The current state of isolated tricuspid valve surgery: how it complements transcatheter tricuspid valve interventions

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Tricuspid valve insufficiency represents a prevalent health burden for many patients worldwide but remains highly undertreated. This is especially true for isolated tricuspid disease, where surgical intervention remains underutilized. Despite historically elevated periprocedural risk, isolated tricuspid valve surgery (iTVS) today can provide an effective and reliable solution to tricuspid disease. Successful iTVS requires careful evaluation of valve anatomy, pathophysiology, and patient risk profile. Available risk calculators can be useful tools in determining patient risk and surgical candidacy. Additionally, intervening within the treatment window before late right ventricular disease and distortion with end-organ damage is integral to success. The application of minimally invasive surgical approaches can further improve outcomes. Furthermore, tricuspid valve repair has been shown to improve long-term survival. For patients who are not candidates for surgery, transcatheter modalities have increased awareness and provide a promising treatment alternative for tricuspid regurgitation (TR) reduction and symptom control, albeit with limited durability data. Currently, surgical and transcatheter interventions address separate populations with distinct risk profiles. Hence, treatment success is dependent on matching the right patient with the right procedure. Patients with suitable anatomy and lower risk profiles should be considered for surgical approaches, particularly if repair may be feasible.

Keywords: Tricuspid valve; tricuspid regurgitation (TR); tricuspid surgery

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Introduction

Significant tricuspid regurgitation (TR) affects over 1.6 million people in the United States and over 70 million patients worldwide (1). Large epidemiologic studies such as the Framingham Heart Study found the prevalence of mild or greater TR to be 14.8% and 18.4% for men and women, respectively (2). Despite data suggesting a large disease prevalence, only 8,000 tricuspid valve surgeries (TVS) are performed annually in the United States (1).

Previously assumed to be benign, any significant TR now has been proven to increase mortality. In 2004, a seminal study from the Veterans Affairs (VA) Health Care System following 5,223 VA patients demonstrated an association between moderate or greater TR and survivorship, independent of pulmonary hypertension (pHTN) and left ventricular function. Specifically, when adjusted for age, right and left ventricular function, and inferior vena cava size, moderate TR [hazard ratio (HR): 1.17, 95% confidence interval (CI): 0.96–1.42; P=0.1] and severe TR (HR: 1.31, 95% CI: 1.05–1.66; P=0.02) both demonstrated incrementally worse survival compared to patients with no TR (3). Since then, additional studies have proven that tricuspid regurgitation affects survival independent of other parameters (4). Despite this, tricuspid regurgitation remains undertreated.

The 2020 American College of Cardiology/American Heart Association (ACC/AHA) guidelines provide a Class IIa recommendation for isolated tricuspid valve surgery (iTVS) for severe, medication-refractory, functional TR with annular dilation in the absence of pHTN or left heart disease. Furthermore, a Class IIa recommendation

Table 1 Select societal guidelines for the management of isolated tricuspid valve disease

ACC/AHA guidelines (2020) (5)	ESC/EACTS guidelines (2025) (6)
No Class 1 Recommendations of isolated tricuspid valve surgery	Level 1 Recommendation for isolated tricuspid valve surgery in the treatment of symptomatic, severe primary tricuspid regurgitation in the absence of severe right ventricular dysfunction and/or severe pulmonary hypertension (Level of Evidence: C) Level 1 Recommendation for tricuspid valve surgery in the treatment of severe, symptomatic tricuspid stenosis (Level of Evidence: C)
Level 2A Recommendation for isolated tricuspid valve surgery for severe primary tricuspid regurgitation in patients with right heart failure symptoms to reduce symptoms and recurrent hospitalization (Level of Evidence: B)	Level 2A Recommendation for isolated tricuspid valve surgery in the treatment of functional tricuspid regurgitation in patients with symptoms or right ventricular dilatation/functional deterioration, but in the absence of severe right ventricular dysfunction or severe pulmonary hypertension (Level of Evidence: B)
Level 2A Recommendation for isolated tricuspid valve surgery for severe, medication refractional, functional TR with annular dilation in the absence of pulmonary hypertension or left heart disease to reduce symptom burden and recurrent hospitalization (Level of Evidence: B)	Level 2A Recommendation for isolated tricuspid valve surgery for asymptomatic patients with severe, primary tricuspid regurgitation with right ventricular dilatation/ functional deterioration, in the absence of severe right ventricular dysfunction and/or severe pulmonary hypertension (Level of Evidence: C) Level 2A Recommendation for transcatheter treatment in high-risk patients with symptomatic, severe tricuspid regurgitation despite optimal medical therapy in the absence of severe right ventricular dysfunction or pre-capillary pulmonary hypertension to improve quality of life and promote positive right ventricular remodeling (Level of Evidence: A)
Level 2B Recommendations for doing isolated tricuspid valve surgery for patients with previous left heart surgery with severe tricuspid regurgitation and right heart failure symptoms in the absence of severe right ventricular systolic dysfunction or severe pulmonary hypertension (Level of Evidence: B) Level 2B Recommendation for isolated tricuspid valve surgery in asymptomatic patients with primary tricuspid regurgitation with progressive right ventricular dilation or systolic dysfunction (Level of Evidence: C)	–

ACC/AHA, American College of Cardiology/American Heart Association; ESC/EACTS, European Society of Cardiology/European Association for Cardio-Thoracic Surgery.

is provided for severe, primary TR in patients with right heart failure (RHF) symptoms. A Class IIb recommendation is provided for iTVS for patients with previous left heart valve surgery with severe TR and RHF symptoms in the absence of severe right ventricular (RV) systolic dysfunction and severe pHTN. Lastly, a Class IIb recommendation is provided for iTVS in asymptomatic patients with progressive RV dilatation or systolic dysfunction (5) (*Table 1*).

The 2025 European Society of Cardiology/European Association for Cardio-Thoracic Surgery (ESC/EACTS) guidelines provide a more aggressive stance on surgical treatment. A Class I recommendation for iTVS is provided for symptomatic, primary TR in the absence of severe RV dysfunction and/or pHTN. Additionally, a Class IIa recommendation is provided for surgical treatment of asymptomatic, severe primary TR in patients presenting with RV dilatation and/or functional deterioration but without severe LV/RV dysfunction and/or pHTN. Next, a Class IIa recommendation is provided for iTVS in the treatment of severe, functional TR in patients with symptoms or RV dilation/functional deterioration in the absence of severe ventricular dysfunction or pHTN. Lastly, a Class I recommendation is provided for the treatment of severe, symptomatic tricuspid stenosis (6).

