Tricuspid valve replacement provides better long-term survival and tricuspid valve function than repair in patients with systemic right ventricle

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Which is the favorable procedure in patients with systemic right ventricle and biventricular circulation system? TVP or TVR?

**Retrospective study**
- April 1979–April 2022
- 34 patients with d- or l-TGA with systemic right ventricle undergoing tricuspid valve surgery
- TVP (n=11) vs. TVR (n=23).
- Comparison in survival and tricuspid valve dysfunction

*Tricuspid valve replacement provided better long-term survival and tricuspid function in patients with systemic right ventricle and biventricular circulation compared to tricuspid valvuloplasty.*

TGA = Transposition of the great arteries; TVP = Tricuspid valvuloplasty; TVR = Tricuspid valve replacement
Tricuspid valve replacement provides better long-term survival and tricuspid valve function than repair in patients with systemic right ventricle

Brief Title: TVR provides better long-term outcomes in patients with systemic RV

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Central Picture Legend:

Tricuspid valve replacement provided better long-term outcomes than valvuloplasty.

Central Message:

Tricuspid valve replacement provided better long-term survival and tricuspid valve function in patients with systemic right ventricle and biventricular circulation compared
to tricuspid valvuloplasty.

Perspective statement:
The favorable procedure for systemic tricuspid regurgitation remains unclear in patients with systemic right ventricle and biventricular circulation. Tricuspid valve replacement will provide better long-term outcomes in terms of survival and tricuspid valve function. This will be applied to both levo- and dextro-transposition of the great arteries.

Authors' contributions
Study conception and design: A. Furuta and T. Shinkawa
Analysis and interpretation: A. Furuta, S. Okugi, and H. Yoshida
Writing the article: A. Furuta, H. Yoshida, and T. Shinkawa
Critical revision of the article: A. Furuta, T. Shinkawa, and H. Niinami
Final approval of the article: A. Furuta, T. Shinkawa, S. Okugi, H. Yoshida, and H. Niinami
Data collection: A. Furuta, S. Okugi, and H. Yoshida
Literature search: A. Furuta and T. Shinkawa
Administrative, technical, or logistic support: T. Shinkawa and H. Niinami
Structured Abstract

Objective:
The purpose of this study is to compare the long-term outcomes of two different tricuspid surgeries including valvuloplasty and replacement for significant tricuspid regurgitation (TR) in patients with systemic right ventricle (RV).

Method:
This is a retrospective study of 34 patients with dextro-transposition of the great arteries (TGA) or levo-TGA with biventricular circulation and systemic RV undergoing tricuspid valve surgery between April 1979 and April 2022. Patients were divided into two groups based on the procedure: tricuspid valvuloplasty (TVP, n=11) and tricuspid valve replacement (TVR, n=23). These groups were compared in terms of survival, tricuspid valve dysfunction, and tricuspid valve-related reoperation.

Results:
There was no significant difference between the groups in operative age, body weight, the proportion of dextro-TGA, Ebstein-like tricuspid dysplasia, and preoperative right ventricular volume/function. During the median follow-up of 9.7 years, there was 1 early death (TVP group) and 4 late deaths (3 in TVP group and 1 in TVR group). There
were 7 tricuspid valve dysfunctions including 6 significant TR in TVP group and 1 prosthetic valve dysfunction in TVR group, and 4 tricuspid valve-related reoperations (3 in TVP group and 1 in TVR group) were performed. There were significant differences between the groups in survival (TVP vs. TVR: 72.7 vs. 94.7% at 10 years after surgery, p=0.0328) and cumulative incidence of tricuspid valve dysfunction at 10 years after tricuspid surgery (TVP vs. TVR: 27.3% vs. 0%, p=0.0121).

Conclusions:

TVR provided better long-term survival and tricuspid function in patients with systemic RV compared to TVP.

Keywords: systemic right ventricle; tricuspid valve regurgitation; tricuspid valve surgery; transposition of the great arteries.
Abbreviation

d-TGA = dextro-transposition of the great arteries

l-TGA = levo-transposition of the great arteries

RV = right ventricle

TR = tricuspid regurgitation

TVP = tricuspid valvuloplasty

TVR = tricuspid valve replacement
Introduction

Levo-transposition of the great arteries (L-TGA) patients without operative history or with a history of conventional repair and dextro-transposition of the great arteries (d-TGA) patients with a history of atrial switch operation have the morphological right ventricle (RV) sustaining systemic circulation in biventricular circulation. Due to the exposure to systemic blood pressure and structural problem of the tricuspid valve, some patients will experience developing tricuspid regurgitation (TR) and require tricuspid valve surgery for significant TR [1-5]. Tricuspid valve surgery was generally divided into two types: tricuspid valvuloplasty (TVP) and tricuspid valve replacement (TVR); however, the optimal procedure remains unclear in patients with the systemic RV because of the small number of patients.

