



# Three decades evolution of the lifetime management approach to tricuspid valve disease: a multidisciplinary European perspective from a high-volume heart valve center

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**Background:** The treatment of tricuspid valve (TV) disease has increased over the last decades. This study evaluates trends, patient characteristics, and outcomes of surgical and transcatheter TV interventions over 30 years.

**Methods:** All consecutive adult patients undergoing TV surgery or transcatheter intervention at the Heart Center Leipzig were included in this unadjusted descriptive analysis. Patients with TV endocarditis were excluded. Surgical data covered 1996–2024, transcatheter edge-to-edge repair (T-TEER) 2016–2024, and transcatheter TV replacement (TTVR) 2021–2025. All information was obtained from the institutional database.

**Results:** A total of 982 patients were analyzed: 450 (46%) surgical, 498 (51%) T-TEER, and 34 (3%) TTVR patients. Surgical patients were younger (67 vs. 79 vs. 81 years, respectively,  $P < 0.001$ ) and had fewer comorbidities than those treated interventionaly. Higher-grade TR was more common in T-TEER and TTVR cohorts. Device leads crossing the TV were present in 109 (24%) surgical, 147 (30%) T-TEER, and seven (21%) TTVR patients ( $P = 0.13$ ). Reoperations accounted for 165 (37%) surgical cases, while prior cardiac operations were documented in 148 (30%) T-TEER and 7 (21%) TTVR patients. Surgery after T-TEER was infrequent ( $n = 4$ , 1%). One-year survival was 88% after surgery, 83% after T-TEER, and 94% after TTVR (log-rank  $P = 0.036$ ). Among surgical patients, 335 (74%) did not require any re-hospitalizations during the first year postoperatively. Surgical reoperations showed survival comparable to primary procedures (actuarial survival at 9 years, 55% vs. 59%, respectively; log-rank  $P = 0.07$ ). Surgical TV replacement was associated with worse survival than surgical TV repair (at 9 years, 55% vs. 65%, respectively; log-rank  $P = 0.03$ ).

**Conclusions:** Surgical TV repair yields better outcomes than replacement. Long-term survival after reoperation parallels that of primary TV surgery. Surgical and transcatheter therapies address distinct patient populations. Multidisciplinary heart team evaluation remains essential for optimal management of TV disease.

**Keywords:** Tricuspid valve (TV); tricuspid regurgitation; transcatheter edge-to-edge repair (T-TEER); transcatheter tricuspid valve replacement (TTVR); cardiac surgery



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## Introduction

Tricuspid valve (TV) disease is associated with substantial morbidity and mortality and has historically been under-treated (1). Isolated medical management of severe tricuspid regurgitation (TR) is associated with 1-year mortality rates of approximately 40% (2,3).

TV surgery, the traditional treatment option, has been associated with relatively poor outcomes, with in-hospital mortality ranging from 10% to 12% for TV replacement (TVR) (4,5). A heterogeneous patient population and late clinical presentation and diagnosis make the management of severe TR difficult and controversial (1,6-8). TR has historically been treated surgically too late in the natural evolution of the disease, leading to RV dysfunction and consequently poor outcomes. These challenges have led to the rapid growth of transcatheter TV interventions, which have expanded the treatment options for patients with TV disease. Leaflet approximation [transcatheter edge-to-edge repair (T-TEER)] and orthotopic valve replacement [transcatheter tricuspid valve replacement (TTVR)] are now considered in all patients for whom the heart team identifies a transcatheter approach as the most appropriate treatment.

The heart team concept, crucial in the treatment of TV disease, has been implemented in the Heart Center Leipzig since its foundation in the 1990s and has evolved since. This tight collaboration between diverse fields of specialty and excellent cross-disciplinary training is now guideline endorsed (9). The recent European Society of Cardiology/European Association for Cardio-Thoracic Surgery (ESC/EACTS) guidelines recommend surgical correction of severe TR during left-sided heart surgery and consider transcatheter therapy in symptomatic high-risk patients (9). Contemporary risk scores like the Tricuspid Regurgitation Impact Surgical Score (TRI-SCORE) have increased their predictive accuracy and have improved patient selection and decision-making (9).

The goal of the current descriptive analysis was to review the surgical and interventional experience in managing TV disease at the Heart Center Leipzig at Leipzig University in the context of evolving transcatheter procedures. We report the acute surgical outcomes and one-year survival of patients receiving their treatment in a large tertiary European heart valve center.

## Methods

Adult patients who underwent TV surgery or transcatheter

intervention at the Heart Center Leipzig, were eligible if TV disease was the primary indication (Figure S1). Patients with TV infective endocarditis were excluded from the analysis. Data for surgical patients were available from June 1996 to December 2024, for T-TEER from July 2016 to December 2024, and for TTVR from September 2021 to August 2025. All data were retrieved from our prospectively maintained institutional registries, which were accessed on Oct. 6, 2025. The Leipzig University Ethical Committee (136/22-ek on March 3, 2023) approved analysis.

