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ORIGINAL RESEARCH

Late Outcomes of Valve Repair Versus Replacement in Isolated and Concomitant Tricuspid Valve Surgery: A Nationwide Cohort Study

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BACKGROUND: Surgery for tricuspid valve (TV) diseases is associated with poor prognosis, but few studies have described the long-term outcomes by comparing TV repair and replacement in isolated and concomitant TV surgeries separately.

METHODS AND RESULTS: Between 2000 and 2013, adult patients who underwent TV repair or replacement surgeries were identified from the Taiwan National Health Insurance Research Database. Outcomes of interest included all-cause mortality, composite outcome, and readmission attributable to any cause. Inverse probability of treatment weighting was used to reduce confounding effects. A total of 2644 patients with a mean follow-up of 4.9 years were included. Of them, 12.6% and 87.4% underwent isolated and concomitant TV surgery, respectively. The in-hospital mortality rates for isolated and concomitant TV surgery were 8.7% and 8.6%, respectively, whereas all-cause mortality rates were 41.7% and 36.8%, respectively. Compared with TV replacement, TV repair demonstrated significantly lower risks of all-cause mortality (concomitant: hazard ratio [HR], 0.76; 95% CI, 0.59–0.99), composite outcome (isolated: subdistribution HR, 0.55; 95% CI, 0.35–0.89; concomitant: subdistribution HR, 0.63; 95% CI, 0.46–0.86), and readmission (isolated: subdistribution HR, 0.64; 95% CI, 0.46–0.91; concomitant: subdistribution HR, 0.72; 95% CI, 0.60–0.86), except insignificant difference in all-cause mortality in isolated surgery.

CONCLUSIONS: Compared with replacement, TV repair is associated with better short- and long-term outcomes in both isolated and concomitant TV surgery. However, further prospective clinical trials are warranted.

Key Words: tricuspid valve disease ■ tricuspid valve repair ■ tricuspid valve replacement ■ tricuspid valve surgery

Tricuspid valve (TV) disease is a forgotten entity and is often undertreated because TV surgery, especially isolated TV surgery, is notorious for its high mortality (8%–14%) and morbidity.[1–9] Patients with mild or moderate tricuspid regurgitation (TR) are often treated conservatively with medical therapies. Surgery is considered a more definitive treatment in patients with severe TR. The 2017 European Society of Cardiology/European Association for Cardio-Thoracic Surgery and 2014 American Heart Association/American College of Cardiology guidelines recommend isolated TV surgery in case of severe primary symptomatic isolated TR without right ventricular dysfunction or mild to moderate symptoms with progressive right ventricular dysfunction. For concomitant TV surgery, the recent guidelines recommend surgery in individuals with mild symptoms with tricuspid annulus dilation or recent signs of right

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CLINICAL PERSPECTIVE

What Is New?

- Tricuspid valve surgery shares less than 9% of overall cardiac valve surgery volume in Taiwan.
- Tricuspid repair demonstrated significantly lower risks of all-cause mortality, composite outcome, and readmission in both isolated and concomitant surgery compared with replacement.

What Are the Clinical Implications?

- Tricuspid valve repair is a preferred option to replacement whenever feasible.
- Further prospective clinical trials are warranted for tricuspid repair versus replacement.

Nonstandard Abbreviations and Acronyms

ICD-9-CM	*International Classification of Diseases, Ninth Revision, Clinical Modification*
IPTW	Inverse probability of treatment weighting
NHI	National Health Insurance
NHIRD	National Health Insurance Research Database
TV	Tricuspid valve

heart failure, in addition to those with severe primary and secondary TR.[10,11]

The decision of the type of TV surgery remains controversial. TV repair is in general preferred to a replacement, although some studies have demonstrated no difference in the outcomes between repair and replacement.[12,13] TV replacement presents the risks of degeneration with bioprosthetic valves and thrombosis and long-term anticoagulant use with mechanical valves, although there may be an increased risk of reoperation in TV repair.[3,9,14,15] A recent landmark study conducted by Zack et al[5] also reported higher in-hospital mortality in TV replacement compared with TV repair in isolated tricuspid TV surgery.

Because TV surgery is much less often performed compared with mitral and aortic valve surgery, existing studies comparing the outcomes of TV repair and replacement have mostly been conducted in a single center limited by a small number of patients, heterogeneous patient profiles in terms of concomitant underlying medical and surgical conditions, and lack of late outcome results other than mortality. Larger-scale studies have been conducted in Western countries with limited data from the Asian population.[1,3,6,7] Therefore, we used a national cohort of Taiwanese patients who underwent TV surgery to compare the long-term outcomes of TV repair and replacement in both isolated and concomitant surgery to address the aforementioned knowledge gap. Considering the increasing interest in transcatheter TV intervention,[16] the outcomes in our study might help highlight key implications to develop a novel intervention for severely ill patients with TR.

METHODS

Data Source

The data that support the findings of this study are available from the corresponding author on reasonable request.

This study was designed as a retrospective cohort design using data obtained from the Taiwan National Health Insurance Research Database (NHIRD) from January 1, 2000, to December 31, 2013. The NHIRD entails data derived from Taiwan's National Health Insurance (NHI) program, a universal compulsory health insurance system offering comprehensive medical coverage to 99% of the total population of 24 million.[9,17–19] The NHI program enables the continuous tracking of all claims from each individual, given that it includes a consistent data encryption process. High-quality comprehensive medical services are offered at a low cost, and major surgical procedures are also financed by the program. Because of the aforementioned advantages, a nearly complete long-term follow-up of patients with minimal dropout is thus possible. This study was exempt from a full review by the Institutional Review Board of Chang Gung Memorial Hospital as all data in the NHIRD are deidentified and anonymized.

Study Population

Using the *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) procedure codes, adult patients (aged >18 years) who underwent TV surgery were identified (Figure 1). Patients were excluded if they had any diagnosis of congenital heart disease, infective endocarditis, cardiac transplant, redo valvular surgery, or TV repair (*ICD-9-CM* procedure code: 35.14) and replacement (*ICD-9-CM* procedure codes: 35.27, 35.28) at the time of admission, as these represent an essentially different group of patient population. Patients who first received TV surgery were further divided into an isolated and concomitant group based on whether concomitant aortic, mitral, or pulmonary valve surgery was performed simultaneously using *ICD-9-CM* procedure codes.