Due to historically elevated mortality rates, iTVS remains uncommon. However, the advent of transcatheter

solutions has increased awareness of tricuspid disease and has prompted more referrals for treatment in TR patients. Given the unknown long-term durability of transcatheter approaches, iTVS can find a greater role. Educated appraisal of surgical risk, especially with available risk calculators, and preoperative optimization can further improve patient candidacy. The etiology of TR may also affect outcomes. Functional TR, the most common form, represents a higher risk etiology due to the onset of terminal RV dysfunction, and end-organ damage. However, if intervention is pursued before the onset of end-organ disease, iTVS can be performed in a safe and efficacious manner. Large database studies have demonstrated improved outcomes over time and modern single-center series report low mortality. Hence, iTVS should remain an important tool in the modern valve surgeon's armamentarium.

Disease etiology

Functional tricuspid regurgitation

In epidemiologic studies, functional TR is represented in more than 90% of all TR cases in developed countries, with left-sided valvular disease being the most common etiology (7-9). When patients are being considered for iTVS, these etiologies represent a higher risk group due to the delayed intervention and the onset of late-stage annular dilatation, leaflet tethering, and RV dysfunction.

In a 2020 study, Dreyfus *et al.* identified 466 cases of iTVS from 2007 to 2017, of which 229 patients (49%) presented with functional TR and 237 patients (51%) presented with primary TR etiologies (9). Patients presenting with functional TR had a higher rate of in-hospital mortality (14% *vs.* 6%, P=0.004) and mortality at midterm follow-up (25% *vs.* 15%, P<0.01) (9). However, on multivariable analysis of predictors of in-hospital mortality, NYHA Class III/IV (P=0.01) and moderate/severe RV dysfunction (P=0.02) were found to be independent determinants of in-hospital mortality, while TR etiology was not (P=0.88) (9). This shows that the elevated risk associated with functional TR is a result of late risk factors including advanced symptoms and RV dysfunction.

The risk associated with iTVS is more associated with inherent patient illness than the difficulty of the operation, particularly since functional TR is often a manifestation of RV dysfunction. Hence, judicious patient selection is required to optimize outcomes. In 2025, a 7-study meta-analysis identified 2,202 patients who received iTVS for functional TR. In-hospital survival was 93%, while 1- and 5-year survival were 84.5% and 69.1% respectively. In total, 58% had previous left-sided valve surgery and 57% had NYHA Class III/IV heart failure, indicating heightened risk in this population. Additionally, more patients received replacement than repair (58.2% *vs.* 41.8%), suggesting the difficulty of repair in patients presenting with end-stage loss of leaflet coaptation (10). Hence, timely referral before the onset of end-stage disease improves the chances of successful tricuspid repair and optimizes postoperative outcomes. Since symptoms are subtle, heightened awareness among primary care providers and cardiologists is paramount to expedite appropriate treatment.

Atrial tricuspid regurgitation

Atrial TR is now being increasingly recognized as a distinct etiology of tricuspid disease with a unique morphology. It is typically the result of right atrial (RA) remodeling due to long-standing atrial fibrillation (AF) or heart failure with preserved ejection fraction. In contrast to ventricular TR, where RV dysfunction results in leaflet tethering, atrial TR results from annular dilation secondary to RA enlargement.

A 2016 echocardiographic study from Cedars-Sinai identified 437 patients with moderate or greater TR, in which 9.2% of patients demonstrated signs of atrial TR (11). Compared to patients with left heart disease, patients with atrial TR were more often older, female, possessed greater RA volumes, and had lower pulmonary artery systolic pressures (P<0.05 for all). On 3D echocardiography, those with atrial TR had a larger TV annular area with a weaker annular contraction, and a smaller tethering angle (P<0.001 for all). Dilation was more posteriorly oriented compared to left heart-associated TR. RA volume and annular enlargement were the only identified determinants of atrial TR severity progression (11). Hence, atrial TR stems from severe annular dilation due to RA enlargement as opposed to leaflet tethering secondary to RV dysfunction.

RA remodeling secondary to long-standing AF can lead to progression of atrial TR. A 2023 South Korean natural history study followed 833 patients with mild, idiopathic TR. Of these, 291 patients had either AF or atrial flutter (AFL). During a 4.6-year median follow-up, 35 patients progressed to significant regurgitation, of which 33 patients had AF or AFL. AF or AFL was identified as an independent risk factor for worsening TR (aHR: 8.33, P<0.001). Furthermore, progression of atrial TR was

associated with a higher 10-year rate of death and major adverse cardiovascular events (MACEs) (P<0.001) (12). Therefore, long-standing arrhythmia can contribute to worsening tricuspid regurgitation and negatively affect long-term outcomes. Hence, treating both the arrhythmia and resultant tricuspid regurgitation is warranted.

In another South Korean single-center study, 43 patients underwent iTVS for atrial TR. In total, 37 patients (86%) received either a ring or suture annuloplasty, while 6 received replacement (14%). Of these patients, 39 (90.7%) received a concomitant Cox-Maze procedure. Operative mortality was 2.3% (n=1). One-year and 5-year survival rates were 90% and 79.3%, respectively. The cumulative incidence of tricuspid valve-related events (TVRE) was 16.3% and 26.5% at 1- and 5-year, respectively. TVRE was significantly associated with the time interval between diagnosis of severe TR and time of surgery (HR: 1.023, 95% CI: 1.005–1.042) (13). These findings suggest that atrial TR can be surgically repaired with good outcomes. However, larger studies with longer follow-up are required before definitive conclusions can be made.

Primary tricuspid regurgitation

Patients with primary TR, although representing a smaller fraction of TR cases, are a population that may benefit from iTVS. Etiologies such as degenerative disease, endocarditis, rheumatic disease, congenital malformation, carcinoid disease, trauma, iatrogenic injury, and pacing lead-induced TR represent subsets of patients with primary TR. Often, patients with primary TR represent a younger cohort with a lower comorbidity burden, due to the absence of concurrent left heart disease. Hence, these patients may be surgical candidates if prompt referral is pursued.

A 2019 study from the group at Baylor Scott & White Heart Hospital identified 95 cases of isolated tricuspid surgery completed between 2007–2017 and reported a low 30-day mortality rate of 3.2% (3/95). Operative volume increased from an average of five cases of iTVS per year to an average of 15 cases of iTVS per year. In total, 55.8% (53/95) of patients had a primary TR etiology, including 16 patients with pacing lead induced injury, 13 patients with endocarditis, 10 patients with congenital malformations, eight patients with chest trauma, and six patients with rheumatic disease. While this cohort is heterogeneous in disease etiology, it demonstrates that iTVS can be performed with low perioperative mortality, especially when treating primary TR. Additionally, 71.6% (68/95) received tricuspid repair instead of replacement (14). The relatively low mortality rate in this study could be attributable to both a healthier group of patients who were able to be treated with surgical repair before the onset of advanced disease, as well as preoperative rehabilitation, often with Swan-Ganz directed diuresis. Large studies examining the effect of iTVS on exclusively primary TR are scarce. Other single-center reviews demonstrate that primary TR constitutes a sizable subset of presenting disease (15,16). However, small sample sizes and lack of follow-up limit the ability to explore outcomes of this population after surgery.