This study aims to assess the long-term outcomes of tricuspid valve surgery for patients with systemic RV and clarify the clinical differences between TVP and TVR.

Patients and Methods

Patient population and study design

This study is a retrospective, cohort study of consecutive patients who were diagnosed
as l-TGA or d-TGA with biventricular circulation and systemic RV and underwent TVP or TVR for significant TR at the Tokyo Women’s Medical University Hospital between April 1979 and April 2022. A total of 34 patients were enrolled herein and divided into two groups based on the procedure: TVP (n=11) and TVR (n=23) groups. Medical records were reviewed, and basic demographic, intraoperative, and postoperative data were analyzed. These groups were compared in terms of survival, tricuspid dysfunction, tricuspid valve-related reoperation, and the size and function of the RV.

This study was approved and monitored by the Tokyo Women’s Medical University’s research ethics committee (institutional review board number: 22-0563, November 25, 2022). The need for patient consent was waived because of the retrospective, registry-based study design. This study was performed in conformity with the Declaration of Helsinki.

**Evaluation and definition**

Pre- and post-operative diameter, volume, and function of RV were assessed by transthoracic echocardiography or angiography. RV end-diastolic volume in angiography was expressed as % of the normal value based on the normal value [6] and RV function was evaluated by fractional shortening and fractional area change. Tricuspid valve
dysfunction was defined as significant TR (more than moderate) or prosthetic valve dysfunction including prosthetic valve stenosis (inflow $>$2m/s) or more than a moderate para-valvular leak. Early mortality was defined as death within 30 days of tricuspid valve surgery regardless of discharge or death in the same admission. Late mortality was defined as any death after discharge.

The primary endpoint of this study was the group difference in long-term survival, and the secondary endpoint was the group difference in long-term tricuspid valve dysfunction.

**Operative indication and procedure**

Tricuspid surgery was performed under general anesthesia with transesophageal echocardiography support. Cardiopulmonary bypass was established with ascending aorta perfusion and bivacal or right atrium drainage. Intermittent cold crystalloid cardioplegia was administered after aortic cross-clamping. Hypothermic perfusion was occasionally introduced based on the patient's status. The choice between TVP and TVR depended on the anatomic conditions and the surgeons’ decision. TVP included resection/plication, artificial chordae tendineae technique, and annuloplasty such as the Kay-Reed technique or ring annuloplasty using a complete ring. The type of prosthetic
valve was decided after consultation with the patient. A concomitant procedure was added based on the hemodynamics, and the epicardial pacemaker system was placed as necessary. For patients with mechanical valves, the postoperative anticoagulation goal was set for INR of 2.0-2.5 with oral coumadin.

Statistical analysis

All statistical analyses were performed with JMP Pro version 16 software (SAS Institute Inc., Cary, NC, USA) and EZR version 1.61 (Jichi Medical University, Saitama, Japan). Data of continuous variables were presented as mean ± standard deviation for normal distribution and as median (25th–75th percentile interval) for non-normal distribution after confirming by the Shapiro–Wilk test. Categorical variables were presented as a number (proportion). A statistical significance in the analysis of contingency tables was assessed by Fisher's exact test. The normally distributed and non-normally distributed continuous variables between the groups were assessed by the student’s t-test and the Mann-Whitney U test, respectively. The actual survival time was estimated from the date of tricuspid valve surgery to the date of all-cause death or the last contact. Actuarial survival rates were analyzed by the Kaplan-Meier curve and a group comparison was conducted by the log-rank test. The competing risks regression model was developed to
describe the cumulative incidence function according to the method of Fine and Gray.

The cumulative incidence of tricuspid valve dysfunction and tricuspid-related reoperation were calculated with death as competing for failure events. P values of <.05 were considered statistically significant.

