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ORIGINAL ARTICLE

Tricuspid Valve Repair at Pulmonary Valve Replacement in Repaired Tetralogy of Fallot

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Abstract

Background Pulmonary valve replacement (PVR) is often performed in patients with repaired tetralogy of Fallot (TOF). Concomitant tricuspid valvuloplasty (TVP) in those with tricuspid regurgitation (TR) at the time of PVR is still controversial.
Method We retrospectively reviewed clinical records of patients who underwent PVR between 2001 and 2012. We analyzed the impact of concomitant TVP on the tricuspid valve function and right ventricle function and size in mid-term.
Results 119 patients with mild to moderate TR at the time of PVR were enrolled. 33 patients underwent concomitant TVP (TVP group) and 86 patients underwent PVR alone (no-TVP group). There was a significant reduction of TR ($p < 0.001$) and right ventricular end-diastolic volume index (RVEDVi) ($p < 0.001$). However, in patients who showed prosthetic pulmonary valve (PV) failure at the last follow-up, there was no significant decrease in TR regardless of concomitant TVP. In the patients with preserved prosthetic PV function, TR was significantly improved ($p < 0.001$ in both groups). The multivariable analysis showed that significant risk factors for recurrence of significant TR were preoperative moderate TR and prosthetic PV failure.
Conclusions After PVR in repaired TOF patients, there was an improvement in the degree of TR and the RVEDVi. Concomitant TVP at the time of PVR may not be able to prevent the recurrence of TR when prosthetic PV failure occurs; however, it may effectively preserve tricuspid valve function until that time.

Keywords Tricuspid valve regurgitation · Pulmonary valve replacement · Congenital heart disease · Tetralogy of Fallot · Valvular diseases

Introduction

The long-term survival after surgical repair of tetralogy of Fallot (TOF) is excellent [1–3]. However, pulmonary valve (PV) and PV annulus were frequently sacrificed and this can induce long-term pulmonary regurgitation (PR) and cause chronic volume overload of the right ventricle (RV). Further complications include progressive RV dilation and dysfunction, and sudden cardiac arrest or death associated with fatal ventricular arrhythmias [4, 5]. Pulmonary valve replacement (PVR) is now one of the most common reoperations in repaired TOF patients, and is a means to eliminate the volume overload and prevent further sequelae [6–8].

Various degrees of tricuspid regurgitation (TR) are observed in up to 30% of repaired TOF patients at the time of PVR. However, the indications and the effectiveness of concomitant tricuspid valvuloplasty (TVP) in this patient group are still controversial [9–16]. We analyzed the tricuspid valve (TV) function after PVR in repaired TOF patients through mid-term follow-up and evaluated the effectiveness of concomitant TVP in this group.

This topic was presented as an "oral presentation" at Congenital Heart Disease Simultaneous Scientific Session of 99th annual meeting of American Association for Thoracic Surgery, May 5th, 2019, Toronto, Canada.

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Methods

Patients

This was a retrospective study conducted in Seoul National University Children's Hospital and Sejong General Hospital. After Institutional Review Board approval from both hospitals (Approval No. 1809-148-973 and 2014-158, respectively), we identified the patients with a history of TOF who underwent reintervention consisting of PVR between January 2001 and December 2012. During this period, PVR was performed in 245 repaired TOF cases, mainly using bio-prosthetic valves. Excluding 9 patients with severe TR, 110 patients with TR grade less than mild, and 7 patients in whom preoperative echocardiography data were not available, 119 cases with mild to moderate TR were included in this study. Demographic data are listed in Table 1.

Indications and Surgical Techniques for TVP

TVP was performed in all patients with severe TR. The patients with TR less than mild were not considered for TVP. When the TR grade was mild or moderate, exploration for TV morphology in operative field was performed in selected patients with specific findings indicating structural deformity that would not be expected spontaneous improvement after PVR such as large gap at TV coaptation area, or unusual valvular motion such as prolapse or restriction eventually resulting in eccentric TR flow on preoperative echocardiography. The decision for concomitant TVP was made according to the presence of surgically correctable factors in the intraoperative exploration in these cases. Commissuroplasty and annuloplasty were used alone or in combination in TVP and various annuloplasty techniques including suture annuloplasty (plication of the posterior leaflet's annulus), DeVega type annuloplasty, and ring annuloplasty were used (Table 1). The surgical techniques for TVP were selected based mainly on the age and the mechanism of TR of individual patients and also on the surgeon's preference.

