

FOCUS ON TRICUSPID INTERVENTIONS

ORIGINAL RESEARCH: STRUCTURAL

Transcatheter Tricuspid Valve Intervention Risk Scores



Assessment in an International Multicenter Cohort

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ABSTRACT

BACKGROUND Accurate risk stratification is crucial for patients undergoing transcatheter tricuspid valve intervention (TTVI). The performance of existing surgical and TTVI risk scores (TRI-SCORE, STS-TR [Society of Thoracic Surgeons Tricuspid Regurgitation], and TRIVALVE [International Multisite Transcatheter Tricuspid Valve Therapies Registry]) has not been comprehensively evaluated and compared in a contemporary, real-world cohort.

OBJECTIVES The aim of this study was to assess the discrimination and calibration of these scores in a large international multicenter population of patients undergoing TTVI.

METHODS This study population included 457 patients from 6 international centers who underwent TTVI (tricuspid transcatheter edge-to-edge repair, transcatheter tricuspid valve replacement, or transcatheter tricuspid annuloplasty) between 2019 and 2024. The performance of the TRIVALVE score was assessed for the 1-year endpoint of death and rehospitalization. The TRI-SCORE and STS-TR scores were assessed for in-hospital and 30-day mortality, respectively. Performance was evaluated using C statistics for discrimination and smoothed calibration plots for calibration.

RESULTS All 3 scores demonstrated limitations. The TRIVALVE score showed low discrimination (area under the curve: 0.609) and was well calibrated after its endpoint was refined to exclude non-cardiovascular-related hospitalizations. The surgically derived TRI-SCORE and STS-TR scores were miscalibrated and significantly overestimated mortality. The TRI-SCORE showed an observed-to-expected mortality ratio of 0.13 (95% CI: 0.07-0.23), and the STS-TR score had an observed-to-expected mortality ratio of 0.35 (95% CI: 0.19-0.60).

CONCLUSIONS The currently available TTVI risk scores derived from surgical or early TTVI cohorts may not be well suited for accurate risk assessment in contemporary TTVI. The surgical scores when applied to TTVI are miscalibrated, and the TRIVALVE score lacks discrimination. There is a need for the development of a contemporary dedicated TTVI risk model validated specifically for this population. (JACC Cardiovasc Interv. 2026;19:665-676)
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ABBREVIATIONS AND ACRONYMS

AUC = area under the curve

GGT = gamma-glutamyltransferase

STS-TR = Society of Thoracic Surgeons Tricuspid Regurgitation

TR = tricuspid regurgitation

TTA = transcatheter tricuspid annuloplasty

T-TEER = tricuspid transcatheter edge-to-edge repair

TTVI = transcatheter tricuspid valve intervention

TTVR = transcatheter tricuspid valve replacement

Significant tricuspid regurgitation (TR) is a prevalent condition and is associated with substantial morbidity and mortality, particularly in elderly individuals and those with multiple comorbidities.¹⁻³ Although surgery is the traditional treatment and outcomes have improved, the associated operative risk is high for this comorbid cohort.^{4,5}

In recent years, transcatheter tricuspid valve interventions (TTVIs) have emerged as effective and safe less invasive alternatives that have rapidly expanded the therapeutic options for patients deemed high risk for surgery.^{6,7}

This growing landscape of treatment choices makes accurate risk stratification and evidence-based patient selection more necessary to optimize outcomes.

Despite this need to properly stratify patients, the tools available for risk assessment may be limited for TTVI patients. Clinicians often rely on scores that were developed and validated in different contexts. Prominent surgical risk models, such as the STS-TR (Society of Thoracic Surgeons Tricuspid Regurgitation) score and the TRI-SCORE, were derived from large surgical cohorts.^{8,9}

The TRI-SCORE has been highlighted in the TR decision algorithm in the recent 2025 European Society of Cardiology guidelines on valvular heart disease.¹⁰ However, the calibration of these surgical scores for the unique procedural risks and patient characteristics inherent to transcatheter therapies remains uncertain.^{8,9} More recently, the TRIVALVE (International Multisite Transcatheter Tricuspid Valve Therapies Registry) score was proposed as the first dedicated TTVI risk model, but it requires external validation with more recent TTVI therapies including transcatheter tricuspid valve replacement (TTVR).¹¹

To date, there has been no comparison of all 3 published TTVI scores in a contemporary real-world cohort. The objective of this study was to assess and compare the performance, including discrimination and calibration, of the TRIVALVE, TRI-SCORE, and STS-TR scores in an international multicenter cohort of contemporary patients undergoing U.S. or European Union commercially available TTVI.

METHODS

STUDY DESIGN AND POPULATION. This international multicenter retrospective observational study was conducted at 6 centers: Northwestern Memorial Hospital (Chicago, Illinois), the Heart and Diabetes Center Bad Oeynhausen (Bad Oeynhausen, Germany), Cologne University Hospital (Cologne, Germany), Essen University Hospital (Essen, Germany), Tübingen University Hospital (Tübingen, Germany), and Inselspital, Bern University Hospital (Bern, Switzerland). Data were collected from patients treated between January 2019 and December 2024. Patients undergoing isolated TTVI, including tricuspid transcatheter edge-to-edge repair (T-TEER), TTVR, or transcatheter tricuspid annuloplasty (TTA) for symptomatic severe or greater TR were included (Figure 1). Exclusion criteria were concomitant major cardiac procedures during the index admission, active endocarditis, or loss to follow-up within the specified analysis window. This study was conducted in accordance with the Declaration of Helsinki, and ethical approval was obtained from the Institutional Review Board or ethics committee of each participating institution.

