Outcomes of minimally invasive isolated tricuspid valve repair and replacement through right mini-thoracotomy

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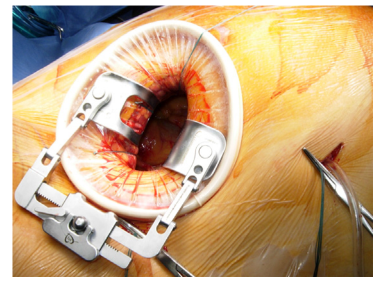
ABSTRACT

Objective: Isolated tricuspid valve surgery is uncommon and associated with high perioperative morbidity and mortality. We aimed to study the overall outcomes of patients who underwent minimally invasive right thoracotomy tricuspid valve surgery (Mini-TVS), consisting of either tricuspid valve repair (TVre) or replacement (TVR).

Methods: We performed a retrospective analysis of all Mini-TVS procedures (2017-2022), through which we identified isolated tricuspid valve surgeries. We examined in-hospital outcomes, survival analysis over a 4-year period, and competing risk analysis for reoperative surgery.

Results: Among a total of 51 patients, the average age was 60 ± 16 years, and 67% (n = 34) were female. Severe tricuspid regurgitation was present in all cases. Infective endocarditis was noted in 7.8% (n = 4), and 24% (n = 12) had preexisting pacemakers. Mini-TVS included TVre in 18 patients (35%) and TVR in 33 patients (65%). The in-hospital and 30-day mortality rates were 4% (n = 2) and 6% (n = 3), respectively. At 4 years, the overall TVS survival was 76% (confidence interval, 62-93%), with no significant difference between TVre and TVR (91% vs 69%, *P* = .16). At follow-up, 3 patients required repeat surgery for recurrent regurgitation after 2.6, 3.3, and 11 months, with a reoperation rate of 7.3% (confidence interval, 2.4-22%) at 2 years. Factors associated with worse overall survival included nonelective surgery, right ventricular dysfunction, serum creatinine >2 g/dL, and concomitant left-sided valve disease.

Conclusions: A nonsternotomy minimally invasive approach is a feasible option for high-risk patients. Midterm outcomes were similar in repair or replacement. Patients with right ventricular dysfunction and left-sided disease had worse outcomes. (JTCVS Open 2024;17:98-110)



Right anterolateral (mini) thoracotomy for tricuspid valve surgery.

CENTRAL MESSAGE

Minimally invasive tricuspid valve surgery can be an important component for achieving excellent outcomes in patients with high operative risk.

PERSPECTIVE

Isolated tricuspid valve surgery is recognized for its high operative risks, particularly in patients with advanced disease or those undergoing nonelective procedures. Minimally invasive surgery demonstrates favorable outcomes for high-risk patients.

Tricuspid valve (TV) disease, often neglected due to its insidious onset and tolerable symptoms, can have a profound impact on patients' lives. Given that this valve is frequently addressed during concomitant surgeries for left-sided valvular diseases, isolated tricuspid valve (ITV) surgery cases tend to involve patients with advanced disease and significant comorbidities. Patients suffering from severe symptomatic tricuspid regurgitation are particularly vulnerable and carry a substantial risk of mortality.[1]

Despite these challenges, the emergence of minimally invasive cardiac surgery techniques has sparked interest in their potential application to tricuspid valve surgery.[2-5] As guidelines are developed for transcatheter options for patients with TV disease,[6] it is imperative to understand the

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Abbreviations and Acronyms

CPB = cardiopulmonary bypass
ICU = intensive care unit
ITV = isolated tricuspid valve
LOS = length of stay
Mini-TVS = minimally invasive right thoracotomy tricuspid valve surgery
RV = right ventricular
TV = tricuspid valve
TVR = tricuspid valve replacement
TVre = tricuspid valve repair
TVS = tricuspid valve surgery
UM = University of Miami

existing context of ITV surgical options, especially performed via a minimally invasive right thoracotomy (Mini-TVS). Therefore, this study aims to contribute to the understanding of the perioperative complications and mortality outcomes associated with Mini-TVS, shedding light on its efficacy and safety in the context of isolated tricuspid valve surgeries.

METHODS

Patient Population

The data for this study were obtained from the "Miami Method" database of the Cardiac Surgery Division of the University of Miami (UM), which includes patients operated on by the same surgeon (J.L.) while he was at Baylor College of Medicine, using a Data Use Agreement (H0641: December 29, 2019). We reviewed the records of all patients who underwent tricuspid valve surgery (TVS) between January 2017 and November 2022. For TVS, we included all symptomatic patients with severe TV regurgitation and mild-to-moderate right ventricular (RV) dysfunction. Patients with intractable ascites and severe RV dysfunction were considered to be at prohibitive surgical risk and excluded from the study.

We analyzed 315 TVS cases, of which 264 were excluded due to associated multivalve surgery, mitral cleft repair, and resection of an intracardiac mass. Additionally, those undergoing sternotomy-based TVS were excluded. As a result, 51 patients were selected for the final analysis.

Written informed consent for the scientific use of the clinical data was waived for all patients as part of the "Miami Method" protocol, approved by UM's institutional review board (20190390: August 14, 2022) and the UM's Human Subject Research Office as part of the "Miami Method" research database.

Outcomes and Covariates

The primary outcomes were in-hospital mortality and overall survival. Secondary outcomes included complications such as stroke, myocardial infarction, transfusions, arrhythmias, prolonged ventilation, and dialysis, in addition to conversion to sternotomy, intensive care unit (ICU) and hospital stay duration, reoperative TVS incidence, and readmissions. Furthermore, we assessed factors associated with mortality.