Data Collection and Statistical Analysis

Perioperative data were collected from the hospital records. Demographic and anatomical data, medical history, operative records, results of transthoracic echocardiography, and available cardiac magnetic resonance imaging (cMRI) were systematically reviewed. According to the American Society of Echocardiography guidelines [17], TR was graded into none/trivial, mild, moderate, or severe. End points for follow-up included reoperation for PV or TV, the last clinical visit, and death. The data from last echocardiography or last cMRI were described as 'final' ones.

Statistical analysis was performed with the software SPSS 23 (SPSS Inc, Chicago, Ill). Continuous variables were expressed as means ± standard deviation. To assess their distribution, a Shapiro–Wilk test was used. A student *t* test was performed to analyze them. A χ^2 test or a Mann–Whitney test was used to analyze categorical variables. To analyze the variation of echocardiographic and cMRI measurements, a Wilcoxon signed rank test or a paired *t* test was used. The follow-up data on survival and reoperation were analyzed with standard Kaplan–Meier analysis. Multivariable analysis was performed to assess for risk factors for the development of significant TR (defined as ≥ moderate regurgitation) after

Table 1 Preoperative and operative features of the patients

Variable	Overall ($n=119$)	TVP group ($n=33$)	No-TVP group ($n=86$)	*p* value
Sex, *n* (%)				0.561
Male	84 (70.6)	22 (66.7)	62 (72.1)	
Female	35 (29.4)	11 (33.3)	24 (27.9)	
Age at TOF repair, year	2.2 ± 3.4	3.3 ± 5.5	1.8 ± 2.0	0.123
Age at PVR, year	14.4 ± 6.7	15.2 ± 8.9	14.2 ± 5.8	0.467
Surgical interval, year	12.2 ± 5.3	11.8 ± 5.2	12.3 ± 5.3	0.687
CPB time, min	158.1 ± 57.4	180.7 ± 67.2	149.7 ± 51.2	0.010
TVP techniques, *n*				
Commissuroplasty		24		
DeVega annuloplasty		10		
Suture annuloplasty		7		
Ring annuloplasty		3		

Continuous variables are expressed as the mean ± standard deviation. Categorical variables are expressed as number and percentages in brackets. A Student *t* test was used to compare continuous variables and a χ^2 test was used to compare categorical variables. $p < 0.05$ was considered statistically significant

TVP tricuspid valve repair, *TOF* tetralogy of Fallot, *PVR* pulmonary valve replacement

PVR with or without concomitant tricuspid valve surgery, using logistic regression analysis. A $p < 0.05$ was considered statistically significant.

Results

Procedure and Overall Findings

Among 119 patients, 33 underwent concomitant TVP with PVR (TVP group) and 86 underwent PVR alone (no-TVP group). The preoperative TR grade was higher ($p < 0.001$) and the cardiopulmonary bypass (CPB) time was longer ($p = 0.010$) in TVP group;however, the other preoperative variables were comparable between these two groups (Tables 1, 2).

After PVR there were no early deaths and 3 late deaths (1 in TVP group and 2 in no-TVP group). Reoperation-free survival for the entire cohort was 92.1%, 74.9%, and 60.6% at 5, 10, and 15 years, respectively. Most of the reoperations were due to problems with the prosthetic PV including prosthetic valve failure and infective endocarditis. There was only one case of reoperation on TV alone, who had moderate TR at the time of PVR alone and showed progressive severe TR. There was no significant difference in overall survival ($p = 0.915$) and reoperation-free survival ($p = 0.826$) between two groups (Figs. 1 and 2).

