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ORIGINAL RESEARCH

Determinants of Morbidity and Mortality Associated With Isolated Tricuspid Valve Surgery

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BACKGROUND: Whether the poor outcomes of isolated tricuspid valve surgery are related to the operation itself or to certain patient characteristics including late referral is unknown.

METHODS AND RESULTS: Adult patients who underwent isolated tricuspid valve surgery were identified in the Nationwide Readmissions Database (2016–2017). Patients who had redo tricuspid valve surgery, endocarditis, or congenital heart disease were excluded. Multivariable logistic regression was performed to identify contributors to postoperative mortality. A total of 1513 patients were included (mean age 55.7±16.6 years, 49.6% women). Surrogates of late referral were frequent: 41% of patients were admitted with decompensated heart failure, 44.3% had a nonelective surgery status, 16.8% had advanced liver disease, and 31% had an unplanned hospitalization in the prior 90 days. The operation was performed on day 0 to 1 of the hospitalization in only 50% of patients, and beyond day 10 in 22% of patients. In-hospital mortality occurred in 8.7% of patients. Median length of stay was 14 days (7–35 days), and median cost was $87 223 ($43 122–$200 872). In multivariable logistic regression analysis, surrogates for late referrals (acute heart failure decompensation, nonelective surgery status, or advanced liver disease) were the strongest predictors of in-hospital mortality (odds ratio [OR], 4.75; 95% CI, 2.74–8.25 [*P*<0.001]). This was also consistent in a second model incorporating unplanned hospitalizations in the 90 days before surgery as a surrogate for late referral (OR, 5.50; 95% CI, 2.28–10.71 [*P*<0.001]).

CONCLUSIONS: The poor outcomes of isolated tricuspid valve surgery may be largely explained by the late referral for intervention. Studies are needed to determine the role of early intervention for severe isolated tricuspid regurgitation.

Key Words: heart failure ■ tricuspid regurgitation ■ tricuspid valve repair ■ tricuspid valve replacement

Isolated tricuspid valve (TV) surgery for severe tricuspid regurgitation (TR) is rarely performed in the United States.[1] This underutilization has been attributed to 2 major factors: (1) the lack of strong societal recommendations for isolated TV repair or replacement, which reflects the paucity of large-scale data on the utility of isolated TV surgery[2]; and (2) the high documented morbidity and mortality associated with isolated TV operations even in contemporary practice, possibly keeping physicians away from referring to surgery.[1,3–8] However, the poor outcomes associated with isolated TV may be related to the underlying risk profile of patients who are referred to surgery at later stages of their disease.[3] A recent study by Axtell et al[9] showed that isolated TV surgery in patients and high prevalence (72%) of heart failure (HF) did not improve survival compared with propensity-matched patients who were treated medically. Another study by Hamandi et al[10] showed that isolated TV in carefully selected patients can be performed with low morbidity and mortality. Furthermore, the recent advances in transcatheter TV interventions have refueled the interest in better understanding of TR and the

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CLINICAL PERSPECTIVE

What Is New?

- The high in-hospital mortality rate associated with isolated tricuspid valve surgery is mainly related to late referral to surgery.

What Are the Clinical Implications?

- A strategy of early referral to surgery in patients with severe isolated tricuspid regurgitation may improve clinical outcomes among these patients.

Nonstandard Abbreviations and Acronyms

HCUP	Healthcare Cost and Utilization Project
NRD	Nationwide Readmissions Database
TR	tricuspid regurgitation
TV	tricuspid valve

drivers of adverse events associated with its treatment in light of the persistent high mortality among patients successful treated with transcatheter TV repair.[11–13] In this study, we hypothesized that the morbidity and mortality of isolated TR surgery in current US practice is largely explained by the patient's risk profile and the late presentation/referral for surgery. We utilized a national representative database to assess the impact of comorbidities and surrogates of advanced disease/late referral on isolated TV surgery outcomes.

METHODS

Study Data

The Nationwide Readmissions Database (NRD) was used to derive patient-relevant information. The NRD is a publicly available, all-payer data set of inpatient stays in hospitals from 28 geographically dispersed states, accounting for ≈60% of hospitalizations in the United States annually. The NRD also contains verified patient linkage numbers that can be used to track readmissions among hospitals for individual patients within the same calendar year. The institutional review board exempted the study because it utilizes public deidentified data.

Study Population

We identified patients aged >18 years who had isolated TV surgery between January 1, 2016, and December 31, 2017, in the NRD using *International Classification of Diseases, Tenth Revision, Clinical Modification* (*ICD-10-CM*) codes (Table S1). Patients with congenital heart disease, endocarditis, or prior cardiac surgery (including prior TV repair/replacement), and those undergoing a concomitant cardiac surgery (coronary artery bypass grafting; aortic, mitral, or pulmonic valve surgery) were excluded (Figure 1). Referral to surgery was considered late if the patient was admitted with acute HF decompensation or had a nonelective surgery status, advanced liver disease, or an unplanned hospitalization within the 90 days before surgery. The *ICD-10-CM* codes used to define acute HF and advanced liver disease are listed in Table S1. Surgery was considered nonelective if the patient was admitted via the emergency department, transferred from another acute care facility, and coded as "nonelective" in the NRD.

Outcomes Measured

The study has 2 specific aims: (1) to describe the risk profile and outcomes of patients undergoing isolated TV surgery in a contemporary US cohort; and (2) to identify the contributors to in-hospital mortality after isolated TV surgery.