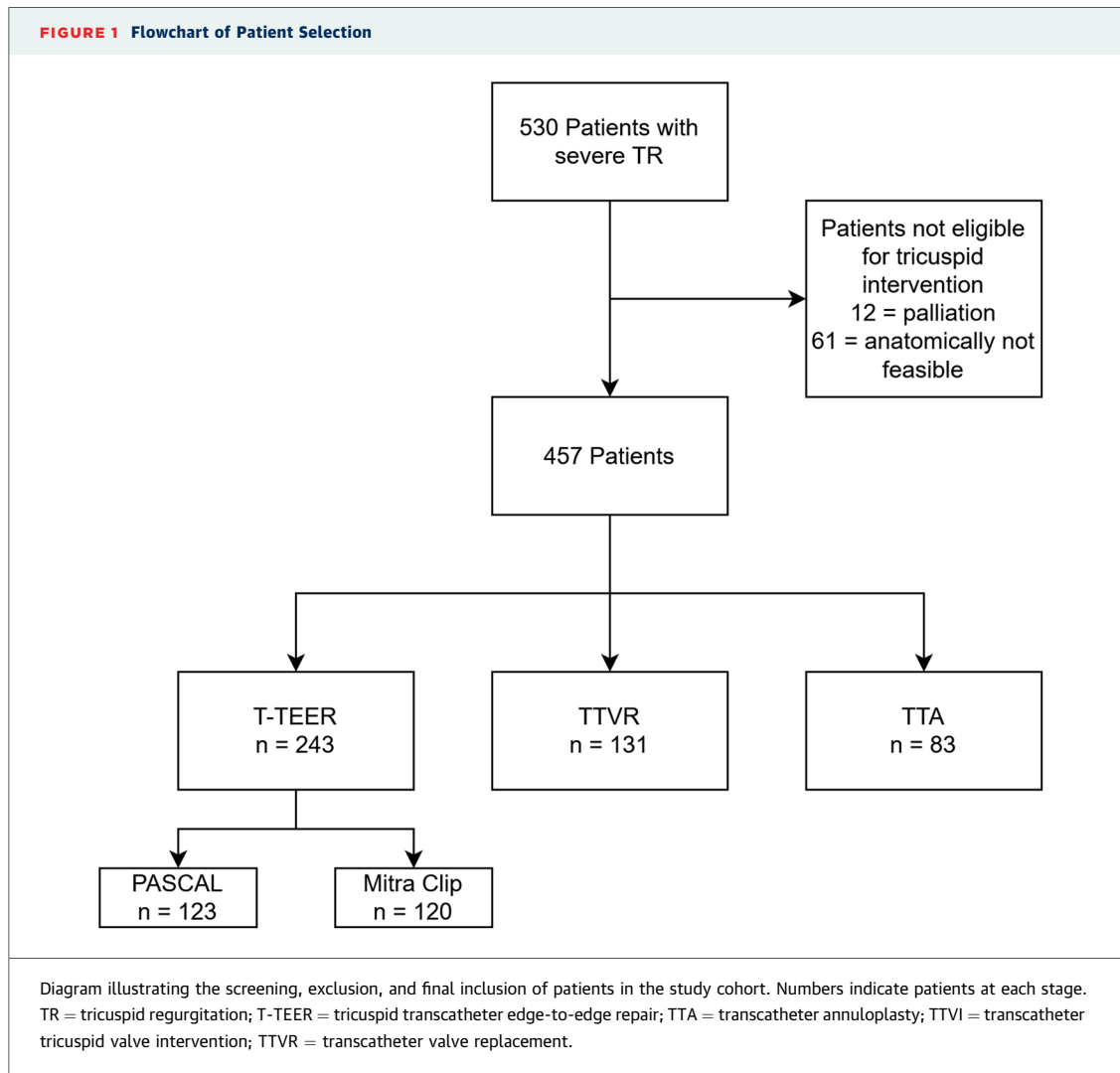
RISK SCORE CALCULATION. The 3 risk scores were calculated for each patient as follows:

STS-TR score. Thirty-day mortality risk was calculated using the published algorithm (version 1.0.2) from the Society of Thoracic Surgeons. Transcatheter repair techniques (T-TEER and TTA) were entered using the “repair” pathway, and TTVR was entered using the “replacement” pathway. This mapping was chosen on the basis of the procedure’s fundamental intent: T-TEER and TTA are valve-preserving repair strategies, whereas TTVR constitutes a full valve replacement with a prosthesis.

Missing data for risk score components were minimal, with the notable exceptions of bilirubin (n = 97 [21.2%] missing) for the TRI-SCORE and the gamma-glutamyltransferase (GGT) or bilirubin component (13.8% missing) for the TRIVALVE score. To address this, a single imputation was performed for all missing values using a random forest algorithm (missForest package in R). Imputation diagnostics confirmed a high-quality fit. The algorithm converged in 4 iterations, and the final out-of-bag error estimate was low

The authors attest they are in compliance with human studies committees and animal welfare regulations of the authors’ institutions and Food and Drug Administration guidelines, including patient consent where appropriate. For more information, visit the [Author Center](#).

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(normalized root mean squared error: 0.191; proportion of falsely classified: 0.049). Furthermore, the summary statistics of the imputed variables were highly consistent with the nonmissing data (eg, mean bilirubin 1.05 mg/dL before vs 1.05 mg/dL after imputation). The robustness of this imputation strategy was further confirmed by a complete case sensitivity analysis that yielded results consistent with the primary imputed analysis. The detailed comparative statistics for this analysis are provided in [Supplemental Tables S1 and S2](#).

TRI-SCORE. The performance of the 8-variable TRI-SCORE was assessed for its primary primary endpoint of in-hospital mortality ([Supplemental Tables S4 and S5](#)). Missing values (notably bilirubin at 21.2%) were imputed using the random forest method described earlier. This strategy is consistent with the original TRI-SCORE development. Robustness was confirmed in a complete case sensitivity

analysis that yielded consistent results to strengthen the validity of the present study.

TRIVALVE score. The score was calculated on the basis of its 5 components ([Supplemental Tables S6 and S7](#)) The definitions were aligned with the original publication: atrial fibrillation, glomerular filtration rate < 30 mL/min, elevated GGT or bilirubin, signs of right heart failure (defined as the presence of pitting edema), and left ventricular ejection fraction < 50%. Missing data for the GGT or bilirubin component (13.8%) were imputed using the aforementioned random forest algorithm.

To ensure adherence to the original models, all component variables for the STS-TR score and TRI-SCORE were defined in accordance with their respective derivation studies.