Results

Patient characteristics

Thirty-four patients were enrolled. There were 11 patients in TVP group and 23 in TVR group. TVP group included 3 d-TGA and 8 l-TGA patients, and 5 l-TGA patients did not have a surgical history, while TVR group included 6 d-TGA and 17 l-TGA patients, and 12 l-TGA patients did not have a surgical history. The mean age in TVP and TVR was 20.7±16.8 years (ranges, 1–50 years) and 26.8±13.4 (ranges 3–51 years) with no significant differences (p=0.8662), and the proportion of the young patients under 15 years was also similar (5/11 in TVP and 7 in TVP, p=0.4382). There were no significant differences between the groups (TVP vs. TVR) in body weight (37.6±17.3 vs. 50.9±17.0, p=0.0637), time from the functional repair (14.8 (7.3–22.6) vs. 23.8 (11.7–35.3), p=0.3361), and comorbidities. Dyslipidemia and chronic renal failure (Creatinine > 2mg/dl) were not found in both groups. Seven patients (1 in TVP group and 6 in TVR
group had a history of pacemaker implantation for sick sinus syndrome or atrioventricular block. Previous atrial switch operations in 9 d-TGA patients were 6 Senning and 3 Mustard operations.

Preoperative echocardiography revealed that almost all patients (97%: 33/34) had more than moderate TR. The most frequent reason for TR was abnormal cusp or chordae in TVP group and annular dilatation in TVR group. Preoperative catheter studies demonstrated that end-diastolic volume (121 (106–167) vs. 133 (121–153) % of normal, p=0.5256) and ejection fraction (51.6±7.4 vs. 47.6±7.4 %, p=0.2401) of RV and cardiac index volume (2.9±0.7 vs. 2.8±0.5, p=0.6159) were not significantly different between groups. Patient characteristics were summarized in Table 1 and the surgical intervention flow chart was described in Figure 1.

Operative and in-hospital outcomes

In TVP group, valvuloplasty included annuloplasty in 7 patients including the Kay-Reed technique in 5 and ring annuloplasty in 2, resection/plication in 4, and artificial chordae tendineae technique in 1. The size of the ring was 30mm in 2 cases. In TVR group, mechanical prosthesis with a mean size of 29.9±2.6 mm (ranging from 26 mm to 33 mm) was used in 21 patients, and bioprosthetic valve were used 2 patients (29 mm and
A total of 36 concomitant procedures except for pacemaker or implantable cardiac defibrillator-related procedures were performed in 23 patients and the most frequent concomitant procedure was surgical ablation. Pacemaker and cardiac resynchronization therapy devices were newly implanted in 4 (1 in TVP and 3 in TVR groups) and 2 (in TVR group) patients, respectively. Cardiopulmonary bypass time was not significantly different between the groups (TVP vs. TVR: 127.9±41.3 vs. 150.0±71.0, p=0.3544), while aortic cross-clamp time was significantly longer in TVR group than that in TVP group (67.4±35.2 vs. 103.4±49.5 min, p=0.0421). Operative results were summarized in Table 2.

There was 1 early mortality in TVP group. A 1-year-old boy, who was diagnosed with d-TGA and underwent the atrial switch operation (the Senning operation) at the age of 9 months, underwent TVP; however, he died of bleeding on the first postoperative day. In-hospital complications were 3 arrhythmia-related events (2 in TVP group and 1 in TVR group) and 2 surgery-related bleeding events only in TVR group. The mean length of intensive care unit stay in TVP and TVR groups was 4.0 (3.3–5.8) and 3.0 (2.3–4.8) days, respectively (p=0.698) and the mean length of hospital stay in TVP and TVR groups was 20.5 (15.8–35.3) and 20.0 (14.0–24.0), respectively (p=0.5864).
Late outcomes

During the median follow-up of 9.6 (2.1–20.0) years, 29 patients were alive and 5 died. There were 4 late mortalities (3 in TVP and 1 in TVR). The cause of late mortalities in TVP group were 2 heart failures and 1 pneumonia. A 50-year-old female without a surgical history was diagnosed with I-TGA and significant TR due to abnormal cusp and underwent TVP. She experienced recurrent TR 20 years after TVP and finally died of RV failure. A 1-year-old boy was diagnosed with I-TGA and severe TR due to Ebstein-like dysplasia and underwent TVP with ventricular septal defect closure. He underwent TVR 1 month after TVP for recurrent TR causing severe heart failure; however, he died of heart failure 1 month after redo surgery. On the other hand, in TVR group, a 2-year-old boy with a history of the Senning operation at 6 months of age for d-TGA, underwent TVR using a mechanical valve. However, he died of sudden death 2 years after TVR. The overall survival at 10 years after tricuspid surgery was 72.7±13.4% in TVP group and 94.7±5.1% in TVR group (20 years, 72.7±13.4% in TVP group and 94.7±5.1% in TVR group) and there were significant differences between the groups (p=0.0328, Figure 2A).
There were 7 tricuspid valve dysfunctions including 6 significant TR in TVP group and 1 prosthetic valve dysfunction in TVR group. The cumulative incidences of tricuspid valve dysfunction at 10 years after tricuspid surgery was 27.3% in TVP group and 0% in TVR group (20 years, 38.2% in TVP group and 18.9% in TVR group) and there were significant differences between the groups (p=0.0121, Figure 2B).