Statistical Analysis

Descriptive statistics were presented as frequencies with percentages for categorical variables. Mean, SD, median, and interquartile ranges were reported for continuous measures. Baseline characteristics were compared between patients who survived and those who did not survive using a Pearson chi-square test for categorical variables and an independent-samples *t* test or Wilcoxon rank sum for continuous variables. To estimate the cost of hospitalization, the NRD data were merged with cost-to-charge ratios available from the Healthcare Cost and Utilization Project (HCUP). We estimated the cost of each inpatient stay by multiplying the total hospital charge with cost-to-charge ratios. Predictors of in-hospital mortality were assessed in univariate logistic regression analysis. Variables with a *P* value <0.1 in the univariate analysis were then further assessed in a multivariable logistic

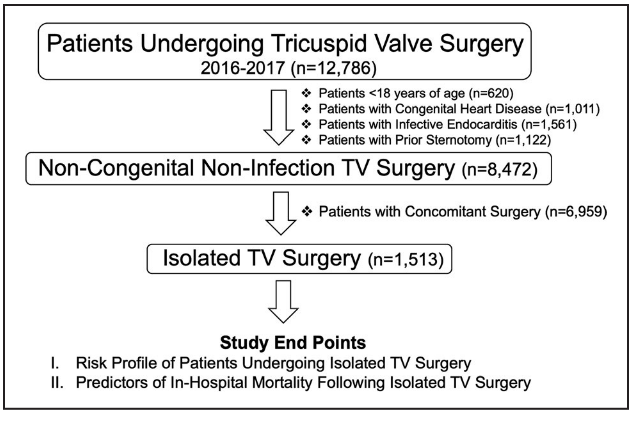

Figure 1. Study flow chart.
TV indicates tricuspid valve.

regression analysis. Two logistic regression analyses were performed: model 1 including the overall cohort and defined late referral as the presence of acute HF decompensation, a nonelective surgery status, or advanced liver disease; and model 2, which defined late referral as the presence of acute HF decompensation, a nonelective surgery status, advanced liver disease, or unplanned hospitalization in the 90 days before surgery. For model 2 we excluded patients discharged in January to March because the NRD does not track patients across calendar years. Our analyses were consistent with the recommendations provided by the HCUP. Type I error <0.05 was considered statistically significant. Odds ratios (ORs) and 95% CIs are used to report the results of regression analysis. Statistical analyses were performed using SPSS version 24 (IBM).

Sensitivity Analysis

We aimed to assess the impact of late referral on the outcomes of TV surgery. However, the parameters that we selected as surrogates for late referral could potentially be colinear (eg, nonelective admission and acute HF decompensation). Hence, to confirm that this does not have a major impact on our results, we performed sensitivity analysis that considered various definitions for late referrals (acute HF or nonelective admission or advanced liver disease; acute HF or advanced liver disease; nonelective admission or advanced liver disease; acute HF alone; nonelective admission alone). We also performed another sensitivity analysis excluding patients with advanced liver disease from the analysis as the presence of advanced liver disease is traditionally a contraindication to surgery.

RESULTS

Characteristics of Patients Undergoing Isolated TV Surgery

A total of 1513 patients who underwent isolated TV surgery were included. The mean age of patients was 55.7±16.6 years, and 49.6% were women. Valve repair was performed in 63.5%, and replacement in 36.5%, mostly with tissue valves (84.6%). Cardiac comorbidities were common including chronic congestive HF (70.5%), atrial fibrillation (50.1%), pulmonary hypertension (34.7%), and conduction disorders (19.3%). Right heart catheterization (RHC) before surgery was only used in 22.4% of patients. Surrogates of late referral were frequent, including 41% of patients admitted with acute decompensated HF, 44.3% had nonelective surgery status, 16.8% had advanced liver disease, and 31% had at least 1 unplanned hospitalization in the 90 days before the index surgery hospitalization (Table 1 and Figure 2).

Characteristics and Outcomes of Isolated TV Surgery

Isolated TV surgery was performed on day 0 to 1 of the hospitalization in only 50% of patients, and beyond day 10 in 22% of patients (Figure 3). Valve replacement was required in 36.5% of patients, mostly with a tissue prosthesis (85%). In-hospital mortality occurred in 132 patients (8.7%). Acute kidney injury and prolonged ventilation were the most common complications following surgery (Table 2). Isolated TV surgery was associated with substantial resource utilization: the median length of stay was 14 days (25th–75th percentile, 7–35 days), and 84.7% of patients had a length of stay >5 days. Median hospital cost was \$87 223 (25th–75th percentile, \$43 122–200 872). Discharge to an intermediate care facility (versus home) was needed in 20.8% of patients.

Predictors of Mortality After Isolated TV Surgery

In a multivariable logistic regression analysis, surrogates for late referrals (acute HF decompensation, nonelective surgery status, and advanced liver disease) were the strongest predictors of in-hospital mortality (OR, 4.75; 95% CI, 2.74–8.25 [$P<0.001$]) (Table 3). This was consistent in a second model incorporating unplanned hospitalizations in the 90 before surgery as a surrogate for late referral (OR, 5.50; 95% CI, 2.28–10.71 [$P<0.001$]) (Table S2). In sensitivity analyses considering various definitions of late referral, the presence of late referral remained the strongest independent predictor of in-hospital mortality (Tables S3 through S7).

DISCUSSION

The main findings of this investigation are that: (1) patients referred for TV surgery are frequently referred late evidenced by the high prevalence of advanced liver disease, acute decompensated congestive heart failure, nonelective surgical status, and substantial rates of unplanned readmissions before surgery; (2) isolated TV surgery remains associated with considerable morbidity, mortality, and cost in the contemporary era; and (3) surrogates for late presentation/referral to surgery were the strongest predictors of mortality after isolated TV surgery.