## Interventions

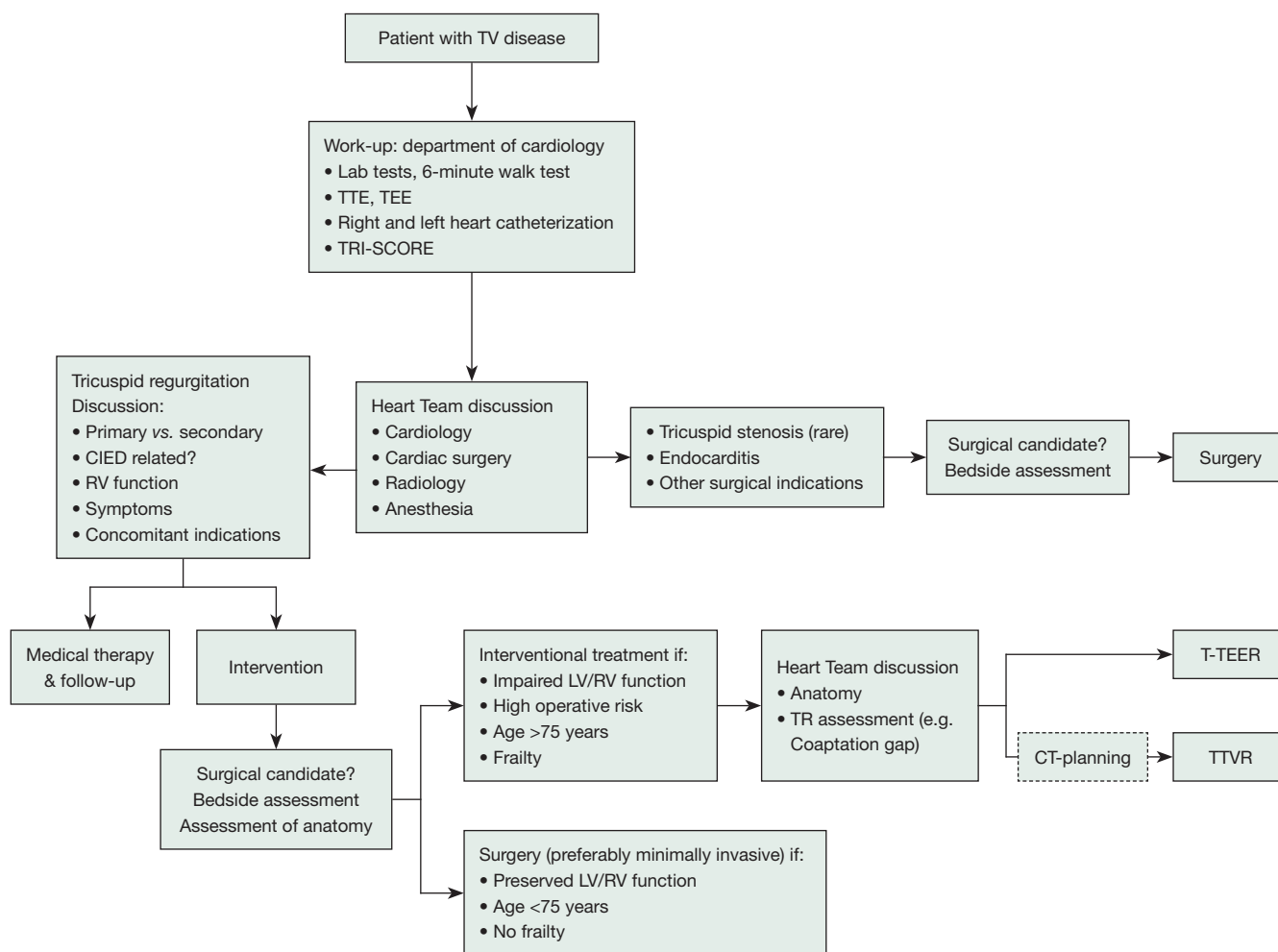
A detailed description of surgical and transcatheter techniques can be found in Appendix 1. All patients were discussed in a heart team meeting, consisting of a cardiologist, cardiac surgeon, anesthesiologist and radiologist. Our local decision-making flowchart is presented in Figure 1.

## Endpoints

This is a descriptive analysis summarizing our experience managing TV disease. We analyzed overall survival rates, with one-year overall survival as the primary outcome measure (all-cause mortality rates were analyzed, procedure date was the start time). Vital status was obtained from a national registry for surgical patients and through structured telephone follow-up for patients undergoing transcatheter treatment. Secondary outcomes were TR grades on discharge and during the follow-up (last available echocardiogram).

## Statistical analysis

Continuous variables are reported as median (interquartile range) and were tested for normality of distribution with the Shapiro-Wilk test. Intergroup differences were analyzed using the Student's *t*-test or Mann-Whitney test for two group comparisons, as appropriate. For comparisons among three groups, since normal distribution was absent, Kruskal-Wallis analysis of variance (ANOVA) was employed. Dunn's test was used for post-hoc pairwise comparisons following significant Kruskal-Wallis analyses. Categorical variables are reported as number and percentage (%) and were analyzed using Chi-squared or Fisher's exact test, as appropriate. Overall survival was compared between groups



**Figure 1** Management of tricuspid valve disease at Heart Center Leipzig. CIED, cardiac implantable electronic device; CT, computed tomography; LV, left ventricle; RV, right ventricle; TEE, transesophageal echocardiography; TTE, transthoracic echocardiography; T-TEER, transcatheter edge-to-edge repair; TRI-SCORE, Tricuspid Regurgitation Impact Surgical Score; TTVR, transcatheter tricuspid valve replacement.

using the log-rank test, and Kaplan-Meier estimates were used to estimate survival. Statistical analysis was performed using Statistica 13.3 (TIBCO, Palo Alto, CA, USA). A two-sided  $P$  value  $<0.05$  was considered statistically significant.  $P$  values for baseline comparisons are exploratory and were not adjusted for multiple testing.

