

Isolated Tricuspid Valve Repair and Right Atrial Plication Performed Using a Beating-Heart Technique for Atrial Functional Tricuspid Valve Regurgitation

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Abstract

Background: Isolated tricuspid valve disease remains a controversial indication for surgical intervention. Many patients referred for surgery already have a poor clinical condition and an advanced New York Heart Association functional class. There is no consensus on the optimal surgical technique for this condition, including on whether to perform the procedure on a beating or an arrested heart and whether to perform valve repair or replacement. **Methods:** We analyzed four case series between 2015 and 2022 in which patients with secondary tricuspid regurgitation (TR) underwent valve repair on a beating heart and right atrial plication for a dilated right atrium. The TRI-SCORE was calculated for each patient. **Results:** All patients experienced a favorable post-operative course with significant improvements in heart failure symptoms. TR was markedly reduced; however, in one patient with concomitant mitral regurgitation (MR) and a high TRI-SCORE, MR worsened postoperatively. This patient later died from unknown causes due to multiple comorbidities in the late phase. **Conclusions:** Tricuspid valve repair on a beating heart was effective for improving the cardiac function, and the TRI-SCORE proved useful as a preoperative risk assessment tool. The underlying mechanism by which TR exacerbates MR requires further investigation.

Keywords

Isolated Tricuspid Valve Surgery, Beating-Heart Surgery, Right Atrial Plication, Atrial Functional Tricuspid Valve Regurgitation, TRI-SCORE

1. Introduction

Isolated tricuspid valve surgery is rarely performed and is typically associated with

a high incidence of postoperative adverse events and reduced survival [1]. Mild-to-moderate tricuspid regurgitation (TR) may be initially managed with diuretics to alleviate symptoms, and surgery is only considered when patients develop severe TR leading to pathologies such as right ventricular dysfunction, liver dysfunction, and renal dysfunction. Functional TR has four major etiologies [2]; these include left-sided heart disease, pulmonary arterial hypertension due to any cause, right ventricular dysfunction due to any cause, and chronic atrial fibrillation. Nevertheless, the final TR forms secondary to these causes seem similar and are further complicated by a giant right atrium and chronic atrial fibrillation, which lead to organ and nutritional damage. The tricuspid valve is also called the “forgotten valve”, because significant TR may remain clinically silent for a long period of time, and progressive right ventricle dilatation and dysfunction may occur [3]. The mortality rates in tricuspid surgery continue to be consistently high in spite of improvements in the operative techniques and postoperative care [4].

Tricuspid valve surgery can be performed either using an on-pump beating-heart technique or an arrested cardioplegic heart technique. Baraki *et al.* were unable to prove that a beating-heart tricuspid valve surgery was superior to an arrested heart surgery [3]. A major disadvantage of beating-heart valve surgery is the limited surgical field secondary to the motion of the heart, a filled aortic root, and excess blood return; all of these challenge precise surgical manipulation [5]. However, beating-heart surgery offers the advantage of eliminating the need for a cardioplegic arrest of the heart, which can otherwise cause myocardial hypoxemia, malnutrition, and electrolyte imbalances [3] [6]. Furthermore, there is no consensus on whether tricuspid valve repair is superior to tricuspid valve replacement. Notably, Raikhelkar *et al.* noted that the early and late survival rates did not differ significantly between the two [7]. However, compared with valve replacement, tricuspid valve repair is reportedly associated with more significantly reduced in-hospital mortality, renal failure, and pacemaker implantation rates [8]. Possible reasons from a surgical point of view include preservation of the tricuspid annulus, which contributes to right heart function, and risk of thromboembolism and bleeding from anticoagulation for prosthetic heart valves [8]. We have aggressively performed tricuspid valve repair with beating-heart techniques for isolated tricuspid valve lesions and have also performed right atrial plication for a giant right atrium [9].