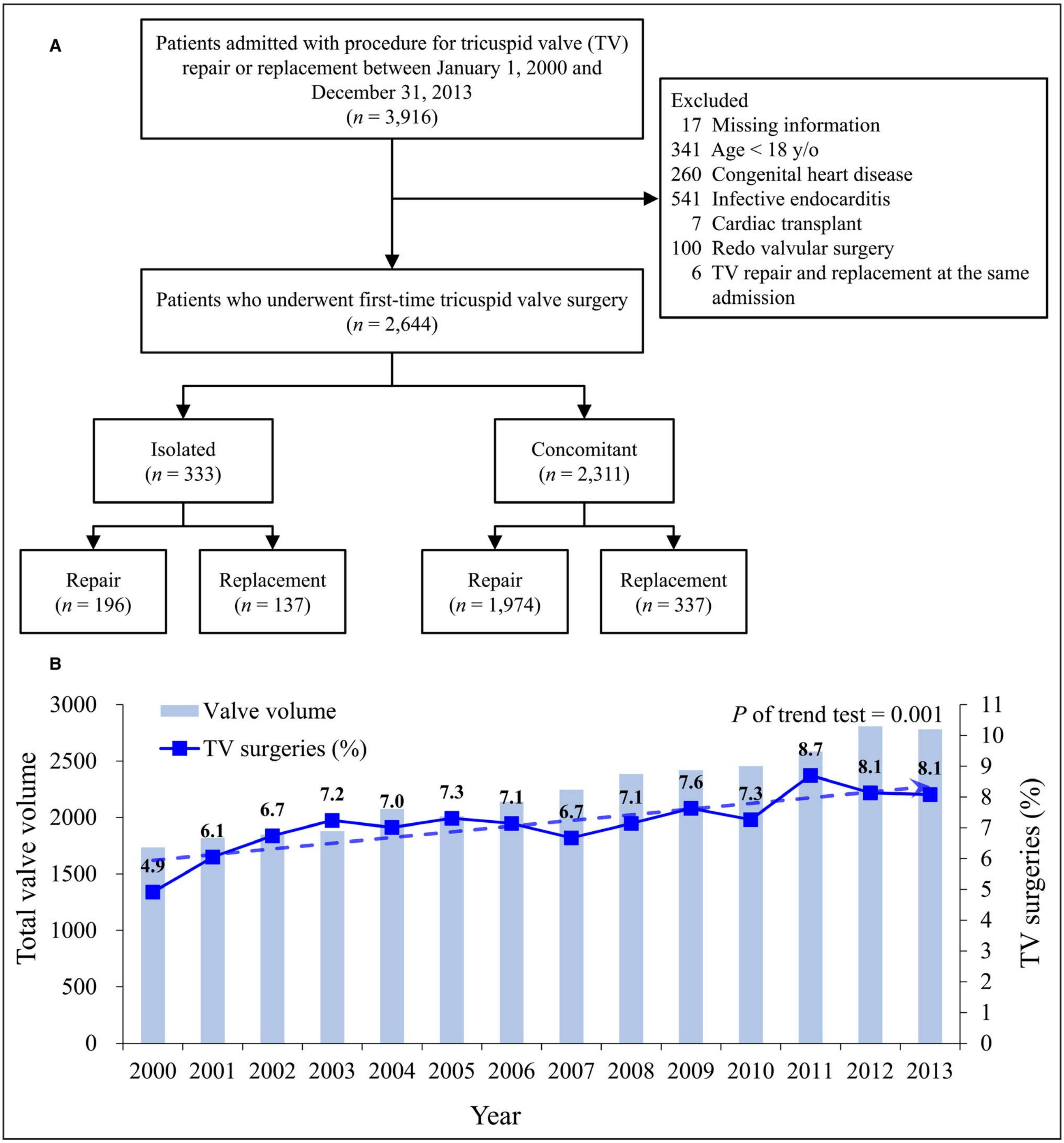

Figure 1. A, Flowchart of the study patient inclusion. B, Valve surgery volume and proportion of tricuspid surgery from 2000 to 2013 in Taiwan.
TV indicates tricuspid valve; and y/o, years old.

Covariates and Outcomes

Demographic information included age, sex, and level of hospital where the patients received surgery. The comorbidities were identified using any inpatient diagnosis before the index date, which could be traced up to 1997. Perioperative complications during the index admission were identified by either *ICD-9-CM* diagnostic codes or Taiwan NHI reimbursement codes. Details of the *ICD-9-CM* codes are listed in Table S1. The late outcomes were all-cause mortality, composite outcome (redo surgery, heart failure, pacemaker, and major bleeding), and readmission attributable to any cause. Mortality was defined by withdrawal from the NHI program.[20] Redo surgery and pacemaker installation information was extracted from Taiwan NHI reimbursement codes. The definition of major bleeding has been widely reported in previous NHIRD studies,[21] which is defined as a primary diagnosis of intracranial hemorrhage or urogenital, gastrointestinal, or other bleeding during a hospitalization or an emergency department visit. The diagnostic codes of heart failure have proved to have high accuracy, which demonstrated 99% sensitivity in agreement of diagnosis among hospital mortality cases in the NHIRD compared with the electronic medical records.[22] All patients were followed up from the index admission date until December 31, 2013, or the date of death.

Statistical Analysis

To reduce confounding when comparing outcomes between TV repair and replacement surgery, we used the inverse probability of treatment weighting based on the propensity scores. To calculate propensity scores (ie, stratification, matching, statistical control, and weighting), the inverse probability of treatment weighting was recently considered the most efficient in reducing confounding and has demonstrated higher statistical power compared with matching.[23] The propensity score was estimated using a logistic regression model in which treatment assignment was regressed on the selected covariates listed in Table 1, except for the follow-up year, which was replaced with the year of index admission. To prevent the effect of extreme value of the estimated propensity score, we used a stabilized weight to mitigate the influence of outliers.[24] The quality of weighting was verified using the absolute value of standardized difference between the groups after weighting, where a value <0.1 was considered negligible difference, and a value <0.2 was considered a small effect size of the group difference. In this study, the analysis was stratified by isolated versus concomitant surgeries; therefore, the propensity scores were generated separately for these 2 different cohorts.

The trend of performing TV surgeries among all the valve surgeries across years was tested using the Cochran-Armitage trend test. Likewise, the changes in the proportion of TV repair surgery received (of all TV surgical procedures) or in the proportion of in-hospital deaths in either groups across the study periods (2000–2004, 2005–2009, and 2010–2013) were also tested through the Cochran-Armitage trend test. The operation-related complications and outcomes during the admission in the repair and replacement groups were compared using a logistic regression model for binary outcomes or a linear regression model for continuous outcomes. For the late outcomes after discharge, the mortality rates between groups were compared using a Cox proportional hazard model. The incidences of nonfatal outcomes between groups were compared using the Fine and Gray subdistribution hazard model that considers death as a competing risk. The study group (repair versus replacement) was the only explanatory variable in the analysis of isolated TV surgery, whereas the age and coronary artery bypass grafting were additionally adjusted in the analysis of concomitant TV surgery to account for the possibility of residual confounding.

The assumption of proportional hazards in either the Cox or the Fine and Gray models was tested using an interaction term of a time-varying covariate by study group (repair versus replacement). The results showed that the *P* values of all-cause mortality, composite outcome, and all-cause readmission were 0.044, 0.929, and 0.142, respectively, in the isolated TV surgeries. For the concomitant TV surgeries, the *P* values of all-cause mortality, composite outcome, and all-cause readmission were 0.001, 0.590, and 0.130, respectively.

To investigate the risk factors of in-hospital death, univariate analyses (*t* test or the χ^2 test) were performed, and variables with $P<0.2$ were further introduced into the multivariable logistic regression analysis with backward selection. Finally, a falsification analysis was conducted to detect residual confounding between the groups after weighting.[25] We selected 2 irrelevant outcomes of relatively high incidence (namely, incident fracture and newly diagnosed malignancy) as the falsification end points. A 2-sided $P<0.05$ was considered statistically significant, and no adjustment of multiple testing (multiplicity) was made to avoid low statistical power in this study. All statistical analyses were performed using SAS, version 9.4 (SAS Institute, Cary, NC).

RESULTS

Epidemiological Characteristics of TV Surgery in Taiwan

Between January 2000 and December 2013, a total of 2644 patients who received TV surgery for the first time were included in our study, of which 333 (12.6%) underwent isolated TV surgery and 2311 (87.4%) underwent concomitant TV surgery. TV surgeries share <9% of overall cardiac valve surgery volume in Taiwan. The trend of performing TV surgeries among all the valve surgeries increased from 4.9% in 2000 to 8.1% in 2013 (Figure 1B). The in-hospital mortality rates were 8.7% in isolated TV surgery and 8.6% in concomitant TV surgery (data not presented). The number of TV operations across the study periods remained relatively constant (Figure 2A).

Table 1. Clinical and Surgical Characteristics of Patients With Isolated TV Surgery

Variable	Data Before IPTW*				Data After IPTW†		
	Isolated (n=333)	Repair (n=196)	Replacement (n=137)	STD	Repair	Replacement	STD
Age, y	54.7±16.2	55.6±16.4	53.5±15.9	0.128	55.2±16.3	56.1±15.6	−0.055
Age group, y							
<40	68 (20.4)	37 (18.9)	31 (22.6)	−0.093	20.2	18.7	0.037
40–59	131 (39.3)	74 (37.8)	57 (41.6)	−0.079	37.6	35.1	0.051
60–79	120 (36.0)	77 (39.3)	43 (31.4)	0.166	39.0	43.1	−0.083
≥80	14 (4.2)	8 (4.1)	6 (4.4)	−0.015	3.3	3.1	0.010
Women	160 (48.0)	99 (50.5)	61 (44.5)	0.120	46.2	41.3	0.099
Medical comorbidities							
Diabetes mellitus	59 (17.7)	36 (18.4)	23 (16.8)	0.041	21.0	19.1	0.046
Hypertension	120 (36.0)	76 (38.8)	44 (32.1)	0.140	36.4	35.9	0.009
Heart failure	124 (37.2)	70 (35.7)	54 (39.4)	−0.076	39.7	37.2	0.052
Myocardial infarction	21 (6.3)	15 (7.7)	6 (4.4)	0.138	6.6	8.6	−0.077
Stroke	23 (6.9)	11 (5.6)	12 (8.8)	−0.122	6.0	5.8	0.005
History of PPM/ICD	10 (3.0)	3 (1.5)	7 (5.1)	−0.201	1.8	2.6	−0.053
Peripheral arterial disease	7 (2.1)	4 (2.0)	3 (2.2)	−0.010	1.5	1.5	0.001
Atrial fibrillation	105 (31.5)	48 (24.5)	57 (41.6)	−0.370	31.7	30.5	0.026
Pulmonary hypertension	54 (16.2)	38 (19.4)	16 (11.7)	0.214	15.8	12.5	0.096
Chronic kidney disease	43 (12.9)	23 (11.7)	20 (14.6)	−0.085	12.6	13.7	−0.033
Dialysis	7 (2.1)	4 (2.0)	3 (2.2)	−0.010	1.8	1.5	0.024
Chronic obstructive pulmonary disease	32 (9.6)	21 (10.7)	11 (8.0)	0.092	10.3	10.0	0.010
Liver cirrhosis	25 (7.5)	7 (3.6)	18 (13.1)	−0.351	7.3	7.2	0.004
Coagulopathy	17 (5.1)	5 (2.6)	12 (8.8)	−0.271	4.2	4.5	−0.016
Gastrointestinal bleeding	57 (17.1)	27 (13.8)	30 (21.9)	−0.213	17.3	17.7	−0.011
Major bleeding	28 (8.4)	12 (6.1)	16 (11.7)	−0.196	6.8	7.2	−0.016
Charlson score	2.2±2.3	2.2±2.4	2.2±2.2	−0.011	2.3±2.5	2.4±2.7	−0.038
Hospital level							
Medical center (teaching hospital)	275 (82.6)	166 (84.7)	109 (79.6)	0.134	83.4	83.4	0.001
Regional/district hospital	58 (17.4)	30 (15.3)	28 (20.4)	−0.134	16.6	16.6	−0.001
Concomitant CABG	46 (13.8)	38 (19.4)	8 (5.8)	0.417	14.0	16.9	−0.080
Maze	65 (19.5)	49 (25.0)	16 (11.7)	0.349	19.5	22.9	−0.083
Follow-up time, y	4.4±3.8	4.7±3.8	4.0±3.8	0.199	4.8±4.0	4.2±4.3	0.129