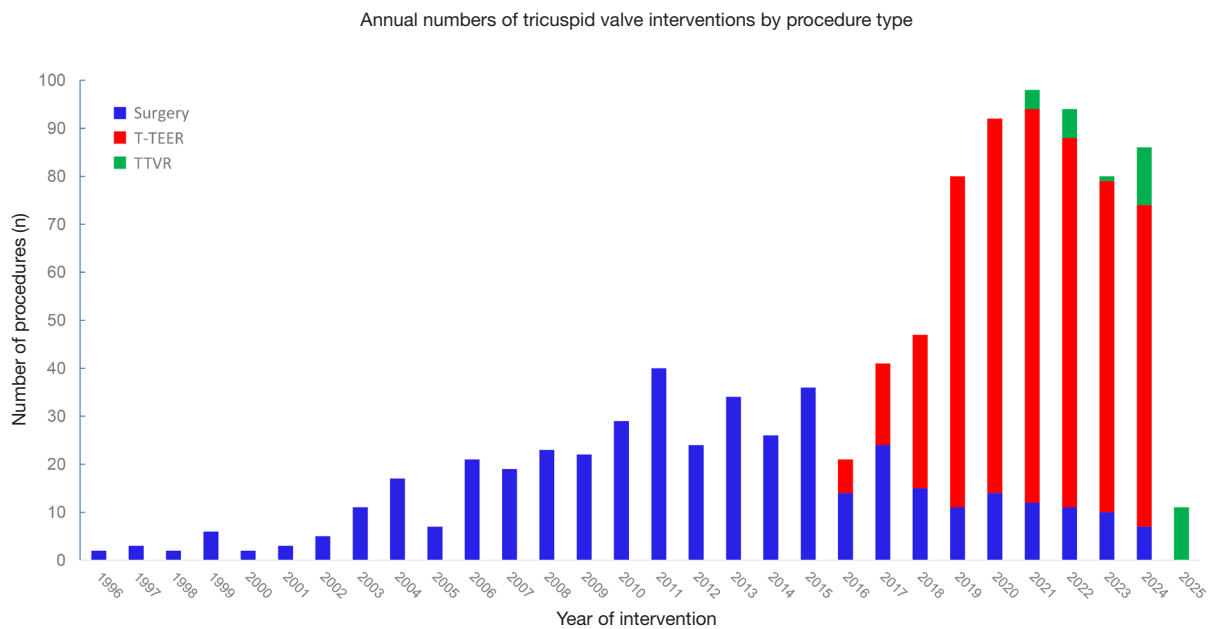
## Results

### Baseline characteristics

A total of 982 patients were studied, including 450 (46%) underwent surgical intervention, 498 (51%) underwent

T-TEER, and 34 (3%) had TTVR (Figure 2). Patient characteristics are presented in Table 1. Surgical patients were younger and comorbidities were less prevalent in this subset than in the other two groups. Surgical risk was higher in the T-TEER cohort compared with both surgical and TTVR patients (both  $P < 0.001$ ), while no difference was observed between surgical and TTVR groups. Patients treated interventional had worse symptoms of heart failure (HF; Table 1).

Baseline echocardiographic characteristics are summarized in Table 1. While left ventricular ejection fraction (LVEF) was preserved in all groups, subjects undergoing T-TEER and TTVR had higher-grade TR



**Figure 2** Annual numbers of tricuspid valve interventions recorded in registries of Heart Center Leipzig. Data for 2025 were available for TTVR only. Bars are stacked, total bar height represents total annual volume. T-TEER, transcatheter edge-to-edge repair; TTVR, transcatheter tricuspid valve replacement.

Table 1 Baseline characteristics				
Variable	Unmatched patients			P value
	Tricuspid surgery (n=450)	T-TEER (n=498)	TTVR (n=34)	
Age (years)	67 (56–74)	79 (75–82)	81 (73–83)	<0.001
Male sex	208 [46]	238 [48]	27 [79]	<0.001
BMI (kg/m <sup>2</sup> )	26.0 (23.4–29.7)	26.1 (23.4–30.1)	25.1 (22.6–29.4)	0.68
BSA (m <sup>2</sup> )	1.88 (1.72–2.05)	1.89 (1.71–2.04)	1.80 (1.64–1.94)	0.04
Diabetes mellitus	99 [22]	165 [33]	6 [17]	<0.001
History of atrial fibrillation	336 [75]	452 [91]	27 [80]	<0.001
Coronary artery disease	83 [18]	196 [40]	10 [30]	<0.001
Implantable device lead in RV	109 [24]	147 [30]	7 [21]	0.13
Previous cardiac surgery	165 [37]	148 [30]	7 [21]	0.02
Previous tricuspid surgery	45 [10]	3 [0.6]	1 [3]	<0.001
Previous heart transplantation	2 [0.4]	0 [0]	0 [0]	0.21
Previous T-TEER	4 [1]	0 [0]	0 [0]	0.04
Previous M-TEER	0 [0]	6 [1]	2 [6]	0.002
Arterial hypertension	320 [71]	435 [87]	31 [91]	<0.001
Hypercholesterolemia	198 [44]	326 [65]	25 [74]	<0.001

Table 1 (continued)

Table 1 (continued)