There is a growing interest in the treatment of severe isolated TR in recent years, fueled by the unprecedented advances in transcatheter TV interventions.[11–14] A major premise of the emerging innovative transcatheter

Table 1. Baseline Characteristics of the Study Cohort

Baseline Characteristics	All Patients (N=1513)	Survivors (n=1381)	Nonsurvivors (n=132)	*P* Value
Demographics				
Age, mean±SD, y	55.7±16.6	55.1±16.8	62.7±12.7	<0.001
Women, %	49.6	50.1	44.7	0.23
Medicare/Medicaid insurance, %	65.4	65.5	65.2	0.62
Lowest quartile household income, %	27.6	28.0	23.3	0.31
Rural hospital location, %	24.3	24.1	25.8	0.67
Teaching hospital, %	92.1	91.7	95.5	0.13
Large hospital bed, %	83.0	82.6	87.1	0.31
Clinical risk factors, %				
Cardiovascular comorbidities				
Smoking	11.6	12.4	3.8	0.003
Hypertension	41.4	40.3	53.0	0.005
Diabetes mellitus	37.4	37.8	33.3	0.31
Chronic HF	70.5	69.1	86.3	<0.001
Atrial fibrillation	50.1	50.5	46.2	0.35
Peripheral vascular disease	4.8	4.5	8.3	0.05
Carotid artery disease	0.4	0.4	0.8	0.49
Coronary artery disease	22.0	22.2	20.5	0.62
Prior stroke	5.6	5.9	2.3	0.08
Conduction disorders	19.3	19.6	15.9	0.30
Prior pacemaker	6.1	6.4	3.0	0.12
Prior defibrillator	10.3	10.4	9.1	0.63
Pulmonary hypertension	34.7	35.0	31.8	0.47
Noncardiovascular comorbidities				
Chronic obstructive lung disease	11.3	11.7	6.8	0.09
Home oxygen therapy	2.7	2.7	3.0	0.81
Anemia	23.8	24.0	21.2	0.47
Chronic kidney disease	36.2	32.7	53.8	<0.001
Dialysis dependence	2.4	2.5	2.3	0.89
Liver disease	19.2	16.7	44.7	<0.001
Advanced liver disease	16.8	14.3	42.4	<0.001
Dementia	0.5	0.4	1.5	0.06
Malignancy	8.7	8.7	9.1	0.87
Obesity	15.7	16.5	6.8	0.003
Surrogates of late referral				
Acute decompensated HF	41.0	38.9	63.6	<0.001
Nonelective surgery	44.3	42.8	71.2	<0.001
Unplanned admissions before surgery				
Within 30 d	17.0	15.9	29.7	<0.001
Within 90 d	31.0	29.7	44.5	<0.001
Within 180 d	37.9	36.2	57.9	0.001

HF indicates heart failure.

solutions is to reduce the substantial morbidity and mortality associated with isolated TV surgery. However, the unfavorable performance of TV surgery may not be related to the surgery itself but rather to the late stages at which patients are being referred. Nonetheless, large-scale data on the predictors of poor outcomes after isolated TV surgery in the United States remain scarce. In this study, we sought to address this knowledge gap by assessing determinants of mortality after isolated TV surgery in a contemporary cohort (2016–2017).

We first described the risk profile of patients who underwent isolated TV surgery for TR. We found that

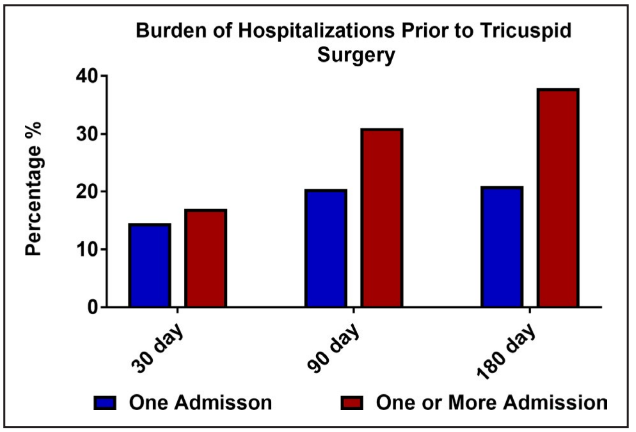

Figure 2. Burden of hospitalizations in the 180 before isolated tricuspid valve surgery.

many of these patients are being referred at late stages of their disease; 41% were admitted with decompensated HF, 44.3% had nonelective surgery status, 16.8% had advanced liver disease, and 31% had unplanned hospitalizations in the 90 days before surgery hospitalization. Reasons for late referral among these patients are likely multifactorial. First, grading of TR is rarely quantitative on routine echocardiographic examinations. Even when quantification is attempted, the highly dynamic nature of TR, with respiratory, load, and beat-to-beat variability, leads to considerable quantitative challenges. This results in a considerable fraction of patients with true severe TR on quantitative evaluation who are reported to have "moderate TR" on 2-dimensional/Doppler echocardiography.[6,15–17] Second, there are no strong indications for surgery in patients with isolated severe TR in current societal guidelines. The American Heart Association/American College of Cardiology guidelines assign a class IIB recommendation for isolated TV surgery and only in patients with severe (stage D) symptoms or those with progressive right ventricular dysfunction. This leads to an inherent referral bias, as patients who should be considered for surgery per the guidelines may already have advanced and perhaps irreversible disease.[18] Third, the poor outcomes of isolated TV surgery documented in multiple studies may deter physicians from referring for surgery.[1,6,9]

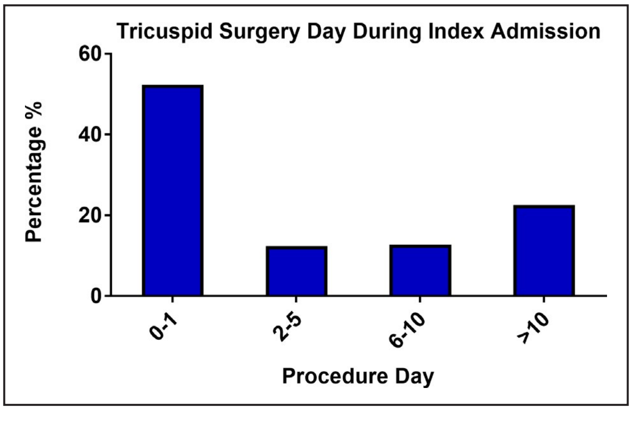

Figure 3. Timing of surgery during admission for isolated tricuspid surgery.