Table 2 Preoperative and final TR grade

	Overall ($n = 119$)	TVP group ($n = 33$)	No-TVP group ($n = 86$)
TR grade			
Preoperative, *n* (%)			
Mild	88 (73.9)	11 (33.3)	77 (89.5)
Mild to moderate	6 (5.0)	4 (12.1)	2 (2.3)
Moderate	25 (21.0)	18 (54.5)	7 (8.1)
Final, *n* (%)			
< Mild	55 (46.2)	16 (48.5)	39 (45.3)
Mild	47 (39.5)	10 (30.3)	37 (43.0)
Mild to moderate	6 (5.0)	1 (3.0)	5 (5.8)
Moderate	10 (8.4)	5 (15.2)	5 (5.8)
> Moderate	1 (0.8)	1 (3.0)	0 (0.0)
p value	< 0.001	< 0.001	< 0.001

Categorical variables are expressed as number and percentages in brackets. A Wilcoxon signed rank test was used to compare categorical variables. $p < 0.05$ was considered statistically significant

TVP tricuspid valve repair, *TR* tricuspid regurgitation

Changes in Degree of TR and RV Volume and Function

For the entire cohort, there was significant improvement in TR grade ($p < 0.001$) in between the preoperative and last echocardiogram. Both TVP group and no-TVP group showed significant reduction in TR grade ($p < 0.001$ in each group) (Table 2, Fig. 3A). The preoperative TR grade was significantly higher in TVP group than in no-TVP group ($p < 0.001$);however, there was no significant difference in final TR degree between two groups ($p = 0.754$).

For evaluation of right ventricular end-diastolic volume index (RVEDVi) and right ventricular ejection fraction (RVEF), cMRI data were reviewed (Table 3). In 34 patients (11 in TVP group; 23 in no-TVP group), cMRI

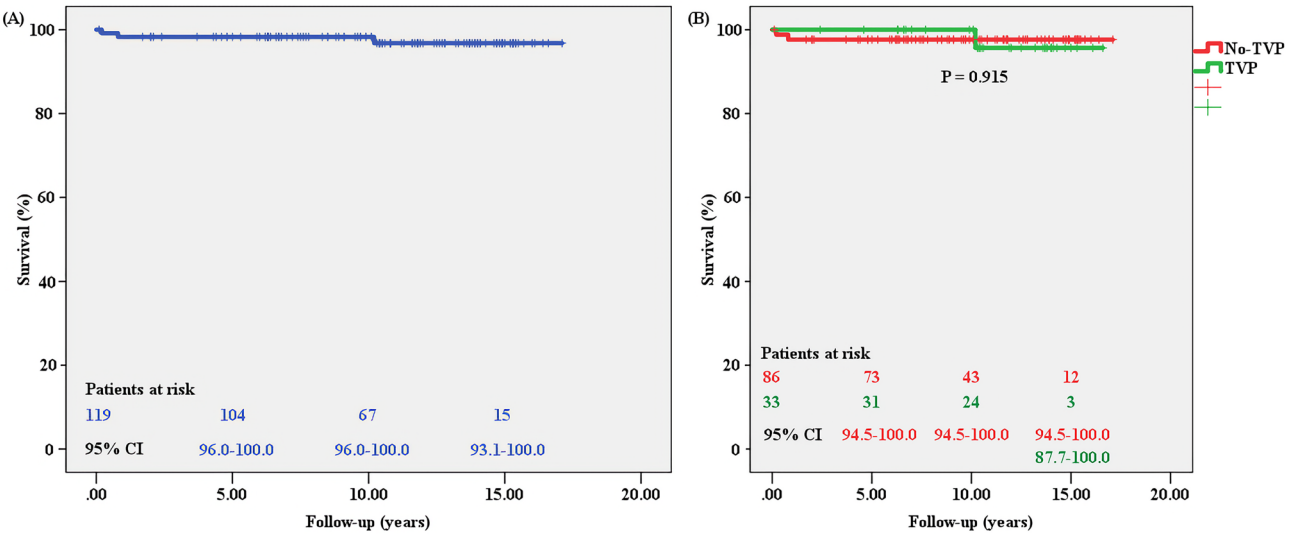

Fig. 1 Kaplan–Meier curve showing **A** overall survival of the entire cohort and **B** overall survival of the patients who underwent PVR alone (red line) and of the patients who underwent concomitant TVP at the time of PVR (green line). *CI* confidence limit