Patients who undergo surgical correction of TR often present with a reduced right ventricular function; published data suggest that establishment of a cardiopulmonary bypass during arrested cardioplegic heart surgery may negatively impact the right ventricular function [1] [10] [11]. Right ventricular function is considered one of the most significant indicators of survival in patients with valvular heart disease [7]. However, its evaluation can be challenging due to the ventricle’s complex morphology. Comprehensive clinical and echocardiographic guidelines, along with early referral to surgery, are imperative for effective surgical interventions before the development of end-stage valvular disease [7]. In 2022,

Dreyfus *et al.* reported the usefulness of the TRI-SCORE for assessing the risk of in-hospital mortality after a single tricuspid valve surgery (<http://www.tri-score.com/>) [12]. In a disease process where the timing of appropriate surgical intervention is still unknown, this score may be a useful indicator of the need for referral to cardiologists as well as of the surgical risk.

The present study aimed to evaluate the outcomes of patients who underwent an isolated tricuspid valve surgery and right atrial plication with a beating-heart technique. We also assessed the TRI-SCOREs in these cases.

2. Methods

This was a single-center, retrospective, cohort study. We reviewed the medical records of consecutive patients who underwent an isolated tricuspid valve surgery at the Aichi Medical University Hospital between 2015 and 2022. During this period, 965 patients underwent cardiac surgeries at the hospital. Those with primary tricuspid valve disease, including infective endocarditis or congenital heart disease, were excluded ($n = 4$). Accordingly, four patients were included for further analyses. Their clinical data were collected from their medical records. Severe TR was confirmed by comprehensive two-dimensional and Doppler echocardiography in all patients.

Surgery was performed on a beating heart. Minimally invasive cardiac surgery for valve diseases is currently gaining popularity worldwide; therefore, a minimally invasive approach was selected in cases deemed anatomically feasible. All patients underwent tricuspid annuloplasty with a semirigid annuloplasty band (Carpentier-Edwards Physio Tricuspid Annuloplasty Ring[®]; Edwards Lifesciences, Irvine, CA, USA), and no procedures were performed to repair the leaflet or subvalvular tissue. All patients underwent concomitant right atrial plication, and two patients additionally underwent left appendage closure because this could be done easily through the full sternotomy and we could dispel the anxiety of thromboembolism due to thrombus from left atrial appendage. Right atrial plication was performed at the interatrial septum, the space between the inferior vena cava and the tricuspid annulus, and the free right atrial wall (including the appendage) [9]. The primary outcomes comprised major adverse cardiac events. Furthermore, the preoperative and postoperative patient symptoms, laboratory data, and echocardiographic data were compared.

The TRI-SCORE was used for preoperative risk assessment [12]. Based on eight easy-to-ascertain parameters, it was created as a dedicated risk score model to inform patients and physicians about the risk of isolated tricuspid valve disease and to guide the clinical decision-making process for patients with severe TR [10]. This score was calculated based on right ventricular function data, signs of right heart failure, and diuretic dosage and renal function.

2.1. Statistical Analysis

Continuous variables are expressed as either mean \pm standard deviation or as

median (range). Categorical variables are expressed as the number (%) of patients. Categorical variables were analyzed using the Fisher's exact test. Continuous variables were compared using the Student's *t*-test; conversely, nonparametric variables were analyzed using the Mann-Whitney *U*-test. All statistical analyses were performed using JMP 16.2.0 (SAS Institute, Cary, NC, USA). Statistical significance was defined by $p < 0.05$.

2.2. Definitions

All procedures were performed according to the tenets of the Declaration of Helsinki. The Ethics Committee of the Aichi Medical University Hospital approved the study on October 6, 2022 (approval number: 2022-570). All patients provided written consent for their clinical data to be used in scientific presentations and publications.

3. Results

The patients' characteristics and pre- and post-operative data are summarized in **Table 1**; the mean age was 76 years (range, 67 - 81 years); 2 patients were male (50%). All patients had atrial functional TR due to chronic atrial fibrillation: two patients had pure atrial functional TR (cases 1 and 2; **Figure 1** & **Figure 2**); one patient had functional TR with pulmonary hypertension related to pulmonary

Table 1. Characteristics of the patients.

