Comparative prognostic performance of risk scores for 12-month mortality and rehospitalization after transcatheter tricuspid valve intervention

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Background: Interventional treatment of tricuspid regurgitation (TR) is a rapidly evolving field, but selecting patients most likely to benefit remains challenging. Currently, no dedicated or widely accepted risk score exists for transcatheter tricuspid valve interventions (TTVIs). In clinical practice, established scores such as Model for End-stage Liver Disease excluding INR (MELD-XI), European System for Cardiac Operative Risk Evaluation II (EuroSCORE II), GLIDE (Gap, Location, Image quality, Density, and En-face tricuspid regurgitation morphology), Tricuspid Regurgitation Impact Score (TRI-SCORE), and TRIVALVE are applied to estimate the risk of mortality and rehospitalization. This study analyzed the prognostic performance of these risk scores for predicting 12-month outcomes following TTVI.

Methods: In this prospective single-center cohort study, 60 consecutive patients undergoing either edge-to-edge repair (n=47) or heterotopic minimally invasive bicaval valve implantation (n=13) were enrolled. Five established risk scores [MELD-XI, EuroSCORE II, GLIDE (Gap, Location, Image quality, Density, and En-face tricuspid regurgitation morphology), TRI-SCORE, and TRIVALVE] were calculated prior to intervention according to their original definitions. The primary outcome was a composite of all-cause mortality or rehospitalization for heart failure at 12 months. Discriminatory ability was assessed using receiver operating characteristic (ROC) curves and the corresponding area under the curve (AUC). Using the score with the best performance, patients were additionally stratified into risk categories based on the optimal cut-off value derived from ROC analysis. Survival analyses were performed using the Kaplan-Meier method and compared using the log-rank test.

Results: No procedure-related deaths occurred. In-hospital mortality was 2.8%. Thirteen patients (21.7%) were rehospitalized for decompensated heart failure, and 11 patients (18.3%) died during the 12-month follow-up period. Among all evaluated risk scores, the TRI-SCORE demonstrated the strongest prognostic performance for the primary endpoint (AUC 0.76, 95% confidence interval: 0.61–0.91; P=0.004) and significantly discriminated survival across predefined risk categories (log-rank P=0.002). All other scores showed lower predictive ability for 12-month mortality or rehospitalization (AUC ≤0.65).

Conclusions: The TRI-SCORE demonstrated the best discriminatory capacity among the evaluated models for predicting 12-month mortality and rehospitalization after TTVI.

Keywords: Tricuspid regurgitation (TR); Tricuspid Regurgitation Impact Score (TRI-SCORE); transcatheter tricuspid valve intervention (TTVI)

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Introduction

Tricuspid regurgitation (TR) is a prevalent and often underrecognized valvular disorder, particularly in elderly patients and those with left-sided heart disease, pulmonary hypertension, or atrial fibrillation (1-3). While mild and intermediate TR are often clinically silent, severe TR has increasingly been associated with adverse outcomes, including progressive right heart failure, reduced exercise capacity, renal and hepatic dysfunction, and elevated mortality (4,5). Historically, isolated TR, without concomitant valvular disease, was rarely treated due to its high perioperative risk and limited success rates associated with surgical repair or replacement, particularly in geriatric patients with advanced cardiovascular disease and multiple comorbidities (3,6,7).

Over the past decade, transcatheter tricuspid valve intervention (TTVI) has emerged as a promising alternative for inoperable or high-risk patients (8-10). Techniques such as edge-to-edge repair and heterotopic valve implantation have demonstrated procedural feasibility and symptomatic benefit (11-14). However, pre-interventional patient selection remains a critical and unresolved issue, as procedural risk-benefit assessment is heavily influenced by comorbidities, right ventricular function, end-organ involvement, and the timing of intervention (15,16). In this context, clinical risk scores may aid treatment decisions, individualize risk assessment, and inform patient counseling. Yet no validated or widely adopted scoring system exists specifically for TTVI (17). Instead, a variety of scores developed for different populations and indications are currently applied, often with limited external validation regarding TTVI.

Among these, the European System for Cardiac Operative Risk Evaluation II (EuroSCORE II), though widely used, was designed for predicting perioperative mortality in cardiac surgery patients and does not account for TR-specific pathophysiology or non-surgical approaches (18). The Model for End-stage Liver Disease excluding INR (MELD-XI) score incorporates renal and hepatic function, parameters often altered in right-sided heart failure, making it potentially useful in TR patients, though it was originally developed for liver transplant allocation (19,20). The TRIVALVE score, GLIDE (Gap, Location, Image quality, Density, and En-face tricuspid regurgitation morphology) score, and Tricuspid Regurgitation Impact Score (TRI-SCORE) have been developed more recently with a focus on right-sided heart failure or TR-specific populations (17,21,22). The TRI-SCORE was initially developed for isolated tricuspid valve surgery and has been evaluated in TTVI cohorts with mixed results. In contrast, the TRIVALVE score was specifically derived for patients undergoing TTVI, although external validation remains limited (23). By integrating echocardiographic parameters with renal and hepatic function and markers of right heart decompensation, the TRI-SCORE provides a comprehensive framework that is particularly well-suited for risk stratification in patients undergoing TTVI (22,24). Reliable prediction of mortality and rehospitalization is particularly important in the TTVI population, where high rates of adverse outcomes persist despite procedural success (25,26). Identifying patients likely to benefit from intervention and, equally important, those unlikely to benefit, remains a core clinical need, especially considering the limited evidence base and resource-intensive nature of the procedures.

The aim of this study was therefore to analyze the predictive value of five commonly used risk scores: MELD-XI, TRIVALVE-score, TRI-SCORE, GLIDE score, and EuroSCORE II for 12-month mortality or heart failure rehospitalization after TTVI, in a prospective cohort of patients undergoing edge-to-edge repair or heterotopic valve implantation. By identifying the most accurate and clinically useful scoring system, this study seeks to improve risk stratification and outcome prediction in this emerging field of structural heart intervention.