Better insight into the role of iTVS in the treatment of primary TR may be found outside the US and Europe, where primary TR has a greater prevalence. For example, a 2024 Australian study using the Admitted Patient Data Collection of New South Wales (Australia) from 2001–2018 identified 575 patients who received isolated tricuspid surgery. Disease etiology was heterogeneous, including a 66% incidence of rheumatic disease and a 10% incidence of endocarditis. In-hospital mortality was 7.4%. At a mean follow-up of 4.8±3.9 years, the mortality was 39.3% (211/575). Tricuspid replacement was associated with increased mortality by univariate analysis (HR =1.35, 95% CI: 1.03–1.77, P=0.03) while repair was protective (HR =0.50, 95% CI: 0.32–0.79, P=0.003). However, on multivariable analysis, only congestive cardiac failure, chronic pulmonary disease, malignancy, and age ≥65 years were predictive of all-cause mortality (P≤0.001 for all). The authors conclude that in-hospital mortality and morbidity rates are a consequence of late referral, resulting in irremediable RV dysfunction, thus reducing rates of repair and maintenance of right heart structural integrity (17). Overall, patients with primary TR may benefit from iTVS, provided that expedient recognition and intervention are practiced. Regardless of TR etiology, iTVS should be performed in the narrow window of opportunity between TR recognition and the onset of terminal disease.

Surgical approach

Isolated tricuspid repair

When considering patients for iTVS, the choice to repair or replace the tricuspid valve may affect the long-term prognosis. Early referral and intervention may improve surgical outcomes by enabling tricuspid repair before the onset of terminal annular dilation and leaflet tethering. Valve repair maintains native RV anatomy, thus improving long-term survival (18) (*Table 2*).

Table 2 Large sample retrospective studies of outcomes of isolated tricuspid valve surgery

Title	Study type	Population	Key results
Isolated Tricuspid Valve Surgery for Functional Tricuspid Regurgitation (10)	Meta-analysis of 7 studies of isolated tricuspid surgery for patients with functional TR	2,202 recipients of isolated tricuspid surgery for functional TR. 42% (734/1,754) underwent repair; 58% (1,020/1,754) underwent replacement (6 studies)	In hospital mortality: 7% (280/2,202) 1-year survival: 84.5%; 5-year survival: 69.1%
Long term outcomes of isolated tricuspid surgery in 3,706 patients: Implications for the future (18)	Retrospective cohort: Department of Health Care Access and Information of California State admission data base. Study Period: 1991–2020	3,706 patients receiving TVS: 2,419 (65.3%) receiving repair; 1,287 (34.7%) receiving replacement. 789 propensity match pairs	Isolated TVS volume increased from 48 to 207 cases per annum from 1991 to 2021 (P<0.001) Operative mortality was similar between repair and replacement (8.2% *vs.* 9.9%, P=0.27) New PPM rates were higher in replacement (32.7% *vs.* 13.7%, P<0.001) Tricuspid repair had reduced 25-year mortality (P=0.005)
A Systemic Review and Meta-Analysis of the Clinical Outcomes of Isolated Tricuspid Valve Surgery (19)	Meta-analysis of 27 studies of patients receiving isolated tricuspid valve surgery. Excluded studies with other concomitant cardiac surgeries, studies without distinct groups (repair *vs.* replacement, and studies exclusively studying congenital TR	10,478 patients receiving isolated tricuspid surgery were identified from years 1978 to 2019 that met inclusion criteria: 4,931 underwent repair; 3,821 underwent bioprosthetic valve replacement; 1,713 underwent mechanical valve replacement; 13 underwent unspecified replacement	Early mortality: 9%. Late mortality (median follow up of 4 years) was 27% Late mortality for replacement was higher compared to repair (30% *vs.* 25%, rate ratio: 1.18, 95% CI: 1.05–1.31, P=0.004)
Prevalence and Outcomes of Isolated Tricuspid Valve Surgery Among Medicare Beneficiaries (20)	Retrospective Review of Medicare and Medicaid Services Medicare Provider Analysis and Review Data. Study period: January 2003 to December 2014	5,164 recipients of isolated tricuspid surgery: 2,494 (48.3%) received repair; 2,670 (51.7%) received replacement	Overall operative mortality: 9.9% Repair: 10% (249/2,494); replacement: 9.8% (261/2,670) Repairs had lower 1-year mortality than replacements (P<0.001) Overall, 1-year mortality: 24.1% Repair: 22.2% (554/2,494); replacement: 691 (25.9%) Overall, 87.1% of hospitals performed 10 or fewer cases during the study time period. Less than 1% of hospitals performed >5 cases per year
Outcomes of isolated tricuspid replacement versus repair among older patients with tricuspid regurgitation in the United States (21)	Medicare data: patients 65 years of age undergoing either isolated tricuspid replacement or repair from 2016 to 2020	1501 recipients of TVS: 610 replacements; 891 repairs	No difference in in-hospital mortality (replacement: 13.2% *vs.* repair:12.8%, P=0.930) 3-year mortality of all patients: 38.8% No significant difference in mortality (P=0.600) or MACE (P=0.910) on propensity matched analysis Replacements had a higher rate of PPM (26.3% *vs.* 13.3%, P<0.001) No significant difference in early mortality between patients (65–75 years old) *vs.* ≥75 years of age

Table 2 (*continued*)

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Title	Study type	Population	Key results
National Trends and Outcomes in Isolated Tricuspid Valve Surgery (22)	Retrospective review of all adult patients from 2004–2013 from the National Inpatient Sample	5,005 isolated tricuspid operations identified (59.2% replacement, 40.8% repair)	Total In-hospital mortality: 8.8% Recipients of repair had a lower in hospital mortality compared to replacements (repair: 5.9%, bioprosthetic replacement: 9.1%, mechanical replacement: 13.6%, P=0.003) On multivariate logistic regression analysis for predictors of in-hospital death, tricuspid replacement over tricuspid repair (OR: 1.91; 95% CI: 1.18–3.09, P=0.009) was an independent predictor (23)
Isolated Tricuspid Valve Repair Versus Replacement: Predictors of Mortality on the National Level (23)	Retrospective review of all patients receiving iTVS in the National Inpatient Sample. Study period: 2011 to 2020	37,931 patients received isolated tricuspid valve operations (66% repair, 34% replacement)	Overall operative mortality: 5.1% Repair: 4.6% *vs.* replacement: 6%, P=0.009 Isolated tricuspid surgery volume increased more than 3-fold from the first to the second half of the study Recipients of repair had less mortality, less stroke, shorter LOS, and reduced cost of stay, while those with replacement had fewer myocardial infarctions (P<0.05) On adjusted analysis, receiving a repair as opposed to replacement reduced in-hospital mortality (aOR: 0.72, P=0.011)
Outcomes of Isolated Tricuspid Valve Replacement: A Systemic Review and Meta-Analysis of 5,316 Patients from 35 Studies (24)	Meta-analysis of 35 studies published between 1974–2019	5,316 patients underwent isolated tricuspid valve replacement (included both bioprosthetic and mechanical valves)	Pooled analysis with random effects model: Short-term outcomes overall: Operative mortality overall: 12%; operative mortality between 1995–2019: 11%; pacemaker implantation: 10%; respiratory complications: 15%; bleeding: 12%; acute renal injury: 15% Late outcomes for bioprosthetic valves: Mortality: 6 per 100 person-years; 2+ TR recurrence: 8 per 100 person-years; reintervention: 1 per 100 person-years; structural valve deterioration: 3 per 100 person-years

CI, confidence interval; iTVS, isolated tricuspid valve surgery; LOS, length of stay; OR, odds ratio; PPM, permanent pacemaker; TR, tricuspid regurgitation; TVS, tricuspid valve surgery.