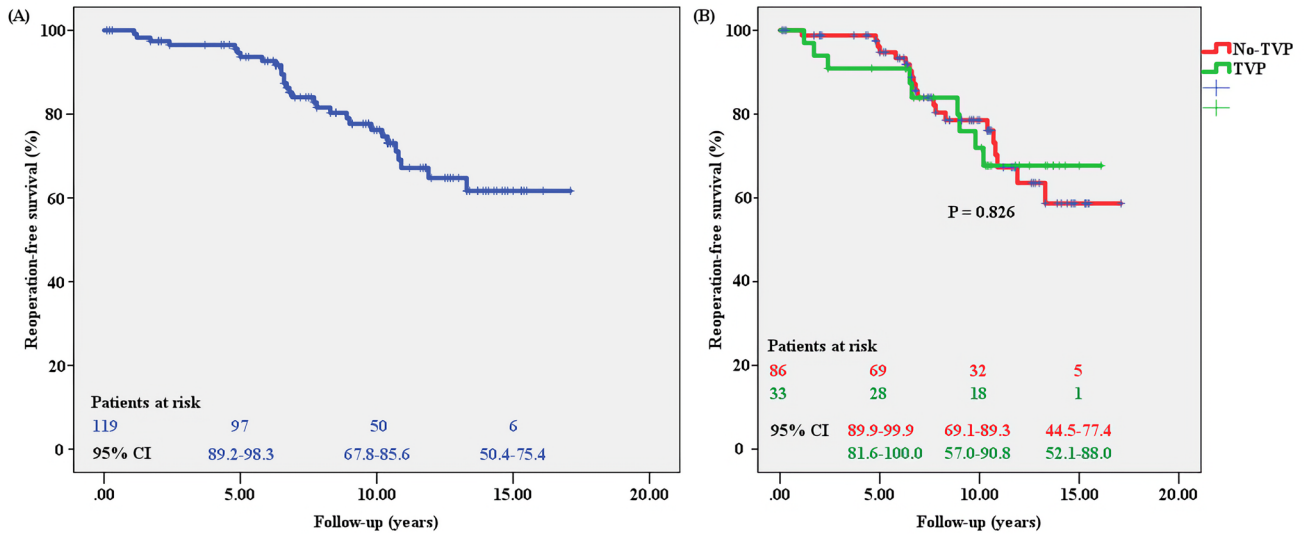

Fig. 2 Kaplan–Meier curve showing **A** overall reoperation-free survival of the entire cohort and **B** reoperation-free survival of the patients who underwent PVR alone (red line) and of the patients who underwent concomitant TVP at the time of PVR (green line). *CI* confidence limit

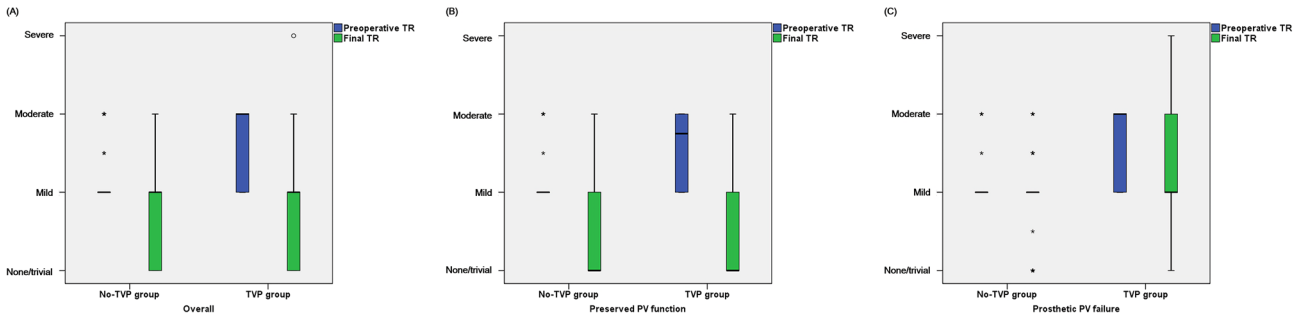

Fig. 3 The changes of TR degree in both no-TVP group and TVP group **A** in the entire cohort, **B** in patients with preserved prosthetic PV function at the last follow-up, and **C** in patients who showed prosthetic PV failure at the last follow-up. *TR* tricuspid regurgitation, *TVP* tricuspid valvuloplasty, *PV* pulmonary valve

were performed both pre- and postoperatively. There was significant reduction in RVEDVi regardless of concomitant TVP ($p = 0.021$ in TVP group; $p < 0.001$ in no-TVP group). No-TVP group showed significant increase of RVEF ($p = 0.007$);however, the increase of RVEF in TVP group was not significant ($p = 0.248$).