CABG indicates coronary artery bypass graft; ICD, intracardiac defibrillator; IPTW, inverse probability of treatment weighting; PPM, permanent pacemaker; STD, standardized difference; and TV, tricuspid valve.
*Values are given as number (percentage) or mean±SD.
†Values are given as percentage or mean±SD.

Of the 333 patients who underwent isolated TV surgery, 196 (58.9%) underwent TV repair and 137 (41.1%) underwent TV replacement. The proportion of patients who received TV repair did not significantly change across the study periods (*P* trend=0.645). The in-hospital mortality rate was not significantly changed across the study periods in both the repair and replacement groups (Figure 2B). In general, the in-hospital mortality rate was lower in the repair group than in the replacement group (6.6% [13/196] versus 11.7% [16/137]).

Of the remaining 2311 patients who underwent concomitant TV surgery, 1974 (85.4%) underwent TV repair and 337 (14.6%) underwent TV replacement. Similarly, the proportion of patients who received TV repair remained unchanged across the study periods (*P* trend=0.129). The in-hospital mortality rate was also stable across the study periods in both the repair and the replacement groups (Figure 2C). As illustrated in the figure, the in-hospital mortality rate was much lower in the repair group than in the replacement group (7.1% [141/1974] versus 17.2% [58/337]).

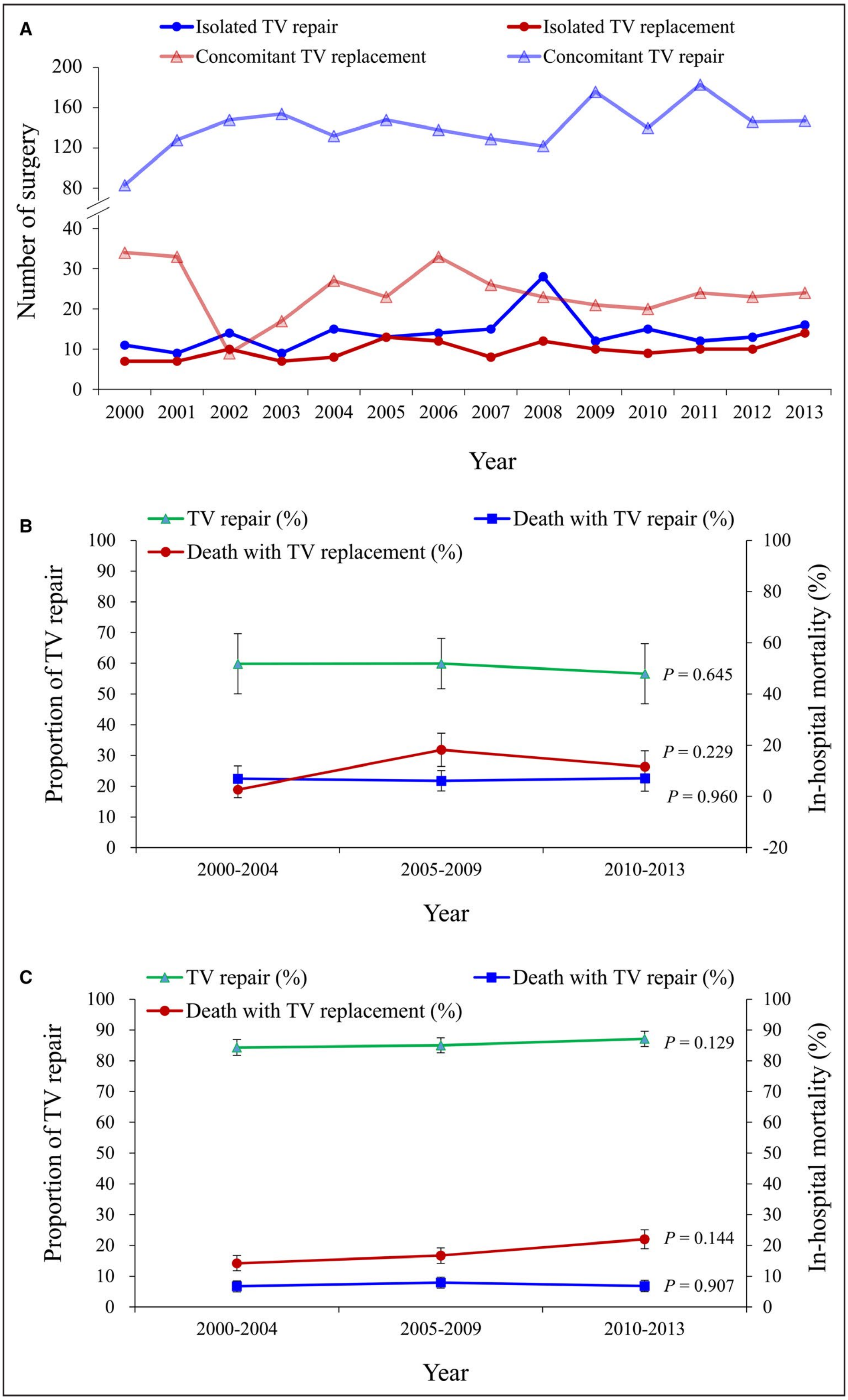

Figure 2. Number of tricuspid valve (TV) operations (A), proportion of TV repair operations received (of all TV operations), or proportion of in-hospital deaths within the repair and replacement groups in patients with isolated surgery (B) and concomitant TV surgery (C) across the study periods.

The error bar represents the 95% CI of the proportion.

Table 2. Clinical and Surgical Characteristics of Patients With Concomitant TV Surgery