Methods

Study design and population

This prospective single-center cohort study included 60 consecutive patients with severe TR who underwent TTVI between November 2022 and March 2024 at the Brandenburg Heart Center, Bernau. Patients were treated either with edge-to-edge repair (n=47) or heterotopic minimally invasive transcatheter valve implantation (n=13), based on an interdisciplinary heart team decision.

Ethical approval

This study was approved by the institutional ethics committee (Reference: E-01-20190503). All participants provided written informed consent prior to enrollment. The study was conducted in accordance with the principles of the Declaration of Helsinki and adhered to Good Clinical Practice guidelines.

Data collection and clinical follow-up

At baseline, clinical, laboratory, and echocardiographic data were collected prior to the intervention. Patients were followed up for 12 months post-procedure. The primary endpoint was a composite of all-cause mortality and rehospitalization for decompensated heart failure within 12 months following TTVI. Heart failure rehospitalization was defined as rehospitalization for decompensated heart failure during follow-up. All rehospitalization events were recorded. Events were assessed based on clinical follow-up and review of hospital records; no independent event adjudication was performed.

Risk score assessment

Five risk scores were calculated before TTVI using standardized definitions and published algorithms:

(I) MELD-XI score: Derived from the original MELD formula, excluding INR: MELD-XI = 5.11 × ln [serum bilirubin (mg/dL)] + 11.76 × ln [serum creatinine (mg/dL)] + 9.44. Values <1.0 were set to 1.0 to avoid negative logarithms (20).

(II) EuroSCORE II: Calculated via the official online calculator (www.euroscore.org), using demographic data, comorbidities, and cardiac procedural risk variables. Although designed for cardiac surgery risk, it is still widely applied in structural and valvular heart interventions (27).

(III) GLIDE score: Its acronym is derived from the echocardiographic variables, with all obtained from the pre-interventional transesophageal echocardiography. The GLIDE score is an exclusively image-based scoring system used before T-TEER. It ranges from 0 to 5 and predicts the likelihood of immediate procedural success (21).

(IV) TRI-SCORE: This score was specifically developed to predict in-hospital mortality in TR patients undergoing isolated tricuspid surgery. It consists of 13 pre-interventional parameters: age ≥70 years, sex, New York Heart Association (NYHA) class III or worse, right-sided heart failure signs, prior left-sided heart valve intervention, having a permanent pacemaker or defibrillator, atrial fibrillation, daily furosemide dose >125 mg, estimated glomerular filtration rate (eGFR) <30 mL/min/1.73 m^2, elevated total bilirubin >21 µmol/L, impaired left ventricular function <55%, moderate/severe right ventricular dysfunction, and the classification of TR etiology as primary, secondary, or mixed. Each parameter counts as one point; the total score ranges from 0 to 12. Predicted in-hospital mortality after isolated tricuspid valve surgery is expressed as a percentage. Three risk categories were established from mild to high risk according to the predefined risk categories. No study-specific cut-off was derived from the present cohort (22).

(V) TRIVALVE score: Developed for patients with severe TR undergoing isolated tricuspid valve surgery. The score includes variables such as right ventricular function, ejection fraction, atrial fibrillation, glomerular filtration rate and bilirubin levels. Each variable is assigned a point value based if applicable, which is added together to yield the final score (17).

Interventional techniques

The indication for TTVI and the choice of procedural strategy were determined by the interdisciplinary heart team based on clinical status, anatomical suitability, and expected procedural feasibility. Transcatheter edge-to-edge repair (TEER) was performed when a reconstructive approach was considered feasible, whereas heterotopic bicaval valve implantation was selected in patients with unfavorable anatomy for repair. Orthotopic transcatheter tricuspid valve replacement, such as EVOQUE, was not part of the treatment algorithm during the study period. Periprocedural imaging was consistently performed by the same echocardiographer who was certified in peri-interventional imaging. Furthermore, each procedure was supported on-site by a technical specialist from the device manufacturer who assisted in device preparation and deployment. The interventional team was formally trained and certified by the device manufacturer at training facilities.

T-TEER

T-TEER is a catheter-based approach aimed at reducing TR by approximating the native leaflets, thereby enhancing coaptation. It is particularly suited for patients with high surgical risk. Two similar devices were employed. The Pascal System™ (Edwards Lifesciences, Irvine, CA, USA) uses a central spacer and broad paddles to bridge the regurgitant orifice while distributing pressure evenly across the valve (28). The TriClip System™ (Abbott, Santa Clara, CA, USA), adapted from the MitraClip technology, applies multiple leaflet-grasping clips without a central spacer, offering precise coaptation (29). While both systems have shown safety and efficacy in clinical trials, a key technical distinction lies in the use of a spacer with the Pascal device versus direct approximation in the TriClip system.

Heterotopic bicaval valve implantation

The TricValve System™ (P&F Products & Features, Vienna, Austria) is a heterotopic percutaneous bicaval valve system for patients deemed unsuitable for T-TEER due to the gap between the leaflets being too wide. It involves the implantation of self-expanding bioprosthetic valves into the superior and inferior vena cava. This approach does not address the tricuspid valve directly but instead alleviates systemic venous congestion by reducing backflow. Clinical improvement is typically seen in reduced signs of right-sided heart failure, such as peripheral edema, hepatomegaly, and ascites. However, symptoms driven by impaired forward flow, like exertional dyspnea, may remain unchanged, as right ventricular output is not significantly improved. The feasibility and symptomatic benefit of this method have been demonstrated in observational studies of high-risk patients (30).

At baseline TR severity was separately assessed using the Hahn classification in 47 patients undergoing T-TEER. Patients receiving heterotopic minimal invasive tricuspid valve implantation were excluded from the following calculations because TR classifications are not affected by the intervention. Procedural success after T-TEER was defined as a post-interventional reduction of ≥2 Hahn grades with residual TR ≤ moderate (grade 2/5) at discharge.