Among 119 patients, 45 underwent PVR in their childhood (aged < 12 years). They showed significant reduction in TR grade regardless of concomitant TVP ($p = 0.026$ in TVP group; $p = 0.002$ in no-TVP group). The other 74 patients who underwent PVR in older age (aged ≥ 12 years) also showed significant improvement in TR grade regardless of concomitant TVP ($p = 0.001$ in TVP group; $p < 0.001$ in no-TVP group) (Table 4).

Table 3 Preoperative and final RVEDVi and RVEF in cMRI

	Overall ($n = 34$)	TVP group ($n = 11$)	No-TVP group ($n = 23$)
RVEDVi			
Preoperative, mL	177.4 ± 31.3	163.4 ± 27.1	184.2 ± 31.5
Final, mL	125.7 ± 47.2	119.8 ± 30.8	128.5 ± 53.8
p value	< 0.001	0.021	< 0.001
RVEF			
Preoperative, %	39.7 ± 7.5	40.2 ± 8.6	39.4 ± 7.1
Final, %	44.8 ± 8.3	43.7 ± 8.4	45.3 ± 8.5
p value	0.005	0.248	0.007

Continuous variables are expressed as the mean ± standard deviation. A paired *t* test and a Wilcoxon signed rank test were used to compare continuous variables. $p < 0.05$ was considered statistically significant

RVEDVi right ventricular end-diastolic volume index, *RVEF* right ventricular ejection fraction, *cMRI* cardiac magnetic resonance imaging

Table 4 Preoperative and final TR grade according to the patients' age at PVR

	< 12 years at PVR ($n=45$)		≥ 12 years at PVR ($n=74$)	
	TVP ($n=15$)	No-TVP ($n=30$)	TVP ($n=18$)	No-TVP ($n=56$)
TR grade				
Preoperative, *n* (%)				
Mild	3 (20.0)	24 (80.0)	7 (38.9)	53 (94.6)
Mild to moderate	2 (13.3)	1 (3.3)	2 (11.1)	1 (1.8)
Moderate	10 (66.7)	5 (16.7)	7 (38.9)	2 (3.6)
Final, *n* (%)				
< Mild	5 (33.3)	12 (40.0)	11 (61.1)	27 (48.2)
Mild	6 (40.0)	13 (43.3)	4 (22.2)	24 (42.9)
Mild to moderate	0 (0.0)	2 (6.7)	1 (5.6)	3 (5.3)
Moderate	3 (20.0)	3 (10.0)	2 (11.1)	2 (3.6)
> Moderate	1 (6.7)	0 (0.0)	0 (0.0)	0 (0.0)
p value	0.026	0.002	0.001	< 0.001

Categorical variables are expressed as number and percentages in brackets. A Wilcoxon signed rank test was used to compare categorical variables. $p < 0.05$ was considered statistically significant

TR tricuspid regurgitation, *PVR* pulmonary valve replacement, *TVP* tricuspid valve repair

Table 5 Preoperative and final TR grade according to the prosthetic PV function at last follow-up

	No prosthetic PV failure ($n=73$)		Prosthetic PV failure ($n=46$)	
	TVP ($n=24$)	No-TVP ($n=49$)	TVP ($n=9$)	No-TVP ($n=37$)
TR grade				
Preoperative, *n* (%)				
Mild	8 (33.3)	44 (89.8)	3 (33.3)	33 (89.2)
Mild to moderate	4 (16.7)	1 (2.0)	0 (0.0)	1 (2.7)
Moderate	12 (50.0)	4 (8.2)	6 (66.7)	3 (8.1)
Final, *n* (%)				
< Mild	15 (62.5)	30 (61.2)	1 (11.1)	9 (24.3)
Mild	6 (25.0)	17 (34.7)	4 (44.4)	20 (54.1)
Mild to moderate	1 (4.2)	1 (2.0)	0 (0.0)	4 (10.8)
Moderate	2 (8.3)	1 (2.0)	3 (33.3)	4 (10.8)
> Moderate	0 (0.0)	0 (0.0)	1 (11.1)	0 (0.0)
p value	< 0.001	< 0.001	0.414	0.070