STUDY ENDPOINTS AND DEFINITIONS. The performance of each risk score was assessed against its specific primary endpoint, as defined in its respective

derivation study. Mortality status was determined through a review of electronic medical records and cross-referenced with national death registries where available.

The specific endpoints for each score were as follows: 1) for the STS-TR score, the endpoint was 30-day all-cause mortality; 2) for the TRI-SCORE, the endpoint was in-hospital all-cause mortality; and 3) for the TRIVALVE score, the primary endpoint for this validation was prespecified as a composite of all-cause mortality or the first cardiovascular-related hospitalization at 1 year. This represented a refinement of the original TRIVALVE publication's endpoint (all-cause mortality or all-cause rehospitalization). This refinement was defined prior to the final analysis on the basis of the hypothesis that all-cause rehospitalization in this elderly, comorbid cohort introduces statistical inaccuracy by including noncardiac events. Therefore, a cardiovascular-specific endpoint was deemed more clinically relevant for assessing procedure-related outcomes and long-term cardiac prognosis. The cause of rehospitalization was determined by reviewing hospital discharge summaries and primary discharge diagnoses. For direct comparison with the original publication and to ensure full transparency, a secondary analysis was performed using its originally defined endpoint: a composite of all-cause mortality or all-cause rehospitalization at 1 year.

STATISTICAL ANALYSIS. Continuous variables are expressed as mean \pm SD or median (Q1-Q3) and categorical variables as frequencies and percentages. The performance of each risk score was assessed for discrimination and calibration. Discrimination was evaluated using the C statistic (area under the curve) with its 95% CI. For the 1-year TRIVALVE endpoint, follow-up data were available for 427 of 457 patients (93.3%), resulting in a low censoring rate of 6.7%. Given this high rate of complete follow-up, the 1-year outcome was treated as a binary endpoint, and the standard C statistic was deemed the appropriate and most direct measure of discrimination. Calibration was assessed visually using smoothed calibration plots generated via generalized additive models and quantitatively using the observed-to-expected ratio. Advanced calibration was assessed using the Brier score, calibration-in-the-large (intercept), and the calibration slope. Analyses were performed for the overall cohort and stratified by TTVI procedure type. *P* values <0.05 were considered to indicate statistical significance. All analyses were performed using R version 4.2.2 (R Foundation for Statistical Computing).

RESULTS

STUDY POPULATION AND BASELINE CHARACTERISTICS. A total of 457 TTVI subjects were included in the analysis (**Central Illustration**). The cohort was composed of patients undergoing T-TEER ($n = 243$ [53.2%]), TTVR ($n = 131$ [28.7%]), or TTA ($n = 83$ [18.2%]). The mean age was 78.6 ± 8.7 years, and 250 patients (54.7%) were women. The patient population was characterized by a substantial burden of comorbidities, including atrial fibrillation in 89.5%, prior cardiac surgery in 44.4%, chronic obstructive pulmonary disease in 21.4%, and median NYHA functional class III (**Table 1** and **Supplemental Table S3**).

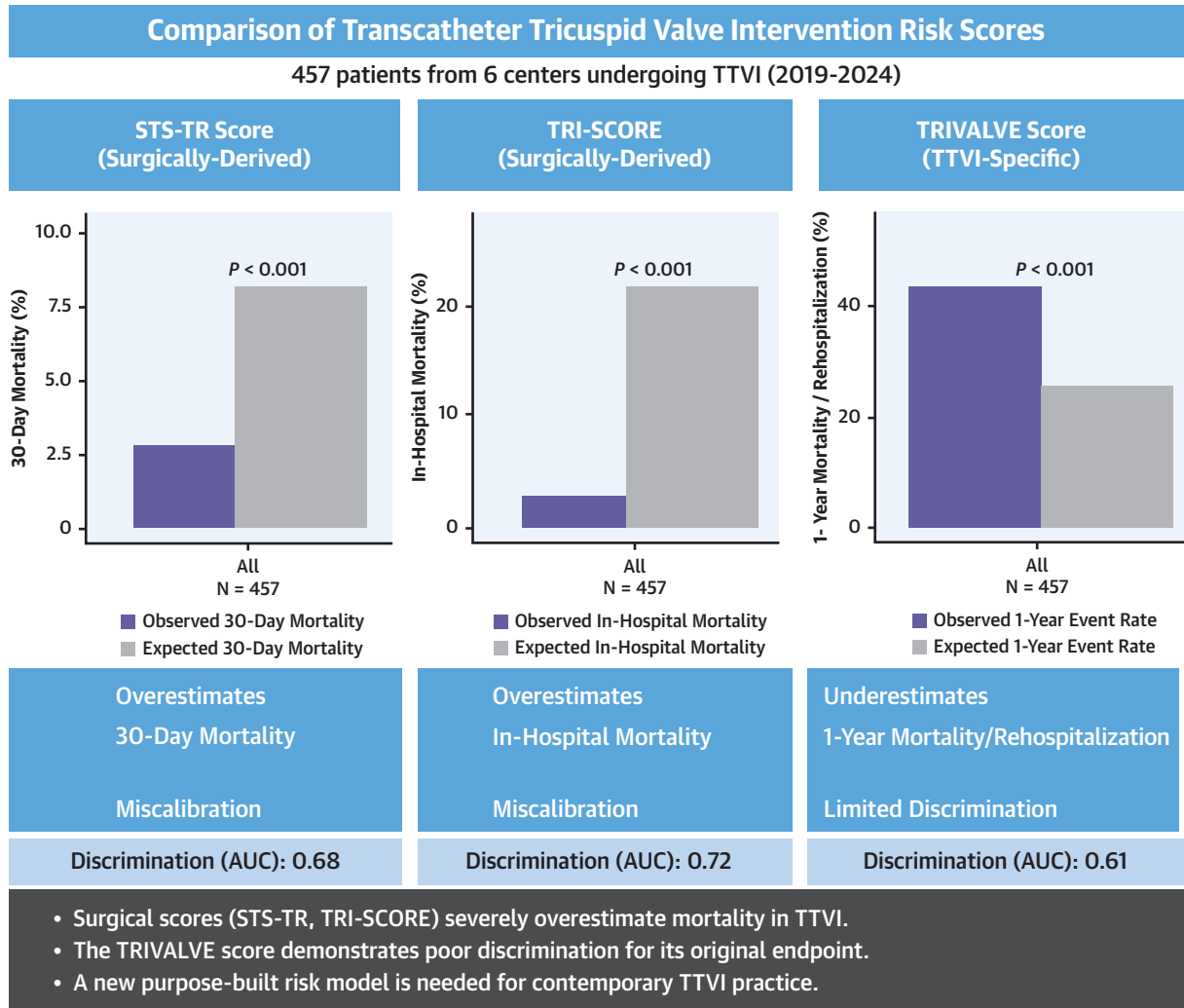
PERFORMANCE OF SURGICAL RISK SCORES (STS-TR AND TRI-SCORE). Both risk scores derived from surgical cohorts demonstrated suboptimal calibration by overestimating short-term mortality in patients undergoing TTVI.