Statistical analysis

Data distribution was evaluated for normality using histograms and the Shapiro-Wilk test. Continuous variables are presented as mean ± standard deviation (SD) or median with interquartile range (IQR), as appropriate. Categorical variables are expressed as counts and percentages. Receiver operating characteristic (ROC) curves were generated for each score, and the area under the curve (AUC) was calculated to evaluate predictive accuracy for the composite endpoint. For the TRI-SCORE, patients were dichotomized according to the predefined risk categories into a high-risk group (TRI-SCORE >5) and a low-/intermediate-risk group (TRI-SCORE ≤5). This approach was applied to the risk score that demonstrated the most promising prognostic performance. Survival distributions were compared using the log-rank test and visualized with Kaplan-Meier curves. Categorical comparisons between risk groups were performed using the chi-square test. A Wilcoxon signed-rank test was used to demonstrate post-procedural benefit across one cohort. A two-sided P value <0.05 was considered statistically significant. Statistical analyses were conducted using SPSS version 25 and Microsoft Excel 2019.

Results

Baseline characteristics

A total of 60 patients undergoing TTVI were included (edge-to-edge repair: n=47; heterotopic tricuspid valve implantation: n=13). Patient flow is shown in *Figure 1*. The mean age was 80.3±7.3 years, and 51.7% were female. Baseline characteristics are shown in *Table 1*; echocardiographic parameters are presented in *Table 2*.

Among patients undergoing TEER, 14 patients (29.7%) received one clip, 31 patients (66.0%) had two clips and 2 patients (4.4%) had three clips. The median NYHA classification at baseline was 3.0 (IQR 0). Most patients (81.0%) presented with NYHA Class III, whereas 15.5% were in Class II and 3.4% in Class IV; no patients were classified as NYHA Class I. The cohort was characterized by advanced TR, with a median 3D effective regurgitant orifice (ERO) of 2.5 (IQR 1.8–3.3) cm^2 and a regurgitant volume of 66.0 (IQR 49.0–96.0) mL. Right ventricular function was moderately impaired at baseline, with a median 3D right ventricular ejection fraction of 42.3% (IQR 34.8–49.9%) and 3D tricuspid annular plane systolic excursion (TAPSE) of 17.0 (IQR 13.0–20.5) mm. In addition, the right atrial area was enlarged at 34.9 (IQR 27.1–40.2) cm^2 and estimated systolic pulmonary artery pressure was 38.0 (IQR 28.0–53.0) mmHg, indicating relevant right heart remodeling.

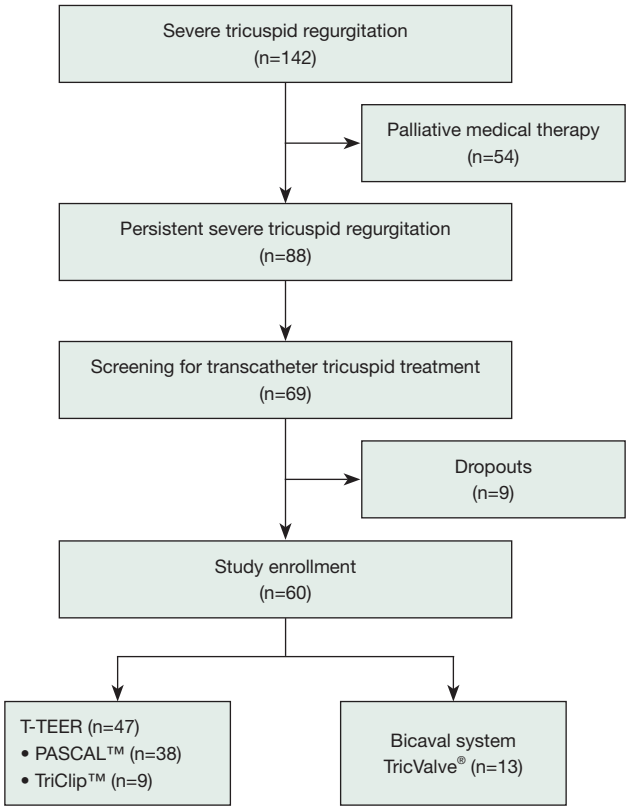

Figure 1 Study flow chart of patient inclusion, allocation to the respective transcatheter tricuspid intervention, and clinical follow-up. T-TEER, transcatheter edge-to-edge repair.

Interventional results

There were no procedure-related deaths. One patient died during the hospital stay, corresponding to an in-hospital mortality of 2.8%. Using the Hahn classification, success rate based on echocardiographic criteria was achieved in 80.4% of patients receiving edge-to-edge procedure, with a median reduction of 2.0 grades (IQR 2.0–4.0). T-TEER yielded a highly significant improvement in TR severity at discharge (P<0.001), which persisted at 3-month and 12-month follow-up (both P<0.001). This was accompanied by a significant reduction in 3D ERO (P<0.001) and regurgitant volume, as well as a decrease in right atrial area from 34.9 (IQR 27.1–40.2) to 30.9 (IQR 25.8–37.7), suggesting early reverse remodeling, whereas right ventricular functional parameters remained largely unchanged.

Follow-up results

Within 12 months post-intervention, 13 patients (21.7%) were rehospitalized for decompensated heart failure, and 11 patients (18.3%) died, as demonstrated in *Figure 2*. Among the 11 patients who died during the follow-up period, seven (63.6%) had received TricValve implantation, while four (36.4%) had undergone an edge-to-edge repair procedure.

In an additional sensitivity analysis restricted to patients undergoing T-TEER, 4 patients (8.0%) died within 12 months after the intervention and 7 patients (14.0%) were rehospitalized for decompensated heart failure.