Variable	Data Before IPTW*				Data After IPTW†		
	Concomitant (n=2311)	Repair (n=1974)	Replacement (n=337)	STD	Repair	Replacement	STD
Age, y	60.7±13.4	60.8±13.3	60.3±14.2	0.034	60.7±13.3	62.9±14.0	−0.157
Age group, y							
<40	165 (7.1)	139 (7.0)	26 (7.7)	−0.026	7.0	4.8	0.096
40–59	874 (37.8)	740 (37.5)	134 (39.8)	−0.047	37.8	34.7	0.065
60–79	1146 (49.6)	994 (50.4)	152 (45.1)	0.105	49.6	50.8	−0.025
≥80	126 (5.5)	101 (5.1)	25 (7.4)	−0.095	5.6	9.7	−0.155
Women	1236 (53.5)	1044 (52.9)	192 (57.0)	−0.082	53.4	56.0	−0.053
Medical comorbidities							
Diabetes mellitus	455 (19.7)	391 (19.8)	64 (19.0)	0.021	19.8	18.5	0.032
Hypertension	883 (38.2)	768 (38.9)	115 (34.1)	0.099	38.3	37.4	0.018
Heart failure	1170 (50.6)	990 (50.2)	180 (53.4)	−0.065	50.7	46.8	0.078
Myocardial infarction	141 (6.1)	127 (6.4)	14 (4.2)	0.102	6.0	4.6	0.063
Stroke	257 (11.1)	216 (10.9)	41 (12.2)	−0.038	11.1	13.3	−0.068
History of PPM/ICD	53 (2.3)	39 (2.0)	14 (4.2)	−0.127	2.3	2.7	−0.025
Peripheral arterial disease	55 (2.4)	44 (2.2)	11 (3.3)	−0.063	2.3	1.8	0.035
Atrial fibrillation	1325 (57.3)	1119 (56.7)	206 (61.1)	−0.090	57.3	56.2	0.021
Pulmonary hypertension	491 (21.2)	424 (21.5)	67 (19.9)	0.039	21.2	18.4	0.071
Chronic kidney disease	274 (11.9)	227 (11.5)	47 (13.9)	−0.073	11.9	12.4	−0.015
Dialysis	60 (2.6)	51 (2.6)	9 (2.7)	−0.005	2.6	1.8	0.054
Chronic obstructive pulmonary disease	201 (8.7)	175 (8.9)	26 (7.7)	0.042	8.8	9.2	−0.016
Liver cirrhosis	85 (3.7)	58 (2.9)	27 (8.0)	−0.224	3.7	4.3	−0.031
Coagulopathy	91 (3.9)	70 (3.5)	21 (6.2)	−0.125	4.0	3.9	0.003
Gastrointestinal bleeding	419 (18.1)	361 (18.3)	58 (17.2)	0.028	18.2	19.2	−0.025
Major bleeding	180 (7.8)	149 (7.5)	31 (9.2)	−0.060	7.8	8.7	−0.032
Charlson score	2.2±2.0	2.2±1.9	2.4±2.2	−0.108	2.2±2.0	2.2±2.0	0.023
Hospital level							
Medical center (teaching hospital)	1985 (85.9)	1725 (87.4)	260 (77.2)	0.270	85.8	87.0	−0.033
Regional/district hospital	326 (14.1)	249 (12.6)	77 (22.8)	−0.270	14.2	13.0	0.033
Concomitant CABG	212 (9.2)	184 (9.3)	28 (8.3)	0.036	9.0	5.7	0.129
Maze	405 (17.5)	369 (18.7)	36 (10.7)	0.228	17.5	16.7	0.022
Concomitant surgery type							
AVR (mechanical)	429 (18.6)	364 (18.4)	65 (19.3)	−0.022	18.6	20.6	−0.050
AVR (tissue)	159 (6.9)	136 (6.9)	23 (6.8)	0.003	6.9	7.3	−0.019
MV repair	672 (29.1)	652 (33.0)	20 (5.9)	0.728	29.1	27.4	0.037
MV replacement (mechanical)	1123 (48.6)	903 (45.7)	220 (65.3)	−0.401	48.6	53.3	−0.094
MV replacement (tissue)	392 (17.0)	322 (16.3)	70 (20.8)	−0.115	17.0	19.2	−0.057
Follow-up time, y	4.9±4.1	4.9±4.0	4.3±4.2	0.147	5.0±4.1	4.1±3.9	0.238

AVR indicates Aortic valve replacement; CABG, coronary artery bypass graft; ICD, intracardiac defibrillator; IPTW, inverse probability of treatment weighting; MV: Mitral valve; PPM, permanent pacemaker; STD, standardized difference; and TV, tricuspid valve.

*Values are given as number (percentage) or mean±SD.

†Values are given as percentage or mean±SD.

Baseline Characteristics of the Study Population

For the isolated TV surgery group, the mean age was 55.6 years (SD, 16.4 years); and the mean age was 53.5 years (SD, 15.9 years) in the repair and replacement group. Most operations (82.6%) were performed in medical centers. There were substantial differences in terms of the characteristics before weighting. However, the group differences in characteristics were negligible after weighting, with all the absolute values of standardized difference <0.1 (Table 1). For the concomitant TV surgery group, the mean age was 60.8 years (SD, 13.3 years); and the mean age was 60.3 years (SD, 14.2 years) in the repair and replacement group. Similarly, most operations (85.9%) were performed in medical centers. Most of the characteristics were well balanced between the 2 groups after weighting, except for age and coronary artery bypass grafting, which exhibited a small effect size of group difference (standardized difference range, 0.1–0.2) (Table 2).

In addition, we further compared the baseline characteristics of patients undergoing valve replacement, and the details are shown in Table S2.

Operation-Related Complications and Outcomes

In patients who underwent isolated TV surgery, the in-hospital mortality rate was significantly lower in the repair than in the replacement group (5.8% versus 13.8%; odds ratio, 0.39; 95% CI, 0.18–0.85). Other perioperative outcomes favored the repair group, including massive blood transfusion, sepsis, in-hospital stay, prolonged hospital stay >28 days, and hospital cost (Table 3). Similarly, the in-hospital mortality rate of patients who underwent concomitant TV surgery was significantly lower in the repair than in the replacement groups (7.3% versus 16.2%; odds ratio, 0.41; 95% CI, 0.31–0.55). With the exception of sepsis, ischemic stroke, and pacemaker installation, the other perioperative outcomes favored the repair group (Table 4).

In addition, we further compared the operation-related outcomes of mechanical with bioprosthetic valve replacement. The details are shown in Table S3.

Late Outcomes After Discharge

In patients who underwent isolated TV surgery, a trend appeared toward a lower all-cause mortality rate in the repair group (35.7% versus 48.3%; hazard ratio [HR], 0.66; 95% CI, 0.42–1.04), although not significant (*P*=0.072; Figure 3A). The repair group had lower incidences of composite outcome (22.5% versus 41.5%; subdistribution HR [SHR], 0.55; 95% CI, 0.35–0.89) and readmission (57.7% versus 70.1%; SHR, 0.64; 95% CI, 0.46–0.91) compared with the replacement group (Figure 3B and 3C).

In patients who underwent concomitant TV surgery, a trend appeared toward a lower all-cause mortality rate in the repair group (35.4% versus 41.4%; HR, 0.76;

Table 3. Operation-Related Complications and Outcomes of Isolated TV Surgery

Variable	Data Before IPTW*			Data After IPTW†			
						Repair vs Replacement	
	Isolated (n=333)	Repair (n=196)	Replacement (n=137)	Repair	Replacement	OR/B (95% CI)	*P* Value
Binary outcome							
In-hospital mortality	29 (8.7)	13 (6.6)	16 (11.7)	5.8	13.8	0.39 (0.18, 0.85)	0.018
New-onset stroke	10 (3.0)	5 (2.6)	5 (3.6)	2.0	5.0	0.39 (0.11, 1.43)	0.156
New-onset ischemic stroke	7 (2.1)	3 (1.5)	4 (2.9)	1.1	4.6	0.23 (0.05, 1.18)	0.079
New-onset hemorrhagic stroke	4 (1.2)	2 (1.0)	2 (1.5)	0.9	0.7	1.28 (0.12, 14.29)	0.839
Cardiogenic shock requiring MCS	14 (4.2)	9 (4.6)	5 (3.6)	4.8	3.9	1.26 (0.44, 3.64)	0.667
Reexploration for bleeding	15 (4.5)	7 (3.6)	8 (5.8)	4.7	5.7	0.80 (0.30, 2.13)	0.661
Massive blood transfusion‡	60 (18.0)	21 (10.7)	39 (28.5)	12.3	30.0	0.33 (0.18, 0.58)	<0.001
De novo dialysis	40 (12.0)	20 (10.2)	20 (14.6)	9.7	15.4	0.59 (0.30, 1.14)	0.115
Sepsis	21 (6.3)	6 (3.1)	15 (10.9)	2.7	12.8	0.19 (0.07, 0.54)	0.002
Pacemaker	14 (4.2)	3 (1.5)	11 (8.0)	2.8	5.8	0.46 (0.15, 1.43)	0.177
Deep wound infection	7 (2.1)	4 (2.0)	3 (2.2)	1.9	1.4	1.40 (0.25, 7.68)	0.702
Prolonged hospital stays >28 d	119 (35.7)	50 (25.5)	69 (50.4)	27.3	49.0	0.39 (0.25, 0.62)	<0.001
Continuous parameter							
ICU duration, d	9.9±14.5	8.3±11.6	12.3±17.6	8.8±11.6	12.0±16.5	−3.23 (−6.98, 0.52)	0.091
In-hospital stay, d	31.3±28.3	25.8±21.8	39.1±34.3	27.5±25.0	36.8±32.2	−9.3 (−17.4, −1.1)	0.027
In-hospital cost, NTD×10^4	54.6±42.8	47.7±35.3	64.5±50.1	49.1±37.5	64.0±47.7	−14.9 (−26.8, −3.0)	0.014

B indicates regression coefficient; ICU, intensive care unit; IPTW, inverse probability of treatment weighting; MCS, mechanical circulatory support; NTD, New Taiwan Dollars; OR, odds ratio; TV, and tricuspid valve.

*Values are given as number (percentage) or mean±SD.