Larger, population-based analyses have allowed us to appreciate the effect of isolated tricuspid valve repair (iTVr). A 2025 study utilizing the California State admissions database of 3,706 isolated tricuspid surgery patients between 1991–2020 included 2,419 (65.3%) who underwent repair and 1,287 (34.7%) who received replacement. Patients receiving repair were less likely to have endocarditis (P<0.001), CHF (P<0.001), or liver disease (P<0.001). Cumulative operative mortality was 9.1%, decreasing from 10.4% to 8.7% to 6.9% through each decade of the study. Additionally, for patients with MELD scores below 10, operative mortality was only 3%. There was no significant difference in operative mortality between recipients of repair and replacement. On propensity-matched analysis with a 25-year follow-up, recipients of repair demonstrated a lower all-cause mortality (58.1% *vs.* 65.5%, P=0.005).

The protective signal with repair demonstrated on matched analysis suggests that tricuspid repair independently bolsters survivorship. Additionally, tricuspid repair was associated with a lower permanent pacemaker (PPM) implantation rate (16.1% *vs.* 32.6%, P<0.001) (18). Regardless of approach, the incidence of PPM implantation was very high in this study. By comparison, between 2011–2022, our group at the University of Michigan reported a rate of 3.7% and 23% for PPM implantation after isolated tricuspid repair and replacement, respectively (25). Hence, outcomes of surgical repair may be even better at high-volume centers. Overall, the long-term survival benefit of valve repair in appropriately selected patients has been demonstrated in this study and others (19). Outcomes of iTVS continue to improve to the present day.

A 2023 analysis using the National Inpatient Sample studied 37,931 patients (repair: 25,027, replacement: 12,904) from 2011–2020 who underwent iTVS. The number of iTVS cases increased more than 3-fold between the first and second half of the study (9,121 *vs.* 28,810), thus reflecting the recent increase in referral volume (23). Tricuspid repair was more frequently performed compared to replacement (66% *vs.* 34%, P<0.05). Most operations were performed for cases of functional TR (repair: 86%, replacement: 64%), while replacements were more commonly performed due to primary TR etiologies such as congenital valve disease, rheumatic valve disease, and endocarditis (P<0.05 for all). Additionally, those receiving replacement, although being almost two decades younger (mean age: replacement: 41 years *vs.* repair: 62 years, P<0.001), presented with significantly higher rates of chronic liver disease and RHF (P<0.001 for both). Cumulative in-hospital mortality was only 5.1%, and even lower for those receiving tricuspid repair (4.6% *vs.* 6%, P=0.009). On multivariable logistic regression analysis, chronic liver disease, CHF, and RHF were all independent determinants of in-hospital mortality (P<0.05 for all). Additionally, patients over 60 years had an approximate three-fold increased risk [60–75 years: 3.28 (95% CI: 2.21–4.89, P<0.001), >75 years: 3.46 (95% CI: 2.24–5.34, P<0.001)] for in-hospital mortality (23). Overall, this study shows the increased utilization of iTVS, especially isolated tricuspid repair, at the national level. Furthermore, surgery was performed with low short-term mortality. However, patients presenting with advanced disease, especially elderly patients, may have missed the treatment window during which iTVr is safe and confers a survival benefit.

The results of the 2022 SUR-TRI registry study further substantiated the merits of surgical repair. In total, 426 patients who received iTVS through a right mini-thoracotomy were identified across 13 international sites, from which 175 matched pairs of patients undergoing repair and replacement were identified. The entire cohort was relatively young (mean age: 55 years old) and intervention was provided for moderate-severe TR. Repair recipients demonstrated half the 30-day mortality rate of those receiving replacement (4% *vs.* 8%, P=0.12). Additionally, repair patients exhibited better survival compared to those receiving replacement at 3-, 5-, and 7-year follow-up (84% *vs.* 71%, 75% *vs.* 66%, and 56% *vs.* 58%, respectively; P=0.001) (26). These findings encourage performing early repair in the iTVS population.

Tricuspid repair in elderly patients

The benefits of isolated tricuspid repair in older populations are less well studied. A 2018 analysis of Medicaid and Medicare data from 2003 through 2014 identified 5,164 recipients of iTVS [repair: 2,494 (48.3%); replacement: 2,670 (51.7%)]. Operative mortality was 9.9% and did not differ significantly by surgery type (replacement: 9.8% *vs.* repair: 10.0%, P=0.80). However, those receiving repair had lower rates of major bleeding, mechanical complications, and postoperative renal failure than those receiving replacement (P<0.001 for all). At 1-year follow-up, those receiving repair had significantly lower mortality (22.1% *vs.* 25.9%, P<0.001). On multivariable analysis, surgical replacement was a predictor of 1-year mortality (HR: 1.15, 95% CI: 1.02–1.30, P<0.013) (20).

A recent 2024 analysis of Medicare claims data focusing on iTVS in patients ≥65 years old also demonstrated suboptimal outcomes. The study identified 1,501 patients receiving iTVS, from which 547 matched pairs compared tricuspid repair with replacement. In the matched cohort, there was no difference in in-hospital mortality (13.2% *vs.* 12.8%, P=0.93) nor mortality at 3-year follow-up (40.2% *vs.* 37.5%, P=0.600). Additionally, there were no differences in MACE (P=0.91) or heart failure hospitalization (P=0.85). Furthermore, sub-analyses comparing patients below 75 years old to those above did not reveal any statistically significant interaction (aHR: 1.10; 95% CI: 0.82–1.48 *vs.* aHR: 1.02; 95% CI: 0.77–1.36). The loss of the protective effects of repair may be explained by the advanced age of the population being studied (median age: 75 years old). Advanced age may be a surrogate marker for delay in intervention, such that the benefits of repair are no longer observable (21).

Isolated tricuspid replacement

Valve replacement also provides an acceptable alternative approach to iTVS when anatomy precludes valve repair. However, patients undergoing replacement face the risks of infection, structural valve degeneration (versus life-long anticoagulation), and conduction abnormalities requiring PPM.