For the STS-TR score, the mean predicted 30-day mortality was 8.16%, compared with the observed mortality of 2.85% ($P < 0.001$). The ability to distinguish between those who experienced events and those who did not was suboptimal, with a C statistic of 0.68 (95% CI: 0.54-0.82). This miscalibration was confirmed by advanced calibration metrics, including a large negative intercept (**Table 2**), and is visualized in **Figure 2**. This significant overestimation of 30-day mortality was consistent across individual TTVI repair and replacement procedures (**Supplemental Figure 1**).

Similarly, the TRI-SCORE predicted an in-hospital mortality rate of 21.5% compared with the observed 2.85% rate ($P < 0.001$), a finding consistent with our preliminary report on this cohort.¹² Although the TRI-SCORE showed adequate discrimination (C statistic = 0.72; 95% CI: 0.56-0.88) (**Table 2**), it was miscalibrated across all risk strata and TTVI subgroups (**Supplemental Figure 2**). This finding was confirmed by advanced calibration metrics (**Table 2**) and is visualized in **Figure 3**.

PERFORMANCE OF THE CONTEMPORARY TRANSCATHETER SCORE (TRIVALVE SCORE). One-year follow-up data were available for 427 of the 457 patients (93.3%). The TRIVALVE score was assessed against the 1-year composite endpoint in this cohort. For the primary analysis using the combined endpoint of all-cause mortality or cardiovascular-related hospitalization, the score demonstrated suboptimal discrimination, with an area under the curve (AUC) of 0.609 (95% CI: 0.56-0.66) (**Table 2**). In contrast to the discrimination error, the score showed good calibration, which was

CENTRAL ILLUSTRATION Study Overview and Findings of Risk Score Assessments



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The illustration compares the performance of the surgically derived STS-TR (Society of Thoracic Surgeons Tricuspid Regurgitation) score and TRI-SCORE against the transcatheter-specific TRIVALVE (International Multisite Transcatheter Tricuspid Valve Therapies Registry) score. It highlights that both surgical scores overestimate short-term mortality (miscalibration), while the TRIVALVE score shows limited discrimination, underscoring the need for a new, purpose-built risk model for patients undergoing transcatheter tricuspid valve intervention. AUC = area under the curve; TTVI = transcatheter tricuspid valve intervention.

statistically confirmed by an intercept near zero (Table 2). The smoothed calibration curve tracked the line of ideal calibration well (Figure 4).

For direct comparison with the original TRI-VALVE publication, we also assessed the score using the TRIVALVE originally defined endpoint of all-cause mortality or all-cause rehospitalization. When using this broader, nonspecific endpoint, the

performance declined. The observed combined event rate increased to 40.7%, and the calibration was limited, with underestimation of risk along with suboptimal discrimination (C statistic = 0.58; 95% CI: 0.53-0.64) (Table 2, Figure 5). This underestimation of the 1-year event rate was statistically significant in the T-TEER and TTVR subgroups (Supplemental Figure 3).

TABLE 1 Baseline Characteristics of Patients by Procedure Type

	T-TEER (n = 243)	TTVR (n = 131)	TTA (n = 83)
Age, y	79.8 ± 6.6	77.4 ± 11.8	76.79 ± 7.9
Female	118 (48.6)	77 (58.8)	55 (66.3)
BMI, kg/m ²	25.54 ± 4.69	26.07 ± 4.4	27.45 ± 5.8
Diabetes	58 (23.9)	29 (22.1)	21 (25.3)
COPD	61 (25.1)	22 (16.8)	15 (18.1)
Cerebrovascular event	55 (22.6)	28 (21.4)	20 (24.1)
Cirrhosis	14 (5.8)	17 (13)	6 (7.2)
MELD score	9.3 ± 3.6	9.08 ± 2.9	9.54 ± 3.7
Creatinine, mg/dL	1.61 ± 0.98	1.54 ± 1.2	1.33 ± 0.6
Preoperative dialysis	11 (4.5)	5 (3.8)	5 (6.0)
Hematocrit, %	30.06 ± 15.3	34.11 ± 12	31.04 ± 14.8
White blood cell count, 10 ³ /μL	7.29 ± 2.63	6.28 ± 1.6	7.11 ± 2.4
History of cancer	19 (7.8)	8 (6.1)	7 (8.4)
Albumin, g/dL			
<2.5	23 (9.5)	2 (1.5)	15 (18.1)
2.5-3.3	57 (23.5)	13 (9.9)	26 (31.3)
≥3.4	163 (67.1)	116 (88.6)	42 (50.6)
Aortic valve stenosis (moderate or higher)	4 (1.7)	0 (0)	3 (3.6)
Mitral valve stenosis (moderate or higher)	0 (0)	0 (0)	0 (0)
Aortic insufficiency (moderate or higher)	12 (4.9)	1 (0.8)	1 (1.2)
Mitral regurgitation (moderate or higher)	9 (3.7)	5 (3.8)	1 (1.2)
Tricuspid regurgitation grade	4 (3-4)	5 (4-5)	4 (3-5)
Atrial fibrillation	216 (88.9)	117 (89.3)	76 (91.6)
NYHA functional class			
I	2 (0.8)	1 (0.8)	0 (0)
II	27 (11.1)	11 (8.4)	7 (8.4)
III	191 (78.6)	102 (77.9)	68 (81.9)
IV	23 (9.5)	17 (13)	8 (9.6)
Elective intervention	216 (88.9)	125 (95.4)	79 (95.2)
Urgent	25 (10.3)	6 (4.6)	4 (4.8)
Emergency	2 (0.8)	0 (0)	0 (0)
Previous CABG	43 (17.7)	22 (16.8)	21 (25.3)
Previous SAVR	19 (7.8)	20 (15.3)	15 (18.1)
Previous MVR	18 (7.4)	20 (15.3)	6 (7.2)
Previous MVr	7 (2.9)	11 (8.4)	2 (2.4)
Previous TVr	6 (2.5)	7 (5.3)	0 (0)