Of 7 patients with tricuspid valve dysfunction, 4 patients underwent tricuspid valve-related reoperations: 3 patients in TVP group underwent TVR for recurrent TR (1 month, 8 months, and 22 years after the TVP), while 1 patient in TVR group underwent redo TVR concomitant with mitral valvuloplasty and the Cox-Maze procedure due to a severe pannus formation 18 years after the first TVR. The cumulative incidence of tricuspid valve-related reoperation at 10 years after tricuspid surgery was 18.2% in TVP group and 0% in TVR group (20 years, 18.2% in TVP group and 18.9% in TVR group) and there were no significant differences between the groups (p=0.1290, Figure 2C).

Although there were 4 new cardiac resynchronization therapy device implantations (1 in TVP and 3 in TVR group), there was no new pacemaker implantation for atrioventricular block or sick sinus syndrome. In TVR group, one patient with a history of atrial fibrillation experienced cerebral infarction 17 days after TVR using mechanical valve. There was no late bleeding or thrombotic events related to anticoagulant therapy.
The latest echocardiography data were obtained from 7 patients in TVP group and 22 patients in TVR group. Among 7 patients in TVP group, 3 had tricuspid valve-related reoperations and 3 had more than moderate TR at the latest echocardiography. There were no significant differences between groups (TVP vs. TVR) in end-diastolic diameter (52.0 (48.0–56.0) vs. 52.5 (45.0–59.8) mm, p=0.8813), end-systolic diameter (42.0 (36.0–43.0) vs. 41.0 (37.0–47.0) mm, p=0.6104), fractional shortening (0.21 vs. 0.22 (0.16–0.25), p=0.6490), and fractional area change (27.0 (23.9–27.1) vs. 22.2 (19.8–30.3) %, p=0.9263) of the systemic RV.

Comparison of d-TGA and l-TGA

There were 9 d-TGA and 25 l-TGA patients. There were no significant differences between the groups in age, body weight, comorbidities, the proportion of males, Ebstein-like tricuspid dysplasia, more than moderate TR, the end-diastolic volume of the RV, and cardiac index, while significant differences were found in the number of patients without a cardiac surgical history and ejection fraction of the RV (p=0.009, Supplementary table). Aortic cross-clamp (d-TGA vs. l-TGA: 86 (68–126) vs. 94 (51 vs. 128), p=0.9133), and cardiopulmonary bypass (124 (78–154) vs. 138 (113–222), p=0.2961) times were similar in both groups.
The overall survival at 10 years after tricuspid surgery was 76.2±14.8% in d-TGA group and 92.0±5.4% in l-TGA group and there were no significant differences between the groups (p=0.3107, Figure 3). The cumulative incidence of tricuspid dysfunction at 10 years after tricuspid surgery was 11.1% in d-TGA group and 8.0% in l-TGA group, and there were no significant differences between the groups (p=0.7650, Supplementary Figure 1A). The cumulative incidence of tricuspid valve-related reoperation at 10 years after tricuspid surgery was 11.1% in d-TGA group and 4.0% in l-TGA group, and there were no significant differences between the groups (p=0.6346, Supplementary Figure 1B). The latest echocardiography revealed that end-diastolic diameter (d-TGA vs. l-TGA: 40.5±6.1 vs. 55.3±6.9 mm, p=0.0001) and end-systolic diameter (32.9±5.5 vs. 43.8±6.9 mm, p=0.0044) of the systemic RV were significantly larger in l-TGA group than those of d-TG group, while fractional shortening (0.22±0.04 vs. 0.21±0.06, p=0.7411) and fractional area change (29.3±9.2 vs. 22.0±6.8, p=0.1459) of the RV were comparable between the group.

Discussion

The systemic RV is frequently associated with late progressive TR, declining RV
function, and consequently, a high incidence of adverse outcomes due to congestive heart failure and eventually decreased survival [1-5]. In the previous studies, TVP provided poor results of a high incidence of recurrent TR, and TVR was advocated despite a high operative risk [7]. In our study, we reviewed the surgical outcomes of tricuspid surgery in patients with systemic RV and compared the outcomes between TVP and TVR as well as a comparison of d-TGA and l-TGA. See Figure 4 for a graphical abstract of the study.