	1	2	3	4
Age, sex	76, F	75, M	67, M	81, F
Etiology	Atrial functional	Atrial functional	PH, RV dysfunction, atrial functional	Left heart disease, atrial functional
TRI-SCORE	5	4	2	6
Predicted in-hospital mortality (%)	14	8	3	22
Preoperative NYHA	II	III	II	III
Preoperative BNP (pg/mL)	499	225	413	230
Procedures	TAP RA plication LAAL	MICS TAP RA plication	TAP RA plication LAAL	MICS TAP RA plication
Duration of intensive care unit stay	3	3	4	3
Duration of hospitalization	21	20	16	18
Postoperative NYHA class	I	I	I	II
Postoperative BNP (pg/mL)	49	49	100	80
In-hospital mortality	no	no	no	no
Late mortality	no	no	no	yes

Abbreviations: BNP, brain natriuretic peptide; LAAL, left atrial appendage ligation; MICS, minimally invasive cardiac surgery; NYHA, New York Heart Association; PH, pulmonary hypertension; RA, right atrial; RV, right ventricular; TAP, tricuspid annuloplasty.

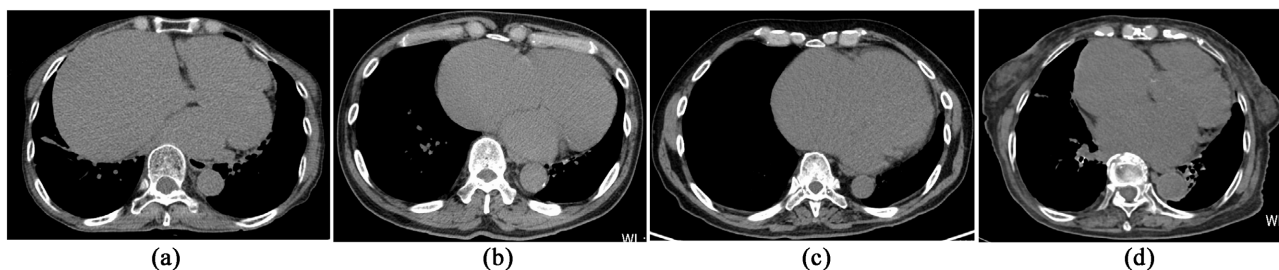


Figure 1. Preoperative chest computed tomography reveals dilatation of the right atrium in all cases ((a) case 1, (b) case 2, (c) case 3, and (d) case 4).

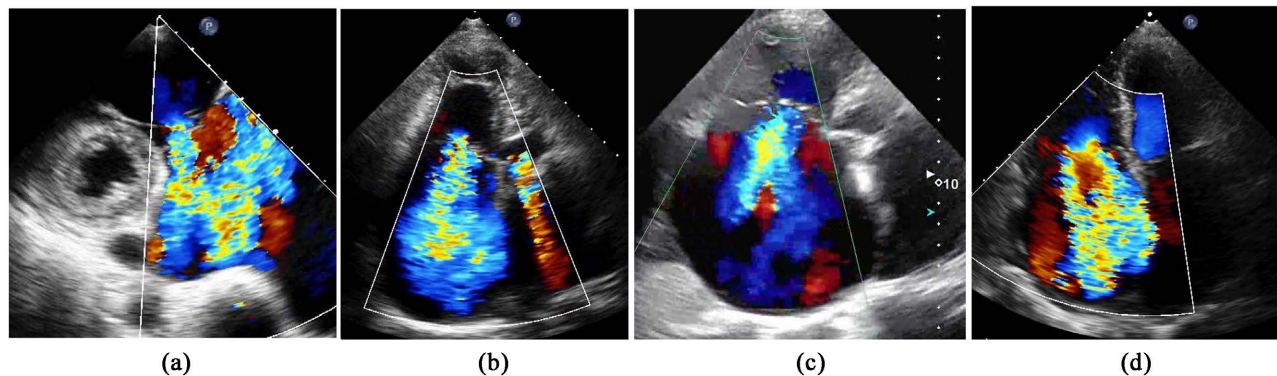


Figure 2. Preoperative echocardiography reveals severe TR in all cases ((a) case 1, (b) case 2, (c) case 3, and (d) case 4). TR, tricuspid regurgitation.