Risk scores

The median MELD-XI score at baseline was 14.0 with an IQR of 6.5. *Figure 3A* depicts the baseline distribution of MELD-XI score results. At baseline, the TRIVALVE-score demonstrated a median of 2.0 (IQR 1.5), with the distribution shown in *Figure 3B*. The median TRI-SCORE result was 5.0 (IQR 2.8) out of a maximum of 12. The corresponding median predicted in-hospital mortality was

Table 1 Baseline characteristics of the study population (n=60)

Parameter	Value
Sex male	29 [48.3]
Age, years	80.3±7.3
Body mass index, kg/m^2	26.9±5.9
NYHA classification	3.0 [0]
NYHA II	9 [15.0]
NYHA III	49 [81.7]
NYHA IV	2 [3.3]
Concomitant at least moderate heart valve disease	33 [55.0]
Of which treated	25 [75.8]
6-minute walk test <100 m	22 [36.7]
eGFR, mL/min/1.73 m^2	42.5±15.6
Type II diabetes	22 [36.7]
Type of intervention	
Edge-to-edge (TriClip)	9 [15.0]
Edge-to-edge (Pascal)	38 [63.3]
Heterotopic bicaval valve implantation (TricValve)	13 [21.7]
Procedure time, min	66.5 [35.0]
Length of hospitalisation, days	9.0 [5.0]
RV pressure, mmHg	11.2±5.8
RA pressure, mmHg	12.1±6.4
PA pressure, mmHg	26.8±7.7
PCW pressure, mmHg	17.9±6.9
Pulmonary vascular resistance, WU	2.0 [0.9]
Cardiac output, L/min	4.30±1.35

Data are presented as mean ± standard deviation or n [%]. eGFR, estimated glomerular filtration rate; IQR, interquartile range; NYHA, New York Heart Association; PA, pulmonary arterial; PCW, pulmonary capillary wedge; RA, right atrial; RV, right ventricular; SD, standard deviation; WU, Wood units.

14.0% (IQR 16.3%). When stratified into predefined risk categories, 25.9% of patients were allocated to the low-risk group, 65.5% to the intermediate-risk group, and 8.6% to the high-risk group, respectively. The baseline TRI-SCORE results are illustrated in *Figure 3C*. The mean GLIDE score was 3.0 (IQR 2.0). The distribution is shown in *Figure 3D*. At baseline, the predicted intraoperative mortality according to EuroSCORE II was 4.4% (IQR 3.5%) as shown in *Figure 3E*.

Predictive accuracy analysis

The MELD-XI score yielded a modest AUC but failed to demonstrate significant predictive value for the combined endpoint of mortality or rehospitalization at 12 months post-TTVI [AUC =0.65, 95% confidence interval (CI): 0.46–0.83; P=0.106; *Figure 4A*]. The GLIDE score (AUC =0.64, 95% CI: 0.47–0.80; P=0.130), TRIVALVE score (AUC =0.64, 95% CI: 0.45–0.84; P=0.110), and EuroSCORE II (AUC =0.61, 95% CI: 0.45–0.78; P=0.205) also showed only

Table 2 Echocardiographic parameters at baseline

Characteristics	Pre-interventional	Post-interventional
Study population	(n=60)	(n=54)
Mean LVEF (%)	50.9±15.4	50.5±7.6
Median TR-Hahn grading scheme	4.0 (3.0–5.0)	2.0 (1.5–2.0)
Median 2D ERO (measured by PISA) (cm^2)	0.7 (0.5–1.3)	0.3 (0.2–0.5)
Median 3D ERO (measured by PISA) (cm^2)	2.5 (1.8–3.3)	0.8 (0.3–1.5)
Median tricuspid regurgitation volume (mL)	66.0 (49.0–96.0)	23.0 (15.0–40.0)
Median 3D right ventricular stroke volume (mL)	65.0 (50.0–83.0)	46.0 (36.0–73.0)
Median 3D right ventricular ejection fraction (%)	42.3 (34.8–49.9)	39.4 (34.6–46.4)
Median 3D right ventricular FAC (%)	37.0 (29.3–43.8)	33.9 (28.2–40.4)
Median 3D TAPSE (mm)	17.0 (13.0–20.5)	16.0 (14.0–19.0)
Median right ventricular longitudinal strain (%)	23.0 (17.0–26.0)	20.0 (16.0–25.0)
Median monoplane right atrial area (cm^2)	34.9 (27.1–40.2)	30.9 (25.8–37.7)
Median systolic pulmonary artery pressure (mmHg)	38.0 (28.0–53.0)	37.0 (27.0–52.0)
Edge-to-edge (TriClip)	(n=9)	(n=9)
Mean LVEF (%)	53.9±7.1	49.8±5.7
Median TR-Hahn grading scheme	4.0 (3.0–5.0)	2.0 (2.0–2.0)
Grade < III/V	0 [0]	9 [100]
Grade III/V	1 [11.1]	0 [0]
Grade IV/V	1 [11.1]	0 [0]
Grade V/V	7 [77.8]	0 [0]
Median 2D ERO (measured by PISA) (cm^2)	0.8 (0.3–1.3)	0.3 (0.2–0.4)
Median 3D ERO (measured by PISA) (cm^2)	2.3 (1.2–2.8)	0.7 (0.5–1.5)
Median tricuspid regurgitation volume (mL)	61.0 (33.0–89.0)	21.0 (15.0–33.0)
Median 3D right ventricular stroke volume (mL)	64.5 (46.0–77.0)	45.0 (36.0–57.0)
Median 3D right ventricular ejection fraction (%)	40.7 (34.8–49.9)	39.4 (35.7–41.0)
Median 3D right ventricular FAC (%)	34.9 (31.9–42.9)	32.0 (23.9–41.1)
Median 3D TAPSE (mm)	17.0 (13.0–21.0)	15.5 (12.0–19.0)
Median right ventricular longitudinal strain (%)	24.0 (18.0–26.0)	21.0 (17.0–25.0)
Median monoplane right atrial area (cm^2)	30.2 (24.5–42.8)	28.2 (22.2–37.5)
Median systolic pulmonary artery pressure (mmHg)	36.0 (26.0–49.0)	31.0 (24.0–49.0)

Table 2 (*continued*)

Table 2 (*continued*)