Values are mean ± SD, n (%), or median (Q1-Q3). Specific device types used were as follows: for T-TEER, PASCAL (Edwards Lifesciences) and MitraClip (Abbott Cardiovascular); for TTA, Cardioband (Edwards Lifesciences); and for TTVR, EVOQUE (Edwards Lifesciences).

BMI = body mass index; CABG = coronary artery bypass graft; COPD = chronic obstructive pulmonary disease; MELD = Model for End-Stage Liver Disease; MVR = mitral valve replacement; MVr = mitral valve repair; SAVR = surgical aortic valve replacement; TTA = transcatheter annuloplasty; T-TEER = tricuspid transcatheter edge-to-edge repair; TTVR = transcatheter tricuspid valve replacement; TVr = tricuspid valve repair.

DISCUSSION

In this large, contemporary multicenter cohort of patients undergoing all major techniques of TTVI, our study suggests that the currently available prognostic risk scores have limited ability to predict outcomes. Although the surgically derived STS-TR SCORE and TRI-SCORE were miscalibrated, the TTVI-derived TRIVALVE score had suboptimal discrimination.

Our analysis confirms that risk models developed for surgery are not directly transferable to transcatheter procedures. Both the STS-TR score and the TRI-SCORE overestimated short-term mortality in the present TTVI cohort. This miscalibration is likely due to the fundamental differences in procedural risk between cardiac surgery in high-risk patients compared with less invasive transcatheter approaches.

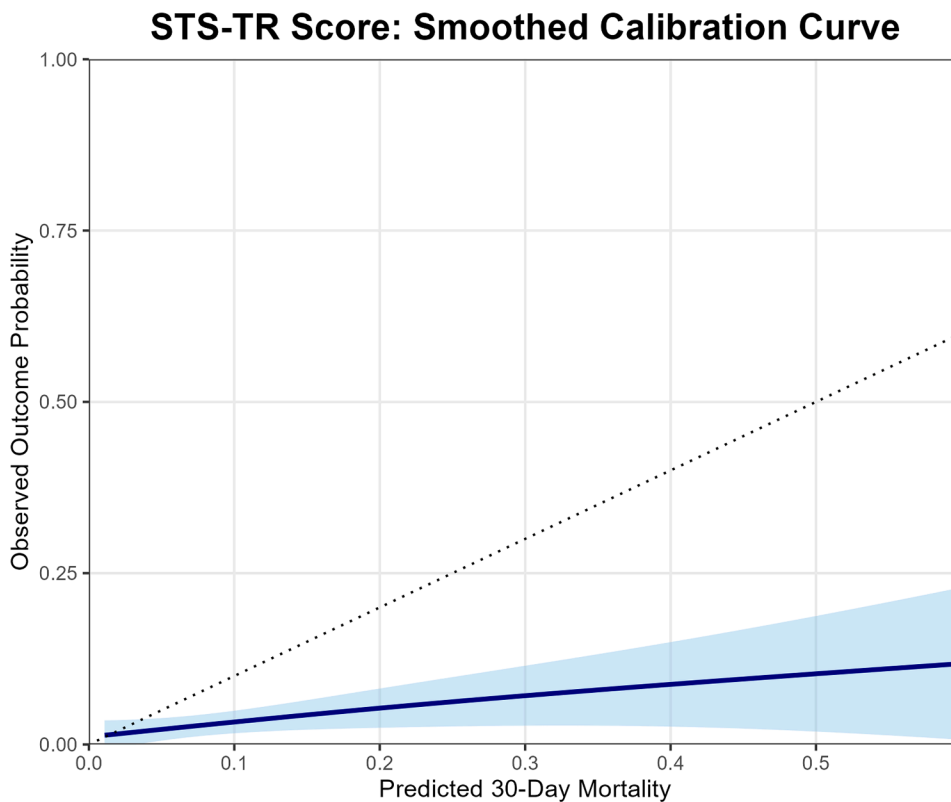
The suboptimal performance of all 3 scores is likely multifactorial. One limitation is the omission of

TABLE 2 Performance and Calibration Metrics of Risk Scores in the Transcatheter Tricuspid Valve Intervention Cohort