Variable	Unmatched patients			P value
	Tricuspid surgery (n=450)	T-TEER (n=498)	TTVR (n=34)	
History of MI	29 [6]	55 [11]	3 [9]	0.04
History of stroke or TIA	30 [7]	16 [3]	4 [12]	0.01
Chronic lung disease	57 [13]	105 [21]	5 [15]	0.002
Dialysis	4 [1]	26 [5]	1 [3]	<0.001
Peripheral arterial disease	32 [7]	14 [3]	3 [9]	0.005
EuroSCORE II (%)	3.8 (1.9–7.3) (n=450)	4.7 (2.7–8.8) (n=338)	4.3 (2.6–7.0) (n=19)	<0.001
NYHA class				<0.001
I	17 [4]	5 [1]	0 [0]	
II	87 [19]	89 [18]	1 [3]	
III	258 [57]	340 [68]	31 [91]	
IV	69 [15]	53 [11]	2 [6]	
Not recorded	19 [4]	6 [1]	0 [0]	
Peripheral edema	68 [15]	309 [53]	18 [53]	<0.001
Ascites	97 [22]	62 [12]	2 [6]	<0.001
Pleural effusion	27 [6]	86 [17]	3 [9]	<0.001
Any symptom of HF	155 [34]	344 [69]	19 [56]	<0.001
Baseline echocardiography				
Left ventricular ejection fraction (%)	56 (49–63) (n=438)	57 (49–62) (n=488)	60 (56–65) (n=34)	0.03
Degree of tricuspid regurgitation				<0.001
Mild	27 [6]	0 [0]	0 [0]	
Moderate	38 [8]	13 [3]	0 [0]	
Severe	310 [69]	298 [60]	10 [29]	
Massive	70 [16]	124 [25]	5 [15]	
Torrential	5 [1]	63 [13]	19 [56]	
TR EROA (cm <sup>2</sup> )	0.5 (0.4–0.8) (n=77)	0.5 (0.4–0.7) (n=454)	1.0 (0.5–1.2) (n=32)	0.02
Tricuspid annulus diameter (mm)	45 (40–48) (n=283)	45 (41–50) (n=381)	46 (43–50) (n=18)	0.06
TAPSE (mm)	18 (15–21) (n=325)	17 (14–20) (n=481)	17 (15–19) (n=33)	0.02
Echo sPAP (mmHg)	30 (22–42) (n=389)	41 (33–52) (n=466)	24 (20–31) (n=33)	<0.001
Severity of mitral regurgitation				<0.001
None	166 [37]	25 [5]	4 [12]	
Trivial	248 [55]	342 [69]	26 [77]	
Mild	28 [6]	123 [25]	4 [12]	
Moderate	8 [2]	7 [1]	0 [0]	
Severe	0 [0]	1 [0.2]	0 [0]	
LVEDD (mm)	45 (40–50) (n=398)	49 (45–53) (n=464)	45 (41–50) (n=33)	<0.001

Table 1 (continued)

**Table 1** (continued)

Variable	Unmatched patients			P value
	Tricuspid surgery (n=450)	T-TEER (n=498)	TTVR (n=34)	
<b>Right heart catheterization</b>				
RHC sPAP (mmHg)	38 (30–47) (n=247)	44 (35–54) (n=414)	38 (31–47) (n=32)	<0.001
mean RHC PAP (mmHg)	26 (19–31) (n=250)	28 (23–34) (n=421)	26 (21–28) (n=32)	<0.001
<b>Baseline laboratory parameters</b>				
Creatinine clearance (mL/min)	62 (47–81) (n=413)	42 (30–55) (n=260)	47 (31–57) (n=34)	<0.001
Hemoglobin (g/dL)	13.0 (11.2–14.4)	11.9 (10.6–13.4)	11.6 (10.6–13.9)	<0.001
Total bilirubin (mg/dL)	0.75 (0.49–1.19) (n=369)	0.72 (0.49–1.01) (n=389)	0.63 (0.48–0.87) (n=34)	0.21
AST (IU/L)	31 (25–41) (n=405)	26 (22–33) (n=484)	28 (23–38) (n=34)	<0.001
Gamma-GT (IU/L)	100 (47–180) (n=379)	95 (52–183) (n=366)	154 (80–198) (n=15)	0.38
Platelets (10 <sup>3</sup> /dL)	206 (157–251) (n=330)	180 (146–225) (n=160)	193 (136–198) (n=34)	0.006
INR	1.18 (1.06–1.41)	1.23 (1.14–1.48)	1.29 (1.12–1.62)	0.008
<b>Medication on admission</b>				
Mineralocorticoid receptor antagonist	71 [16]	181 [36]	20 [59]	0.02
Loop diuretic	149 [33]	473 [95]	31 [91]	<0.001
Beta blocker	129 [29]	428 [86]	29 [85]	<0.001
RASI	117 [23]	114 [23]	21 [61]	0.02

Data are presented as median (interquartile range) or number [percentage]. AF, atrial fibrillation; AST, aspartate aminotransferase; BMI, body mass index; BSA, body surface area; EROA, effective regurgitant orifice area; Gamma-GT, gamma-glutamyl transferase; HF, heart failure; INR, international normalized ratio; LVEDD, left ventricular end-diastolic diameter; M-TEER, transcatheter mitral edge-to-edge repair; MI, myocardial infarction; MRA, mineralocorticoid receptor antagonist; MR, mitral regurgitation; NYHA, New York Heart Association; PAP, pulmonary artery pressure; RASI, renin-angiotensin system inhibitor; RHC, right heart catheterization; RV, right ventricle; sPAP, systolic pulmonary artery pressure; TAPSE, tricuspid annular plane systolic excursion; TIA, transient ischemic attack; TR, tricuspid regurgitation; T-TEER, transcatheter tricuspid edge-to-edge repair; TV, tricuspid valve; TVR, tricuspid valve replacement.

