging, which can complicate the intervention [23].

Initially developed for managing functional mitral regurgitation, the Cardioband system has been adapted for the tricuspid valve. It consists of a sutureless Dacron band that is delivered to the tricuspid annulus via transfemoral venous access. The device is deployed circumferentially around the atrial side of the annulus and can be adjusted to decrease the annular size, thereby enhancing leaflet coaptation and reducing TR [57].

Clinical studies have demonstrated the safety and efficacy of the Cardioband device in reducing annular dimensions and TR severity. For instance, the TRI-REPAIR study reported significant reductions in annular size and TR grade, along with improvements in functional status and quality of life at six-month follow-up. However, the procedure is technically demanding and requires precise imaging for accurate deployment, which can extend procedural duration and increase complexity [33].

Table 2. Transcatheter tricuspid valve devices.

Mechanism	Name	Description	Main outcomes
Coaptation enhancement and spacers	TriClip* [Abbott]	TEER device with two clip arms for leaflet grasping [28]	The TRILUMINATE trial demonstrated that 90% of patients experienced at least one grade reduction in TR severity at six months [27]. At the two-year follow-up, 75% of patients maintained this reduction. The trial also reported sustained improvements in quality of life, reduced heart failure-related hospitalization rates, favorable right ventricular (RV) remodeling, and low mortality rates [48]. TEER has shown significant benefits in improving TR severity, New York Heart Association (NYHA) functional class, and performance on the six-minute walk test [49]. At one year, TEER was strongly associated with reduced mortality and fewer hospitalizations related to heart failure [50].
	Pascal [Edwards Lifesciences]	TEER device with two paddles and a spacer [45]	
	Dragonfly [Valgen Medtech]	TEER device used in mitral valve disease [46]	
	Tri-Flo [TriFlo Cardiovascular]	Implantable device with polymer leaflets [47]	
Annuloplasty	Cardioband [Edwards Lifesciences]	Sutureless dacron band that decreases annular size [33]	The TRI-REPAIR trial demonstrated that at six months, significant reductions in TR were achieved through decreased annular dilation, along with notable improvements in heart failure symptoms and quality of life [33]. At the two-year follow-up, 82% of patients experienced improved New York Heart Association (NYHA) classification, even though TR was reduced to moderate or less in only 72% of cases.
	DaVingi [Cardiac Implants LLC]	Multielement ring with an outer fabric layer, pre-set stakes array, and internal adjustment cord [51]	
	PASTA	Pledgeted Assisted Suture Tricuspid Annuloplasty [52]	
Orthotopic replacement	Evoque* [Edwards lifesciences]	Trileaflet bovine pericardium tissue valve with a nitinol frame and a fabric skirt [36]	The TRISCEND I trial reported clinical success in 73% of patients at 30 days [36]. At the one-year follow-up, 97% of patients had TR reduced to mild or less, with significant improvements in New York Heart Association (NYHA) class, cardiac output, and six-minute walk test performance [35]. More recently, the TRISCEND II trial, involving 267 patients, demonstrated that transcatheter tricuspid valve replacement was superior to medical therapy alone, particularly in improving symptoms and quality of life [19]. The Lux-Valve device achieved significant reductions in TR severity to <2+ and <1+ in 94.7% and 90.8% of patients, respectively, with these results well-sustained at a one-month follow-up. Major in-hospital events occurred in 6.6% of patients, including a 3.9% rate of pacemaker implantation [54]. The Cardiovalve was successfully implanted in 90% of cases during compassionate use in a cohort of 20 patients. At 30 days, TR was reduced to less than mild in 95% of patients, with a mortality rate of approximately 10% [55].
	Intrepid [Medtronic]	A circular self-expanding tri-leaflet bovine pericardial valve within a nitinol frame [42]	
	V-Dyne [VDyne]	Asymmetric valve with porcine pericardium leaflets with pop-off hole [53]	
	Trisol [Trisol Medical]	Sail-like pericardial leaflets with an RV pressure relief system [Vaturi, 2021, https://trisol-medical.com]	
	Lux/Lux Plus [Ningbo Jenscare Biotechnology Co]	Self-expandible bovine pericardium trileaflet valve mounted on a nitinol valved stent/second generation valve [40]	
	Topaz [TRICares SAS]	Three leaflet bovine pericardium valve [39]	
	Cardiovalve [Venus Medtrech]	Three scallop-shaped leaflets in a self-expandable nitinol frame with a short height and narrowed outflow [41]	

Table 2. Continued.