Characteristics	Pre-interventional	Post-interventional
Edge-to-edge (Pascal)	(n=38)	(n=33)
Mean LVEF (%)	49.2±9.5	50.6±8.0
Median TR-Hahn grading scheme	4.0 (3.0–5.0)	1.5 (1.0–2.0)
Grade < III/V	0 [0]	28 [84.8]
Grade III/V	9 [23.7]	5 [15.2]
Grade IV/V	15 [39.5]	0 [0]
Grade V/V	14 [36.8]	0 [0]
Median 2D ERO (measured by PISA) (cm^2)	0.7 (0.5–1.2)	0.2 (0.16–0.43)
Median 3D ERO (measured by PISA) (cm^2)	2.5 (1.9–3.3)	0.7 (0.3–1.2)
Median tricuspid regurgitation volume (mL)	67.0 (50.0–101)	23.5 (15.0–40.0)
Median 3D right ventricular stroke volume (mL)	65.0 (50.0–83.0)	46.0 (36.0–73.0)
Median 3D right ventricular ejection fraction (%)	42.6 (36.9–49.2)	39.4 (34.6–46.6)
Median 3D right ventricular FAC (%)	37.4 (29.3–42.1)	33.9 (28.6–40.4)
Median 3D TAPSE (mm)	16.0 (13.0–20.0)	16.0 (14.0–19.0)
Median right ventricular longitudinal strain (%)	23.0 (16.0–25.0)	19.0 (15.0–24.0)
Median monoplane right atrial area (cm^2)	34.9 (27.8–39.7)	30.9 (26.4–37.8)
Median systolic pulmonary artery pressure (mmHg)	38.0 (28.0–53.0)	37.0 (27.0–52.0)
Heterotopic bicaval valve implantation (TricValve)	(n=13)	(n=12)
Mean LVEF (%)	55.0±20.8	51.0±7.8
Median TR-Hahn grading scheme	4.0 (3.5–5.0)	4.0 (3.5–5.0)
Grade III/V	0 [0]	0 [0]
Grade IV/V	2 [15.4]	2 [15.4]
Grade V/V	11 [84.6]	11 [84.6]
Median 2D ERO (measured by PISA) (cm^2)	0.9 (0.6–1.3)	0.9 (0.6–1.15)
Median 3D ERO (measured by PISA) (cm^2)	2.7 (1.9–3.6)	1.3 (0.5–2.7)
Median tricuspid regurgitation volume (mL)	62.0 (39.0–107)	37.0 (21.0–44.0)
Median 3D right ventricular stroke volume (mL)	57.0 (49.0–82.0)	59.0 (38.0–84.0)
Median 3D right ventricular ejection fraction (%)	42.6 (36.9–49.2)	40.8 (36.0–46.6)
Median 3D right ventricular FAC (%)	38.0 (27.3–46.5)	35.4 (28.2–43.9)
Median 3D TAPSE (mm)	17.5 (13.0–23.0)	17.5 (14.0–23.0)
Median right ventricular longitudinal strain (%)	23.0 (17.0–26.0)	20.0 (16.0–26.0)
Median monoplane right atrial area (cm^2)	38.4 (30.6–45.4)	36.3 (29.1–42.9)
Median systolic pulmonary artery pressure (mmHg)	42.0 (30.0–55.0)	45.0 (29.0–57.0)

Data are presented as mean ± standard deviation, median (interquartile range), or n [%]. ERO, effective regurgitant orifice; FAC, fractional area change; LVEF, left ventricular ejection fraction; PISA, proximal isovelocity surface area; TAPSE, tricuspid annular plane systolic excursion; TR, tricuspid regurgitation.

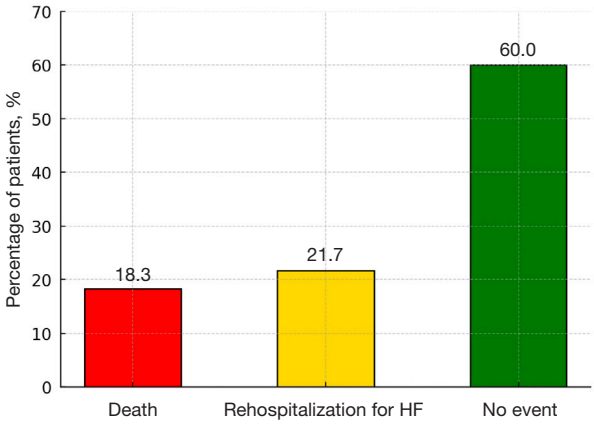

Figure 2 Twelve-month clinical outcome following transcatheter tricuspid valve intervention. HF, heart failure.