We assessed baseline patient characteristics, TVS type (tricuspid valve repair [TVre] or tricuspid valve replacement [TVR]), and preoperative hemodynamic parameters. Hemodynamic data were obtained from either transthoracic or transesophageal echocardiography assessment. Additional hemodynamic variables included RV dysfunction (RV ejection fraction $\leq$35% or equivalent echocardiographic parameters), reduced left ventricular ejection fraction (<50%), and pulmonary hypertension (systolic pulmonary artery pressure of 60+ mm Hg). Other covariates included age, New York Heart Association functional class, diabetes, obesity, renal and hepatic function, previous cardiac surgery, surgery on a beating heart, crossclamp and cardiopulmonary bypass times, concomitant arrhythmia surgery, and procedure urgency.

Statistical Analysis

Distributions of quantitative variables were described as means ($\pm$ standard deviation) and/or medians (interquartile range) after normality assessment using the Shapiro–Wilk test and QQ-plots, and categorical variables were summarized by counts (with percentages). Trend plots were constructed for continuous outcome variables. For mortality outcome, survival estimates were calculated from the date of surgery to the date of death or the date last known to be alive (censored observations). We used the Kaplan–Meier method to estimate the overall mortality following Mini-TVS for up to 4 years. To compare survival curves based on patient characteristics, we used the log-rank test. In addition, we employed the standard univariable Cox proportional hazards model to assess the magnitude and direction of survival change in relation to each pertinent variable. For reoperative TVS over the follow-up period, a model of competing risk analysis using the cumulative incidence function was used to calculate the incidence rates, accounting for death as a competing event; in this analysis, patients with previous TVR via sternotomy (n = 1) were excluded. The time-to-event was calculated from the first TVR surgery to the time of reoperative TVR, death, or the last date the patient was known to be alive.

Analysis was performed using R (4.2.2 [2022-10-31 ucrt], R Foundation for Statistical Computing, Vienna, Austria) with multiple packages, including 'gtsummary,' 'survival,' 'cmprsk,' and 'survminer' (Table E1).

Surgical Technique

All surgeries were performed with the patient under general anesthesia. The patient was placed in the supine position, with men positioned with the right arm at their side and women with the arm over their head. With the use of a modified Seldinger technique, peripheral femoral artery and vein cannulation were performed. In those patients with peripheral artery disease, an alternative strategy was employed, cannulating the subclavian artery (accessed below the clavicle when patients were prepped with the arm at the side) and the axillary artery (accessed directly in the axilla when patients were prepped with the arm up) along with the femoral vein.[7] Of note, a screening computed tomography scan was not performed for cannulation planning. Instead, intraoperative fluoroscopy was used if peripheral artery disease was suspected during cannulation.

Thereafter, a 5-cm incision was made over the right chest wall, lateral to the anterior axillary line and subsequently entering the fourth intercostal space. All primary cases underwent direct aortic crossclamping, and most reoperative surgeries were performed with a beating-assisted approach without caval snaring, avoiding dissection in the presence of adhesions. On primary cases, if the operative field was obscured with blood, the venous cannula was pulled into the inferior vena cava and snared, and a sump suction was placed into the superior vena cava directly through the atriotomy and snared. After exposure of the tricuspid valve, a repair or replacement was performed. In 2 cases with endocarditis, a pericardial tube was used to replace the native valve,[8] which could have increased operative times. After closing the atriotomy and discontinuing cardiopulmonary bypass time (CPB), transesophageal echocardiography was used to confirm TV function before approximating the ribs and closing the incision.

RESULTS

Patient Characteristics

Among the 51 patients undergoing Mini-TVS, the mean age was 60 $\pm$ 16 years; 43% had previous median-sternotomy cardiac surgery, most commonly not involving TV. Severe symptomatic TV regurgitation was present in all patients, in which 7.8% was attributed to infective endocarditis and 26% secondary to leaflet damage from a pacer lead. Chronic liver disease was present in 24%, with 7.8% on dialysis, and 22% had RV dysfunction. Elective surgery was performed in 88% (Table 1). Intraoperative echocardiograms revealed that 27% had concomitant mitral or aortic disease (Table 2).

Procedural Characteristics

All patients underwent Mini-TVS without conversion to sternotomy. TVR (65%) and TVre (35%) were performed. Beating-heart surgery was more common in TVR cases (79%), and CPB times were shorter (80 minutes for TVR vs 109 minutes for TVre). Concomitant arrhythmia surgeries were more frequent in TVre cases (39% vs 3%), which included left atrial appendage ligation[9] and/or maze (with cryoenergy) (Table 3).

Outcomes

In-hospital mortality was 4% (n = 2, secondary to pancreatitis and respiratory failure) with 6% at 30 days. No in-hospital postoperative strokes or myocardial infarctions occurred. Fifteen patients required blood transfusions (Table 4). The median ventilation time was 4 hours, with no difference between TVR and TVre (Figure 1, *A*). The median ICU stay was 35 hours, trending higher for TVR (Figure 1, *B*). The median hospital stay was 6 days, trending lower for TVre (Figure 1, *C*).