Mechanism	Name	Description	Main outcomes
Heterotopic replacement	TricValve [Products Features Vertriebs]	Implantation system of two self-expanding nitinol structures with leaflets made of bovine pericardium [IVC and SVC [43]]	The TricValve was successfully implanted in 94% of patients in a 35-patient cohort, with 79% of patients showing improved New York Heart Association (NYHA) scores at six-month follow-up [43]. In the initial TRICENTO trial, all six patients who underwent valve implantation experienced improvements in NYHA scores and a reduction in TR grade by one or more levels [44].
	TriCento [NVT]	Self-expandable bioprosthesis with a stent graft that spans from the SVC to the IVC and a lateral bicuspid valve element [44]	
	Trillium [Innoventric]	Cross-caval stent graft with multiple fenestrations around the RA portion [34]	
	Sapien valve [Edwards Lifesciences]	Heterotopic valve replacement SVC/IVC [56]	

*, Food and Drug Administration (FDA)-approved devices; TEER, Transcatheter Edge to Edge Repair; IVC and SVC, Inferior Vena Cava and Superior Vena Cava.

Transcatheter Tricuspid Replacement (TTVR)

Several bioprosthetic transcatheter tricuspid valve replacement (TTVR) devices are under investigation in clinical trials, with the EVOQUE valve being the only one currently FDA-approved. The EVOQUE system utilizes a transfemoral delivery system and comes in three sizes (44, 48, and 52 mm) along with a dedicated dilator kit, offering flexibility for different patient anatomies [35].

The Topaz system is another device designed for transfemoral tricuspid valve replacement. It features a three-leaflet valve made from bovine pericardium and is currently indicated for tricuspid annuli up to 45 mm in diameter [39].

The LuX valve represents a novel approach, consisting of an expandable bovine pericardial trileaflet valve mounted on a nitinol valved stent. It accommodates a wide range of annulus sizes and leaflet anatomies. Its fixation system requires less pressure, theoretically reducing the risk of complications such as bundle branch blocks [40].

The Cardiovalve features three scallop-shaped leaflets mounted within a self-expanding nitinol frame. Delivered via the transfemoral approach, it is available in medium, large, and extra-large sizes, designed to fit annuli ranging from 36 to 55 mm [41].

The INTREPID system, originally developed for mitral valve replacement, is a bovine pericardium valve mounted on a dual nitinol stent frame. While initially intended for mitral applications, it has been successfully adapted for use in the tricuspid position and is currently under investigation [42].

Heterotopic Valve Replacement

Caval valve implantation (CAVI) has recently emerged as a treatment option for severe TR, aiming to prevent venous backflow in the superior vena cava (SVC) and inferior vena cava (IVC). By reducing regurgitant flow, CAVI alleviates liver and renal congestion, increases right ventricular (RV) stroke volume, and improves overall cardiac output [34].

The TricValve system consists of two self-expanding nitinol stents, each with leaflets made of bovine pericardium. One stent is implanted in the SVC and the other in the IVC, without interfering with the native tricuspid valve, thereby preserving options for future tricuspid interventions [43].

The Tricento is a self-expandable bioprosthesis featuring a stent graft that extends from the SVC to the IVC. It includes a lateral bicuspid valve element to effectively prevent backflow by isolating the caval veins from the right atrium [43].

Trillium is currently in early clinical trials. This device is a cross-caval stent graft with multiple fenestrations along the portion located in the right atrium. These fenestrations allow inflow into the right atrium while preventing backflow into the venous system [34].

Conclusion

The expansion of transcatheter tricuspid valve (TTV) interventions has made it possible for many patients, previously unsuitable for surgical repair due to high anesthetic risk and significant comorbidities, to undergo tricuspid valve repair or replacement. As new devices are introduced to the market, it is essential to carefully assess patient-specific risk factors and anticipate potential procedural complications to provide optimal care. With the field continuing to grow rapidly, further research is needed to better understand the safety and efficacy of different anesthetic strategies for these procedures.

Availability of Data and Materials

Data sharing is not applicable to this article, as no data sets were generated or analyzed during the current study.

Author Contributions

IG contributed to the design of this manuscript. IL, JS, AM drafted the work. CC, IG, JS, AM and SK revised critically for important intellectual content. All authors contributed to editorial changes in the manuscript. All authors read and approved the final manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

Not applicable.

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Conflict of Interest

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