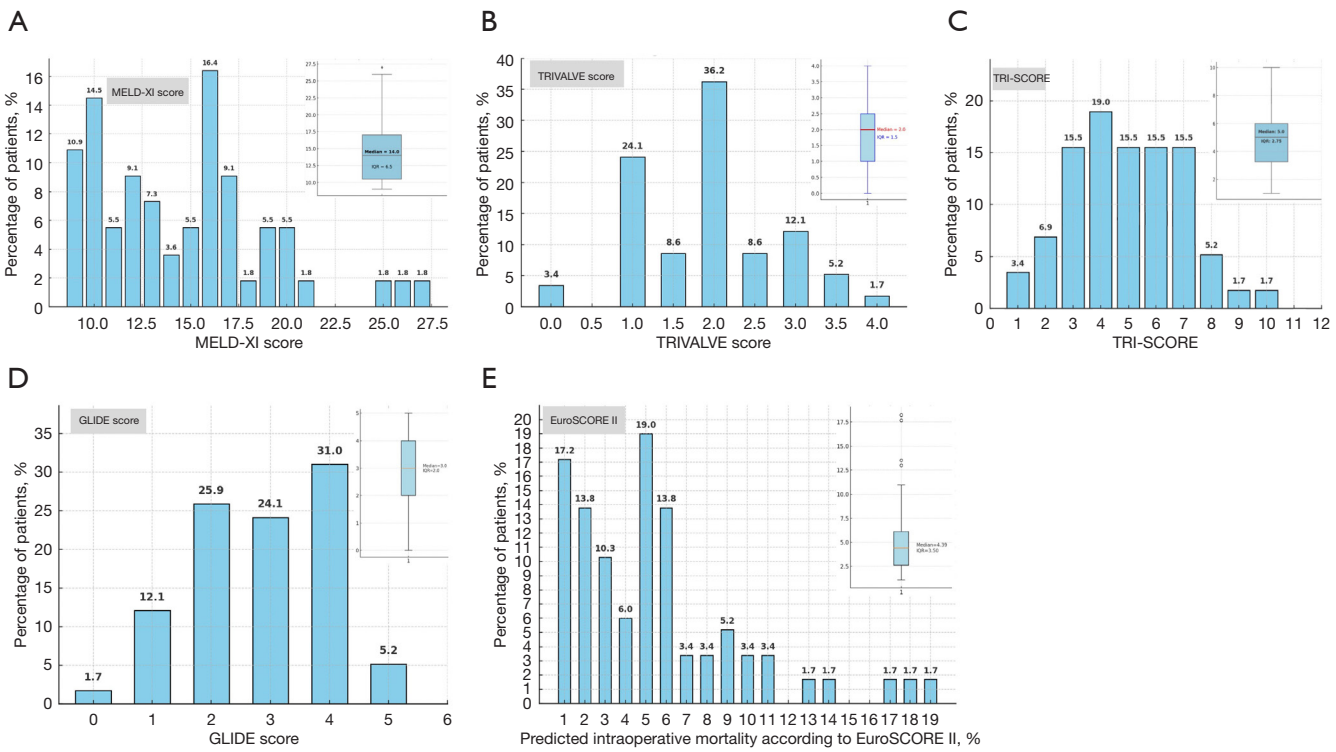

Figure 3 Baseline distribution of the evaluated risk scores. Baseline distribution of MELD-XI score (A), TRIVALVE score (B), TRI-SCORE (C), GLIDE score (D), and EuroSCORE II (E). EuroSCORE II, European System for Cardiac Operative Risk Evaluation II; GLIDE, Gap, Location, Image quality, Density, and En-face tricuspid regurgitation morphology; IQR, interquartile range; MELD-XI, Model for End-stage Liver Disease excluding INR; TRI-SCORE, Tricuspid Regurgitation Impact Score.

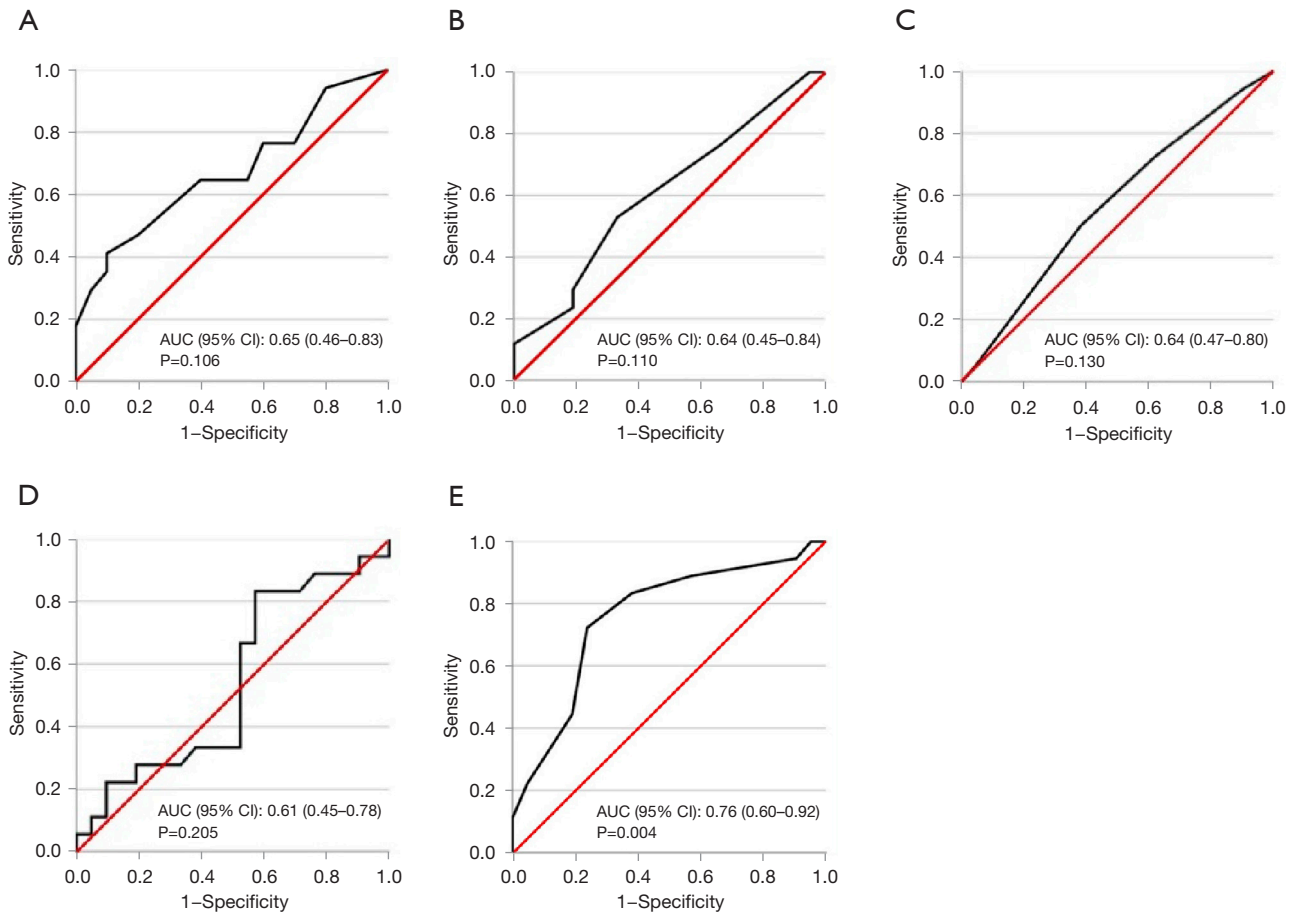

Figure 4 Predictive performance of the evaluated risk scores for the combined 12-month endpoint of all-cause mortality or rehospitalization for decompensated heart failure. MELD-XI score (A), TRIVALVE score (B), GLIDE score (C), EuroSCORE II (D), and TRI-SCORE (E). AUC, area under the curve; CI, confidence interval; EuroSCORE II, European System for Cardiac Operative Risk Evaluation II; GLIDE, Gap, Location, Image quality, Density, and En-face tricuspid regurgitation morphology; MELD-XI, Model for End-stage Liver Disease excluding INR; TRI-SCORE, Tricuspid Regurgitation Impact Score.

limited discriminatory capacity (*Figure 4B-4D*).