†Values are given as percentage or mean±SD.

‡Packed red blood cells >10 U.

Table 4. Operation-Related Complications and Outcomes of Concomitant TV Surgery

Variable	Data Before IPTW*			Data After IPTW†			
	Concomitant (n=2311)	Repair (n=1974)	Replacement (n=337)	Repair	Replacement	Repair vs Replacement: OR/B (95% CI)‡	Repair vs Replacement: *P* Value
Binary outcome							
In-hospital mortality	199 (8.6)	141 (7.1)	58 (17.2)	7.3	16.2	0.41 (0.31, 0.55)	<0.001
New-onset stroke	54 (2.3)	42 (2.1)	12 (3.6)	2.2	4.3	0.48 (0.30, 0.79)	0.004
New-onset ischemic stroke	42 (1.8)	34 (1.7)	8 (2.4)	1.8	2.1	0.82 (0.45, 1.49)	0.507
New-onset hemorrhagic stroke	13 (0.6)	9 (0.5)	4 (1.2)	0.5	2.2	0.20 (0.08, 0.50)	0.001
Cardiogenic shock requiring MCS	53 (2.3)	37 (1.9)	16 (4.7)	1.9	6.8	0.26 (0.16, 0.42)	<0.001
Reexploration for bleeding	86 (3.7)	67 (3.4)	19 (5.6)	3.5	5.8	0.62 (0.41, 0.93)	0.020
Massive blood transfusion§	359 (15.5)	272 (13.8)	87 (25.8)	14.3	24.8	0.50 (0.40, 0.62)	<0.001
De novo dialysis	212 (9.2)	158 (8.0)	54 (16.0)	8.2	21.1	0.34 (0.27, 0.45)	<0.001
Sepsis	67 (2.9)	52 (2.6)	15 (4.5)	2.7	2.7	0.94 (0.56, 1.58)	0.810
Pacemaker	63 (2.7)	51 (2.6)	12 (3.6)	2.5	4.2	0.63 (0.39, 1.01)	0.055
Deep wound infection	43 (1.9)	31 (1.6)	12 (3.6)	1.6	6.5	0.25 (0.14, 0.42)	<0.001
Prolonged hospital stays >28 d	639 (27.7)	490 (24.8)	149 (44.2)	25.1	47.8	0.37 (0.31, 0.44)	<0.001
Continuous parameter							
ICU duration, d	8.3±12.4	7.6±11.3	12.8±16.6	7.7±11.6	11.3±14.3	−3.21 (−5.01, −1.40)	<0.001
In-hospital stay, d	26.4±22.0	24.9±19.9	35.5±30.1	25.1±20.3	34.3±26.3	−8.7 (−12.1, −5.3)	<0.001
In-hospital cost, NTD×10⁴	53.1±34.8	50.6±32.0	67.8±45.4	50.9±32.6	66.6±42.0	−14.9 (−20.4, −9.4)	<0.001

B indicates regression coefficient; ICU, intensive care unit; IPTW, inverse probability of treatment weighting; MCS, mechanical circulatory support; NTD, New Taiwan Dollars; OR, odds ratio; and TV, tricuspid valve.

*Values are given as number (percentage) or mean±SD.

†Values are given as percentage or mean±SD.

‡Additionally adjusted for age and coronary artery bypass graft.

§Packed red blood cells >10 U.

95% CI, 0.59–0.99) (Figure 3D). The repair group had lower incidences of composite outcome (28.0% versus 39.6%; SHR, 0.63; 95% CI, 0.46–0.86), pacemaker implantation (5.2% versus 14.2%; SHR, 0.37; 95% CI, 0.17–0.81), and readmission (66.1% versus 76.8%; SHR, 0.72; 95% CI, 0.60–0.86) compared with the replacement group (Figure 3E and 3F). The detailed data of each outcome being compared are provided in Tables S4 and S5.

In addition, we further compared the late outcomes of mechanical with bioprosthetic valve replacement, and the details are shown in Table S6.

Risk Factors of In-Hospital Mortality

After introducing the variables with $P<0.2$ in the univariate analyses (Table S7) into the multivariable analysis with backward selection, the result indicated the following risk factors for patients who underwent isolated TV surgery: male sex, history of diabetes mellitus, myocardial infarction, and major bleeding. For patients who underwent concomitant TV surgery, the result indicated the following risk factors: older age, male sex, history of permanent pacemaker/intracardiac defibrillator, chronic kidney disease, coagulopathy, receiving surgery in nonmedical centers, the presence of concomitant coronary artery bypass grafting, and the absence of concomitant maze (Table S8).

Sensitivity Analysis for Unmeasured Confounding

Using 2 irrelevant falsification end points (namely, incident fracture and newly diagnosed malignancy), the results demonstrated that the incidence of both outcomes did not significantly differ in the repair and replacement groups in either the isolated or the concomitant TV surgery groups, which may provide supportive evidence against the existence of unmeasured confounding (Table S9).

DISCUSSION

The present study demonstrated 3 main findings, as follows: first, the volume and death rate of isolated and concomitant TV repair and replacement surgery remained constant over the 14-year study period in Taiwan; second, in-hospital mortality was lower in both the isolated and the concomitant TV repair groups;

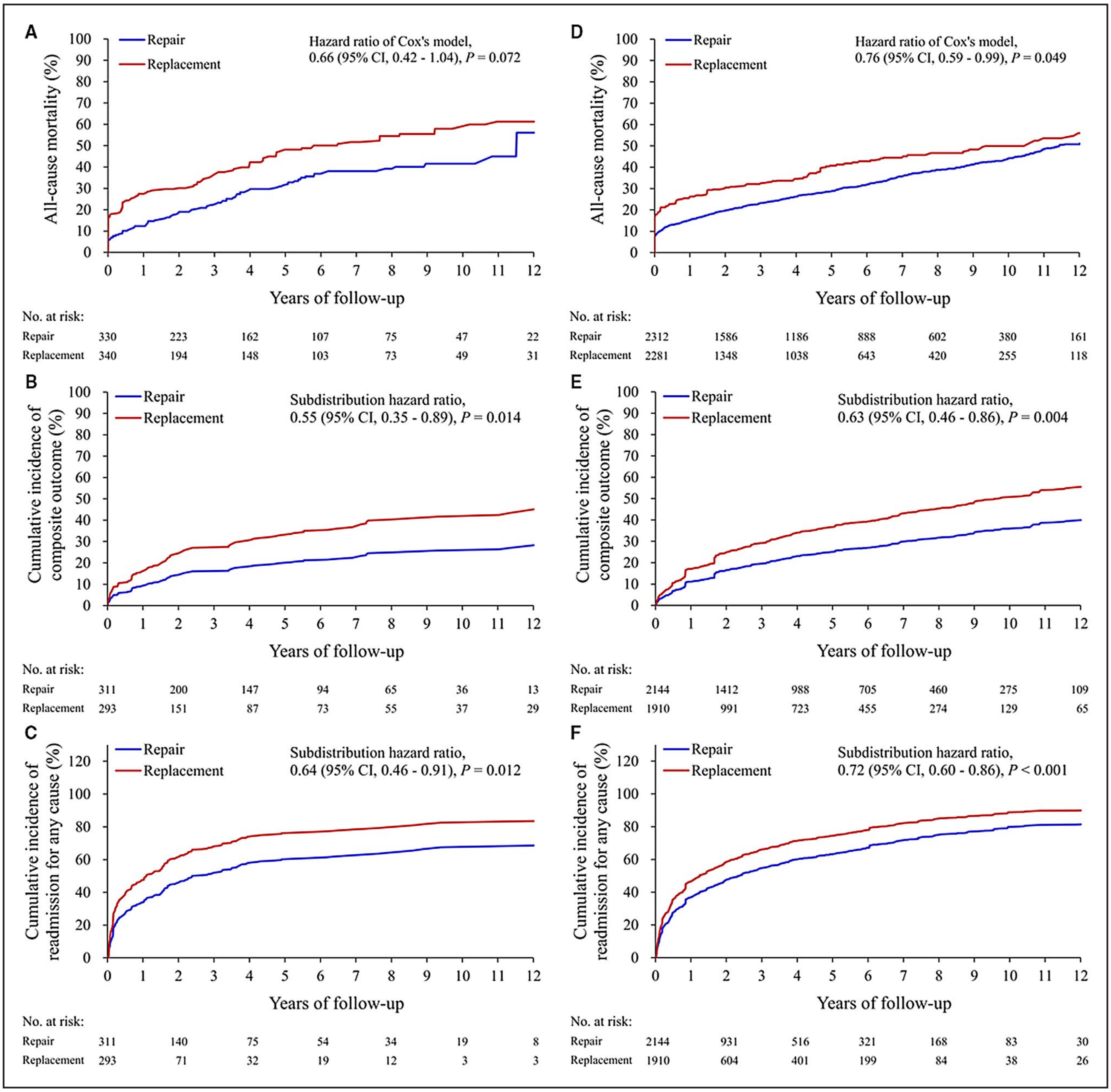

Figure 3. Unadjusted cumulative event rate of all-cause mortality in patients who underwent isolated (A) and concomitant tricuspid valve (TV) surgery (D); cumulative incidence function of composite outcome in patients who underwent isolated (B) and concomitant TV surgery (E); and cumulative incidence function of admission in patients who underwent isolated (C) and concomitant TV surgery (F) after inverse probability of treatment weighting.

third, the long-term outcomes in terms of composite outcome (redo surgery, heart failure, pacemaker, and major bleeding) and readmission attributable to any cause were significantly lower in both the isolated and the concomitant TV repair groups.