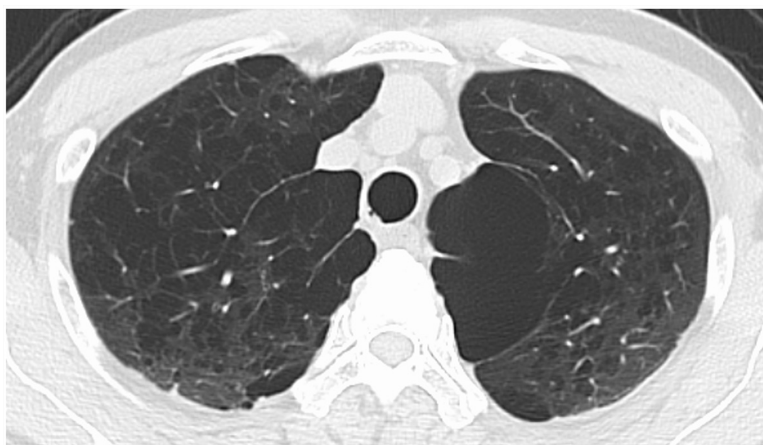


Figure 3. Preoperative chest computed tomography scan of the patient with chronic obstructive pulmonary disease (case 3).

disease (case 3; **Figure 2(c)** and **Figure 3**); and one patient had functional TR related to left heart disease, *i.e.*, moderate mitral regurgitation (MR; case 4; **Figure 2(d)** and **Figure 4**). The TRI-SCOREs (risk scores for single tricuspid valve surgery) were 5, 4, 2, and 6 points in cases 1, 2, 3, and 4, respectively; the corresponding predicted in-hospital mortality rates were 14%, 8%, 3%, and 22%, respectively [12].

All patients were successfully weaned from cardiopulmonary bypass, and none required the use of nitric oxide or mechanical heart assist devices. All patients

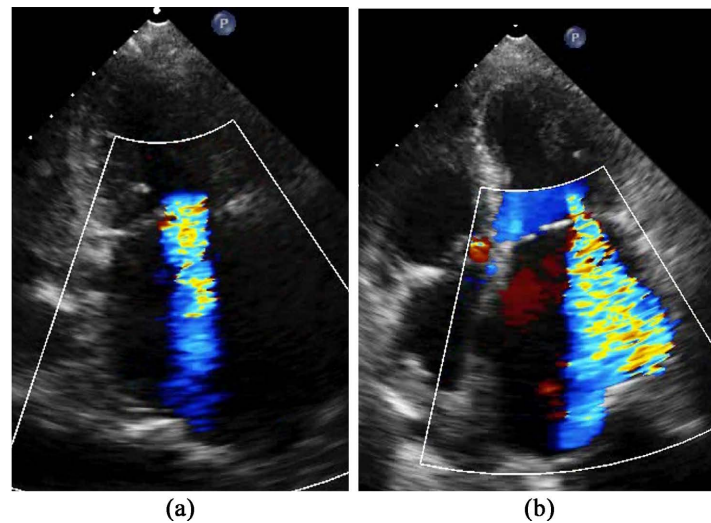


Figure 4. Echocardiograms of the patient with left heart disease (case 4) reveal moderate mitral valve regurgitation preoperatively (a), which worsened after surgery (b).

were extubated within 1 day after surgery and started gait training the next day. No patients suffered from anticoagulation-related hemorrhage. Furthermore, no patients required permanent pacemaker implantation postoperatively, because atrial fibrillation was maintained in all patients. Finally, no patients presented with neurological complications. The mean duration of intensive care unit stay was 3.3 ± 0.5 days; the mean duration of hospitalization was 18.8 ± 2.2 days. Early mortality did not occur in any case; however, in case 4 (TR secondary to MR), the patient died in the late postoperative phase from multiplied comorbidities. No patient developed postoperative heart failure that required hospitalization.