To account for procedural heterogeneity, an additional sensitivity analysis was performed only in the T-TEER subgroup. In this subgroup, the TRI-SCORE again showed the highest predictive accuracy for the combined 12-month endpoint of all-cause mortality or heart-failure rehospitalization (AUC =0.74, 95% CI: 0.52–0.95; P=0.031), whereas MELD-XI (AUC =0.61, 95% CI: 0.33–0.88; P=0.441), GLIDE (AUC =0.51, 95% CI: 0.24–0.77; P=0.959), TRIVALVE (AUC =0.57, 95% CI: 0.30–0.84; P=0.622), and EuroSCORE II (AUC =0.48, 95% CI: 0.18–0.77; P=0.874) showed only limited discriminatory capacity.

Among all evaluated risk scores, the TRI-SCORE demonstrated the highest predictive accuracy for the combined endpoint of mortality or rehospitalization, with an AUC of 0.76 (95% CI: 0.61–0.91; P=0.004). The ROC curve is displayed in *Figure 4E*.

Stratification based on the TRI-SCORE revealed significantly lower rates of rehospitalization and death in the low-/intermediate-risk group compared to the high-risk group (P=0.002), as illustrated by Kaplan-Meier survival analysis (*Figure 5*).

Discussion

TTVI has rapidly evolved as a promising therapeutic option for patients with advanced TR who are at high surgical risk. Recent data confirm the high procedural feasibility and

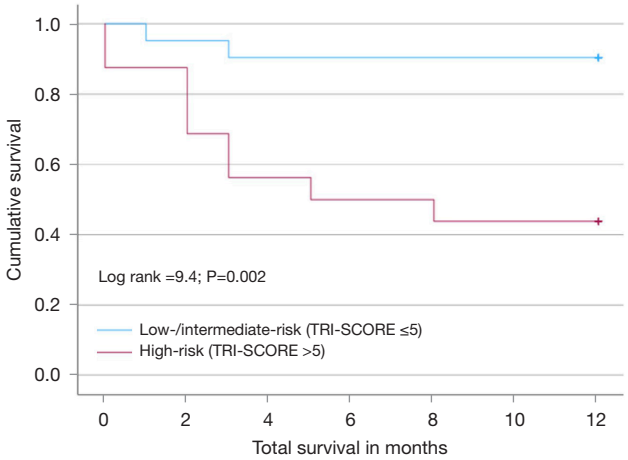

Figure 5 Kaplan-Meier curves for the combined 12-month endpoint of all-cause mortality or rehospitalization for decompensated heart failure, stratified by TRI-SCORE risk category. TRI-SCORE, Tricuspid Regurgitation Impact Score.

excellent safety profile of TTVI, with device success rates exceeding 85% and low in-hospital complication rates (31). In this study population, a similarly high procedural success rate was observed (80.4%), accompanied by a sustained echocardiographic treatment effect, defined as a relevant TR reduction of >2 grades combined with a residual TR grade ≤2, in 66.3% of patients at 12-month follow-up. The expanded echocardiographic assessment confirms advanced TR and relevant right heart remodeling at baseline. After intervention, the marked reduction in ERO and regurgitant volume indicated effective reduction of valvular incompetence, while conventional right ventricular functional parameters changed only modestly, likely due to their load dependency. The decrease in right atrial size further supports early reverse remodeling (32).

In-hospital mortality was likewise low (2.8%), comparable to rates reported in larger studies. Taken together, these findings confirm the comparability of our cohort to larger study populations with respect to procedural success, safety profile, and baseline characteristics, thereby supporting the validity of the present clinical data. While procedural feasibility and short-term outcomes are favorable, larger studies have not yet demonstrated a consistent mid- to long-term benefit, and mortality rates as well as rehospitalization rates remain substantial (33). Against this backdrop, accurate preprocedural risk stratification is critically needed, not only to guide clinical decision-making, but also to ensure optimal patient selection, informed consent, and appropriate use of increasingly complex and resource-intensive technologies.

In this prospective cohort study, we systematically analyzed five commonly used risk scores for their ability to predict 12-month all-cause mortality or rehospitalization following TTVI. Among these, the TRI-SCORE showed the highest discriminatory performance among the evaluated risk scores and allowed stratification into clinically meaningful risk categories. These findings suggest that the TRI-SCORE may be a useful tool for pre-interventional risk stratification, while larger studies are needed to confirm its role in identifying patients at increased risk for adverse outcomes after TTVI. Our findings support and extend previous evidence regarding the prognostic value of the TRI-SCORE in patients undergoing TTVI (18). In the single-center cohort reported by Gröger *et al.*, the TRI-SCORE showed excellent predictive accuracy for both 30-day and 1-year mortality after transcatheter edge-to-edge repair, with AUCs of 0.903 and 0.931, respectively, and significantly outperformed conventional surgical risk scores such as EuroSCORE II and the Society of Thoracic Surgeons (STS) score. However, these favorable results were not fully replicated in the larger multicenter TriValve validation study, in which the overall performance of the TRI-SCORE was considered suboptimal, although a TRI-SCORE ≥8 still identified patients at increased risk of 30-day mortality and adverse mid-term outcomes (34). This discrepancy may be explained by differences in cohort size, case mix, and procedural heterogeneity, as the latter study included a broader contemporary TTVI population rather than a more homogeneous T-TEER cohort. In this context, our results are of particular interest, as they confirm the comparatively strong discriminatory performance of

the TRI-SCORE in a real-world cohort including both edge-to-edge repair and heterotopic valve implantation. In contrast, the recently proposed TRIVALVE score, which was specifically derived for patients undergoing TTVI, showed only moderate discriminatory ability in its derivation study, with a bias-corrected AUC of 0.68 for 12-month mortality or rehospitalization. Together, these findings suggest that the TRI-SCORE remains a practical tool for pre-interventional risk stratification, although further refinement and external validation of TTVI-specific models are still needed.