Compared with previous editions, the latest European Society of Cardiology and American Heart Association guidelines advocate early intervention in patients with TR. In contrast to the increasing use of TV surgery in the Western countries,[1,5] the number of TV surgeries and the TV repair rate in both isolated and concomitant surgery performed in Taiwan remained constant over the 14-year period. The absence of increase in the use may reflect the reluctance of both surgeons and patients to undergo surgery when medical treatment is available and hence the possible delay referral for surgical evaluation by cardiac surgeons, because of the high perceived mortality of up to 14% in large-scale studies.[1–8]

In accordance with the findings in a study conducted in the United States that repair rate was 41.7% (569/1364) in isolated and 83.8% (6563/7830) in concomitant TV surgery,[1] the present study also demonstrated the proportion of TV repair was lower in isolated TV surgery than that in concomitant surgery (58.9% versus 85.4%, respectively). The choice of TV repair or replacement depends on several factors, such as disease cause, surgical timing, anatomical features of annulus and leaflet, and clinical experience of the surgeon.[26] Although TV repair is a preferred option to prevent complications of tissue and mechanical valve replacement, the lower TV repair rate in isolated surgery may be explained by primary leaflet problems constituting most isolated TV surgery cases that render repair impossible, whereas secondary TR constitutes most concomitant TV surgery cases and repair is often feasible. In addition, there may be a delay in referral to isolated TV surgery because patients remain asymptomatic for a long period of time and by the time they are referred, repair is usually not feasible,[27] which is not the case in concomitant TV surgery.

The overall in-hospital mortality rates for TV surgery in the present study were 8.7% in isolated TV surgery and 8.6% in concomitant TV surgery. Consistent with large-scale studies conducted on the basis of the US Nationwide Inpatient Sample database, our study also revealed that repair was superior to replacement in isolated and concomitant TV surgery and a higher mortality in the concomitant group than in the isolated group.[1,5,6] Regardless of the advancement in surgical techniques, the mortality did not decrease significantly over a 14-year period. This is probably because of multiple preexisting medical comorbidities in patients with TV diseases, such as atrial fibrillation and heart failure. These patients are usually referred to surgical interventions late with severe right ventricular dysfunction or end-organ damage, especially in those patients with primary TR for isolated TV surgery.[9] Endovascular intervention has been attempted to improve the mortality in the high-risk group.[16]

A meta-analysis by Choi and colleagues, pooling 17 retrospective studies comparing TV repair and TV replacement in patients with TR for all-cause mortality as the primary outcome, demonstrated that replacement was associated with higher all-cause mortality compared with repair (HR, 1.59; 95% CI, 1.26–2.00).[28] A recent study conducted by Saran et al[29] on long-term outcomes demonstrated a better long-term survival in repair compared with replacement. The aforementioned studies may be subject to the limitations of pooling all types of TV surgery for analysis or not imposing strict exclusion criteria to reduce the heterogeneous nature of the study population. We therefore set strict exclusion criteria in the study groups and used a 2-arm design to separate patients into isolated and concomitant groups to overcome these problems. Although we only demonstrated a significant difference in all-cause mortality between repair and replacement in concomitant but not in isolated TV surgery, the composite outcome and readmission attributable to any cause were significantly superior in TV repair than in TV replacement in both isolated and concomitant TV surgery. The composite outcome rather than the individual outcome is more translational in the clinical context, considering multiple adverse events can occur in any individual patient.

The demerit of replacement is that when a rigid prosthetic valve is placed in a deformable, low-pressure cavity, it could lead to progressive right ventricular dysfunction in the long run.[8] Mechanical prosthetic valves are also associated with the risk of thrombosis and anticoagulant use.[12] Although tricuspid repair was reported in several previous studies as associated with a higher recurrence of severe TR, which warrants reoperation,[4,9,14] overall, other studies, together with ours, have favored TV repair because of its superior long-term outcomes.[28–30] Our study did not intend to differentiate the severity of tricuspid disease in the study population. A point to note is that the benefits of TV repair observed may reflect the greater disease burden in patients who underwent replacement, who may not survive well even after surgical correction, despite the improvement in perioperative and postoperative care.

Study Strengths

The main strength of this study is the application of a 2-arm design separating patients into isolated and concomitant groups for the analysis of long-term outcomes. This study also benefits from a relatively unselected population of a national cohort with not only early but also multiple late outcome parameters capturing both isolated and concomitant TV surgery. Taiwan's NHI program covers nearly all residents in Taiwan, given that it is a compulsory national insurance scheme, unlike the insurance system in other regions, which could possibly reject certain patients receiving surgical treatment. Our study can also overcome the pitfalls of only early outcome, single-center design with a small number of patients, and inability to demonstrate the wide variety of complications that can arise later on. We evaluated multiple late outcome parameters with a mean follow-up of 4.9 years.

Limitations

This study is subject to the inherent limitations of an administrative database, such as the NHIRD. Detailed clinical and surgical data, including laboratory data, left ventricular ejection fraction, right ventricular function, severity of TR, heart failure symptoms, pulmonary arterial pressure, surgical timing and indication, TV repair technique, and prosthesis detail of TV replacement, are not available. This constituted the major limitation of our study (ie, the inability to adjust for the severity of tricuspid disease). The results on the superiority of repair observed may be attributable to residual confounding of unknown or unmeasured confounders that could not be excluded, although inverse probability of treatment weighting based on the propensity scores was used when comparing the outcomes. Because of the retrospective nature of this administrative database study, we can only establish association but not causal relationship of TV repair and superior results. Despite the aforementioned, the accuracy of the NHIRD in cardiac surgery or cardiovascular diseases has been validated in previous studies.[31] Another problem with the NHIRD is that it may be prone to misclassification and coding errors, because it classifies patients and operative procedures on the basis of *ICD-9-CM* codes. However, the NHI program strictly regulates examination, medication, and surgery reimbursements. Comprehensive medical records review the entailing laboratory data and imaging study safeguard examination or interventions granted to patients with clinical indications, thus limiting potential bias. In addition, the NHIRD guarantees limited missing data with nearly complete follow-up by means of linkage to the national mortality records. At last, the lack of correction for multiple testing may preserve some statistical power but increases the risk of type I error in this study.

CONCLUSIONS

Although TV surgeries share <9% of overall cardiac valve surgery volume in Taiwan, they carry a high mortality rate and have not improved over the past years. Both TV repair and TV replacement are associated with high in-hospital and all-cause mortality in both isolated and concomitant TV surgery. However, TV repair is associated with superior short- and long-term (composite) outcomes in both isolated and concomitant TV surgery. Our findings suggest TV repair may be strongly considered first; however, further prospective clinical trials are warranted.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Materials

Tables S1–S9

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Supplemental Material

Table S1. **List of ICD-9-CM codes used to define variables.**

Variable	ICD-9 CM Code
Congenital heart disease	745.xx, 746.xx
Infective endocarditis	421.0x, 421.1x, 421.9x
Diabetes mellitus	250.xx
Hypertension	401.xx-405.xx
Heart failure	428.xx
Old myocardial infarction	410.xx, 412.xx
Stroke	430.xx-437.xx
Ischemic stroke	433.xx-437.xx
Hemorrhagic stroke	430.xx-432.xx
Peripheral arterial disease	440.0x, 440.2x, 440.3x, 440.8x, 440.9x, 443.xx, 444.0x, 444.22, 444.8x, 447.8x, 447.9x
Atrial fibrillation	427.31
Pulmonary hypertension	416.0x, 416.8x, 416.9x
Chronic kidney disease	580.xx-589.xx, 403.xx-404.xx, 016.0x, 095.4x, 236.9x, 250.4x, 274.1x, 442.1x, 447.3x, 440.1x, 572.4x, 642.1x, 646.2x, 753.1x, 283.11, 403.01, 404.02, 446.21
Dialysis	585.xx (Catastrophic illness card)
Chronic obstructive pulmonary disease	491.xx, 492.xx, 496.xx
Liver cirrhosis	571.2x, 571.5x, 571.6x
Coagulopathy	286.0-286.9, 287.1, 287.3-287.5, 289.81, 289.82
Gastrointestinal bleeding	530.21, 530.7, 530.82, 531.xx-534.xx, 535.xx, 537.83, 537.84, 578.xx
Major bleeding	430.xx-432.xx, 578.xx, 719.1x, 423.0, 599.7, 626.2, 626.6, 626.8, 627.0, 627.1, 786.3, 784.7, 459.0
Sepsis	038.xx, 790.7
Deep wound infection	998.3, 998.5x
Malignancy	140.xx-208.xx

ICD-9 CM, International Classification of Diseases, Ninth Revision, Clinical Modification.