than surgical patients, with 187 (38%) and 24 (71%) having massive-or-torrential TR, respectively. An implantable device lead was present in RV, transiting through TV, in 109 (24%) surgical patients, 147 (30%) T-TEER and seven TTVR patients (21%;  $P=0.13$ ). TR etiology was recorded for all surgical patients and for 477 T-TEER patients. In surgical cohort, TR was primary in 83 (18%), secondary in 340 (76%) and mixed in 27 (6%) cases, while in T-TEER group, TR was primary in 6 (1%), secondary in 456 (96%) and mixed in 15 (3%) patients ( $P<0.0001$ ). TR effective regurgitant orifice area (EROA) was larger in the TTVR group compared with both T-TEER ( $P<0.001$ ) and surgical patients ( $P=0.001$ ), with no difference between surgical and T-TEER groups. RV function was similar in all patients. T-TEER patients had a higher prevalence of concomitant

MR and larger left ventricle (LV) end-diastolic diameter compared with surgical patients ( $P<0.001$ ) and TTVR patients ( $P=0.01$ ), while no differences were observed between surgical and TTVR groups (*Table 1*). On right heart catheterization, systolic pulmonary artery pressure was higher in T-TEER patients compared with surgical ( $P<0.001$ ) and TTVR patients ( $P=0.04$ ), while mean pulmonary artery pressure was higher in T-TEER than in surgical patients ( $P<0.001$ ), with no differences between surgical and TTVR groups for either parameter. Both T-TEER and TTVR groups exhibited more pronounced laboratory abnormalities compared with surgical patients, with no significant differences between the T-TEER and TTVR groups (*Table 1*). Surgical patients received the HF medication less frequently than the remaining two groups

(Table 1). Almost 40% of operations were re-do surgeries (n=165/450), while previous cardiac operations were present in 148 (30%) T-TEER and 7 (21%) TTVR patients (Table 1). Four patients in the surgical group previously received T-TEER (1%), while in the T-TEER and TTVR groups, 6 (1%) and 2 (6%) patients previously received M-TEER, respectively (Table 1). Operation was urgent in 121 (27%) of surgical patients, while only 8 (2%) T-TEER procedures were urgent. All TTVRs were elective.

### Surgical approach

Isolated TV operation was performed in 191 (42%) of cases, and majority received a valve repair (Table 2). In cases of TV repair, annuloplasty was employed in 91% of procedures. Of patients who received a re-do surgery, 72/165 (44%) received a reoperation in minimally-invasive technique and there was no difference in incidence of reoperations among patients receiving sternotomy and minimally-invasive operations [93/232 (40%) vs. 72/218 (33%),  $P=0.12$ ]. Concomitant procedures were done in 259 (58%) cases, and most commonly included ablation, patent foramen ovale or atrial septal defect closure, and epicardial pacemaker implantation (Table 2). In 61 cases (14%), TR operation was a part of congenital anomaly repair.

There were 8 (2%) patients, who received surgical TVR due to tricuspid stenosis (TS), with mean transvalvular gradient of 11 (interquartile range, 9–13) mmHg and concomitant TR. Postoperative gradient was 5 (4–6) mmHg in this subset of patients.

Since 2005, selected low-risk patients were managed without intensive care unit (ICU) admission; among patients admitted to ICU, median ICU stay was 7 (3–14) days. Four (1.8%) patients operated through mini-thoracotomy had sternotomies; two were due to bleeding, two were due to adhesions. The most prevalent postoperative complications were atrial fibrillation (n=209, 46%) and acute kidney injury (n=112, 25%), and the in-hospital mortality was 8% (n=35). Complications are summarized in Table 2.

### T-TEER

Procedures were performed successfully in 496/498 cases (99.6%). Implanted devices included TriClip (Abbott Structural Heart, Santa Clara, CA, n=319, 64%), Pascal (Edwards Lifesciences, Irvine, CA, USA, n=172, 35%) and others (n=5, 1%). Most patients received one (n=103, 21%) or two devices (n=297, 60%), while three or more were

implanted in 92 cases (19%). Median procedural time was 67 (46–96) min. Three (0.6%) patients received T-TEER after previous surgical TV repair.

### TTVR

Procedural success was achieved in all TTVR cases. In 28 patients (82%) EVOQUE valve (Edwards Lifesciences, Irvine, CA, USA) was implanted, and LuxValve (Jenscare Scientific, Ningbo Hangzhou Bay New Area, China) in the remaining six. There was 1 (3%) conversion to sternotomy due to bleeding. Median procedural time was 90 (74–118) min. One (3%) patient received TTVR after previous surgical TV repair.

### Echocardiography at discharge.

TR reduction was most evident among surgical patients and those who received a percutaneous valve replacement. At discharge, 90% (388/430) of surgical patients, 97% (32/33) of TTVR patients and 43% (211/488) T-TEER patients had no or mild TR (Table 3). Surgical patients who received TVR had expectedly less TR than those who received a TV repair [3.5% of TVR (n=6) vs. 14% (n=36) of TV repair had moderate or more TR postoperatively,  $P<0.001$ ].