The preoperative and postoperative symptoms, laboratory data, and echocardiographic findings are listed in **Table 2**. The patients' clinical New York Heart Association classes improved significantly ($p = 0.026$) 1 month after surgery. All patients showed a significant decrease in the size of the right atrium (**Figure 1** and **Figure 5**; $p = 0.0033$) and improvement in severe TR. The B-type natriuretic peptide level was significantly improved after surgery ($p = 0.0078$). In case 4 (TR secondary to MR), MR worsened within 1 week from the surgery when TR was reduced (**Figure 4**). The TR pressure gradient changed from 26 mmHg (range, 14 - 44 mmHg) to 36 mmHg (range, 21 - 55 mmHg). Furthermore, the tricuspid annular plane systolic excursion (TAPSE) changed from 20 mm (range, 9 - 24 mm) to 18 mm (range, 10 - 37 mm). The relationship between the TRI-SCOREs and the postoperative findings are listed in **Table 3**.

4. Discussion

Since marked right atrial contraction and decreased TR were noted and the symptoms related to cardiac failure improved significantly, we considered our approach of tricuspid valve repair and right atrial plication with a beating heart acceptable. Only few reports have discussed the usefulness of right atrial plication in TR; however, this procedure is important, because a giant right atrium

Table 2. Preoperative and postoperative data.

	Preoperative Data	Postoperative Data	<i>p</i> -value
NYHA grade: case 1, 2, 3, and 4	II, III, II, III	I, I, I, II	0.026
Left ventricular ejection fraction, (%)	66 (52 - 74)	70 (63 - 73)	0.44
Right atrial dimension (mm)	97 (58 - 109)	35 (29 - 44)	0.0033
TRPG (mmHg)	26 (14 - 44)	36 (21 - 55)	0.39
TAPSE (mm)	20 (9 - 24)	18 (10 - 37)	0.69
Albumin (g/dL)	3.8 (3.5 - 4.5)	3.6 (3.1 - 4.0)	0.32
Hemoglobin (g/dL)	13 (9.8 - 15.8)	12 (10.8 - 12.4)	0.55
Platelet ($\times 10^5/\mu\text{L}$)	13 (11 - 13)	16 (10 - 23)	0.21
Cholinesterase (U/L)	208 (190 - 227)	205 (128 - 345)	0.79
Bilirubin (mL/dL)	1.7 (0.9 - 2.4)	1.2 (0.7 - 2.9)	0.77
Estimated glomerular filtration rate (mL/min/1.73m ²)	54 (45 - 80)	54 (42 - 70)	0.75
BNP (pg/mL)	322 (225 - 499)	65 (49 - 100)	0.0078
	Preoperative Data	Postoperative Data	<i>p</i> -value

Abbreviations: BNP, brain natriuretic peptide; NYHA, New York Heart Association; TAPSE, tricuspid annular plane systolic excursion; TRPG: tricuspid regurgitation pressure gradient.

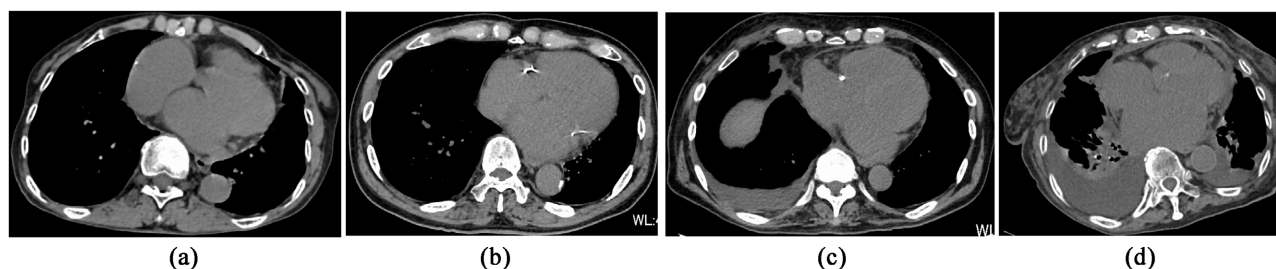


Figure 5. Postoperative chest computed tomography reveals improved dilatation of the right atrium in all cases ((a) case 1, (b) case 2, (c) case 3, and (d) case 4).