Historically, isolated tricuspid valve replacement has had the highest mortality of any valve surgery. A 2022 meta-analysis of 35 studies reporting outcomes of 5,316 cases of replacement between 1974 and 2019 reported an elevated operative mortality of 12%. Operative mortality for cases performed before 1995 was 18%, while those after 1995 averaged an 11% operative mortality rate (24).

A retrospective review of the National Inpatient Sample identified 5,005 isolated tricuspid operations conducted between 2004–2013. The overall in-hospital mortality rate was 8.8%. When stratified by procedure type, operative mortality was 5.9% for tricuspid repair recipients, 9.1% for bioprosthetic replacement recipients, and 13.6% for mechanical valve replacement recipients (P=0.003). Recipients of valve replacement were more often cirrhotic, had an ICD, or were undergoing re-operative surgery (P<0.001 for all). On adjusted analysis, age ≥60 years old (P=0.006), coagulopathy (P<0.001), ESRD (P=0.005), and valve replacement (P=0.009) were all predictors of in-hospital mortality (22). This may indicate that valve replacement may have been a result of late referral and the existence of end-stage cardiomyopathy and terminal organ malfunction. More importantly, the immediate procedural risk may not be justified in these patients, especially in the current era where transcatheter therapies are available. Furthermore, despite a volume increase in both tricuspid repair and replacement during the study time period (P<0.001, 2004–2013), in-hospital mortality did not improve (P=0.51). These findings indicate that while disease recognition has improved, earlier referral is required to improve patient outcomes.

Outcomes after tricuspid valve replacement may differ on an institutional basis. Our group at the University of Michigan reported outcomes on 272 tricuspid valve replacements, including 196 isolated procedures, completed between 2000–2023, and categorized into three eras: 2000–2013, 2014–2019, 2020–2023. Operative mortality over more than 20 years was 7%. From Era 1 to Era 3, the composite morbidity and mortality dropped from 48% to 21% (P=0.002). Furthermore, pacemaker implantation rates decreased from 28% to 10% (P=0.02). Lastly, midterm survival improved from 63% in Era 1 to 82% in Era 3 (P<0.001). Patients presenting in later eras were referred at earlier NYHA stages (<0.001), suggesting that early recognition and referral may have helped improve outcomes. Lastly, an increase in volume across the eras suggests that improved experience and better patient selection also contributed to improved outcomes (27).

Over 54% (136/250) of tricuspid valve replacements in our experience were performed as redo surgery (27). Multivariable analysis demonstrated that redo surgery was a predictor of composite morbidity and mortality (aOR: 2.82, P=0.002). Other series have examined the outcomes of tricuspid valve replacement after previous left heart surgery. A 2013 Italian study from Alfieri and colleagues looked at outcomes of 117 patients undergoing tricuspid valve replacement after previous left heart surgery, including 61 patients (52%) who underwent isolated valve replacement. Thirty-day mortality was 6% for all patients and 8.2% for isolated replacement cases. Freedom from cardiac death at 1- and 5-year follow-up was 79.4% and 42.9%, respectively. EuroSCORE (P=0.002), presence of ascites (P=0.004), greater than moderate RV dysfunction (P=0.033), and PASP (P=0.046) were predictors of mortality. However, the number of previous operations (P=0.09) was not predictive of mortality (28). Perhaps improving management of redo cases may also improve survival after tricuspid valve replacement. Further study is needed before definitive conclusions can be made.

Long-term outcomes of tricuspid valve replacement also play a role in treatment decisions. A 2025 international, multi-center analysis of 675 bioprosthetic tricuspid valve replacements, included 358 patients receiving isolated tricuspid valve replacement. Overall, 30-day mortality was 10.4%; recipients of isolated replacement demonstrated a lower 30-day mortality (6.7% *vs.* 14.6%, P=0.0001) and complication rate (P=0.030) compared to recipients of TVR with other concomitant procedures. Regression modelling of the entire cohort identified age, higher AST, higher MELD score, and urgency of surgery as predictors of mortality. Overall, survival was 69%, 47.2%, and 28.9% at 5, 10, and 15 years respectively. Rates of re-intervention were 6.1%, 10.8%, and 23.3% at those respective time points, demonstrating that the need for re-intervention increased approximately a decade after the index surgery (29). Furthermore, at 15-year follow-up, the incidence of PPM implantation was 77.3%, the incidence of tricuspid valve endocarditis was 84%, and the incidence of thrombo-

embolic complications was 86.4%. Hence, the long-term morbidity burden after bioprosthetic valve replacement remains consequential.

It remains unclear how mechanical valves perform in the tricuspid position by comparison. Some studies report improved long-term survival and lower reoperation rates, while others report higher bleeding rates, thromboembolic risk, and valve failure rates (30-32). A 2022 study of the Korean National Health Insurance Service (NHIS) looking at all TVR recipients between 2003 and 2018 identified 562 patients with bioprosthetic valves and 679 patients with mechanical valves who met inclusion criteria (33). Replacement with a bioprosthetic valve resulted in higher operative mortality (bioprosthetic: 16.5% *vs.* mechanical: 8%, P=0.005). Additionally, those with bioprosthetic valves had higher long-term, all cause mortality (aHR: 1.57; CI: 1.25–1.98, P<0.001) and higher rates of cardiac death (aHR: 1.59; CI: 1.18–2.13, P=0.002). When stratified by age, the difference in all-cause mortality reached significance specifically for patients between ages 50 to 65 years old (HR: 1.75; CI: 1.10–2.78, P=0.019). Recipients of mechanical valves had a higher incidence of stroke (P=0.003) but had a lower incidence of reoperation (P<0.001). The 2025 ESC/EACTS guidelines, while not providing official recommendations, do suggest that bioprosthetic valves are better suited to the right heart's low pressures and may reduce the risk of valve thrombosis (6). Thus, mechanical valves in the tricuspid position may only provide benefit in a narrow selection of patients, who are younger, already need anticoagulation, and possess enough RV function to support valve function in a lower pressure system. Practitioners considering mechanical valve implantation must weigh the risks and benefits on an individual basis.

Minimally invasive isolated tricuspid surgery

Innovations in surgical approach have further redefined the risk-benefit profile of iTVS. Adoption of minimally invasive thoracotomy or thoracoscopic approaches instead of sternotomy has reduced bleeding risk. Reducing bleeding and blood transfusions better preserves RV function. Additionally, avoiding violation of the anterior pericardium during sternotomy is also protective. A 2023 retrospective study from the SUR-TRI Registry compared 72 patients receiving minimally invasive iTVS (MIS) to 404 patients who received a sternotomy. Those who underwent minimally invasive surgery required postoperative blood transfusions less frequently (P=0.002), had shorter ICU lengths of stay (P<0.001), and had lower adjusted all-cause mortality compared to conventional sternotomy [adjusted HR: 0.430 (95% CI: 0.228–0.819); P=0.009] (34).