The median follow-up time was 17 months (interquartile range, 9.3-26.6 months), with a maximum of 55.7 months (4.6 years). Estimated 30-day survival rate was 94%, remaining steady up to 1 year and declining to 76% at 2 years and remaining steady at 76% at 4 years. Survival rates at 1 year were 100% for TVre versus 91% for TVR (Figure 2, *A*). Survival remained constant at 2 and 4 years, with 91% for TVre and 69% for TVR (Figure 2, *B*).

Overall survival did not significantly differ between TVre and TVR (Figure 2, *B*; log-rank $P = .160$). No difference in survival was observed for patients with or without new permanent pacemaker implantation (Figure 2, *C*; log-rank $P = .720$).

The reoperation rate following Mini-TVS was 0% at 1 month, 4.2% at 3 months, and 7.3% at 1 and 2 years (Figure 2, *D*). These patients' original surgeries were TVre (n = 1) or TVR with a bioprosthetic valve (n = 2). Patients with preoperative creatinine >2, mitral valve regurgitation greater than mild, RV dysfunction, or nonelective surgery had a significantly greater risk of mortality ($P < .05$) (Table 5).

DISCUSSION

In our analysis, we have identified several key findings. Mini-TVS demonstrates excellent perioperative outcomes, characterized by low blood transfusion requirements, short length of stay (LOS), and low short- and midterm mortality. Upon follow-up, our cohort exhibited reasonable reoperation rates and favorable midterm survival. Most of our patients presented with multiple comorbidities, including chronic renal and liver diseases, often due to late presentation. Factors associated with decreased overall survival included nonelective surgery, high preoperative creatinine levels, RV dysfunction, and concomitant mitral valve regurgitation (moderate to severe). We did not find a statistically significant difference between TVre and TVR in terms of in-hospital mortality, morbidity, LOS, ventilation, or ICU times, but we observed a potential trend toward decreasing LOS for TVre over the study period.

Our in-hospital mortality of 4% was lower than the 7% reported in a study from the Society of Thoracic Surgeons national database from 2011 to 2020 and was on the lower end of the range reported in previously published Mini-TVS studies (4.1-17%).[10,11] Other studies have reported in-hospital mortality rates within a varying range of 10 to 13%.[12-14] The individualized perioperative care provided by a single surgeon in our Mini-TVS experience may have contributed to the positive surgical outcomes in this cohort. Furthermore, our previous ITV national outcomes study showed no difference in in-hospital mortality between TVR and TVre. The current study adds important midterm outcomes data that demonstrate no increase in mortality between TVR and TVre over time following ITV surgery.[15]

TVre Versus TVR

In patients with primary TV disease, studies demonstrating improved outcomes of TVre versus TVR have reached mixed conclusions.[16-18] Chen and colleagues[19] found that although there was no early mortality difference between the 2 procedures, TVre was associated with fewer adverse outcomes and improved late survival. We did not observe differences in outcomes, but we did see a potential trend toward increasing ICU time over the study period for TVR, whereas TVre had a potential trend of decreasing hospital LOS. These results paralleled those of our national ITV study that showed a trending and statistically significant decrease of the median LOS for TVre, potentially due to evolving surgical practices over time. When our Mini-TVS study outcomes are compared with the national ITV outcomes, which are mainly composed of sternotomy-based cases, we find a lower hospital LOS for TVRe (5 days [4-8] vs 11 days [7-22]) and TVR (6 days [4-8] vs 17 days [8-34]). In our patients who received TVre, one (1/18 vs 3/33 TVR) required reoperative TVR. Chang and colleagues[17] recommend TVR when the TV had hostile pathology or the patient is in critical condition. We agree and consider both of those contexts as more likely to result in inadequate repair, leaving TVR as a better option. For example, in our cohort, most patients with

TABLE 1. Baseline demographic characteristics of the overall cohort

	Tricuspid valve surgery			
Characteristic	Overall N = 51*	Replacement N = 33*	Repair N = 18*	*P* value†
Age, y				.6
Mean (SD)	60 (16)	59 (15)	61 (17)	
Median (IQR)	64 (49, 71)	63 (48, 68)	65 (51, 76)	
Age groups, y				>.9
<45	8 (16%)	5 (15%)	3 (17%)	
45-65	18 (35%)	12 (36%)	6 (33%)	
65+	25 (49%)	16 (48%)	9 (50%)	
Sex				>.9
Female	34 (67%)	22 (67%)	12 (67%)	
Male	17 (33%)	11 (33%)	6 (33%)	
BMI	27.3 (23.4, 30.5)	27.0 (22.5, 29.3)	28.7 (24.5, 31.5)	.2
BMI categories				.4
BMI <25	17 (33%)	12 (36%)	5 (28%)	
BMI 25-29	20 (39%)	14 (42%)	6 (33%)	
BMI 30-39	14 (27%)	7 (21%)	7 (39%)	
Hypertension	32 (63%)	18 (55%)	14 (78%)	.10
Diabetes	9 (18%)	5 (15%)	4 (22%)	.7
Chronic liver disease	12 (24%)	8 (24%)	4 (22%)	>.9
MELD score				.7
No liver disease	39 (78%)	25 (78%)	14 (78%)	
≤9	3 (6.0%)	1 (3.1%)	2 (11%)	
10-19	5 (10%)	4 (12%)	1 (5.6%)	
20-29	3 (6.0%)	2 (6.2%)	1 (5.6%)	
Unknown	1	1	0	
Endocarditis	4 (7.8%)	2 (6.1%)	2 (11%)	.6
PAD	3 (5.9%)	3 (9.1%)	0 (0%)	.5
NYHA 3/4	14 (27%)	10 (30%)	4 (22%)	.7
Creatinine >2 mg/dL	7 (14%)	6 (18%)	1 (5.6%)	.4
Preexisting dialysis	4 (7.8%)	3 (9.1%)	1 (5.6%)	>.9
Preexisting pacemaker	12 (24%)	11 (33%)	1 (0.5%)	**.035**
Previous cardiac surgery	22 (43%)	16 (43%)	6 (33%)	.3
Urgency				.4
Elective	45 (88%)	28 (85%)	17 (94%)	
Nonelective	6 (12%)	5 (15%)	1 (5.6%)	