Survival

The RV function and TR are key determinants of clinical status and long-term outcomes, especially in patients with systemic RV. In addition, a preoperative low ejection fraction below 40% and a large end-diastolic dimension were reported to be a predictor of postoperative mortality in TVR for l-TGA patients [8-10]. Although there are few studies regarding RV function and TR in d-TGA patients undergoing atrial switch operation, a large follow-up study on 468 atrial switch operations in Sweden and Denmark [5] concluded that long-term survival in these patients is primarily determined by tricuspid valve and RV factors, not the timing or type of surgery in childhood. In our study, of 4 late mortalities, 3 patients died of heart failure or sudden death and 2 of these
326 3 patients had postoperative significant recurrent TR, suggesting that significant TR
327 might have a relationship with late mortality. TVP group, which had a higher incidence
328 of postoperative significant recurrent TR, had significantly lower survival compared to
329 TVR group. Although we could not identify a potential factor of late mortality due to
330 the small number of patients, a good late outcome might be obtained from a favorable
331 control of TR.
332
333 *Tricuspid surgery*
334 Tricuspid surgery is an exclusive measure to improve TR and maintain RV function.
335 Recent several studies proved that tricuspid surgery in the early stage of RV dysfunction
336 could bring favorable short- and long-term outcomes [7, 8, 12, 13]. As tricuspid surgery,
337 TVP is not generally recommended because of previous unsatisfactory outcomes such
338 as a high incidence of recurrent TR in patients with systemic RV dysfunction, while
339 TVR was advocated despite a high operative risk [7, 10-14]. Certainly, TVR seems to
340 have some operative risks because longer aortic cross-clamp time and 2 bleeding events
341 were found in TVR group of our study; however, there was no early mortality in TVR
342 group.
343 Although the cumulative incidence of tricuspid valve-related reoperation was not
significantly different between the groups, the cumulative incidence of tricuspid valve
dysfunction was significantly higher in TVP group in our study. In TVP group, a total of
6 patients experienced significant TR: 2 eventually died of heart failure (1 of 2
underwent TVR), 2 underwent TVR, and 2 are outpatients with significant TR. Thus,
more than half of TVP patients seemed to be associated with significant recurrent TR.
Similar results were seen in the report by Deng and colleagues [10], where recurrent
TR, defined as above mild degree, was observed in 60% of patients undergoing TVP.
TVP is challenging in some patients with systemic RV due to tethering and plastering.
More than mild tethering seems to predict a high rate of residual TR [15] and might be a
reason to replace a valve because this cannot be treated with annuloplasty alone.
Ebstein-like tricuspid dysplasia such as plastering is occasionally found in I-TGA
patients and makes it more difficult to complete TVP. Myers et al [16] reviewed TVP in
younger groups with I-TGA with Ebstein-like dysplasia of tricuspid valve undergoing
anatomic repair and concluded that valvuloplasty should be considered for significant
TR associated with Ebstein-like dysplasia. However, as this report included the tricuspid
valve in the pulmonary RV, the same outcomes might not be applied to patients with
systemic RV. In our study, TVP was performed on only 1 patient with Ebstein-like
tricuspid dysplasia; however, the patient underwent TVR 1 month after TVP. In recent
years, we have performed TVR in patients with systemic RV and Ebstein-like tricuspid dysplasia.

Comparison of d-TGA and l-TGA

As underlying pathological mechanisms between d-TGA and l-TGA are not basically the same, postoperative course including RV function and the mode of TR also seem to be different. Previous studies showed that the clinical course of d-TGA and l-TGA showed similarities in RV dysfunction and the mode of TR though most studies focused on 1 group, making an accurate comparison difficult [14,17-19]. Morcos et al [19] showed that l-TGA and d-TGA patients had similar RV size and shape, while global RV function was lower in d-TGA than that of l-TGA patients using ejection fraction and normalized tricuspid annular systolic plane excursion. In our study, the preoperative ejection fraction of the RV by angiography was significantly lower in d-TGA group, while the postoperative RV size was significantly larger in l-TGA group compared with d-TGA group, and the postoperative RV function was similar between the groups. As both groups have a small number of patients making bias in comparison, more patients and further studies will be required. Regarding survival and recurrence of TR, Koolbergen et al [14] compared l-TGA and d-TGA patients and showed no difference in
the composite end-point of survival or recurrence of TR. Our study also showed similar outcomes: no significant differences between d-TGA and l-TGA patients in survival and tricuspid valve-related reoperation.