Additionally, beating-heart approaches have decreased perioperative myocardial ischemia and RV strain. A 2021 SUR-TRI Registry study compared 153 iTVS patients receiving beating-heart surgery with 253 iTVS patients receiving arrested-heart surgery. On propensity-matched analysis of 129 matched pairs, arrested heart surgery was associated with higher rates of post-operative renal replacement therapy (10% *vs.* 3%, P=0.02) and stroke (1.6% *vs.* 0%, P=0.08). At 6-year follow-up, recipients of a beating-heart approach had a higher 6-year composite cardiac death and reoperation rates compared to those receiving an arrested-heart approach (P=0.024) (35). Mortality rates are promisingly low in other studies, ranging from 3% to 8.6% (36,37). Minimally invasive approaches have also seen success in redo cases by limiting the need for mediastinal dissection (38,39). Certain centers have also explored these advantages through robotic platforms (40). Lastly, increased adoption of subvalvular repair techniques, including papillary muscle reapposition to prevent septal tethering, demonstrates an improved understanding of the disease process and further advancement in repair techniques (41). As innovation continues, outcomes will further improve. Therefore, when characterizing the role of iTVS one must consider both where the field was and where the field is going.

Pre-operative optimization

Preoperatively managing RV function is also integral to optimizing outcomes. The 2020 ACC/AHA guidelines provide a Class IIa recommendation for diuresis in the setting of RHF to limit RV overload. Fluid management with goal-directed diuresis should be employed to reduce RV volume overload. Hemodynamic monitoring with a Swan-Ganz catheter and trending pro-BNP can help guide diuresis. Preoperative diuresis helps reduce renal and hepatic congestion and other manifestations of volume overload such as peripheral edema and ascites. The AHA/ACC guidelines also provide a Class IIa recommendation for the medical management of the primary cause of RHF, including management of left heart failure with reduced ejection fraction, pHTN, and AF. AF should at least be adequately rate controlled before heading to the operating room. Improved medical optimization is a result of an improved understanding of the disease process (6,42).

Risk assessment calculators

Various calculators have been constructed to quantify predicted morbidity and mortality after iTVS. Numeric scores provide practitioners with a universal metric to assess risk relative to outcomes from large datasets (*Table 3*).

Model for End-Stage Liver Disease (MELD) score

The sequelae of advanced TR result from the incompetence of the right heart system. When left untreated, it can result in congestive hepatopathy, ascites, and end-stage renal disease (ESRD). Therefore, the severity of end-organ damage can predict outcomes in tricuspid surgery patients. Our group identified the MELD score as a simple predictor of mortality in recipients of TVS. This study included patients with tricuspid surgery, including those with concomitant procedures. In total, 22% (37/168) of patients had significant liver disease, defined as a history of cirrhosis or a MELD score of 15 or greater. Patients with liver disease had a higher mortality rate compared to those without liver disease [(7/37) 18.9% *vs.* (8/131) 6.1%, P=0.024]. Additionally, patients with liver disease had a higher risk of postoperative hemodialysis [(8/37) 21.6% *vs.* (3/131) 2.3%, P<0.0001]. Furthermore, when the entire population was stratified by MELD score, 30-day mortality (P=0.0015) and multisystem organ failure (P=0.019) were more common with worse MELD scores. Thirty-day mortality at MELD score ranges of 15–19.9 and ≥20 were 27.3% and 30.8%, respectively (43). The association between an elevated MELD score and poor outcomes demonstrates the impact of delayed referral and resultant end-organ dysfunction on patient outcomes.

Clinical Risk Score (CRS)

The first isolated tricuspid surgery risk calculator developed was created as a collaborative effort between the Michigan Society of Thoracic and Cardiovascular Surgeons (MSTCVS) and the Virginia Cardiac Surgery Quality Initiative (VCSQI) using 2,050 cases of isolated tricuspid surgery cases performed between 2002 and 2014. In total, 86% of patients received repair, while 14% underwent replacement. Operative mortality was 9% and composite major morbidity was 42%. With this sample, parsimonious risk prediction models were created, which identified nine risk factors predictive of short-term outcomes, including age, sex, history of stroke, hemodialysis, moderate/severe chronic lung disease, ejection fraction <55%, NYHA Class III/IV, redo operation, and emergent surgical status. Using these variables, the CRS was constructed as a predictive model of short-term morbidity and mortality. The CRS, ranging from scores 0–10+, provides a simple method for risk assessment for candidates awaiting iTVS. The area under the curve (AUC) for mortality and morbidity were 0.74 and 0.76, respectively (44). By including parameters such as age, ESRD, and cardiac function, the model accounts for the effects of end-organ dysfunction on short-term outcomes.

TRI-SCORE

TRI-SCORE, introduced in 2022 by Dreyfus and colleagues, is a simplified scoring system that includes eight risk parameters to predict in-hospital morbidity and mortality for patients receiving isolated tricuspid surgery. The risk parameters include demographic and clinical factors, laboratory values, and echocardiographic parameters. Using these variables, a score ranging from 0 to ≥9 was created, where a score ≥9 predicts a 65% risk of operative mortality. Patients with functional TR have higher risk scores than those with primary TR (4.3±2 *vs.* 2.7±1.9, P<0.001) due to a higher prevalence of advanced right heart dysfunction and ESRD. The final model demonstrated good predictive accuracy (AUC =0.817) (45).

In a 2024 update, Dreyfus and colleagues utilized TRI-SCORE to stratify those with isolated, severe, functional tricuspid regurgitation into those with low (≤3), intermediate (4–5), and high (≥6) cohorts. On analysis of 1,768 patients (medical management: 1,217, surgical repair: 200, replacement: 351), both repair and replacement provided a survival benefit when compared to conservative management for low TRI-SCORE patients at 10-year follow-up [surgical repair: 84% (P<0.0001), surgical replacement: 61% (P=0.009), medical management: 44%]. Only repair demonstrated a survival benefit in the intermediate TRI-SCORE group [surgical repair: 59% P<0.0001 (protective), surgical replacement: 25% P=0.0002 (harm), medical management: 37%], while no survival benefit was experienced with either surgical technique for the high TRI-SCORE group [repair: 28% (P=0.2), replacement: 17%; P<0.001 (harm)], conservative management: 24%) (46). Overall, these findings highlight the importance of prompt intervention before patients incur high-risk status. TRI-SCORE has been validated for

Table 3 Published risk scores for ascertaining mortality risk after tricuspid surgery