P <.05 values in bold indicates statistically significant. *SD*, Standard deviation; *IQR*, interquartile range; *BMI*, body mass index; *MELD*, Model of End-Stage Liver Disease; *PAD*, peripheral arterial disease; *NYHA*, New York Heart Association heart failure classification. *Mean (SD); n (%); median (IQR). †Wilcoxon rank sum test; Fisher exact test; Pearson χ^2 test.

pacemaker-induced TV regurgitation had leaflet injury or the lead was fixed to the leaflet; under this context, repair is less favorable than TVR. In contrast, TVre procedures may have the benefit of proving more durable in patients with RV dysfunction if subannular techniques are performed concomitantly along with an annuloplasty,[20,21] similar to mitral valve repair.[22,23]

We used bioprosthetic valves for TVR as the primary prosthesis of choice, consistent with patient preference and most other published series,[24-27] including our national ITV study (75% bioprosthetic [n = 6262] vs 25% mechanic valves [n = 2051] in secondary TV disease [supplementary material]).[15] However, within TVR surgery recommendations, the debate between mechanical versus bioprosthetic prostheses is still ongoing. Said and colleagues[28] found that ITV with a mechanical prosthesis is associated with increased early mortality. This result may be independent of hemodynamic

TABLE 2. Echocardiographic data

	Tricuspid valve surgery			
Characteristic	**Overall N = 51***	**Replacement N = 33***	**Repair N = 18***	***P* value†**
LVEF <50%	7 (14%)	7 (21%)	0 (0%)	.042
RV dysfunction	11 (22%)	10 (30%)	1 (5.6%)	.072
Pulmonary hypertension	4 (7.8%)	1 (3.0%)	3 (17%)	.12
LVEF <50%	7 (14%)	7 (21%)	0 (0%)	.042
Mitral stenosis				
MS (none/trivial)	50 (98%)	0 (97%)	0 (100%)	
MS (mild)	0 (0%)	0 (0%)	0 (0%)	
MS (moderate)	1 (2%)	1 (3%)	0 (0%)	
Mitral regurgitation				.3
MR (none/trivial)	27 (53%)	21 (64%)	6 (33%)	
MR (mild)	16 (31%)	7 (21%)	9 (50%)	
MR (moderate)	7 (14%)	4 (12%)	2 (11%)	
MR (moderate-to-severe)	1 (2%)	1 (3%)	1 (6%)	
Aortic regurgitation				.3
AI (none/trivial)	14 (82%)	11 (85%)	3 (75%)	
AI (mild)	1 (5.9%)	0 (0%)	1 (25%)	
AI (moderate)	2 (12%)	2 (15%)	0 (0%)	
Aortic stenosis				>.9
AS (none/trivial)	18 (95%)	13 (93%)	5 (100%)	
AS (mild)	1 (5.3%)	1 (7.1%)	0 (0%)	
AS (moderate)	0 (0%)	0 (0%)	0 (0%)	
CPB time, min	88 (62, 115)	80 (60, 93)	109 (90, 127)	**.007**
With beating heart	66 (57, 85)	69 (58, 85)	52 (41, 71)	.3
With crossclamp	117 (98, 134)	116 (96, 128)	117 (102, 166)	.6
Beating heart (no crossclamp)	30 (59%)	26 (79%)	4 (22%)	**<.001**
Crossclamp time, min	83 (70, 94)	77 (60, 82)	88 (76, 112)	.2
Concomitant LAAL/maze	8 (16%)	1 (3.0%)	7 (39%)	**.002**

P <.05 values in bold indicates statistically significant. *LVEF*, Left ventricular ejection fraction; *RV*, right ventricle; *MS*, mitral valve stenosis; *MR*, mitral valve regurgitation; *AI*, aortic valve incompetence; *AS*, aortic valve stenosis; *CPB*, cardiopulmonary bypass time; *LAAL*, left atrial appendage ligation; *IQR*, interquartile range. *n (%); median (IQR). †Fisher exact test; Pearson χ^2 test; Wilcoxon rank sum test; Wilcoxon rank sum exact test.

deterioration, given that Altaani and Jaber[29] found no significant hemodynamic difference between the 2 prostheses. In our cohort, the selection of bioprosthetic porcine valves was also supported by their average age at TVR of 59 years and one patient's coagulopathic liver failure. Solomon and colleagues[30] favored bioprosthetic valves because their failure was more predictable and found no difference between bovine and porcine valves. Based on the survival probability

TABLE 3. Operative characteristics

	Tricuspid valve surgery			
Characteristic	**Overall N = 51***	**Replacement N = 33***	**Repair N = 18***	***P* value†**
CPB time, min	88 (62, 115)	80 (60, 93)	109 (90, 127)	**.007**
With beating heart	66 (57, 85)	69 (58, 85)	52 (41, 71)	.3
With crossclamp	117 (98, 134)	116 (96, 128)	117 (102, 166)	.6
Beating heart (no crossclamp)	30 (59%)	26 (79%)	4 (22%)	**<.001**
Crossclamp time, min	83 (70, 94)	77 (60, 82)	88 (76, 112)	.2
Concomitant LAAL/maze	8 (16%)	1 (3.0%)	7 (39%)	**.002**

P <.05 values in bold indicates statistically significant. *CPB*, Cardiopulmonary bypass time; *LAAL*, left atrial appendage ligation; *IQR*, interquartile range. *n (%); median (IQR). †Fisher exact test; Pearson χ^2 test; Wilcoxon rank sum test; Wilcoxon rank sum exact test.