We then described the characteristics and the in-hospital outcomes of isolated TV surgery in this most updated national survey of TV surgery in the United States. Our study illustrated that only half of the patients who had isolated TV surgery had the operation on day 0 to 1 of the admission, and ≈25% of them had surgery after >10 days into their hospitalizations. This also supports the hypothesis that patients referred for TV surgery are frequently considered for surgery late compared with those referred for mitral valve surgery for instance. In this study, we also found an increase in valve repair rate compared with prior reported repair rates.[4] However, this could be related to the differences in the centers included in the different data sets used in these studies. Our analysis also documented a persistently high (>8%) in-hospital mortality rate after isolated TV surgery in contemporary practice (2016–2017). This is consistent with prior studies demonstrating similarly high operative mortality with isolated TV surgery among cohorts of patients who underwent the operation before 2014.[1,4,6] Although small single-center studies have shown much lower operative mortality with isolated TV surgery, our study represents a 60% national sample and therefore is more representative of the nationwide practice than that in selected experienced centers.[7,10]

A key finding in our study is the strong association between late referral and in-hospital mortality. Albeit intuitive, this association has not been documented in a contemporary nationwide cohort and has important implications. This finding supports the hypothesis that the isolated TV operation itself may not be as high risk as it is perceived, as its poor outcomes are indeed mostly explained by the high-risk features of patients who are referred for it at late stages of their disease. This argues for the need of a better understanding of TR, its staging, and the optimal timing for intervention.[3] The current emphasis in the valve community is to invest in transcatheter novel transcatheter approaches to treat TR. However, even when those transcatheter therapies become mature and well validated, they will likely have similar issues of treating TR at its late stages. Indeed, patients referred for transcatheter TV intervention in the current era are significantly older (mid-70s) and have poor midterm prognosis even when successful reduction in TR is achieved.[13] In addition to developing minimally invasive therapies for what appears to be a commonly undertreated problem, considerations should be given to construct parallel studies to optimize clinical and imaging assessment of isolated TR and to assess the role of early intervention in its management irrespective of the treatment modality (medical therapy versus transcatheter or surgical interventions). This is especially prudent

Table 2. Characteristics and Outcomes of Isolated Valve Surgery

Clinical Outcomes	All Patients (N=1513)	Survivors (n=1381)	Nonsurvivors (n=132)	*P* Value
Valve repair	63.5	63.3	65.9	0.55
Valve replacement	36.5	36.7	34.1	0.55
With tissue valve	30.9	31.1	28.8	0.58
With mechanical valve	5.6	5.6	5.3	0.90
Cardiogenic shock	26.8	24.0	56.1	<0.001
Intra-aortic balloon pump	10.0	9.3	16.7	<0.001
Impella device	2.7	2.1	9.1	<0.001
Extracorporeal membrane oxygenation	3.6	2.2	17.4	<0.001
Acute ischemia stroke	1.2	0.9	4.5	<0.001
Acute hemorrhagic stroke	0.9	0.2	7.6	<0.001
Acute kidney injury	41.3	37.1	85.6	<0.001
New dialysis	4.2	3.0	16.7	<0.001
Blood transfusion	24.3	24.4	23.5	0.81
Vascular complication	6.7	5.7	16.7	<0.001
Non–ST-segment–elevation myocardial infarction	4.5	3.7	12.9	0.78
ST-segment–elevation myocardial infarction	1.3	1.2	1.5	0.60
Tracheostomy	0.5	0.4	0.8	<0.001
Gastrointestinal bleed	7.1	5.4	24.2	<0.001
Prolonged mechanical ventilation	20.2	16.5	58.3	0.08
Permanent pacemaker implantation	9.5	9.9	5.2	<0.001
Length of stay, median (25th–75th percentile)	14 (7–35)	13 (7–32)	31 (15–49)	<0.001
Hospital cost in US$, median (25th–75th percentile)	87 223 (43 122–200 872)	78 841 (41 796–183 618)	212 297 (122 606–393 438)	<0.001
Length of stay >5 d	84.7	84.4	87.9	0.29
Palliative care consultation	4.8	2.5	29.5	<0.001
Non-home discharge	20.8	20.8	0.0	NA

All values are presented as percentages unless otherwise indicated. NA indicates not available.

considering the increasing use of right minithoracotomy approach in valve surgery and its potential utility in the TV space.[19–22] Last, it has been shown that TV repair may confer better outcomes than TV replacement.[23] However, in this analysis, TV replacement was not an independent predictor of mortality. This may be because of the dominant association between late referral and mortality over other potentially important associations. Additional studies are needed to delineate the role of valve repair in timely referred patients.

Limitations

Our study has a number of limitations. First, data in the NRD are collected primarily for billing purposes and hence are subject to undercoding or overcoding. However, coding for major procedures, major complications, and in-hospital mortality are less prone to coding errors as they are key determinants of reimbursement. Also, because of the administrative nature of the database, granular information on patient's symptomatic status, duration of TR, medical therapy before surgery, and cause of operative death is not available. Second, we are unable to distinguish in this study between patients who underwent surgery for primary versus secondary TR. However, the majority of TV surgery is performed for secondary functional TR and hence this limitation is unlikely to impact the overall results. In addition, we excluded common reasons for primary TV surgery such as those related to adult congenital heart disease and endocarditis and had low prevalence of other potential cause for primary TR such as prior pacemaker placement. Furthermore, the prevalence of chronic HF in >70% of studied patients suggests a secondary TR cause in the majority of patients. Third, by limiting our patient cohort to those with isolated TR, we may have excluded the majority of patients with TR. However, the aim of this study was to address the population of severe isolated TR. Additional studies with more granular data will be needed to adjust for concomitant valve disease to study the larger population of TR. Fourth, echocardiographic (eg, right ventricular function), laboratory, and hemodynamic data were not available in the NRD. Hence, possible surrogates of late referral such as right ventricular dysfunction, TV annular dilation, and inferior vena cava incompressibility could not be assessed.