Model	Title	Study type	Population	Key results
MELD score	Model for End-Stage Liver Disease Predicts Mortality for Tricuspid Valve Surgery (43)	Retrospective review of recipients of tricuspid surgery from 1994 to 2008 at University of Virginia. Liver disease was defined as a history of cirrhosis or a MELD score ≥15	168 patients received tricuspid surgery with 156 patients receiving repair and 12 receiving replacement; 37 patients had either a history of cirrhosis or a MELD ≥15	Increasing MELD was associated with higher 30-day mortality (P=0.0019) 30-day mortality: MELD <10 (n=54): 1.9%; MELD 10-14.9 (n=44): 6.8%; MELD 15-19.9 (n=11): 18.2%; MELD ≥20 (n=13): 23.1% Patients with a history of cirrhosis or MELD ≥15 had a higher 30-day mortality compared to those who did not [18.9% (7/37) *vs.* 6.1% (8/131), P=0.024] The AUC of MELD as a predictor of 30-day mortality was 0.79, which was similar to EuroScore (AUC =0.78)
Clinical Risk Score	Development of a Risk Prediction Model and Clinical Risk Score for Isolated Tricuspid Valve Surgery (44)	Retrospective review of STS database records across 50 participating hospitals including members of the Virginia Cardiac Surgery Quality Initiative (VCSQI) and the Michigan Society of Thoracic and Cardiovascular Surgeons (MSTCVS). Inclusion criteria: surgery type: isolated tricuspid surgeries; study period: 2002–2014; Risk models were constructed using parsimonious preoperative risk prediction models	2050 cases of isolated TV surgery were identified: repairs: 86% (1755/2050); replacements: 14% (295/2050)	Operative mortality was 9% Composite major morbidity was 42% Multivariate logistic regression analysis identified age (>60 years), female sex, history of stroke, hemodialysis, severe chronic lung disease, NYHA class III/IV, reoperation, and emergent status surgery as predictors of operative mortality (P<0.05) The Clinical Risk Score (CRS) model includes age, sex, history of stroke, hemodialysis, moderate/severe chronic lung disease, EF <55%, NYHA Class III/IV, reoperation, and emergent surgery status to predict operative mortality and major morbidity CRS Scores range from 0–10+ AUC for mortality: 0.74; AUC for major morbidity: 0.76
TRI-SCORE	TRI-SCORE: a new risk score for in-hospital mortality prediction after isolated tricuspid valve surgery (45)	Recipients of isolated tricuspid valve surgery for severe non-congenital TR from 12 French tertiary care centers. Study period: 2007–2017. A scoring system was created to predict hospital mortality using multivariate logistic regression and bootstrapping (1,000 re-samples)	466 patients received isolated tricuspid surgery; 111 (24%) had previous left-sided surgery. 229 (49%) patients presented with functional TR; 237 (51%) patients presented with primary TR; 193 patients (41%) underwent tricuspid repair, and 273 patients (51%) underwent tricuspid replacement	TRI-SCORE risk calculator included 8 variables: age >70 years; NYHA class III/IV; right sided heart failure symptoms; daily furosemide dose ≥125 mg; GFR <30 m/min; elevated total bilirubin; LVEF <60%; moderate/severe right ventricular dysfunction Scores range from 0 to ≥9 and correlated with 1-65% predicted in-hospital mortality AUC: 0.81 for prediction of short-term mortality, AUC: 0.71 for major post operative complications, 0.78 for predicting 1-year mortality

Table 3 (*continued*)

Table 3 (*continued*)

Model	Title	Study type	Population	Key results
	Benefit of isolated surgical valve repair or replacement for functional tricuspid regurgitation and long-term outcomes stratified by TRI-SCORE (46)	Patients enrolled in the TRIGISTRY multi-center registry from 33 centers across 10 countries	1,768 with isolated severe TR: 1,217 conservatively managed; 200 underwent repair; 351 underwent replacement	Low TRI-SCORE (≤3): In hospital mortality: 2.7% Both repair (HR: 0.11, P<0.0001) and replacement (HR: 0.65, P=0.009) conferred a survival benefit on 10-year follow up Intermediate TRI-SCORE (4–5) In hospital mortality: 9.2% Only repair (HR: 0.49, P<0.0001) conferred a survival benefit on 10-year follow up High TRI-SCORE (≥6): In hospital mortality: 16.9% Neither surgical technique provided survival benefit on 10-year follow up
	Predictive Value of the TRI-SCORE for in-hospital mortality after redo isolated tricuspid valve surgery (47)	All patients receiving redo isolated tricuspid valve surgery across 12 French tertiary care institutions. Study period: 2007–2017	70 patients met inclusion criteria of which all received tricuspid valve replacement	In hospital mortality: 10% Major complication rates: 34% AUC of TRI-SCORE: 0.83 and outperformed EuroScore (0.58) and EuroScore II (0.61)
Society of Thoracic Surgery (STS) Risk Calculator	Outcomes of Isolated Tricuspid Valve Surgery: A Society of Thoracic Surgeons Analysis and Risk Model (48)	All patients who underwent isolated tricuspid surgery between years 2017 and 2023 within the STS Adult Cardiac Surgery Database	13,587 met inclusion criteria: 5,583 (41.1%) underwent repair; 8,004 (58.9%) underwent replacement	Operative mortality was 5.6% (5.5% for repair, 5.7% for replacement) Model AUC: 0.81 for operative mortality and 0.76 for composite morbidity and mortality Recipients of replacement were younger and had twice the rate of infective endocarditis compared to repair recipients (45.7% *vs.* 21.1%)

AUC, area under the curve; CRS, Clinical Risk Score; HR, hazard ratio; MELD, Model for End-Stage Liver Disease; NYHA, New York Heart Association; TR, tricuspid regurgitation.

other populations including recipients of redo tricuspid surgery (47) and different ethnic demographics (49). Risk calculators such as these can provide crucial knowledge to help guide patient care. In fact, the 2025 ESC/EACTS guidelines, which provide a level I recommendation for assessment of patient preoperative risk, cite TRI-SCORE as a reliable risk calculator due to its integration of clinical factors, echocardiographic measurements of RV function, and signs of secondary organ impairment (6).

Society of Thoracic Surgery (STS) risk calculator

More recently, the STS released a risk calculator for isolated tricuspid surgery, based on 13,587 isolated tricuspid valve procedures listed in the adult STS cardiac surgery database from July 2017 to June 2023. Operative mortality was lower than previously reported at 5.6% (repair: 5.5%, replacement: 5.7%) and may better reflect the current mortality risk associated with isolated tricuspid surgery. Furthermore, patients with endocarditis represented 35.6%

(4,831/13,587) of the population. Patients with endocarditis were younger and less frequently had the chronic disease associated with chronic tricuspid regurgitation. In patients with endocarditis, the operative mortality was 2.7% for repair and 4.1% for replacement (48). Overall, the STS risk calculator provides updated risk estimates based on a modern dataset and may be more predictive of outcomes today.

iTVS and transcatheter tricuspid valve intervention (TTVI)

TTVI provide new percutaneous approaches for treating TR. Their use in high-risk patients to improve quality of life and promote positive RV remodeling has been upgraded to a Class IIa recommendation in the most recent 2025 ESC/EACTS guidelines (6). Recent randomized studies have demonstrated safety, technical success, and symptom reduction compared with medical therapy (50-54) (*Table 4*). Longer follow-up is required before conclusions about treatment durability and survival can be made.