TABLE 4. Surgical outcomes

Characteristic	Tricuspid valve surgery Overall N = 51*	Replacement N = 33*	Repair N = 18*	*P* value†
In-hospital mortality	2 (3.9%)	2 (6.1%)	0 (0%)	.5
Overall survival				
30-d survival	94% (88, 100)	91% (81, 100)	100% (100, 100)	.2
12-mo survival	94% (88, 100)	91% (81, 100)	100% (100, 100)	.2
24-mo survival	76% (62, 93)	69% (52, 92)	91% (75, 100)	.2
Permanent stroke	0 (0%)	0 (0%)	0 (0%)	
Any postoperative RBC transfusion	15 (29%)	9 (27%)	6 (33%)	.6
RBC units				.3
0	36 (71%)	24 (73%)	12 (67%)	
1-2	9 (18%)	5 (15%)	4 (22%)	
3-4	4 (7.8%)	2 (6.1%)	2 (11%)	
5+	2 (3.9%)	2 (6.1%)	0 (0%)	
FFP units				>.9
0	48 (94%)	31 (94%)	17 (94%)	
1-2	2 (3.9%)	1 (3.0%)	1 (5.6%)	
3-4	1 (2.0%)	1 (3.0%)	0 (0%)	
5+	0 (0%)	0 (0%)	0 (0%)	
Platelet units				>.9
0	49 (96%)	31 (94%)	18 (100%)	
1-2	1 (2.0%)	1 (3.0%)	0 (0%)	
3-4	0 (0%)	0 (0%)	0 (0%)	
5+	1 (2.0%)	1 (3.0%)	0 (0%)	
Cryo units				>.9
0	49 (96%)	31 (94%)	18 (100%)	
1-2	1 (2.0%)	1 (3.0%)	0 (0%)	
3-4	1 (2.0%)	1 (3.0%)	0 (0%)	
Perioperative MI	0 (0%)	0 (0%)	0 (0%)	
New postoperative dialysis	2 (3.9%)	2 (6.1%)	0 (0%)	.5
New postoperative Afib	12 (23.5%)	9 (27.2%)	3 (16.6%)	.5
Ventilation time, h	4 (3, 6)	4 (3, 6)	4 (3, 6)	>.9
Prolonged ventilation (>24 h)	2 (3.9%)	2 (6.1%)	0 (0%)	.5
ICU time, h	35 (24, 49)	30 (24, 48)	37 (25, 54)	.5
LOS, d	6.0 (4.0, 8.0)	6.0 (4.0, 8.0)	5.0 (4.0, 8.0)	>.9
30-d readmission	7 (14%)	6 (18%)	1 (5.6%)	.4
Postoperative PPM	7 (14%)	5 (15%)	2 (11%)	>.9

RBC, Red blood cells; *FFP*, fresh-frozen plasma; *MI*, myocardial Infarction; *Afib*, atrial fibrillation; *ICU*, intensive care unit; *LOS*, length of stay; *PPM*, permanent pacemaker; *IQR*, interquartile range. *n (%); median (IQR). †Log rank test; Fisher exact test; Pearson χ^2 test; Wilcoxon rank sum test.

of patients who underwent TVR, we found mortality rates at 1 and 4 years to be 9% and 31%, respectively. In a series of 81 patients (61 ± 16 years) with significant comorbidities, the early- and 10-year mortality rates were 22% and 50%.[31] In this study, there was a low reoperation rate of 2.5% (n = 2), with little valve thrombosis or structural deterioration, and no significant superiority of bioprosthetic over mechanical valves. Multiple other studies did not find survival benefits based on valve type.[32,33]

Reoperation Risk

The reoperative risk in our cohort of 4.2% in 3 months and 7.3% in 1 and 2 years is acceptable, which could be related to the durability of the bioprosthetic valves. Early mortality rates following reoperative TVS range from 35% to 37%, with significant major morbidity up to 65%.[34,35] McCarthy and colleagues[34] reported that 14% of patients whose surgery involves an annuloplasty ring develop moderate-to-severe TV regurgitation within