Table 3. Predictors of In-Hospital Mortality Following Isolated TV Surgery

Predictors of In-Hospital Mortality	Univariate Regression				Multivariate Regression			
	OR	95% CI		*P* Value	OR	95% CI		*P* Value
Demographics								
Age	1.03	1.02	1.04	<0.001	1.03	1.02	1.05	<0.001
Female sex	0.79	0.55	1.14	0.21				
Medicare insurance (vs private)	0.93	0.63	1.37	0.67				
Lowest income (vs highest)	0.89	0.52	1.52	0.68				
Rural hospital location	1.09	0.72	1.64	0.67				
Teaching hospital	0.53	0.23	1.23	0.14				
Large hospital bed (vs small)	1.42	0.84	2.41	0.19				
Cardiovascular comorbidities								
Hypertension	1.67	1.17	2.39	0.005	0.86	0.56	1.32	0.49
Diabetes mellitus	0.82	0.56	1.20	0.31				
Atrial fibrillation	0.84	0.59	1.21	0.35				
Peripheral vascular disease	1.93	0.99	3.77	0.05	1.20	0.60	2.42	0.61
Coronary artery disease	1.11	0.71	1.72	0.65				
Prior stroke	0.37	0.12	1.20	0.10	0.40	0.12	1.30	0.127
Conduction disorders	0.77	0.48	1.26	0.30				
Prior pacemaker	0.45	0.16	1.25	0.13				
Prior defibrillator	0.86	0.46	1.59	0.63				
Pulmonary hypertension	0.87	0.59	1.27	0.48				
Noncardiovascular comorbidities								
Home oxygen therapy	1.13	0.40	3.23	0.81				
Anemia	0.85	0.55	1.31	0.47				
Chronic kidney disease	2.24	1.56	3.21	<0.001	1.54	1.01	3.38	0.047
Malignancy	1.05	0.56	1.96	0.88				
TV replacement	0.89	0.61	1.30	0.55				
Surrogates for late referral*	3.99	2.49	6.38	<0.001	4.75	2.74	8.25	<0.001

OR indicates odds ratio; and TV, tricuspid valve.
*Nonelective admission or acute decompensated heart failure or advanced liver disease.

Despite these limitations, this data set represents the most contemporary nationwide data set of patients with isolated TR undergoing TV surgery.

CONCLUSIONS

The poor outcomes associated with isolated TV surgery may largely be caused by the late referral for intervention. Studies are needed to determine the role of early intervention in patients with severe isolated TR.

ARTICLE INFORMATION

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Disclosures

None.

Supplementary Material

Tables S1–S7

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SUPPLEMENTAL MATERIAL

Table S1. International Classification of Diseases, 10th Revision, Clinical Modification Codes Used in the Study.

Tricuspid Valve Repair	*** Annuloplasty:** 02UJ07Z Supplement Tricuspid Valve with Autologous Tissue Substitute, Open Approach 02UJ08Z Supplement Tricuspid Valve with Zooplastic Tissue, Open Approach 02UJ0JZ Supplement Tricuspid Valve with Synthetic Substitute, Open Approach *** Other Repair:** 027J04Z Dilation of Tricuspid Valve with Drug-eluting Intraluminal Device, Open Approach 027J0DZ Dilation of Tricuspid Valve with Intraluminal Device, Open Approach 027J0ZZ Dilation of Tricuspid Valve, Open Approach 02NJ0ZZ Release Tricuspid Valve, Open Approach 02QJ0ZZ Repair Tricuspid Valve, Open Approach
Tricuspid Valve Replacement	*** Tissue valve replacement:** 02RJ07Z Replacement of Tricuspid Valve with Autologous Tissue Substitute, Open Approach 02RJ08Z Replacement of Tricuspid Valve with Zooplastic Tissue, Open Approach 02RJ0KZ Replacement of Tricuspid Valve with Nonautologous Tissue Substitute, Open Approach *** Mechanical valve replacement:** 02RJ0JZ Replacement of Tricuspid Valve with Synthetic Substitute, Open Approach
Mitral Valve Repair	*** Annuloplasty:** 02UG07Z Supplement Mitral Valve with Autologous Tissue Substitute, Open Approach 02UG08Z Supplement Mitral Valve with Zooplastic Tissue, Open Approach 02UG0JZ Supplement Mitral Valve with Synthetic Substitute, Open Approach 02UG0KZ Supplement Mitral Valve with Nonautologous Tissue Substitute, Open Approach *** Other Repair:** 027G04Z Dilation of Mitral Valve with Drug-eluting Intraluminal Device, Open Approach 027G0DZ Dilation of Mitral Valve with Intraluminal Device, Open Approach 027G0ZZ Dilation of Mitral Valve, Open Approach 02NG0ZZ Release Mitral Valve, Open Approach 02QG0ZZ Repair Mitral Valve, Open Approach 02VG0ZZ Restriction of Mitral Valve, Open Approach 028D0ZZ Division of Papillary Muscle, Open Approach 02QD0ZZ Repair Papillary Muscle, Open Approach 02890ZZ Division of Chordae Tendineae, Open Approach 02Q90ZZ Repair Chordae Tendineae, Open Approach 02QG0ZZ Repair Mitral Valve, Open Approach
Mitral Valve Replacement	*** Tissue valve replacement:** 02RG07Z Replacement of Mitral Valve with Autologous Tissue Substitute, Open Approach 02RG08Z Replacement of Mitral Valve with Zooplastic Tissue, Open Approach 02RG0KZ Replacement of Mitral Valve with Nonautologous Tissue Substitute, Open Approach *** Mechanical valve replacement:** 02RG0JZ Replacement of Mitral Valve with Synthetic Substitute, Open Approach
Congenital Heart Disease Diagnoses	Q22 Congenital malformations of pulmonary and tricuspid valves Q24 Other congenital malformations of heart Q23.8 Other congenital malformations of aortic and mitral valves Q24.8 Other specified congenital malformations of heart Q20.0 Common arterial trunk Q20.1 Double outlet right ventricle Q20.2 Double outlet left ventricle Q20.3 Discordant ventriculoarterial connection Q20.4 Double inlet ventricle Q20.5 Discordant atrioventricular connection Q20.8 Other congenital malformations of cardiac chambers and connections