Categorical variables are expressed as number and percentages in brackets. A Wilcoxon signed rank test was used to compare categorical variables. $p < 0.05$ was considered statistically significant

TR tricuspid regurgitation, *PV* pulmonary valve, *TVP* tricuspid valve repair

Prosthetic Valve Function and TR Degree

We defined prosthetic PV failure as moderate or severe PR, or pulmonary stenosis with peak velocity more than 3.5 m/s on most recent echocardiography. Forty-six patients showed prosthetic PV failure and the other 73 patients showed preserved PV function at the last follow-up (Table 5). The patients with preserved PV function maintained a significantly improved status of TR degree in both TVP group and no-TVP group ($p < 0.001$ in each group) (Fig. 3B). However, in the patients who showed prosthetic PV failure at the last follow-up, improved TR degree that we had achieved after PVR did not maintain well regardless of concomitant TVP ($p = 0.414$ in TVP group, $p = 0.070$ in no-TVP group) (Fig. 3C).

Among 25 patients with moderate TR at the time of PVR, 9 patients showed prosthetic PV failure and the other 16 patients showed preserved PV function at the last follow-up (Table 6). In this subgroup, TR degree stayed in improved status in the patients with preserved PV function in TVP group at discharge ($p = 0.002$ in TVP group; $p = 0.063$ in no-TVP group) and at the last follow-up ($p = 0.004$ in TVP group; $p = 0.102$ in no-TVP group). Regarding the patients with prosthetic PV failure, improved TR grade still maintained well only in TVP group at discharge ($p = 0.024$ in TVP group; $p = 0.102$ in no-TVP group);however, TR tended to be developed in both groups by time when we compared preoperative TR degree with TR at the last follow-up ($p = 0.317$ in TVP group; $p = 0.157$ in no-TVP group).

Eleven patients with mild TR underwent concomitant TVP at PVR. Among them, 3 patients showed prosthetic PV failure at the last follow-up. TR progressed to moderate in only one patient with prosthetic PV failure and remained mild or less in the other 10 patients.

Risk Factors for TR Development After Repair

To identify risk factors for moderate or severe TR at the last follow-up echocardiography, we analyzed the variables including patients' age at PVR, TR grade at PVR, concomitant TVP at PVR, follow-up duration after PVR, and presence of prosthetic valve failure at last follow-up (Table 7). By multivariable analysis, moderate TR at PVR and the presence of prosthetic valve failure at last follow-up were the risk factors for moderate or severe TR with statistical significance ($p = 0.001$ and $p = 0.013$, respectively).

Discussion

Despite the high incidence of TR, the role of concomitant TVP at the time of PVR in repaired TOF patients is still debated. Cramer et al. [12] reported the outcomes of 36 patients who had greater than or equal to moderate TR at

Table 6 TR grade at discharge and final TR grade of the patients with moderate preoperative TR according to the prosthetic PV function at last follow-up

	No prosthetic PV failure ($n=16$)		Prosthetic PV failure ($n=9$)	
	TVP ($n=12$)	No-TVP ($n=4$)	TVP ($n=6$)	No-TVP ($n=3$)
TR grade				
At discharge, *n* (%)				
< Mild	8 (66.7)	2 (50)	6 (100)	1 (33.3)
Mild	4 (33.3)	2 (50)	0 (0)	2 (66.7)
Mild to moderate	0 (0)	0 (0)	0 (0)	0 (0)
Moderate	0 (0)	0 (0)	0 (0)	0 (0)
> Moderate	0 (0)	0 (0)	0 (0)	0 (0)
p value	0.002	0.063	0.024	0.102
Final, *n* (%)				
< Mild	7 (58.3)	3 (75)	0 (0)	0 (0)
Mild	2 (16.7)	0 (0)	3 (50)	2 (66.7)
Mild to moderate	1 (8.3)	0 (0)	0 (0)	0 (0)
Moderate	2 (16.7)	1 (25)	2 (33.3)	1 (33.3)
> Moderate	0 (0)	0 (0)	1 (16.7)	0 (0)
p value	0.004	0.102	0.317	0.157