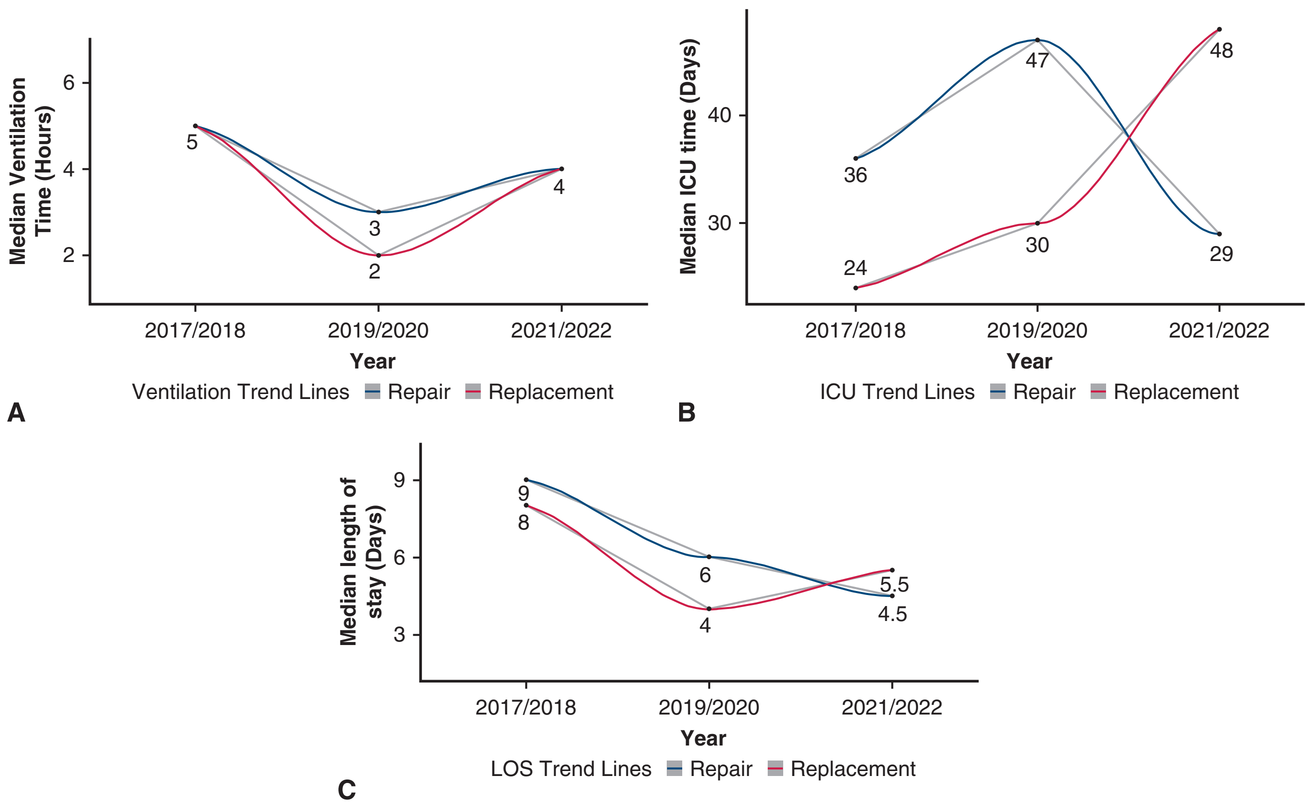

FIGURE 1. Time-based trend analyses of tricuspid valve repair and replacement regarding (A) ventilation time; (B) intensive care unit (*ICU*) time; and (C) length of stay (*LOS*).

1 week. However, if the regurgitation is mild or slightly moderate, patients may be able to tolerate this, as the right atrium is relatively compliant, and they may not present with apparent hemodynamic changes or clinical signs and symptoms. In patients with reoperative TVR, up to 27% may need a third TVR surgery.[35] The overall reoperation rate in our cohort of first-time patients with ITV was 6% (3/50), which increased to 7.3% after accounting for early death as a competing event. These reoperations were related to hemodynamic deterioration, possibly associated with left-sided lesion severity upon presentation, a factor that was significantly associated with mortality. Since previous research suggested that left-sided disease was the main indication for reoperative TVR, rather than intrinsic dysfunction of the valve,[35] future studies need to confirm this finding in the context of reoperative TVS risk. In our study, patients presenting with a left-sided lesion had greater overall mortality. The decision to leave a left-sided lesion unaddressed was due to a hostile mediastinum. Our study considered the greatest deterioration severity before surgery for the analysis. Patients with moderate or moderate-to-severe MR with extensive adhesions, prohibitive of crossclamping, were considered for TVR on CPB with a beating heart. Intraoperatively, if we felt that anatomical constraints prohibited mitral surgery, the mitral valve could be addressed at a later date by a transcatheter approach. However, considering our findings, we recommend a future study adjudicated by a core laboratory.

Late mortality is acceptable in cases in which initial TVR followed a left-sided operation, where 5-year and 10-year mortality were 20% and 39%, respectively.[36] In cases with late bioprosthetic TV dysfunction, pannus formation of the cusps on the ventricular side was related to the cause of reoperation in almost 60% of cases.[35] Operative mortality was as high as 35%.[35] The aggressive approach to performing reoperative TVS, regardless, was thought to be associated with superior outcomes.[31] A larger study is needed to evaluate the association of left-sided disease with event-free survival (including reoperation) after adjusting for relevant factors, such as valve type, as late survival may depend on many factors other than valve durability. Furthermore, transcatheter approaches for patients with a bioprosthetic TV may have a role in best practice guidelines for high-risk patients as well as those with bioprosthetic TV failure.