	Q20.9 Congenital malformation of cardiac chambers and connections, unspecified Q21.0 Ventricular septal defect Q21.2 Atrioventricular septal defect Q21.3 Tetralogy of Fallot Q21.4 Aortopulmonary septal defect Q21.8 Other congenital malformations of cardiac septa Q21.9 Congenital malformation of cardiac septum, unspecified Q22.0 Pulmonary valve atresia Q22.1 Congenital pulmonary valve stenosis Q22.2 Congenital pulmonary valve insufficiency Q22.3 Other congenital malformations of pulmonary valve Q22.4 Congenital tricuspid stenosis Q22.5 Ebstein's anomaly Q22.6 Hypoplastic right heart syndrome Q22.8 Other congenital malformations of tricuspid valve Q22.9 Congenital malformation of tricuspid valve, unspecified Q23.0 Congenital stenosis of aortic valve Q23.1 Congenital insufficiency of aortic valve Q23.2 Congenital mitral stenosis Q23.3 Congenital mitral insufficiency Q23.4 Hypoplastic left heart syndrome Q23.8 Other congenital malformations of aortic and mitral valves Q23.9 Congenital malformation of aortic and mitral valves, unspecified Q24.2 Cor triatriatum Q24.3 Pulmonary infundibular stenosis Q24.4 Congenital subaortic stenosis Q24.9 Congenital malformation of heart, unspecified Q25.5 Atresia of pulmonary artery Q25.6 Stenosis of pulmonary artery
Infective Endocarditis	I33.0 Acute and subacute infective endocarditis I39 Endocarditis and heart valve disorders in diseases classified elsewhere I33.9 Acute and subacute endocarditis, unspecified
Acute Heart Failure	I50.21 Acute systolic (congestive) heart failure I50.23 Acute on chronic systolic (congestive) heart failure I50.31 Acute diastolic (congestive) heart failure I50.33 Acute on chronic diastolic (congestive) heart failure I50.41 Acute combined systolic (congestive) and diastolic (congestive) HF I50.43 Acute on chronic combined systolic (congestive) and diastolic (congestive) heart failure
Advanced Liver Disease	K70.11 Alcoholic hepatitis with ascites K70.2 Alcoholic fibrosis and sclerosis of liver K70.3 Alcoholic cirrhosis of liver K70.31 Alcoholic cirrhosis of liver with ascites K70.4 Alcoholic hepatic failure K70.40 Alcoholic hepatic failure without coma K70.41 Alcoholic hepatic failure with coma K71.1 Toxic liver disease with hepatic necrosis

	K71.10 Toxic liver disease with hepatic necrosis without coma K71.11 Toxic liver disease with hepatic necrosis with coma K71.7 Toxic liver disease with fibrosis and cirrhosis of liver K72 Hepatic failure, not elsewhere classified K72.0 Acute and subacute hepatic failure K72.00 Acute and subacute hepatic failure without coma K72.01 Acute and subacute hepatic failure with coma K72.1 Chronic hepatic failure K72.10 Chronic hepatic failure without coma K72.11 Chronic hepatic failure with coma K72.9 Hepatic failure, unspecified K72.90 Hepatic failure without coma K72.91 Hepatic failure with coma K73.0 Chronic persistent hepatitis, not elsewhere classified K73.2 Chronic active hepatitis, not elsewhere classified K74 Fibrosis and cirrhosis of liver K74.0 Hepatic fibrosis K74.1 Hepatic sclerosis K74.2 Hepatic fibrosis with hepatic sclerosis K74.3 Primary biliary cirrhosis K74.4 Secondary biliary cirrhosis K74.5 Biliary cirrhosis, unspecified K74.6 Other and unspecified cirrhosis of liver K74.60 Unspecified cirrhosis of liver K74.69 Other cirrhosis of liver K76.1 Chronic passive congestion of liver K76.2 Central hemorrhagic necrosis of liver K76.3 Infarction of liver K76.6 Portal hypertension K76.7 Hepatorenal syndrome I85 Esophageal varices I85.0 Esophageal varices I85.00 Esophageal varices without bleeding I85.01 Esophageal varices with bleeding I85.1 Secondary esophageal varices I85.10 Secondary esophageal varices without bleeding I85.11 Secondary esophageal varices with bleeding

Table S2. Predictors of In-Hospital Mortality Following Isolated Tricuspid Valve Surgery.

Predictors of In-Hospital Mortality	Univariate Regression				Multivariate Regression			
	OR	95% CI		P value	OR	95% CI		P value
Demographics								
Age	1.03	1.02	1.04	<0.001	1.04	1.02	1.06	<0.001
Female sex	0.79	0.55	1.14	0.21				
Medicare insurance (vs. private)	0.93	0.63	1.37	0.67				
Lowest income (vs. highest)	0.89	0.52	1.52	0.68				
Rural hospital location	1.09	0.72	1.64	0.67				
Teaching hospital	0.53	0.23	1.23	0.14				
Large hospital bed (vs. small)	1.42	0.84	2.41	0.19				
Cardiovascular co-morbidities								
Hypertension	1.67	1.17	2.39	0.005	0.68	0.42	1.11	0.12
Diabetes	0.82	0.56	1.20	0.31				
Atrial fibrillation	0.84	0.59	1.21	0.35				
Peripheral vascular disease	1.93	0.99	3.77	0.05	1.19	0.54	2.61	0.67
Coronary artery disease	1.11	0.71	1.72	0.65				
Prior stroke	0.37	0.12	1.20	0.10	0.29	0.07	1.24	0.09
Conduction disorders	0.77	0.48	1.26	0.30				
Prior pacemaker	0.45	0.16	1.25	0.13				
Prior defibrillator	0.86	0.46	1.59	0.63				
Pulmonary hypertension	0.87	0.59	1.27	0.48				
Non-CV co-morbidities								
Home oxygen therapy	1.13	0.40	3.23	0.81				
Anemia	0.85	0.55	1.31	0.47				
Chronic kidney disease	2.24	1.56	3.21	<0.001	1.74	1.06	2.84	0.03
Malignancy	1.05	0.56	1.96	0.88				
Surrogates for Late Referral*	3.99	2.49	6.38	<0.001	5.50	2.82	10.71	<0.001