Median follow-up time to last echocardiographic follow-up was 46.9 (10.3–112.7) months in surgical patients, 12.0 (3.0–12.3) months in T-TEER group and 12.4 (6.2–35.1) months in TTVR patients ( $P<0.001$ ). Seventy-three percent of surgical patients (91/125), all TTVR patients (n=13) and 33% of T-TEER patients (137/421) had none-to-mild TR on follow-up examination (Table 3).

### Overall survival

Survival data were available for 417 surgical patients (93%, median 5.8 years, range, 0.003–28.0 years), 218 T-TEER patients (44%, median 1 year, range, 0.0–3.5 years) and 33 TTVR patients (97%, median 0.4 years, range, 0.0–3.2 years). In the T-TEER cohort, patients without available survival data more frequently exhibited signs of right-sided HF and had more severe TR at baseline, whereas most other baseline characteristics were comparable between groups (Table S1). At one year, the estimated survival was 88% in surgical patients, 83% for T-TEER and 94% in TTVR recipients (log-rank  $P=0.036$ , Figure 3A).

Among the surgical patients, 335 (74%) did not require any re-hospitalizations during the first year postoperatively.

**Table 2** Operative and postoperative characteristics

Variable	n=450
<b>Operative characteristics</b>	
Isolated TV surgery	191 [42]
Urgent procedure	121 [27]
Tricuspid valve repair	272 [60]
Annuloplasty	248 [91]
Chordal repair	7 [3]
Other techniques used	54 [20]
Tricuspid valve replacement	178 [40]
Bioprosthesis	166 [37]
Mechanical prosthesis	12 [3]
Aortic cross-clamp time (minutes) <sup>†</sup>	54 (40–77)
CPB time (minutes)	95 (71–127)
Any concomitant procedure	259 [58]
Concomitant Cryo-MAZE	53 [12]
LAA closure	25 [6]
Concomitant ASD/PFO closure	71 [16]
CABG	2 [0.4]
Mitral valve repair	19 [4]
Cardiac tumor removal	30 [7]
Pericardiectomy	35 [8]
Congenital anomaly repair	61 [14]
Lead extraction	35 [8]
Epicardial pacemaker implantation	60 [13]
Other	23 [5]
Minimally-invasive operation	218 [48]
<b>In-hospital outcomes and complications</b>	
Conversion to sternotomy	4 [1.8] (when operated on minimally-invasively, n=218)
Stroke	10 [2]
Postoperative pacemaker implantation	47 [10]
Postoperative AF	209 [46]
Acute right heart failure	32 [7]
Pericardial tamponade	46 [10]
Washout for bleeding	61 [14]
Postoperative MI	2 [0.4]
Wound infection	10 [2]
Acute kidney injury	112 [25]
Postoperative ECMO	12 [3]
In-hospital mortality	35 [8]

Data are presented as median (interquartile range) or number [percentage]. <sup>†</sup>, when cardioplegia was administered (n=244). AF, atrial fibrillation; ASD, atrial septal defect; CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; ECMO, extracorporeal membrane oxygenation; LAA, left atrial appendage; MI, myocardial infarction; PFO, patent foramen ovale; TV, tricuspid valve.

**Table 3** Echocardiography after the intervention

Variable	Tricuspid surgery	T-TEER	TTVR
Discharge echocardiography	430	488	33
Postprocedural TR severity			
None	248 [58]	9 [2]	16 [48]
Mild	140 [33]	202 [41]	16 [48]
Moderate	33 [8]	190 [39]	1 [3]
Severe	9 [2]	74 [15]	0
Massive	0	9 [2]	0
Torrential	0	4 [1]	0
Follow-up echocardiography	125	421	13
Follow-up TR severity			
None	45 [36]	1 [0.2]	6 [46]
Mild	46 [37]	136 [32]	7 [54]
Moderate	21 [17]	171 [41]	0 [0]
Severe	10 [8]	93 [22]	0 [0]
Massive	2 [2]	12 [3]	0 [0]
Torrential	1 [1]	8 [2]	0 [0]

Data are presented as n or n [%]. TR, tricuspid regurgitation; T-TEER, transcatheter edge-to-edge repair; TTVR, transcatheter tricuspid valve replacement.

Patients who received surgical TVR had worse actuarial survival than those who received a TV repair (at 9 years 55% vs. 65%, respectively; log-rank  $P=0.03$ , *Figure 3B*). There was no difference in overall survival for surgical patients, who received a primary vs. reoperation (actuarial survival at 9 years, 55% vs. 59%, respectively; log-rank  $P=0.07$ , *Figure 3C*). Survival did not differ between isolated and combined operations (5-year: 78% vs. 71%;  $P=0.625$ ) or between sternotomy and minimally-invasive access (5-year: 71% vs. 77%;  $P=0.742$ ), whereas urgent procedures resulted in worse survival compared with elective cases (5-year: 67% vs. 77%;  $P=0.004$ ).