Limitations

This study was a retrospective, single-center study. Because of the rarity, the number of patients was not enough for an accurate group comparison. Significant differences were identified in terms of survival and tricuspid dysfunction between the groups; however, it is necessary to validate these findings through additional studies, such as a propensity score-matched analysis conducted in a larger multicenter study. Although both d-TGA and l-TGA patients have the RV as a systemic ventricle, these pathological conditions were different. As this was a long and wide retrospective study, our study also included bias regarding postoperative management, surgical techniques, and uncommon surgical strategies. The comparison of RV dimension and function between TVP and TVR was inaccurate because some patients in TVP group died or underwent TVR.

Conclusions

TVR provided better long-term survival and tricuspid function in patients with systemic
RV compared to TVP, and postoperative significant TR was found in more than half of the patients in TVP group. Significant differences between d-TGA and l-TGA were found in the size of the RV, while there were no significant differences in survival, tricuspid function, and RV function.

Conflicts of interest: none

Funding statement: none
References


Figure legends

Figure 1. Surgical intervention flow chart

The proportion of d- and l-TGA patients was similar in both groups. The most frequent reason for TR was abnormal cusp or chordae in TVP group and annular dilatation in TVR group. Tricuspid valve-related reoperations were performed in 4 patients. There were 1 early mortality and 4 late mortalities in this study.

Figure 2. Comparison of TVP and TVR

Comparison of TVP (black line) and TVR (red line) showing A: overall survival, B: cumulative incidence of tricuspid valve dysfunction and C: cumulative incidence of tricuspid valve-related reoperation.

(A) The overall survival was 72.7±13.4% (95% CI: 37.1–90.3%) at 10–20 years after tricuspid surgery and 54.6±18.7% (95% CI: 16.0–81.9%) at 25 years in TVP group, while that was 94.7±5.1% (95% CI: 68.1–99.2%) at 10–25 years in TVR group (p=0.0285).

(B) The cumulative incidence of tricuspid valve dysfunction was 27.3% (95% CI: 6.5–53.9%) at 10 years after tricuspid surgery, 38.2% (95% CI: 11.5–65.2%) at 20 years, and 52.7% (95% CI: 18.1–78.7%) at 22 years in TVP group, while that was 0% at 10–15 years and 18.9% (95% CI: 0.8–56.1%) at 20 years in TVR group. There were
significant differences between the groups (p=0.0121).

The cumulative incidence of tricuspid valve-related reoperation was 18.2% (95% CI: 6.5–53.9%) at 10–22 years after tricuspid surgery and 42.0% (95% CI: 7.4–74.9%) at 23 years in TVP group, while that was 0% at 10–15 years and 18.9% (95% CI: 0.8–56.1%) at 20 years in TVR group. There were no significant differences between the groups (p=0.1290).

Figure 3. Comparison of d-TGA (black line) and l-TGA (red line) showing overall survival.

The overall survival was 76.2±14.8% (95% CI: 33.2–93.5%) at 10–22 years after tricuspid surgery in d-TGA group, while that was 92.0±5.4% (95% CI: 71.6–97.9%) at 10–20 years and 76.7±14.7% (95% CI: 33.5–93.8%) at 25 years in l-TGA group (p=0.3107).

Figure 4. Summary of our study.

A total of 34 d- or l-TGA patients with biventricular circulation and systemic right ventricle were divided into two groups based on the tricuspid procedure: TVP (n=11) and TVR (n=23). There were significant differences between the groups in survival and freedom from tricuspid valve dysfunction.

Supplementary Figure 1. Comparison of d-TGA (black line) and l-TGA (red line)
showing A: cumulative incidence of tricuspid dysfunction and B: cumulative incidence of tricuspid valve-related reoperation.

(A) The cumulative incidence of tricuspid dysfunction was 11.1% (95% CI: 0.6–38.8%) at 10–20 years after tricuspid surgery in d-TGA group, while that was 8.0% (95% CI: 1.4–22.5%) at 10–15 years after tricuspid surgery, 27.6% (95% CI: 7.2–53.2%) at 20 years, and 54.9% (95% CI: 19.2–80.5%) at 25 years in l-TGA group. There were no significant differences between the groups (p=0.7650).

(B) The cumulative incidence of tricuspid valve-related reoperation was 11.1% (95% CI: 0.6–38.8%) at 10–20 years after tricuspid surgery in d-TGA group, while that was 4.0% (95% CI: 0.3–17.0%) at 15 years after tricuspid surgery, 13.2% (95% CI: 1.8–36.3%) at 20 years, and 27.0% (95% CI: 5.0–56.3%) at 25 years in l-TGA group. There were no significant differences between the groups (p=0.6346).
### Table 1. Patient characteristics