OR; odds ratio, CI; confidence interval, CV; cardiovascular

*Non-elective admission or acute decompensated heart failure or advanced liver disease or unplanned admission within 90 days prior to valve surgery

Table S3. Predictors of In-Hospital Mortality Following Isolated Tricuspid Valve Surgery.

Predictors of In-Hospital Mortality	Univariate Regression				Multivariate Regression			
	OR	95% CI		P value	OR	95% CI		P value
Demographics								
Age	1.03	1.02	1.04	<0.001	1.03	1.02	1.04	<0.001
Female sex	0.79	0.55	1.14	0.21				
Medicare insurance (vs. private)	0.93	0.63	1.37	0.67				
Lowest income (vs. highest)	0.89	0.52	1.52	0.68				
Rural hospital location	1.09	0.72	1.64	0.67				
Teaching hospital	0.53	0.23	1.23	0.14				
Large hospital bed (vs. small)	1.42	0.84	2.41	0.19				
Cardiovascular co-morbidities								
Hypertension	1.67	1.17	2.39	0.005	0.82	0.53	1.26	0.37
Diabetes	0.82	0.56	1.20	0.31				
Atrial fibrillation	0.84	0.59	1.21	0.35				
Peripheral vascular disease	1.93	0.99	3.77	0.05	1.30	0.65	2.61	0.46
Coronary artery disease	1.11	0.71	1.72	0.65				
Prior stroke	0.37	0.12	1.20	0.10	0.37	0.11	1.21	0.10
Conduction disorders	0.77	0.48	1.26	0.30				
Prior pacemaker	0.45	0.16	1.25	0.13				
Prior defibrillator	0.86	0.46	1.59	0.63				
Pulmonary hypertension	0.87	0.59	1.27	0.48				
Non-CV co-morbidities								
Home oxygen therapy	1.13	0.40	3.23	0.81				
Anemia	0.85	0.55	1.31	0.47				
Chronic kidney disease	2.24	1.56	3.21	<0.001	1.61	1.05	2.48	0.03
Malignancy	1.05	0.56	1.96	0.88				
Tricuspid valve replacement	0.89	0.61	1.30	0.55				
Surrogates for Late Referral*	3.80	2.53	5.72	<0.001	3.32	2.16	5.08	<0.001

OR; odds ratio, CI; confidence interval, CV; cardiovascular

*Acute decompensated heart failure or advanced liver disease

Table S4. Predictors of In-Hospital Mortality Following Isolated Tricuspid Valve Surgery.

Predictors of In-Hospital Mortality	Univariate Regression				Multivariate Regression			
	OR	95% CI		P value	OR	95% CI		P value
Demographics								
Age	1.03	1.02	1.04	<0.001	1.03	1.02	1.05	<0.001
Female sex	0.79	0.55	1.14	0.21				
Medicare insurance (vs. private)	0.93	0.63	1.37	0.67				
Lowest income (vs. highest)	0.89	0.52	1.52	0.68				
Rural hospital location	1.09	0.72	1.64	0.67				
Teaching hospital	0.53	0.23	1.23	0.14				
Large hospital bed (vs. small)	1.42	0.84	2.41	0.19				
Cardiovascular co-morbidities								
Hypertension	1.67	1.17	2.39	0.005	0.85	0.55	1.32	0.47
Diabetes	0.82	0.56	1.20	0.31				
Atrial fibrillation	0.84	0.59	1.21	0.35				
Peripheral vascular disease	1.93	0.99	3.77	0.05	1.25	0.61	2.54	0.54
Coronary artery disease	1.11	0.71	1.72	0.65				
Prior stroke	0.37	0.12	1.20	0.10	0.38	0.11	1.23	0.10
Conduction disorders	0.77	0.48	1.26	0.30				
Prior pacemaker	0.45	0.16	1.25	0.13				
Prior defibrillator	0.86	0.46	1.59	0.63				
Pulmonary hypertension	0.87	0.59	1.27	0.48				
Congestive heart failure	2.49	1.57	3.96	<0.001	1.39	0.84	2.32	0.20
Non-CV co-morbidities								
Home oxygen therapy	1.13	0.40	3.23	0.81				
Anemia	0.85	0.55	1.31	0.47				
Chronic kidney disease	2.24	1.56	3.21	<0.001	1.38	0.89	2.15	0.15
Malignancy	1.05	0.56	1.96	0.88				
Tricuspid valve replacement	0.89	0.61	1.30	0.55				
Surrogates for Late Referral*	4.52	2.90	7.03	<0.001	4.50	2.81	7.19	<0.001

OR; odds ratio, CI; confidence interval, CV; cardiovascular

*Non-elective admission or advanced liver disease

Table S5. Predictors of In-Hospital Mortality Following Isolated Tricuspid Valve Surgery.