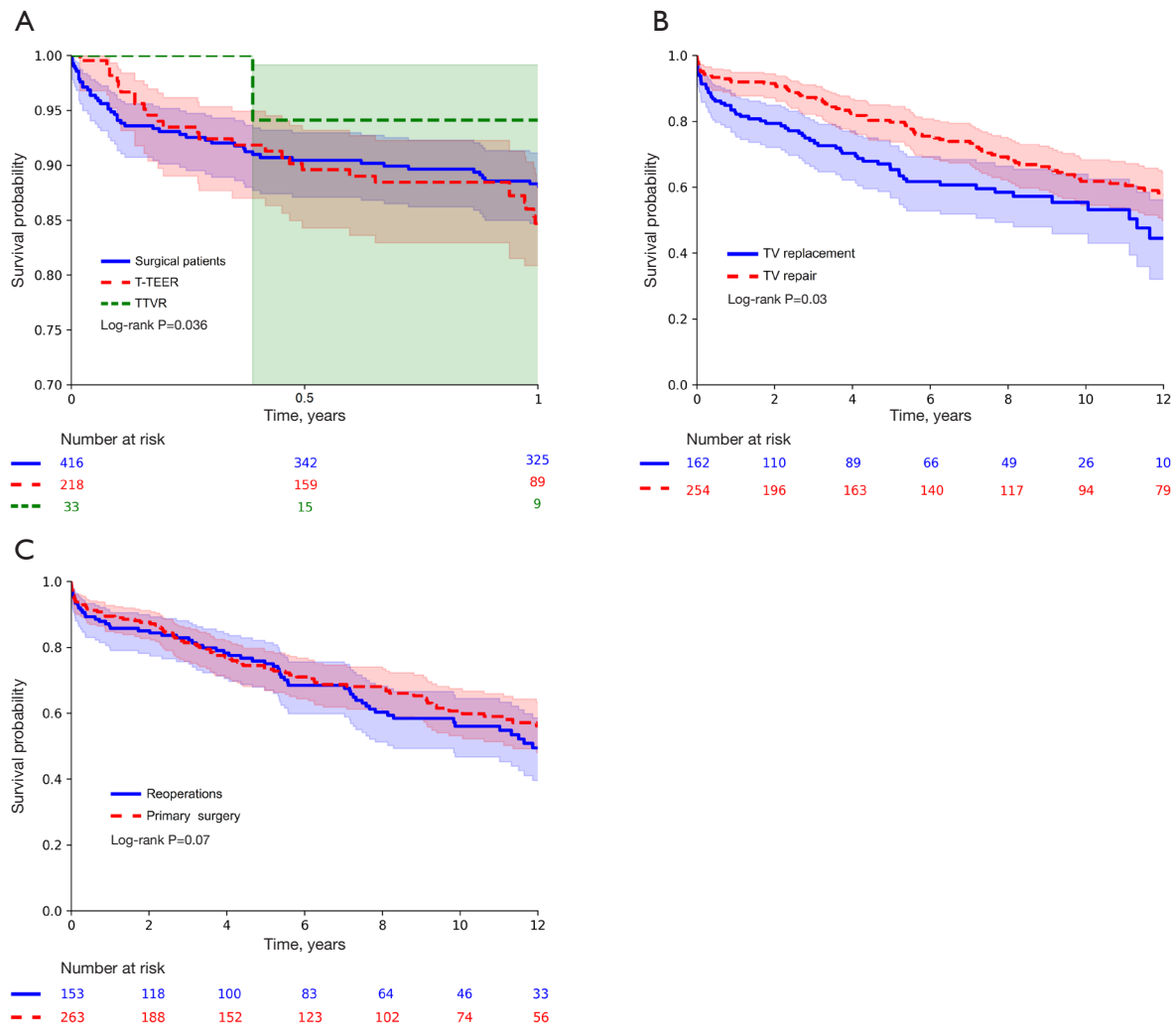
### Two-period comparison

Data after the beginning of year 2016 (arbitrary onset of T-TEER) was compared against data for the preceding period. European System for Cardiac Operative Risk Evaluation II (EuroSCORE II) in surgical patients operated after the beginning of 2016 was the same as in those operated before 2016 [3.8% (1.9–6.3%) vs. 3.9% (1.9–

7.5%),  $P=0.91$ ], and there were no differences in survival in this subset [actuarial survival at 6 years: 71% vs. 70%, respectively, log-rank,  $P=0.99$ , crude survival during the whole follow-up: 73/94 (78%) vs. 183/325 (56%)]. In the whole cohort ( $n=982$ ), however, EuroSCORE II after 2016 was higher than before [6.4% (2.5–8.2%) vs. 3.8% (1.9–7.5%),  $P=0.008$ ], and overall survival was worse [actuarial survival at 6 years: 70% vs. 63%, log-rank,  $P=0.02$ , crude survival during the whole follow-up: 183/325 (41%) vs. 268/345 (78%)]. In patients treated from 2016 onwards alone, 1-year truncated Kaplan-Meier survival was 86% after surgery, 75% after T-TEER, and 94% after TTVR (log-rank  $P=0.117$ ).

### Risk stratification

Among the surgical subset, survival was significantly worse in patients whose EuroSCORE II was higher than median (3.8%), compared to those whose EuroSCORE II was equal or lower than median (actuarial survival at nine years, 51% vs. 71%, respectively log-rank,  $P<0.001$ ). EuroSCORE



**Figure 3** Overall survival after tricuspid valve interventions. Comparison of surgery, T-TEER and TTVR in 1-year observation (A) and comparison of surgical TV repair vs. replacement (B) and primary operations vs. reoperations (C) in long-term observations. T-TEER, transcatheter edge-to-edge repair; TTVR, transcatheter tricuspid valve replacement; TV, tricuspid valve.

II category above or below median (4.7%) did not affect survival in T-TEER recipients (actuarial survival at 1.2 years: 77% vs. 76%, respectively, log-rank, P=0.37).