Categorical variables are expressed as number and percentages in brackets. A Wilcoxon signed rank test was used to compare categorical variables. $p<0.05$ was considered statistically significant

TR tricuspid regurgitation, *PV* pulmonary valve, *TVP* tricuspid valvuloplasty

the time of PVR, of whom 18 underwent concomitant TVP at PVR and 18 underwent PVR alone. After PVR, there was significant reduction in the degree of TR and RV, with a similar TR grade at 6 months postoperatively regardless of TVP. Similarly, Kogon et al. [16] reported that in the patients with at least moderate TR, significant improvement in TV function and RV size occurred in the first postoperative month after PVR, irrespective of concomitant TVP. In this study, however, patients who underwent concomitant TVP had significantly higher grade of TR, compared with patients who underwent PVR alone over the mid-term follow-up. In the report by Roubertie et al. [11], in case of severe TR at the time of PVR, concomitant TVP had significantly better outcomes on both TV function and functional status of the patients than PVR alone at mid-term follow-up. However, the benefit of concomitant TVP was not significant in the patients with moderate TR at PVR.

Our study showed that PVR with or without concomitant TVP in the patients with repaired TOF was associated with significant improvement in TV function and RV volume. This finding is consistent with most of previous studies, supporting the hypothesis that, PVR being efficient at reduction of RV volume, the changes in loading condition subsequently improves TR.

Except moderate degree of TR at the time of PVR, the occurrence of prosthetic PV failure was the only significant risk factor for recurrence of significant TR (moderate or severe) on the multivariable analysis. Indeed, in the patients with prosthetic PV failure at the most recent follow-up, the final TR degree did not show significant improvement compared to TR degree at the time of PVR. In the presence of prosthetic PV failure, volume or pressure overload to RV may worsen TV function again and it seems that concomitant TVP cannot prevent the progression of TR recurrence in this condition. However, in the patients who showed preserved prosthetic PV function at the last follow-up, TV function was well maintained, and stayed significantly improved status with or without concomitant TVP at PVR, and we have higher portion of the patients with improved status of TR in the TVP group. This suggests that the positive effect of concomitant TVP on TV function may be persistent before prosthetic PV failure occurs.

Some previous literatures were mainly focusing on the degree of preoperative TR and tried to provide some guidelines or algorithms for decision making based on the degree of TR. Those seem to be simple and straightforward; however, we doubt if those guidelines or algorithms could be the best for the individual patients. According to our

Table 7 Analysis of risk factors for significant TR (≥ moderate) at last follow-up

Variables	Univariable			Multivariable		
	OR	95% CI	*p* value	OR	95% CI	*p* value
Age at PVR	0.97	0.88–1.08	0.591			
Surgical interval	0.84	0.72–0.99	0.031	0.93	0.79–1.10	0.399
Moderate TR at PVR	8.75	2.32–33.04	0.001	11.67	2.72–50.03	0.001
Concomitant TVP	3.60	1.02–12.75	0.047	1.99	0.34–11.61	0.443
Follow-up duration	0.97	0.83–1.13	0.658			
Prosthetic PV failure	4.91	1.23–19.61	0.024	6.88	1.48–31.89	0.014

TR tricuspid regurgitation, *OR* odds ratio, *CI* confidence interval, *PVR* pulmonary valve replacement, *TVP* tricuspid valve repair, *PV* pulmonary valve

$p<0.05$ was considered statistically significant

experience, TR in repaired TOF patients may have various mechanisms, not only functional. We believe that there are still meaningful portion of patients who has TR with different mechanisms, that mimics functional TR which could be improved after eradication of PR after PVR. In these cases, even though their TR degree is less than moderate, there exists the role of TVP. Our study may seem to be confusing because we performed TVP in some patients and did not in other patients even if they have similar degree of TR. Some may think that the outcomes of PVR alone were quite acceptable. However, we would like to emphasize the importance of individualized decision making based on patients' tricuspid anatomical abnormalities causing TR as well as the TR degree in our indications for patient selection for TVP. Probably, this individualized decision making led to good outcomes in both groups, the TVP group and the no-TVP group.