Predictors of In-Hospital Mortality	Univariate Regression				Multivariate Regression			
	OR	95% CI		P value	OR	95% CI		P value
Demographics								
Age	1.03	1.02	1.04	<0.001	1.03	1.02	1.04	<0.001
Female sex	0.79	0.55	1.14	0.21				
Medicare insurance (vs. private)	0.93	0.63	1.37	0.67				
Lowest income (vs. highest)	0.89	0.52	1.52	0.68				
Rural hospital location	1.09	0.72	1.64	0.67				
Teaching hospital	0.53	0.23	1.23	0.14				
Large hospital bed (vs. small)	1.42	0.84	2.41	0.19				
Cardiovascular co-morbidities								
Hypertension	1.67	1.17	2.39	0.005	0.86	0.56	1.33	0.51
Diabetes	0.82	0.56	1.20	0.31				
Atrial fibrillation	0.84	0.59	1.21	0.35				
Peripheral vascular disease	1.93	0.99	3.77	0.05	1.27	0.64	2.54	0.49
Coronary artery disease	1.11	0.71	1.72	0.65				
Prior stroke	0.37	0.12	1.20	0.10	0.35	0.11	1.12	0.07
Conduction disorders	0.77	0.48	1.26	0.30				
Prior pacemaker	0.45	0.16	1.25	0.13				
Prior defibrillator	0.86	0.46	1.59	0.63				
Pulmonary hypertension	0.87	0.59	1.27	0.48				
Decompensated heart failure	***2.75***	***1.90***	***3.98***	***<0.001***	***2.4***	***1.61***	***3.50***	***<0.001***
Non-CV co-morbidities								
Home oxygen therapy	1.13	0.40	3.23	0.81				
Anemia	0.85	0.55	1.31	0.47				
Chronic kidney disease	2.24	1.56	3.21	<0.001	1.72	1.12	2.63	0.01
Malignancy	1.05	0.56	1.96	0.88				
Tricuspid valve replacement	0.89	0.61	1.30	0.55				

OR; odds ratio, CI; confidence interval, CV; cardiovascular

Table S6. Predictors of In-Hospital Mortality Following Isolated Tricuspid Valve Surgery.

Predictors of In-Hospital Mortality	Univariate Regression				Multivariate Regression			
	OR	95% CI		P value	OR	95% CI		P value
Demographics								
Age	1.03	1.02	1.04	<0.001	1.04	1.02	1.05	<0.001
Female sex	0.79	0.55	1.14	0.21				
Medicare insurance (vs. private)	0.93	0.63	1.37	0.67				
Lowest income (vs. highest)	0.89	0.52	1.52	0.68				
Rural hospital location	1.09	0.72	1.64	0.67				
Teaching hospital	0.53	0.23	1.23	0.14				
Large hospital bed (vs. small)	1.42	0.84	2.41	0.19				
Cardiovascular co-morbidities								
Hypertension	1.67	1.17	2.39	0.005	0.87	0.56	1.35	0.53
Diabetes	0.82	0.56	1.20	0.31				
Atrial fibrillation	0.84	0.59	1.21	0.35				
Peripheral vascular disease	1.93	0.99	3.77	0.05	1.17	0.58	2.37	0.66
Coronary artery disease	1.11	0.71	1.72	0.65				
Prior stroke	0.37	0.12	1.20	0.10	0.35	0.11	1.16	0.08
Conduction disorders	0.77	0.48	1.26	0.30				
Prior pacemaker	0.45	0.16	1.25	0.13				
Prior defibrillator	0.86	0.46	1.59	0.63				
Pulmonary hypertension	0.87	0.59	1.27	0.48				
Congestive heart failure	2.49	1.57	3.96	<0.001	1.54	0.93	2.54	0.09
Non-CV co-morbidities								
Home oxygen therapy	1.13	0.40	3.23	0.81				
Anemia	0.85	0.55	1.31	0.47				
Chronic kidney disease	2.24	1.56	3.21	<0.001	1.43	0.92	2.21	0.11
Malignancy	1.05	0.56	1.96	0.88				
Tricuspid valve replacement	0.89	0.61	1.30	0.55				
Non-elective admission	***3.22***	***2.19***	***4.74***	***<0.001***	***3.27***	***2.16***	***4.96***	***<0.001***

OR; odds ratio, CI; confidence interval, CV; cardiovascular

Table S7. Predictors of In-Hospital Mortality Following Isolated Tricuspid Valve Surgery After Excluding Patient with Advanced Liver Disease.

Predictors of In-Hospital Mortality	Univariate Regression				Multivariate Regression			
	OR	95% CI		P value	OR	95% CI		P value
Demographics								
Age	1.04	1.02	1.06	<0.001	1.04	1.02	1.06	<0.001
Female sex	1.01	0.63	1.61	0.95				
Medicare insurance (vs. private)	1.15	0.69	1.91	0.58				
Lowest income (vs. highest)	0.64	0.31	1.32	0.23				
Rural hospital location	0.77	0.46	1.28	0.31				
Teaching hospital	1.75	0.62	4.89	0.28				
Large hospital bed (vs. small)	1.00	1.00	0.23	4.27				
Cardiovascular co-morbidities								
Hypertension	1.67	1.05	2.67	0.02	0.76	0.43	1.32	0.32
Diabetes	1.02	0.63	1.64	0.95				
Atrial fibrillation	1.04	0.65	1.65	0.87				
Peripheral vascular disease	1.14	0.40	3.23	0.80				
Coronary artery disease	0.68	0.36	1.27	0.22				
Prior stroke	0.63	0.19	2.06	0.44				
Conduction disorders	0.61	0.31	1.21	0.15				
Prior pacemaker	0.36	0.09	1.50	0.16				
Prior defibrillator	1.26	0.61	2.59	0.53				
Pulmonary hypertension	1.06	0.65	1.74	0.80				
Non-CV co-morbidities								
Home oxygen therapy	1.52	0.46	5.11	0.49				
Anemia	0.85	0.47	1.51	0.58				
Chronic kidney disease	2.67	1.67	4.26	<0.001	1.94	1.11	3.38	0.02
Malignancy	1.02	0.46	2.28	0.96				
Tricuspid valve replacement	0.75	0.46	1.25	0.27				
Surrogates for Late Referral*	3.44	1.96	6.04	<0.001	3.31	1.84	5.96	<0.001

OR; odds ratio, CI; confidence interval, CV; cardiovascular

*Non-elective admission or acute decompensated heart failure