Early Versus Late Presentation

Patients undergoing ITV are typically at high risk of early perioperative mortality and morbidity due to advanced

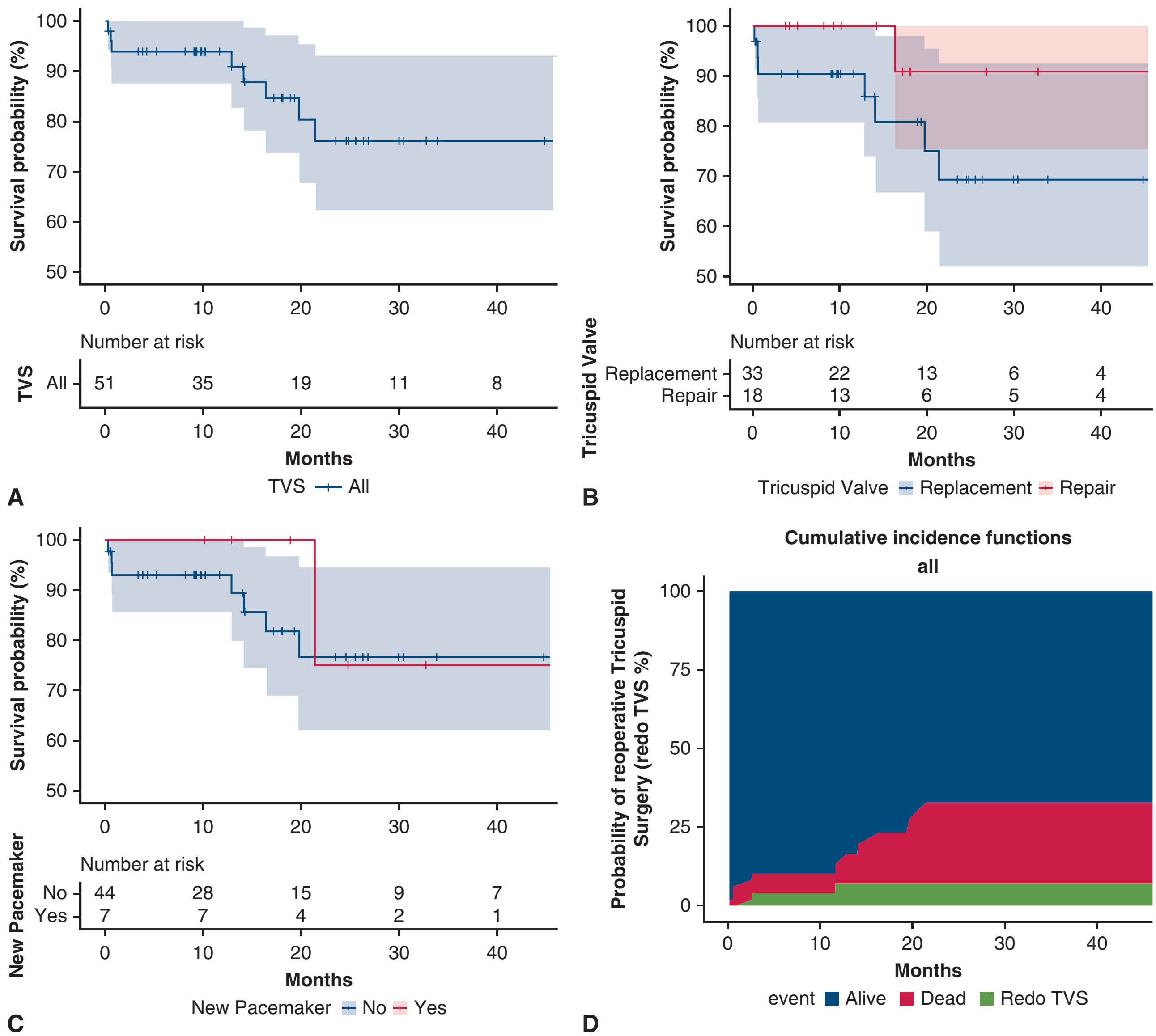

FIGURE 2. Survival analyses showing (A) KM curves for the overall cohort; (B) KM curves for tricuspid valve repair and replacement; and (C) KM curves for patients with or without new permanent pacemaker implantation; and (D) cumulative incidence function accounting for death as a competing event for reoperative tricuspid surgery. *TVS*, Tricuspid valve surgery; *KM*, Kaplan–Meier

disease presentation, previous surgery, and end-stage heart failure.[31,37] Our current experience demonstrated that patients who presented for ITV had high New York Heart Association class III and IV (27%) and various degrees of concomitant left-sided disease (53%), as well as RV dysfunction (22%) and kidney (14%) and liver (24%) disease. Our national ITV study estimated an increased risk of in-hospital mortality due to late presentation—patients admitted nonelectively, with heart failure, and liver disease—of more than 2-fold.[15] Most Mini-TVS procedures involved a beating-assisted approach (59%) in order to optimize myocardial protection and limit dissection in these high-risk comorbid patients, especially in redo scenarios. However, beating-heart surgery showed no significant association with overall survival, perhaps due to a small sample size. Furthermore, the overall mortality in patients with left-2sided disease increased by 8-fold over time following Mini-TVS, which could be attributed to changes in structural and geometrical characteristics of the right ventricle and the hemodynamics of pulmonary vasculature. Despite late presentation and complex comorbidity profiles, our patients had relatively favorable outcomes, potentially owing to the minimally invasive approach.