<table>
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<th>TVP group</th>
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<tr>
<td><strong>Age (years)</strong></td>
<td>20.7±16.8</td>
<td>26.8±13.4</td>
<td>0.8662</td>
</tr>
<tr>
<td><strong>Male, n (%)</strong></td>
<td>5 (45%)</td>
<td>15 (65%)</td>
<td>0.4575</td>
</tr>
<tr>
<td><strong>Body weight (kg)</strong></td>
<td>37.6±17.3</td>
<td>50.9±17.0</td>
<td>0.0637</td>
</tr>
<tr>
<td><strong>Primary disease</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dextro-transposition of the great arteries, n (%)</td>
<td>3 (27%)</td>
<td>6 (26%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Levo-transposition of the great arteries, n (%)</td>
<td>8 (73%)</td>
<td>17 (74%)</td>
<td>1.0000</td>
</tr>
<tr>
<td><strong>Without a history of cardiac surgery</strong></td>
<td>5 (45%)</td>
<td>12 (52%)</td>
<td>1.0000</td>
</tr>
<tr>
<td><strong>Time from the functional repair (years)</strong></td>
<td>14.8 (7.3–22.6)</td>
<td>23.8 (11.7–35.3)</td>
<td>0.3361</td>
</tr>
<tr>
<td><strong>Comorbidity</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>2 (18%)</td>
<td>6 (26%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Hyperuricemia</td>
<td>1 (9%)</td>
<td>2 (9%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>1 (9%)</td>
<td>0 (0%)</td>
<td>0.3235</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>5 (45%)</td>
<td>13 (57%)</td>
<td>0.7166</td>
</tr>
<tr>
<td>Advanced or complete atrioventricular block</td>
<td>2 (18%)</td>
<td>6 (26%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Atrioventricular nodal re-entrant tachycardia</td>
<td>1 (9%)</td>
<td>3 (13%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Atrial fibrillation</td>
<td>1 (9%)</td>
<td>3 (13%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Sick sinus syndrome</td>
<td>1 (9%)</td>
<td>1 (4%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Ebstein-like tricuspid dysplasia</td>
<td>1 (9%)</td>
<td>4 (17%)</td>
<td>1.0000</td>
</tr>
<tr>
<td><strong>Tricuspid valve regurgitation</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild-moderate</td>
<td>1 (9%)</td>
<td>0 (0%)</td>
<td>0.3235</td>
</tr>
<tr>
<td>Moderate</td>
<td>4 (36%)</td>
<td>9 (39%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Severe</td>
<td>6 (55%)</td>
<td>14 (61%)</td>
<td>1.0000</td>
</tr>
<tr>
<td><strong>Preoperative catheter study</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right ventricular end-diastolic volume (% of normal)</td>
<td>121 (106–167)</td>
<td>133 (121–153)</td>
<td>0.5256</td>
</tr>
<tr>
<td>Right ventricular ejection fraction (%)</td>
<td>51.6±7.4</td>
<td>47.6±7.4</td>
<td>0.2401</td>
</tr>
<tr>
<td>Cardiac index (L/min/m²)</td>
<td>2.9±0.7</td>
<td>2.8±0.5</td>
<td>0.6159</td>
</tr>
</tbody>
</table>

Tricuspid valvuloplasty, TVP
Tricuspid valve replacement, TVR
Table 2. Operative results

<table>
<thead>
<tr>
<th></th>
<th>TVP group</th>
<th>TVR group</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiopulmonary bypass time (minutes)</td>
<td>127.9 ± 41.3</td>
<td>150.0 ± 71.0</td>
<td>0.3544</td>
</tr>
<tr>
<td>Aortic cross-clamp time (minutes)</td>
<td>67.4 ± 35.2</td>
<td>103.4 ± 49.5</td>
<td>0.0421</td>
</tr>
<tr>
<td>Concomitant procedure, n (%)</td>
<td>9 (82%)</td>
<td>14 (61%)</td>
<td>0.2714</td>
</tr>
<tr>
<td>Surgical ablation</td>
<td>2 (18%)</td>
<td>5 (22%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Atrial septal defect/patent foramen ovale closure</td>
<td>3 (27%)</td>
<td>3 (13%)</td>
<td>0.3627</td>
</tr>
<tr>
<td>Pulmonary surgery</td>
<td>3 (27%)</td>
<td>2 (9%)</td>
<td>0.2999</td>
</tr>
<tr>
<td>Mitral surgery</td>
<td>3 (27%)</td>
<td>1 (4%)</td>
<td>0.0889</td>
</tr>
<tr>
<td>Ventricular septal defect closure</td>
<td>3 (27%)</td>
<td>1 (4%)</td>
<td>0.0889</td>
</tr>
<tr>
<td>Left ventricle-pulmonary artery conduit replacement</td>
<td>0 (0%)</td>
<td>4 (17%)</td>
<td>0.2799</td>
</tr>
<tr>
<td>Pulmonary artery plasty</td>
<td>1 (9%)</td>
<td>0 (0%)</td>
<td>0.3235</td>
</tr>
<tr>
<td>Others</td>
<td>3 (27%)</td>
<td>2 (9%)</td>
<td>0.2999</td>
</tr>
<tr>
<td>Early mortality, n</td>
<td>1 (9%)</td>
<td>0 (0%)</td>
<td>0.3235</td>
</tr>
<tr>
<td>Late mortality, n</td>
<td>3 (27%)</td>
<td>1 (4%)</td>
<td>0.0889</td>
</tr>
</tbody>
</table>