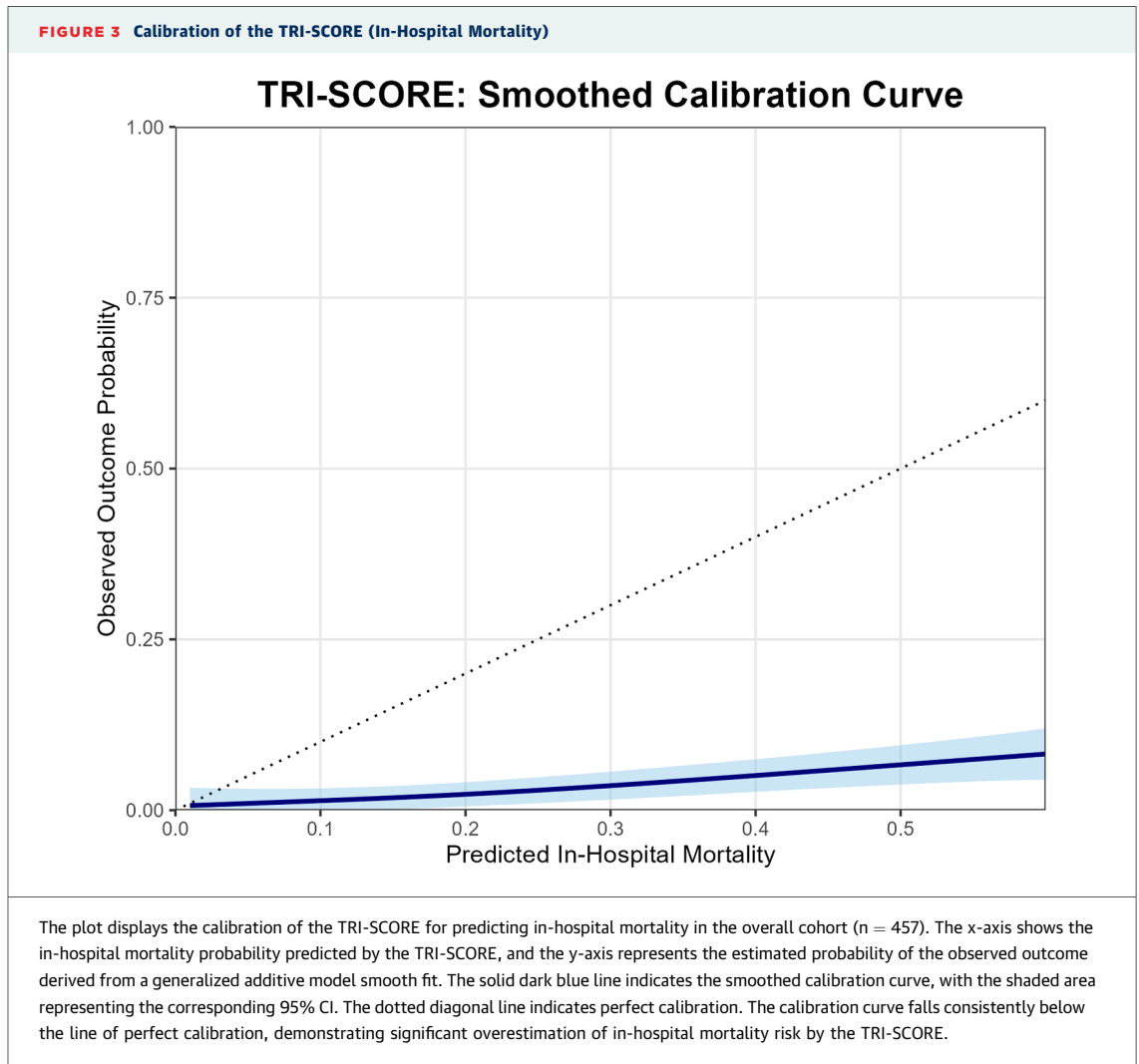
	n	AUC (95% CI)	O/E Ratio (95% CI)	Brier Score (Overall Error)	Calibration Intercept (Ideal = 0)	Calibration Slope (Ideal = 1)
STS-TR score (30-d mortality)	457	0.68 (0.54-0.82) ^a	0.35 (0.19-0.60)	0.033	-1.76	0.72
TRI-SCORE (in-hospital mortality)	457	0.72 (0.56-0.88) ^a	0.13 (0.07-0.23)	0.084	-2.68	0.72
TRIVALVE score (1-y original endpoint)	427	0.57 (0.53-0.64) ^a	1.71 (1.48-1.98)	0.279	0.17	0.35
TRIVALVE score (1-y modified endpoint)	427	0.61 (0.56-0.66) ^a	1.34 (1.13-1.57)	0.227	-0.11	0.48

^aAUCs and CIs for STS-TR score, TRI-SCORE, and TRIVALVE (original and modified) are from the primary analysis for consistency.
 AUC = area under the curve; O/E = observed-to-expected; STS-TR = Society of Thoracic Surgeons Tricuspid Regurgitation; TRIVALVE = International Multisite Transcatheter Tricuspid Valve Therapies Registry.

FIGURE 2 Calibration of the STS-TR Score (30-Day Mortality)



The plot displays the calibration of the STS-TR (Society of Thoracic Surgeons Tricuspid Regurgitation) score for predicting 30-day mortality in the overall cohort (n = 457). The x-axis shows the 30-day mortality probability predicted by the STS-TR score, and the y-axis represents the estimated probability of the observed outcome derived from a generalized additive model smooth fit. The solid dark blue line indicates the smoothed calibration curve, with the shaded area representing the corresponding 95% CI. The dotted diagonal line indicates perfect calibration. The calibration curve falls consistently below the line of perfect calibration, demonstrating significant overestimation of 30-day mortality risk by the STS-TR score.