It is difficult to know the optimal timing of TVR, whether as an index case or reoperation. Our study indicates that urgent surgery was associated with greater overall mortality,

TABLE 5. Univariable analysis of potential factors associated with overall mortality

Characteristic	HR	95% CI	*P* value
Age	1.06	1.00-1.12	.055
Aortic regurgitation (greater than mild)	3.88	0.47-31.9	.2
Beating heart (no crossclamp)	1.62	0.32-8.15	.6
BMI categories			
BMI <25	–	–	
BMI 25-29	1.81	0.33-9.91	.5
BMI 30-39	1.25	0.18-8.91	.8
Chronic liver disease	2.97	0.70-12.7	.14
Concomitant LAAL/maze	0.68	0.08-5.61	.7
Concomitant mitral/aortic valve disease	8.79	1.07-72.4	**.043**
CPB time, min	1.00	0.98-1.02	.7
Crossclamp time, min	0.98	0.91-1.06	.6
Creatinine >2 mg/dL	13.1	3.11-55.4	**<.001**
Diabetes	0.82	0.10-6.65	.9
Mitral regurgitation (greater than mild)	13.4	2.15-82.9	**.005**
NYHA 3/4	1.35	0.32-5.75	.7
Preexisting dialysis	2.09	0.25-17.3	.5
Preexisting pacemaker	2.38	0.59-9.57	.2
Previous cardiac surgery	0.90	0.22-3.66	.9
RV dysfunction	13.2	2.66-65.8	**.002**
TVS			
Repair	–	–	
Replacement	4.06	0.50-33.1	.2
Urgency			
Elective	–	–	
Urgent	5.39	1.28-22.6	**.021**

$P < .05$ values in bold indicates statistically significant. *HR*, Hazard ratio; *CI*, confidence interval; *BMI*, body mass index; *LAAL*, left atrial appendage ligation; *CPB*, cardiopulmonary bypass time; *NYHA*, New York Heart Association heart failure functional classification; *RV*, right ventricular; *TVS*, tricuspid valve surgery.

as they usually present at with a greater risk profile and advanced disease. Delaying surgery may lead to worsening TV regurgitation and end-stage heart failure, whereas early surgery may improve early outcomes despite the risk of increased morbidity. According to McCarthy and Sales,[18] early intervention is justified in the course of TV disease, before the onset of irreversible ventricular deterioration. RV function is a known determinant of clinical symptoms and perioperative outcomes.[38] However, due to the complex geometry of the right ventricle, functional evaluation can be challenging to perform reliably and reproducibly. In our national analysis, right heart failure increased in-hospital mortality by 2-fold (odds ratio, 2.11; 95% confidence interval [CI], 1.43-3.12, $P < .001$), similar to the mortality risk in sternotomy-based mitral valve surgery (hazard ratio, 2.36; 95% CI, 1.25-4.47, $P < .05$).[39] In our series, 65% of patients presented with RV dysfunction, which increased mortality by 13% over the study period. This compares favorably with our national ITV study, in which the adjusted in-hospital mortality increased by 70% (odds ratio, 1.70; 95% CI, 1.11-2.59, $P = .015$) and was also compared favorably with minimally invasive mitral surgery in patients with RV dysfunction, in which the in-hospital mortality increased by 57% (hazard ratio, 1.57; 95% CI, 0.49-4.99, $P < .05$).[39] In addition to RV dysfunction, pulmonary hypertension could also increase mortality. The urgent nature of the surgery, as well as age >50 years, functional etiology, and hepatic dysfunction were described as predictors in previous studies.[15,38,40,41] Due to the severity of TV regurgitation in our patients, the estimated pulmonary artery pressure by preoperative echocardiogram could be misleading. Although most patients underwent elective surgeries in our series, nonelective surgery was performed in 12% of patients (n = 6) and strongly associated with decreased overall survival, therefore suggesting the need for earlier surgical referral.

Limitations

Our study has several strengths but also some limitations. One major strength is the consistency of operative technique and patient care provided, since all procedures were performed by a single surgeon. However, although a single-surgeon experience may partially limit our study's generalizability, the overall principles of TV surgery are well-established. This study supports that TV surgery can be performed with very good results. Whether the surgery is performed through a sternotomy approach or in a minimally invasive manner, the most important determinant of patient survival is surgery before the development of RV dysfunction, renal insufficiency, and addressing mitral regurgitation that is moderate or severe. The study was limited by its retrospective nature, its relatively small number of patients, and the lack of invasive hemodynamic data to better characterize patients preoperatively for comparison. Preoperative echo reports were not adjudicated under a core laboratory so there may have been discrepancies based on the report of an outside cardiologist. Furthermore, due to the retrospective study design, data on the reasons for re-hospitalization, reoperative surgeries, and quality of life were not available. Future larger studies should incorporate follow-up echo data.

CONCLUSIONS

In summary, although ITV had greater mortality and morbidity in the setting of previous operation, concomitant left-sided valve disease, right heart failure, and liver disease, the operative outcomes of the minimally invasive approach were satisfactory. Mini-TVS, with adequate myocardial protection strategies and high-quality perioperative care, offers numerous outcomes advantages for high-risk patients. Since delayed ITV increases operative mortality, early referral before irreversible RV failure is recommended.

Conflict of Interest Statement

Dr Lamelas reported receiving honoraria as a speaker for Edwards and Medtronic as well as owning stocks and on the medical advisory board of Cardiac Success. All other authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: tricuspid valve, isolated tricuspid, outcomes, survival, minimally invasive

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TABLE E1. Supplementary references for R packages utilized in the analysis

Package name	Package version	Use
survival[E1]	3.5-3	Survival analysis
cmprsk[E2]	2.2-11	Competing risk analysis
survminer[E3]	0.4.9	Creating survival plots
gtsummary[E4]	1.6.0	Creating pretty tables
flextable[E5]	0.7.2	Converting gtsummary tables into docx
officer[E6]	0.4.3	Modify docx file orientation and margins
tidyverse[E7]	1.3.1	Compose simple functions with the pipe
R[E8]	4.2.1	R software package provides environment for statistical computing and graphics