Tricuspid valvuloplasty, TVP

Tricuspid valve replacement, TVR
Which is the favorable procedure in patients with systemic right ventricle and biventricular circulation system? TVP or TVR?

Retrospective study
- April 1979–April 2022
- 34 patients with d- or l-TGA with systemic right ventricle undergoing tricuspid valve surgery
- TVP (n=11) vs. TVR (n=23).
- Comparison in survival and tricuspid valve dysfunction

Tricuspid valve replacement provided better long-term survival and tricuspid function in patients with systemic right ventricle and biventricular circulation compared to tricuspid valvuloplasty.

TGA = Transposition of the great arteries; TVP = Tricuspid valvuloplasty; TVR = Tricuspid valve replacement
## Supplementary Table

**Supplementary Table.** Patient characteristics of d-TGA and l-TGA patients

<table>
<thead>
<tr>
<th></th>
<th>d-TGA</th>
<th>l-TGA</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient number, n</td>
<td></td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>33 (10–36)</td>
<td>23 (15–32)</td>
<td>0.6563</td>
</tr>
<tr>
<td>Male, n (%)</td>
<td>5 (45%)</td>
<td>15 (65%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Body weight (kg)</td>
<td>53.3 ± 16.3</td>
<td>44.7 ± 18.2</td>
<td>0.2844</td>
</tr>
<tr>
<td>Without history of cardiac surgery</td>
<td>0 (0%)</td>
<td>17 (74%)</td>
<td>0.0009</td>
</tr>
<tr>
<td>Time from the functional repair (years)</td>
<td>14.8 (7.3–22.6)</td>
<td>23.8 (11.7–35.3)</td>
<td>0.3361</td>
</tr>
<tr>
<td>Comorbidity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hypertension</td>
<td>2 (18%)</td>
<td>6 (26%)</td>
<td>0.1648</td>
</tr>
<tr>
<td>Dyslipidemia</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>—</td>
</tr>
<tr>
<td>Hyperuricemia</td>
<td>1 (9%)</td>
<td>2 (9%)</td>
<td>0.5488</td>
</tr>
<tr>
<td>Chronic renal failure (Creatinine &gt; 2mg/dl)</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
<td>—</td>
</tr>
<tr>
<td>Cerebrovascular disease</td>
<td>1 (9%)</td>
<td>0 (0%)</td>
<td>0.2467</td>
</tr>
<tr>
<td>Arrhythmia</td>
<td>5 (45%)</td>
<td>13 (57%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Ebstein-like tricuspid dysplasia</td>
<td>0 (0%)</td>
<td>5 (22%)</td>
<td>0.2933</td>
</tr>
<tr>
<td>Tricuspid valve regurgitation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild-moderate</td>
<td>1 (9%)</td>
<td>0 (0%)</td>
<td>0.2467</td>
</tr>
<tr>
<td>Moderate</td>
<td>4 (36%)</td>
<td>9 (39%)</td>
<td>0.7041</td>
</tr>
<tr>
<td>Severe</td>
<td>6 (55%)</td>
<td>14 (61%)</td>
<td>1.0000</td>
</tr>
<tr>
<td>Catheter study</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right ventricular end-diastolic volume (% of normal)</td>
<td>121 (108–145)</td>
<td>139 (121–190)</td>
<td>0.2340</td>
</tr>
<tr>
<td>Right ventricular ejection fraction</td>
<td>42.7 (40.6–46.0)</td>
<td>47.4 (45.3–57.0)</td>
<td>0.0254</td>
</tr>
<tr>
<td>Cardiac index</td>
<td>2.7 (2.5–2.9)</td>
<td>2.9 (2.5–3.1)</td>
<td>0.7383</td>
</tr>
</tbody>
</table>

d-TGA, dextro-transposition of the great arteries
l-TGA, levo-transposition of the great arteries