Table S2. Clinical and surgical characteristics of patients who received mechanical or bioprosthetic tricuspid valve (TV) replacement.

Variable	TV replacement (*n* = 474)	Mechanical (*n* = 321)	Bioprosthetic (*n* = 153)	*P* value
Age (years)	58.3±15.0	57.6±15.3	59.8±14.4	0.132
Age group				0.397
< 40 years	57 (12.0)	42 (13.1)	15 (9.8)	
40-59 years	191 (40.3)	134 (41.7)	57 (37.3)	
60-79 years	195 (41.1)	124 (38.6)	71 (46.4)	
≥ 80 years	31 (6.5)	21 (6.5)	10 (6.5)	
Female	253 (53.4)	172 (53.6)	81 (52.9)	
Medical comorbidities				0.896
Diabetes mellitus	87 (18.4)	52 (16.2)	35 (22.9)	0.079
Hypertension	159 (33.5)	115 (35.8)	44 (28.8)	0.128
Heart failure	234 (49.4)	158 (49.2)	76 (49.7)	0.927
Myocardial infarction	20 (4.2)	14 (4.4)	6 (3.9)	0.824
Stroke	53 (11.2)	31 (9.7)	22 (14.4)	0.127
History of PPM/ICD	21 (4.4)	9 (2.8)	12 (7.8)	0.013
Peripheral arterial disease	14 (3.0)	8 (2.5)	6 (3.9)	0.390
Atrial fibrillation	263 (55.5)	181 (56.4)	82 (53.6)	0.567
Pulmonary hypertension	83 (17.5)	47 (14.6)	36 (23.5)	0.017
Chronic kidney disease	67 (14.1)	41 (12.8)	26 (17.0)	0.217

Variable	TV replacement (*n* = 474)	Mechanical (*n* = 321)	Bioprosthetic (*n* = 153)	*P* value
Dialysis	12 (2.5)	7 (2.2)	5 (3.3)	0.481
Chronic obstructive pulmonary disease	37 (7.8)	20 (6.2)	17 (11.1)	0.064
Liver cirrhosis	45 (9.5)	33 (10.3)	12 (7.8)	0.397
Coagulopathy	33 (7.0)	19 (5.9)	14 (9.2)	0.196
Gastrointestinal bleeding	88 (18.6)	58 (18.1)	30 (19.6)	0.687
Major bleeding	47 (9.9)	29 (9.0)	18 (11.8)	0.352
Charlson’s score	2.4±2.2	2.3±2.2	2.5±2.0	0.346
Hospital level				0.163
Medical center (teaching hospital)	369 (77.8)	244 (76.0)	125 (81.7)	
Regional / district hospital	105 (22.2)	77 (24.0)	28 (18.3)	
Concomitant CABG	36 (7.6)	27 (8.4)	9 (5.9)	0.331
Maze	52 (11.0)	32 (10.0)	20 (13.1)	0.312
Concomitant surgery type				
AVR-mechanical	65 (13.7)	58 (18.1)	7 (4.6)	<0.001
AVR-tissue	23 (4.9)	4 (1.2)	19 (12.4)	<0.001
MV repair	20 (4.2)	10 (3.1)	10 (6.5)	0.083
MV replacement- mechanical	220 (46.4)	202 (62.9)	18 (11.8)	<0.001
MV replacement- tissue	70 (14.8)	8 (2.5)	62 (40.5)	<0.001
Follow-up years	4.2±4.1	4.7±4.2	3.2±3.6	<0.001

STD, standardized difference; TV, tricuspid valve; PPM, permanent pacemaker; ICD, intracardiac defibrillator; CABG, coronary artery bypass graft.

Table S3. Operation-related complications and outcomes of patients who received mechanical or bioprosthetic tricuspid valve (TV) replacement.

	TV replacement	Mechanical	Bioprosthetic	Mechanical *vs*. Bio prosthetic	
Variable	(*n* = 474)	(*n* = 321)	(*n* = 153)	OR / B (95% CI)	*P* value
Binary outcome					
In-hospital mortality	74 (15.6)	47 (14.6)	27 (17.6)	0.80 (0.48, 1.34)	0.400
New-onset stroke	17 (3.6)	9 (2.8)	8 (5.2)	0.52 (0.20, 1.38)	0.191
New-onset ischemic stroke	12 (2.5)	7 (2.2)	5 (3.3)	0.66 (0.21, 2.11)	0.484
New-onset hemorrhagic stroke	6 (1.3)	2 (0.6)	4 (2.6)	0.23 (0.04, 1.29)	0.095
Cardiogenic shock requiring MCS	21 (4.4)	9 (2.8)	12 (7.8)	0.34 (0.14, 0.82)	0.017
Re-exploration for bleeding	27 (5.7)	16 (5.0)	11 (7.2)	0.68 (0.31, 1.50)	0.335
Massive blood transfusion*	126 (26.6)	83 (25.9)	43 (28.1)	0.89 (0.58, 1.37)	0.605
de novo dialysis	74 (15.6)	47 (14.6)	27 (17.6)	0.80 (0.48, 1.34)	0.400
Sepsis	30 (6.3)	17 (5.3)	13 (8.5)	0.60 (0.29, 1.27)	0.185
Pacemaker	23 (4.9)	13 (4.0)	10 (6.5)	0.60 (0.26, 1.41)	0.243
Deep wound infection	15 (3.2)	12 (3.7)	3 (2.0)	1.94 (0.54, 6.98)	0.310
Prolong hospital stays > 28 days	218 (46.0)	139 (43.3)	79 (51.6)	0.72 (0.49, 1.05)	0.089
Continuous parameter					
ICU duration (days)	12.6±16.8	12.1±16.0	13.7±18.5	-1.54 (-4.95, 1.86)	0.375
In-hospital stay	36.6±31.4	35.6±31.4	38.6±31.3	-3.04 (-9.06, 2.99)	0.323
In-hospital cost (NTD×10^4)	66.8±46.8	64.7±44.7	71.4±50.6	-6.75 (-16.12, 2.62)	0.158

OR, odds ratio; B, regression coefficient; CI, confidence interval; ICU, intensive care unit; MCS, mechanical circulatory support; PRBC, packed red blood cell; * PRBC > 10U.

Table S4. **Late outcomes after discharge of isolated tricuspid valve surgery.**

Variable	Data before IPTW‡			Data after IPTW†		Data after IPTW	
	Isolated (*n* = 304)	Repair (*n* = 183)	Replacement (*n* = 121)	Repair (*n* = 183)	Replacement (*n* = 121)	Repair *vs*. Replacement	
						HR / SHR (95% CI)	*P* value
Mortality after discharge	110 (36.2)	58 (31.7)	52 (43.0)	31.7%	40.0%	0.76 (0.45, 1.28)	0.296
Composite outcome	86 (28.3)	40 (21.9)	46 (38.0)	22.3%	41.5%	0.55 (0.35, 0.89)	0.014
Re-do surgery	13 (4.3)	1 (0.5)	12 (9.9)	1.5%	8.9%	0.16 (0.02, 1.24)	0.079
Heart failure	42 (13.8)	24 (13.1)	18 (14.9)	11.9%	16.0%	0.71 (0.34, 1.49)	0.364
Pacemaker	11 (3.6)	4 (2.2)	7 (5.8)	1.8%	4.6%	0.48 (0.13, 1.86)	0.290
Major bleeding	42 (13.8)	22 (12.0)	20 (16.5)	13.5%	20.1%	0.82 (0.45, 1.49)	0.506
Readmission for any cause	194 (63.8)	112 (61.2)	82 (67.8)	57.7%	70.1%	0.64 (0.46, 0.91)	0.012

IPTW, inverse-probability-of-treatment weighting; HR, hazard ratio; subdistribution hazard ratio; CI, confidence interval;

‡ Value are given as number (%) or mean±SD;

† Values are given as %.