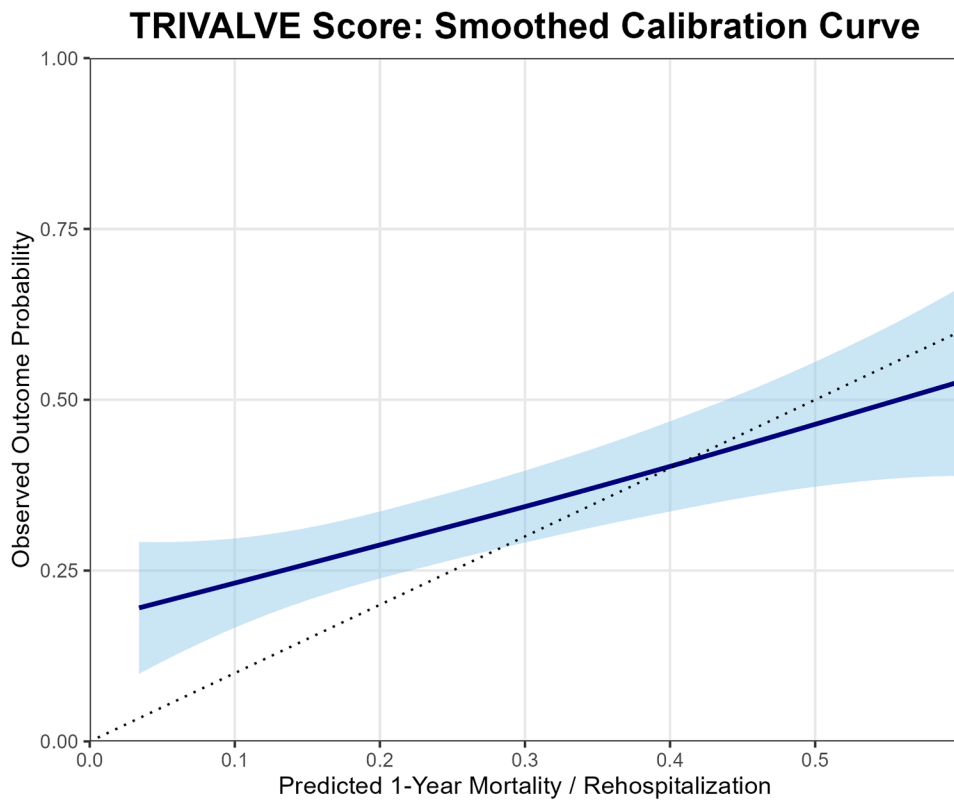
critical prognostic variables that are well-established drivers of outcomes in this population. Both the surgical and transcatheter scores lack incorporation of key hemodynamic and imaging parameters, such as the degree of pulmonary hypertension, baseline right ventricular size and function, left ventricular function, and the presence of ischemic heart disease. These are fundamental for accurate risk stratification in patients with severe TR. Their absence from the models likely contributes to a significant portion of the poor discrimination and miscalibration observed in the present study. Furthermore, this study validates the scores in a “contemporary” cohort treated between 2019 and 2024, when rapid technological and procedural evolution in TTVI occurred. There was significant device evolution, steep operator learning curves, and dynamic improvement in patient selection. This rapid temporal evolution further challenges the application of legacy risk models that

were derived from either surgical or earlier TTVI cohorts that contribute to the severe miscalibration observed.

Additionally, a recalibration analysis of the TRI-SCORE was performed. This analysis confirmed that although the score’s severe miscalibration could be statistically corrected (intercept = 0.0, slope = 1.0), its underlying discrimination remained suboptimal (AUC: 0.719). This demonstrates that the limitations are fundamental to the variables and weights, not merely a calibration error, reinforcing the need for a dedicated TTVI risk model.

Despite the miscalibration for predicting absolute risk, the TRI-SCORE still demonstrates utility in relative risk stratification to guide therapeutic strategy. In the large TRIGISTRY registry, Dreyfus et al¹³ showed that an intervention (surgical or transcatheter repair) was associated with a 2-year survival benefit compared with conservative management

FIGURE 4 Calibration of the TRIVALVE Score (Modified Endpoint)



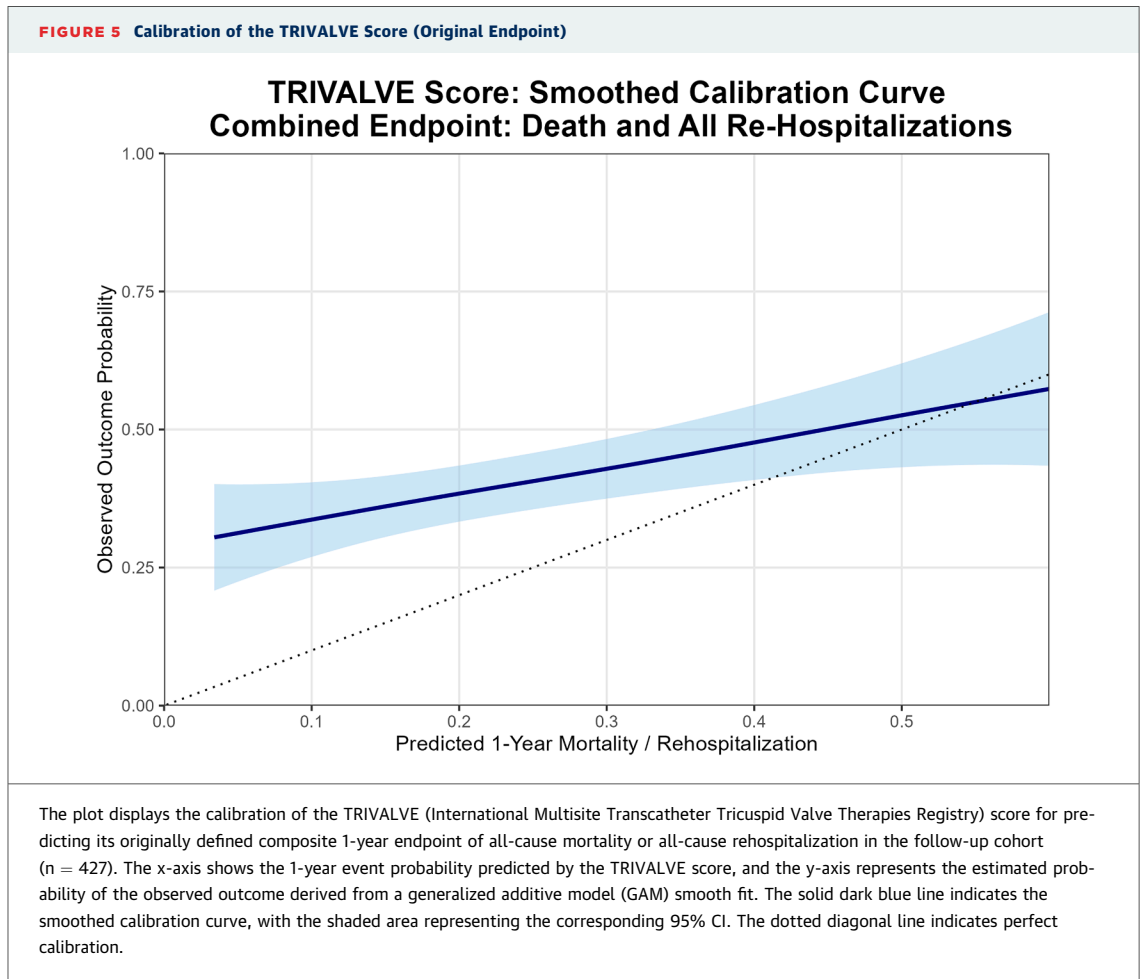
The plot displays the calibration of the TRIVALVE (International Multisite Transcatheter Tricuspid Valve Therapies Registry) score for predicting the composite 1-year endpoint of all-cause mortality or cardiovascular-related rehospitalization in the follow-up cohort (n = 427). The x-axis shows the 1-year event probability predicted by the TRIVALVE score, and the y-axis represents the estimated probability of the observed outcome derived from a generalized additive model smooth fit. The solid dark blue line indicates the smoothed calibration curve, with the shaded area representing the corresponding 95% CI. The dotted diagonal line indicates perfect calibration.