Currently, candidates for iTVS and for TTVI represent two separate populations with different risk profiles. In a 2023 retrospective review of 2,413 patients in the TRIREGISTRY [1,217 conservative management, 551 iTVS, 645 transcatheter tricuspid repairs (TTVr)], treatment effect on 2-year survival was tested at low (≤3), intermediate (4–5) and high (≥6) TRI-SCORE risk strata. Both iTVS and TTVr demonstrated significant survival benefits (93% for iTVS *vs.* 87% for TTVr *vs.* 79% for medical management), P=0.0002) in the lowest risk tercile. iTVS and TTVr only showed survival benefits in the

Table 4 Key randomized trial data on transcatheter tricuspid valve therapies

Title	Study type	Population	Key results
Tricuspid Transcatheter Edge-to-Edge Repair for Severe Tricuspid Regurgitation: Outcomes From the TRILUMINATE Cohort (50-52)	TRILUMINATE Pivotal: International, multi-center randomized control trial accessing TR reduction with T-TEER using the TriClip device for patients with symptomatic, severe TR	Subjects were randomized between T-TEER and Control groups. n=572 patients (350 primary cohort + 222 subsequent enrollment). Patients who were deemed intermediate or greater surgical risk. PASP <70 mmHg and stable on medical therapy for 30 days	1-year follow-up: Composite outcome: all cause death, tricuspid surgery, heart failure hospitalization, and KCCQ improvement of at least 15 points [Win-ratio: 1.8 (1.4–2.5), P<0.0001, favoring T-TEER] Freedom from all-cause mortality and tricuspid valve surgery: T-TEER: 90.6% *vs.* control: 89.9% (P=0.82) Annualized HFH (0.17 *vs.* 0.20 events/patient-year; P=0.40) ≥15 improvement in KCCQ score compared to control subjects (P<0.0001) T-TEER had lower rates of moderate or less TR and improved 6-minute walk distances (P<0.0001 for all) 2-year follow-up: Freedom from all-cause mortality and tricuspid valve surgery/intervention (T-TEER: 77.6% *vs.* conservative management: 29.3%, P<0.001) Similar rates of all-cause mortality (T-TEER: 17.9% *vs.* conservative management: 17.1%) Moderate or less TR was present in 84% of T-TEER patients

Table 4 (*continued*)

Table 4 (*continued*)

Title	Study type	Population	Key results
Transcatheter Edge-to-Edge Repair for Severe Isolated Tricuspid Regurgitation: The Tri-Fr Randomized Clinical Trial (53)	Tr-Fr Trial: randomized control trial across 24 centers in France and Belgium (3/2021–3/2023) T-TEER device: TriClip	300 patients with severe, symptomatic TR despite 30 days of guideline-directed medical therapy were enrolled to T-TEER + medical therapy (n=152) *vs.* medical therapy alone (n=148). Randomization was stratified by TR etiology (atrial, ventricular, or mixed). Patients with leaflet gap ≥10 mm or highly advanced disease were excluded from analysis	1-year follow up T-TEER + medical therapy demonstrated lower rates of unchanged clinical composite score (P=0.0.001). Greater absolute change in KCCQ score (P<0.001), and patient global assessment (P<0.001) compared to medical therapy alone T-TEER showed lower rates of +4 TR (3.76% *vs.* 38.6%, P<0.001) There was no difference in percentage of patients free from MACE at 1 year (P=0.38) or patients free from cardiovascular death (P=0.37) at 1 year follow-up on Kaplan Meier analysis
Transcatheter Valve Replacement in Severe Tricuspid Regurgitation (TRISCEND II) (54)	TRISCEND II: Multi-national, prospective, RCT testing outcomes of the EVOQUE valve replacement system	400 patients with symptomatic, severe or greater TR were randomized 2:1 to intervention and control groups; 267 receiving transcatheter valve replacement + medical management and 133 receiving isolated medical therapy	1-year follow up: Win ratio calculated for all patient pairs for composite primary outcome favored valve replacement (2.02, 95% CI: 1.56–2.02, P<0.001) After valve replacement, 95.2% of patients had mild or less TR compared to 2.3% in the control group There was no difference in all-cause mortality between groups (valve replacement: 11.6% *vs.* control: 10.5%, P=0.87) Recipients of valve replacement had significantly higher rates of severe bleeding (15.4% *vs.* 5.3%, P=0.003) and permanent pacemaker implantation (17.4% *vs.* 2.3%, P<0.001) When landmarked for 30-day, Kaplan-Meier mortality estimates at 1-year were 9.4% for the valve replacement group and 15.2% for the control group

CI, confidence interval; HFH, heart failure hospitalization; KCCQ, Kansas City Cardiomyopathy Questionnaire; RCT, randomized controlled trial; T-TEER, tricuspid-transcatheter edge-to-edge repair; TR, tricuspid regurgitation.

intermediate tercile when restricted to procedures with procedural success (80% *vs.* 81% *vs.* 71%, P=0.009). Of note, 34% of all TTVI cases did not reach procedural success. No survival benefit was seen in the high-risk group; however, when restricted to interventions reaching procedural success, TTVI had significantly better 2-year survival (P=0.006). However, these findings demonstrate how various risk pools are better suited for different interventions (55).

Anatomy also may help determine the best treatment. Parameters such as annular dilatation and coaptation depth affect procedural success and mortality. In the TriValve dataset, multivariate analysis indicated that greater coaptation depth was predictive of procedural success (OR:

24.1, P=0.002) and protective against mortality at 1.5-year follow-up (OR: 0.18, P=0.01). Additionally, annular diameter demonstrated an increased risk of procedural failure (OR: 7.2, P=0.06) (56). The heart team at Columbia University has also explored the role of tricuspid leaflet morphology in treatment outcomes based on leaflet number and type. Type I anatomy, or the 3-leaflet valve, was the most common morphology (54%), with a 4-leaflet structure with a second posterior leaflet or Type IIIB anatomy being the most common aberrancy (39%) (57). Further study is required to elucidate the role of leaflet structure and treatment success.

Overall, iTVS and TTVI are currently suited for different risk cohorts and are complementary. The growing popularity of TTVI has increased awareness of tricuspid disease among practitioners in general and has increased referral volume for consideration of both transcatheter and surgical treatment modalities (58). At this point, surgical intervention remains the gold standard of care for appropriately selected patients and can provide excellent results when performed in a timely fashion. However, transcatheter modalities have expanded treatment options to a wider array of patients. Hence, optimizing both iTVS and TTVI outcomes is integral to improving results overall.

Conclusions

Surgery for isolated TR can be performed with excellent outcomes through well-timed intervention and appropriate patient selection. Recognizing and acting within the narrow treatment window improves the likelihood of repair, thus improving long-term survival. Available risk calculators provide practitioners a quantifiable method to assess patient risk. For patients at too high a risk for surgery, transcatheter modalities provide an acceptable option for symptom reduction, with long-term results still under further study.

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