Table 5. Late outcomes after discharge of concomitant tricuspid valve surgery.

	Data before IPTW‡			Data after IPTW†		Data after IPTW	
	Concomitant	Repair	Replacement	Repair	Replacement	Repair *vs*. Replacement	
Variable	(*n* = 2,112)	(*n* = 1,833)	(*n* = 279)	(*n* = 1,833)	(*n* = 279)	HR / SHR (95% CI)§	*P* value
Mortality after discharge	651 (30.8)	546 (29.8)	105 (37.6)	30.3%	30.0%	0.96 (0.71, 1.30)	0.783
Composite outcome	608 (28.8)	507 (27.7)	101 (36.2)	28.0%	39.6%	0.63 (0.46, 0.86)	0.004
Re-do surgery	26 (1.2)	22 (1.2)	4 (1.4)	1.2%	1.1%	0.98 (0.30, 3.24)	0.979
Heart failure	320 (15.2)	260 (14.2)	60 (21.5)	14.4%	17.1%	0.79 (0.55, 1.13)	0.203
Pacemaker	110 (5.2)	95 (5.2)	15 (5.4)	5.2%	14.2%	0.37 (0.17, 0.81)	0.013
Major bleeding	287 (13.6)	242 (13.2)	45 (16.1)	13.6%	14.4%	0.84 (0.55, 1.28)	0.416
Readmission for any cause	1,414 (67.0)	1,205 (65.7)	209 (74.9)	66.1%	76.8%	0.72 (0.60, 0.86)	<0.001

IPTW, inverse-probability-of-treatment weighting; HR, hazard ratio; subdistribution hazard ratio; CI, confidence interval;

‡ Value are given as number (%) or mean±SD;

† Values are given as %;

§ Additionally adjusted for age and CABG.

Table S6. Late outcomes of patients who received mechanical or bioprosthetic tricuspid valve (TV) replacement.

Variable	TV replacement (n = 474)	Mechanical (n = 321)	Bio prosthetic (n = 153)	Mechanical *vs*. Bio prosthetic HR (95% CI) #	Mechanical *vs*. Bio prosthetic P value
All-cause mortality	231 (48.7)	158 (49.2)	73 (47.7)	0.84 (0.64, 1.09)	0.191
Outcomes after discharge	n = 400	n = 274	n = 126		
Composite outcome	147 (36.8)	110 (40.1)	37 (29.4)	1.22 (0.84, 1.78)	0.295
Readmission for any cause	291 (72.8)	203 (74.1)	88 (69.8)	0.90 (0.70, 1.16)	0.422

HR, hazard ratio; CI, confidence interval;

Estimated using Fine and Gray (1999) subdistribution hazard model which considered death as a competing risk. The results of all-cause mortality was derived from Cox proportional hazard model.

Table S7. **Clinical and surgical characteristics of patients by status of survival during the index admission.**

	Isolated tricuspid valve surgery			Concomitant tricuspid valve surgery		
Variable	In-hospital survivor (*n* = 304)	In-hospital death (*n* = 29)	*P*	In-hospital survivor (*n* = 2,112)	In-hospital death (*n* = 199)	*P*
Age (years)	54.1±16.3	61.0±13.6	0.028	60.1±13.3	67.0±12.4	<0.001
Female	151 (49.7)	9 (31.0)	0.055	1,149 (54.4)	87 (43.7)	0.004
Medical comorbidities						
Diabetes mellitus	47 (15.5)	12 (41.4)	<0.001	394 (18.7)	61 (30.7)	<0.001
Hypertension	104 (34.2)	16 (55.2)	0.025	799 (37.8)	84 (42.2)	0.224
Heart failure	107 (35.2)	17 (58.6)	0.013	1,050 (49.7)	120 (60.3)	0.004
Myocardial infarction	14 (4.6)	7 (24.1)	<0.001	114 (5.4)	27 (13.6)	<0.001
Stroke	22 (7.2)	1 (3.4)	0.442	233 (11.0)	24 (12.1)	0.659
History of PPM/ICD	9 (3.0)	1 (3.4)	0.883	41 (1.9)	12 (6.0)	<0.001
Peripheral arterial disease	6 (2.0)	1 (3.4)	0.597	48 (2.3)	7 (3.5)	0.271
Atrial fibrillation	95 (31.3)	10 (34.5)	0.720	1,225 (58.0)	100 (50.3)	0.035
Pulmonary hypertension	48 (15.8)	6 (20.7)	0.494	457 (21.6)	34 (17.1)	0.133
Chronic kidney disease	34 (11.2)	9 (31.0)	0.002	219 (10.4)	55 (27.6)	<0.001
Dialysis	7 (2.3)	0 (0.0)	0.409	52 (2.5)	8 (4.0)	0.186
Chronic obstructive pulmonary disease	26 (8.6)	6 (20.7)	0.034	178 (8.4)	23 (11.6)	0.134
Liver cirrhosis	24 (7.9)	1 (3.4)	0.385	73 (3.5)	12 (6.0)	0.065

	Isolated tricuspid valve surgery			Concomitant tricuspid valve surgery		
Variable	In-hospital survivor (*n* = 304)	In-hospital death (*n* = 29)	*P*	In-hospital survivor (*n* = 2,112)	In-hospital death (*n* = 199)	*P*
Coagulopathy	16 (5.3)	1 (3.4)	0.671	66 (3.1)	25 (12.6)	<0.001
Gastrointestinal bleeding	50 (16.4)	7 (24.1)	0.293	365 (17.3)	54 (27.1)	0.001
Major bleeding	22 (7.2)	6 (20.7)	0.013	161 (7.6)	19 (9.5)	0.333
Hospital level			0.318			0.057
Medical center (teaching hospital)	253 (83.2)	22 (75.9)		1,823 (86.3)	162 (81.4)	
Regional / district hospital	51 (16.8)	7 (24.1)		289 (13.7)	37 (18.6)	
Concomitant CABG	40 (13.2)	6 (20.7)	0.261	170 (8.0)	42 (21.1)	<0.001
Maze	62 (20.4)	3 (10.3)	0.192	386 (18.3)	19 (9.5)	0.002

TV, tricuspid valve; PPM, permanent pacemaker; ICD, intracardiac defibrillator; CABG, coronary artery bypass graft.

Table S8. Risk factor analysis of in-hospital mortality in patients with isolated or concomitant tricuspid valve surgeries.

Population / Variable	Adjusted odds ratio (95% CI)	*P*
Isolated TV surgery		
Female sex	0.37 (0.15, 0.90)	0.029
Diabetes mellitus	4.66 (1.96, 11.11)	<0.001
Myocardial infarction	5.86 (2.05, 16.77)	<0.001
Major bleeding	4.40 (1.48, 13.14)	0.008
Concomitant TV surgery		
Age, per 10 years	1.42 (1.25, 1.62)	<0.001
Female sex	0.65 (0.48, 0.89)	0.007
History of PPM/ICD	2.16 (1.08, 4.33)	0.030
Chronic kidney disease	2.51 (1.75, 3.59)	<0.001
Coagulopathy	4.24 (2.54, 7.09)	<0.001
Medical center	0.66 (0.44, 0.98)	0.038
Concomitant CABG	1.84 (1.23, 2.77)	0.003
Maze	0.52 (0.32, 0.86)	0.011

TV, tricuspid valve; CI, confidence interval; PPM, permanent pacemaker; ICD, intracardiac defibrillator; CABG, coronary artery bypass graft.

Table S9. Sensitivity analysis to unmeasured confounding.

Population / Falsification end point	Data before IPTW‡			Data after IPTW†		Data after IPTW†	
						Repair *vs*. Replacement	
	Total	Repair	Replacement	Repair	Replacement	SHR (95% CI)	*P* value
Isolated							
Patients number	304	183	121	—	—	—	—
Incident fracture	15 (4.9)	6 (3.3)	9 (7.4)	2.5%	6.6%	0.39 (0.13, 1.20)	0.102
New-diagnosed malignancy	16 (5.3)	8 (4.4)	8 (6.6)	3.6%	4.3%	0.82 (0.30, 2.26)	0.702
Concomitant							
Patients number	2,112	1,833	279	—	—	—	—
Incident fracture	142 (6.7)	128 (7.0)	14 (5.0)	7.2%	4.9%	1.33 (0.62, 2.84) §	0.460
New-diagnosed malignancy	135 (6.4)	113 (6.2)	22 (7.9)	6.2%	6.5%	0.85 (0.45, 1.61) §	0.624

SHR, subdistribution hazard ratio; CI, confidence interval;

‡ Value are given as number (%) or mean±SD;

† Values are given as % or mean±SD;

§ Additionally adjusted for age and CABG.