Nevertheless, some may still not regard mild TR as a surgical indication and may still be interested in only moderate TR. Therefore, we also analyzed only patients with moderate preoperative TR. The degree of TR decreased significantly in TVP group at discharge and this improvement of TV function was maintained until the last follow-up in the patients with preserved prosthetic PV function. However, the significant improvement of TV function at discharge after concomitant TVP was not maintained after prosthetic PV failure occurred. Patients in no-TVP group did not show significant decrease of TR degree either at discharge or at the last follow-up. Although the statistical power is weakened by the small number of patients in each subgroups, these results may support the positive effect of concomitant TVP on the TV function before prosthetic PV failure occurs and the negative effect of prosthetic PV failure, which were discussed above.

We expected concomitant TVP to have a positive effect on RV function; however, the analysis of RVEF with cMRI data showed opposite results to our expectations. RVEF was significantly increased in no-TVP group; however, the increase of RVEF was not significant in TVP group. This does not necessarily mean that concomitant TVP affects negatively RV function rather than PVR alone, because there is possibility of overestimation of preoperative RVEF and underestimation of RVEF improvement due to the higher degree of preoperative TR in TVP group. Further research is needed to determine the effect of concomitant TVP on RV function.

The mean age of 14.4 ± 6.7 years may seem to be too young for PVR after TOF repair. However, we believe that earlier PVR before deterioration of RV function occurs and symptoms are manifested has beneficial effects even though these younger patients could have more chance to undergo reoperation for prosthetic valve in the future. We have reported that older age at PVR and longer interval from TOF repair to PVR are risk factors that may cause poor late outcomes [18]. As a large number of young patients was included in this study, we wanted to determine whether younger age affected the outcome of concomitant TVP. Young age is well known as a significant risk factor for early bio-prosthetic valve failure in pulmonary portion and, in our study, the last echocardiography also showed that the childhood patients had higher incidence of prosthetic PV failure (25 of 45 (55.6%) in childhood patients and 21 of 74 (28.4%) in older patients). However, both age group (childhood patients and older patients) showed significant improvement of TV function and age at PVR was not a significant risk factor for significant TR recurrence in the multivariable analysis.

This study has several limitations. Inherent to its retrospective and observational aspect, the major limitation comes from the heterogeneity between the two groups, TVP group and no-TVP group. Not surprisingly, more patients with worse degree of preoperative TR were included in TVP group. However, we concluded that just comparing the patients with the same degree of preoperative TR could not resolve this heterogeneity, as we decided whether to perform concomitant TVP according to the characteristics and mechanisms of TR and the intraoperative findings as well as the degree of TR. Therefore there still exists heterogeneity between the two groups even in patients with same degree of TR. As the lack of detailed records of the intraoperative findings on the morphology of TV made it difficult to divide the patients into homogenous subgroups, we included all the patients in the study regardless of the degree of preoperative TR. However, we also performed some analysis on the patients with moderate TR and the results were similar to those of the entire cohort. Although we have reported the benefit of TVP at PVR over a mid-term follow-up, longer-term studies are needed to determine the longevity of TVP. The number in entire cohort was not small comparing with previously published studies; however, when we divided these patients into subgroups to look at our outcomes in detail, the numbers in subgroups were not large enough to perform statistical analysis. Finally, cMRI was performed in only a small number of patients.

In conclusion, after PVR in repaired TOF patients, there was an improvement in the degree of TR and the RVEDVi regardless of concomitant TVP. Concomitant TVP at the time of PVR may not be able to prevent the recurrence of TR when prosthetic PV failure occurs; however, it may effectively preserve TV function until that time.

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Data Availability The deidentified participant data will not be shared.

Declarations

Conflict of interests The authors have no relevant financial or non-financial interests to disclose.

Ethical Approval Institutional Review Board of Seoul National University Hospital: Approval No. 1809-148-973. Institutional Review Board of Sejong General Hospital: Approval No. 2014-158.

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