Table 3. Relationship between the TRI-SCORE and outcomes.

		<i>p</i> -value
OP time (minutes)	277 (259 - 293)	0.38
CPB time (minutes)	145 (121 - 193)	0.83
Duration of hospitalization (days)	19 (16 - 21)	0.45
MACE (%)	1 (late mortality, 25%)	0.034

Abbreviations: CPB, cardiopulmonary bypass; MACE, major adverse cardiac events; OP, operation.

may compress the lungs, thereby reducing the lung volume and causing respiratory distress and congestive organ damage. We believe that the present study

makes a significant contribution to the literature on functional TR with a giant right atrium. The right atrial wall was not reinforced with materials despite an existing risk of bleeding because the wall strength was sufficient and some suture lines were placed within the right atrium.

Isolated tricuspid surgery is no longer associated with a high mortality when performed in patients with a preserved right ventricular function [13]. However, patients are typically diagnosed with severe clinical conditions and develop symptoms of right ventricular failure. Comprehensive clinical and echocardiographic guidelines and early referral to surgery before the development of end-stage valvular disease are imperative for improving patient outcomes [14]. In case 4, the deceased patient had a high TRI-SCORE and received a somewhat delayed surgical intervention. The relationship between the TRI-SCOREs and the postoperative findings in the present cases suggested a remarkable association of the TRI-SCORE with major adverse cardiac events (one late death). The TRI-SCORE is a useful alternative to right ventricular function assessment and could also serve as an indicator for cardiologists to refer patients to cardiac surgeons.

TAPSE has been proposed as a parameter for the evaluation of right ventricular function. However, in the present study, TAPSE decreased postoperatively despite symptomatic improvement. TAPSE can change easily due to invasiveness of the surgery, right atrial plication, and even the skill of the sonographer. Thus, though useful for assessing right ventricular function, it is not as favorable as the TRI-SCORE is. The TR pressure gradient may increase due to an increased blood flow through the tricuspid valve secondary to a decreased regurgitation flow. Further studies must determine whether pulmonary hypertension actually worsens in such a scenario.

Secondary TR can have four etiologies [2]. Although all four patients in this study had atrial functional TR, one patient had concomitant pulmonary hypertension due to emphysema and one patient had left heart disease. Each etiology of secondary TR should be evaluated and an appropriately tailored strategy should be considered. It is speculated that MR may worsen after isolated tricuspid valve repair in patients with atrial functional TR with pulmonary hypertension related to left heart disease, thereby worsening their prognoses. It is unknown whether these two conditions, functional TR and MR, are related to each other; however, aggravation of MR has been observed after atrial septal defect closure in some patients [15] [16]. Further investigation is needed to determine whether MR worsens after TR repair. Detailed investigations into the cause of functional TR may help avoid this postoperative complication. Further, in cases of moderate-to-severe MR, surgical involvement of the mitral valve should be considered.

Although a minimally invasive tricuspid valve repair was successfully performed on a beating heart in the present cases, development of transcatheter therapies may offer an alternative to surgery in the near future and further enable early intervention if proved to be safe and efficient [11].

5. Limitations

This study had some limitations. First, only four patients were included owing to the rarity of the condition. Second, this was a retrospective, single-center study lacking any form of randomization. Because of its single-center nature, we could not exclude selection bias related to care received outside of our system. Third, the surgical technique (including minimally invasive cardiac surgery for tricuspid valve repair) has evolved over the study period. To resolve these limitations, a multi-institutional study is required.

6. Conclusion

Isolated tricuspid valve surgery with right atrial plication performed on a beating heart has a favorable outcome. Research into the optimal surgical timing and patient selection is critical; the TRI-SCORE could be helpful in decision making.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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