Interestingly, our findings also provide important insight into the limitations of existing risk scores. The GLIDE score, which has recently gained attention for its apparent correlation with procedural success in transcatheter mitral and tricuspid interventions (31), did not demonstrate prognostic value for 12-month mortality or heart failure rehospitalization in our cohort. This discrepancy highlights the distinction between procedural feasibility and long-term clinical benefit. While favorable anatomical and functional parameters may predict technical success, they do not necessarily equate to sustained hemodynamic improvement or survival benefit, particularly in the presence of advanced right heart dysfunction or systemic congestion. Therefore, its modest discriminatory capacity in the present analysis does not indicate that the score is inadequate per se, but rather reflects the conceptual difference between procedural and long-term prognostic risk assessment.

Given the broad clinical heterogeneity among TR patients, ranging from compensated individuals with isolated leaflet tethering to those with advanced right heart failure and multiorgan dysfunction, accurate risk prediction is indispensable. The ability to estimate long-term clinical benefit is particularly relevant in patients with irreversible end-organ damage, severely impaired right ventricular function, or refractory volume overload. In these individuals, even technically successful interventions may fail to translate into clinical benefit. Incorporating validated risk scores such as the TRI-SCORE into clinical workflows may help avoid late or inappropriate interventions in patients with limited physiological reserve.

Based on the findings of our study and in line with the existing literature, patients presenting with a high GLIDE score (≥4 points), reflecting unfavorable anatomical and imaging characteristics with a low likelihood of procedural success, in combination with a high TRI score (≥6/12 points), indicating elevated clinical risk, appear to have a significantly impaired short- and long-term prognosis with regard to long-term success rates, rehospitalization, and all-cause mortality. In this context, the indication for TTVI in such patients should be evaluated particularly carefully, as the expected therapeutic benefit may be more limited in this subgroup.

Moreover, structured risk assessment may have implications beyond individual treatment decisions. It may contribute to procedural planning by helping clinicians evaluate whether a reconstructive approach (e.g., edge-to-edge repair) or a heterotopic implantation strategy appears more appropriate in the context of anatomical feasibility, hemodynamic profiles, and overall prognosis. In borderline or high-risk patients, it may support a more nuanced interdisciplinary discussion regarding expected benefit, procedural risk, and overall treatment goals.

Importantly, TTVI technologies are sophisticated and costly, requiring dedicated heart teams, specialized imaging, and substantial operator expertise. Considering an aging population and the growing prevalence of valvular heart disease, the sustainability of offering such interventions on a broad scale should be considered. While therapeutic innovation is both welcome and necessary, its implementation should remain closely linked to careful, evidence-based patient selection. Tools such as the TRI-SCORE may provide an accessible and reproducible framework to support this process and may help improve the consistency of preprocedural risk assessment.

Strength

This prospective study systematically assessed risk prediction in a real-world cohort of patients undergoing TTVI, including high-risk individuals. All five risk scores were calculated before intervention according to standardized definitions, enabling an objective head-to-head comparison. The clearly defined 12-month endpoints of mortality and heart failure rehospitalization provide clinically meaningful outcome data. Together, these factors support the practical relevance of the findings.

Limitations

This study is limited by its single-center design, relatively small sample size and limited number of events may have affected the stability of ROC-based estimates and contributed to wide confidence intervals. Therefore, the present findings should be interpreted as exploratory and hypothesis-generating and require validation in larger

multicenter cohorts. Furthermore, although all scores were calculated prospectively, the performance of risk scores could vary in larger or more diverse populations. Future multicenter studies with external validation cohorts are warranted to confirm the utility of the TRI-SCORE in broader clinical settings.

All patients were treated at a single high-volume heart center, which may limit the generalizability of the findings to other institutions with different experience levels or patient populations. The cohort included only 60 patients (47 T-TEER, 13 heterotopic valve), reducing statistical power and potentially limiting the precision of AUC estimates. Also, the study population underwent two different TTVI procedures (edge-to-edge repair *vs.* heterotopic valve implantation), which may have distinct risk profiles and long-term outcomes, potentially confounding the predictive performance of the scores.

The primary endpoint focused on 12-month all-cause mortality and heart failure rehospitalization. Other clinically relevant outcomes, such as quality of life, symptomatic improvement, or long-term right heart remodelling, were not assessed. Finally, despite standardized risk assessment, other factors (e.g., frailty, functional reserve, or comorbidities not captured in the scores) could have influenced outcomes.

Importantly, TRI-SCORE-based risk stratification was based on predefined categories and not on a data-driven threshold derived from the study cohort, thereby reducing the risk of optimism bias.

Formal calibration of the evaluated risk scores was not assessed, and no formal statistical comparison between AUCs was conducted. Therefore, differences in predictive performance between the models should be interpreted with caution.

Future perspectives

Combining the TRI-SCORE with biomarkers and right heart parameters may further refine patient selection, particularly in high-risk individuals (35). This concept is supported by recent data showing that next-generation biomarkers such as GDF-15 and suPAR may provide incremental prognostic value for both short- and long-term risk stratification after TTVI (36,37). Ultimately, the development of a single, widely accepted risk score that incorporates clinically relevant variables across multiple domains, including clinical profile, right heart hemodynamics, and biomarkers, should be the long-term goal. Such a comprehensive tool may facilitate standardized risk stratification, improve comparability across studies, and support more individualized therapeutic decision-making.

Conclusions

In this prospective cohort study, the TRI-SCORE showed the highest discriminatory performance among the evaluated risk models for predicting 12-month mortality or heart failure rehospitalization following TTVI. Compared with the other assessed scores, it provided the most informative prognostic stratification in this cohort and identified patients at increased risk of adverse outcomes. These findings support the potential value of structured preprocedural risk assessment for patient selection and shared decision-making, while larger studies are needed to confirm these results.

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Footnote

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