**Discussion**

This analysis describes the early and long-term outcomes of surgical and interventional management of TV disease and indicates that transcatheter therapies provide a treatment option for patients at increased surgical risk. In spite of increasing surgical risk, survival after TV operations did not show a temporal decline in the surgical cohort. The number of transcatheter interventions vastly surpassed that

of classic operations. At 1 year, all procedures demonstrated good overall survival rates, although this report was not designed as a comparative analysis. In our studied cohort, TR reduction at discharge was numerically lower after T-TEER compared with surgical treatment and TTVR, reflecting differences in patient selection, procedural mechanisms, and the technique itself. Approximately one-third of patients uniformly suffered from implantable device lead-related TV problems in all treatment groups. TV surgery after T-TEER and T-TEER after TV surgery are uncommon. Differences in characteristics of patients managed surgically and interventionally suggest that these treatment modalities serve distinct patient populations. Our

experience underscores the role of the heart team approach.

Conceptually, management of TV disease requires understanding of the interplay between valve pathology, RV function, and intervention modality (10). Surgical TV repair and TVR aim to restore valve competence but differ in invasiveness, risk profiles, and need for concomitant procedures. T-TEER mimics surgical leaflet approximation to reduce regurgitation without the option to intervene on the annulus or address other cardiac problems, while TTVR offers a definitive but isolated valve replacement through catheter-based techniques (11). These interventions must be tailored to patient anatomy, comorbidities, and disease severity to optimize outcomes.

The in-hospital mortality rates reported here for surgical patients (8%) are similar to those from other studies of surgical patients, but higher than for transcatheter TV interventions (1%) (12-14). In our unadjusted cohort, one-year mortality appeared numerically higher after T-TEER than after surgery; however, the groups differed substantially in baseline characteristics. A meta-analysis of 25 studies with 5,702 patients reported 15% 1-year mortality in surgical cohort and 18% in T-TEER group (14). Head-to-head comparisons are difficult due to non-overlapping patient populations. Notably, the differences in HF medication between the groups reflect the current indications for T-TEER in individuals who remain symptomatic despite optimal medical treatment (10). Data on outcomes in TTVR group are still very sparse and further studies are needed to evaluate the outcomes, as well as the cost-effectiveness. Overall, outcomes presented in the current analysis (with worse survival rates after the introduction of transcatheter therapies) reflect the fact that currently managed patients present an increasingly complex high-risk group that would otherwise be untreated.

In terms of TR reduction, the TRILUMINATE study found TR reduction to moderate or less in 79% of T-TEER patients at 3 years (15). These findings are in line with our 1-year transthoracic echocardiography (TTE) follow-up data and additionally confirm the typical age and risk profile of T-TEER patients (15). Excellent TR reduction is achieved with TTVR, but our limited follow-up data do not allow direct comparisons with surgical outcomes. Forty percent of patients required a TVR, which impacts the outcomes: 1-year mortality rates are doubled after TVR, when compared to valve repair. In 2018, Alkhouli and colleagues compared the outcomes of surgical TVR and TV repair, reporting similar mortality discrepancy already during the hospital stay: 12% for TVR and 7% for valve

repair (12). Better patient selection and surgical technique are needed to improve these outcomes.

One of the frequently discussed problems in TV disease management is the absence of credible validated risk scores to guide management. In our study, only EuroSCORE II data were available. In surgical patients, higher EuroSCORE II values were associated with worse survival, but the same was not true for T-TEER recipients. Recently, TRI-SCORE has been proposed to improve risk stratification in tricuspid surgery (16). A report by Dreyfus *et al.* showed that a successful TV intervention, irrespective of the modality, is associated with better survival rates than conservative management in patients with low TRI-SCORE (17). Arguably, improved surgical and interventional outcomes can be achieved by intervening at earlier stage of the disease.

### Limitations

This study has several limitations. First, it is a single-center retrospective observational analysis and was designed as a descriptive overview of institutional practice rather than a comparative effectiveness study. Consequently, no matching or multivariable risk adjustment between treatment groups was performed. Given the substantial differences in baseline characteristics and clinical profiles across cohorts, inter-group outcome comparisons should be interpreted as descriptive and hypothesis-generating.

Second, follow-up completeness and duration differed substantially between groups (93% at a median of 5.8 years for surgery *vs.* 44% at 1-year for T-TEER and 97% at 0.4 years for TTVR). These differences may introduce informative censoring and limit the validity of inter-group survival comparisons. In the T-TEER cohort, patients without available survival data had more advanced disease at baseline, suggesting potential selection bias. In addition, vital status was obtained from different sources across treatment groups, which may have contributed to ascertainment bias.

Third, echocardiographic follow-up timing differed between the groups, which precludes a direct comparison of follow-up TR severity. Retrospective harmonization of TR grading to the five-grade scale may have resulted in misclassification and potential underestimation of baseline severity in earlier surgical patients. Finally, registry data were incomplete for some variables. Causes of death were not recorded, and only EuroSCORE II was used for risk stratification. Data on in-hospital complications for transcatheter procedures were not available for analysis. In addition, the small number of TTVR patients and the short

duration of follow-up in this cohort limit the precision of outcome estimates.

## Conclusions

Observed early TR reduction was within a similar range for TTVR and surgery, although comparisons are limited by cohort differences. Long-term survival after reoperations is similar to that of primary TV operations. Outcomes of surgical TV repair in our cohort are better than those of surgical TVR. Surgical and transcatheter approaches address different patient populations depending on the clinical profile and anatomical suitability. Treatment selection should be individualized within a multidisciplinary heart team, and this approach is crucial for successful management of TV disease.

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## Footnote

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