only in patients with low or intermediate TRI-SCOREs. In high-risk patients, no survival benefit was observed, suggesting potential therapeutic futility. The TRI-SCORE appears to retain value for staging disease severity and informing the heart team's decision on whether TTVI is likely to be beneficial. This utility for risk stratification is now recognized in the 2025 European Society of Cardiology guidelines on the management of valvular heart disease, which encourage the use of the TRI-SCORE as part of the stepwise evaluation and assessment of patients with severe TR.¹⁰

Given the limitations of applying surgical scores to high-risk TR cohorts, a dedicated model such as the TRIVALVE score could be an alternative. However, the TRIVALVE score demonstrated limited discrimination (AUC: 0.609) for its 1-year

composite endpoint in our cohort. Furthermore, calibration was highly dependent on the endpoint definition. Although the score showed good visual calibration when applied to a clinically specific endpoint of mortality or cardiovascular-related hospitalization, its performance degraded when using the originally defined nonspecific endpoint of all-cause rehospitalization, likely related to noncardiac rehospitalization.

Recent studies have assisted in prediction of procedural and clinical outcomes with T-TEER. The GLIDE score, an acronym for gap (septolateral coaptation), location (of the TR jet), image quality, density (of chordal structures), and en face TR morphology, is a tool designed for predicting acute T-TEER procedural success on the basis of specific echocardiographic parameters. The GLIDE score effectively



predicts significant TR reduction, which correlated with improvements in functional status including NYHA functional class and 6-minute walk distance.¹⁴

However, a score predicting anatomical success is conceptually distinct from one designed to predict clinical events such as mortality and rehospitalization. Although the former helps answer the technical question of whether TR be treated successfully, the latter addresses the crucial patient-centered question of whether TR should be treated (ie, whether a patient is likely to benefit from the procedure in addition to optimized medical therapy). The challenges of the STS-TR, TRI-SCORE, and TRIVALVE scores suggest that a specific tool to address this prognostic question in a transcatheter population that is medically optimized is still needed.

STUDY LIMITATIONS. First, this was an international, multicenter, but retrospective observational study, which carries an inherent risk for selection

bias and relies on the accuracy and completeness of data documented in electronic medical records.

Second, the patient cohort was drawn from 6 specialized, tertiary, high-volume centers, and the findings may not be fully generalizable to patients undergoing TTVI in different clinical settings. Third, although the sample size is substantial for this emerging field, the overall cohort remains relatively modest for a definitive validation of predictive ability. Furthermore, the observed short-term mortality rate was low (n = 13 events). This limits the statistical power for this specific endpoint and contributes to the CIs observed for performance metrics.

Finally, although missing data were minimal for most variables, imputation using a random forest algorithm was necessary for some components of the TRI-SCORE and TRIVALVE score (notably bilirubin and GGT). In contrast, for the STS-TR score, we relied on the official calculator's internal mechanism to handle missing values, per its intended use. This was

most notable for total albumin (31.7% missing). However, this missing rate was lower than the 38.3% reported in the score's original derivation cohort. Our imputation strategy for the TRI-SCORE was consistent with the original development and its robustness was confirmed by a complete case sensitivity analysis.

Despite these limitations, this study represents a comprehensive validation of existing risk scores in a multinational contemporary real-world TTVI cohort.

CONCLUSIONS

The findings of the present study demonstrate a limitation in risk stratification for TTVI patients. Surgically derived scores are miscalibrated, and the only available dedicated transcatheter score is hampered by limited discrimination and reliance on all-cause rather than cardiac-related rehospitalization. These scoring tools could negatively affect patient selection and avoidance of TTVI in those with favorable risk benefit profiles. There is a clinical need for the development and validation of alternative risk models for TTVI therapies and patient populations using contemporary TTVI cohorts using clinically relevant endpoints to accurately guide management of this complex patient population. Future research potentially leveraging artificial intelligence to develop more sophisticated models may address these gaps in current risk stratification.

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PERSPECTIVES

WHAT IS KNOWN? Significant TR is a prevalent condition associated with substantial morbidity and mortality, for which TTVI have emerged as a less invasive alternative to high-risk surgery. Accurate risk stratification is crucial for patient selection, but the tools available are limited, including surgically derived scores such as the TRI-SCORE and STS-TR score. Their performance in TTVI cohorts is uncertain. A dedicated TTVI score, the TRIVALVE score, has been developed but needs external validation in a contemporary population that includes current patient selection and technologies as well as increased operator experience.

WHAT IS NEW? This is the first study to comprehensively validate and compare the 3 major risk scores in a large, contemporary, multicenter TTVI cohort. Our findings demonstrate that the surgically derived STS-TR score and TRI-SCORE are miscalibrated, significantly overestimating short-term mortality in patients undergoing TTVI. Furthermore, the dedicated TRIVALVE score showed limited discrimination for its primary composite endpoint of mortality and rehospitalization in this real-world population.

WHAT IS NEXT? The limitations of all currently available risk models demonstrate a clinical need for a new prognostic tool for patients undergoing TTVI. Future research must focus on the development and validation of a contemporary dedicated risk model that is derived from modern TTVI cohorts using clinically relevant endpoints. Such a tool is essential to accurately guide patient management, inform the shared decision-making process, and optimize outcomes for this complex patient population.

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KEY WORDS prognosis, risk scores, transcatheter valve therapy, tricuspid regurgitation

APPENDIX For supplemental figures, tables, and detailed risk score definitions and calculation methodologies, please see the online version of this paper.