The impact of a bicuspid pulmonary valve in the aortic position after arterial switch for transposition of the great arteries on neoaortic root dimension and function: a propensity score matched analysis

Bobae Jeon a, Eun Seok Choi b, Bo Sang Kwon a, b, Tae-Jin Yun b, Seul Gi Cha c, Jae Suk Baek a, c, Jeong Jin Yu a, c and Chun Soo Park b, *

a Division of Cardiothoracic Surgery, GangNeung Asan Hospital, Gangwon-do, Korea
b Division of Pediatric Cardiac Surgery, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea
c Division of Pediatric Cardiology, Asan Medical Center, University of Ulsan College of Medicine, Seoul, Korea

* Corresponding author. Division of Pediatric Cardiac Surgery, Asan Medical Center, University of Ulsan College of Medicine, 88, Olympic-ro 43-gil, Songpa-gu, Seoul, Korea, 05505. Tel: +82-2-3010-3583; fax: +82-2-3010-6966; e-mail: hopang1974@hanmail.net, chunsoo@amc.seoul.kr (Chun Soo Park).

Received 24 October 2021; accepted 7 March 2022

Abstract

OBJECTIVES: This study investigated the effect of a bicuspid pulmonary valve on neoaortic root morphology, function, and the clinical outcomes of early survivors after the arterial switch operation using propensity score matching.

METHODS: From 1997 to 2018, a total of 442 patients underwent the arterial switch operation for transposition of the great arteries. After exclusion of patients who underwent a staged repair, were repaired beyond 1 year of age, died before discharge and who lacked echocardiographic data at discharge, propensity score matching was used for analysis.

Presented at the 34th Annual Meeting of the European Association for Cardio-Thoracic Surgery, Barcelona, Spain, 8–10 October 2020.

© The Author(s) 2022. Published by Oxford University Press on behalf of the European Association for Cardio-Thoracic Surgery. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (https://creativecommons.org/licenses/by/4.0/), which permits unrestricted reuse, distribution, and reproduction in any medium, provided the original work is properly cited.
RESULTS: Among 352 eligible patients, 18 patients (5.1%) had a bicuspid pulmonary valve. After propensity score matching (1:4), 15 patients with bicuspid valve (bicuspid group) and 60 patients with tricuspid valve (tricuspid group) were enrolled. The median follow-up duration was 9.9 years (4 months–22.3 years). All-cause reoperation-free survival at 10 years was 93.3% in the bicuspid group and 87.0% in the tricuspid group (P = 0.839), and reoperation for neoaortic valve or root was required in 2 patients in the bicuspid group and 1 in the tricuspid group without intergroup difference. The z-score of the neoaortic annulus did not change in either group, although there was an increasing tendency in the z-score of the neoaortic sinus without intergroup difference (P = 0.690). Deterioration in neoaortic valve function was more prominent in the bicuspid group (p = 0.028).

CONCLUSIONS: The neoaortic sinus might outgrow the norm regardless of the number of neoaortic valve cusps, whereas the neoaortic annulus remained unchanged. Deterioration of valve function was more prominent in the bicuspid group, which suggests that a bicuspid valve might play a significant role in deterioration of neoaortic valve function, without an additional effect on root pathology.

Keywords: Transposition of the great arteries • Arterial switch operation • Bicuspid pulmonary valve • Neoaortic root • Neoaortic regurgitation

INTRODUCTION

The arterial switch operation (ASO) has been used as a standard surgical treatment for transposition of the great arteries (TGA) since its first documented success (1). For now, the ASO can be performed with very low operative mortality in experienced centres (2, 3), although concerns still remain regarding residual problems including neoaortic root dilatation, neoaortic valve regurgitation (neoAR), coronary insufficiency and pulmonary artery stenosis in the long term.

In the normal position, a bicuspid aortic valve is known to be associated with aortic root dilatation with varying prevalence and degree of dilatation depending upon the phenotype. Moreover, a bicuspid pulmonary valve is more likely to be degenerated than a pulmonary valve with three cusps (4). Therefore, it is reasonable to ask what happens to the bicuspid pulmonary valve that becomes an aortic valve during ASO in the long term. Some studies have investigated clinical outcomes after ASO for TGA with a bicuspid pulmonary valve, changes in aortic root dimensions and progression of neoAR (4, 5). However, a small number of cases, lack of comparison among patients with different cusp morphologies and the use of a simple paired comparison for evaluating changes in neoaortic root dimensions with different time intervals are limitations of previous studies.

This study investigated the effect of a bicuspid neoaortic valve on neoaortic root morphology and function, and the long-term clinical outcomes of early survivors after ASO for TGA using propensity score matching.

METHODS

Ethics statement

The study was approved by Asan Medical Center institutional review board approval: 2020-09-18 and S2020-2228-0001). The requirement for informed consent was waived because of the retrospective nature of the study design.

Patient selection and data collection

From January 1997 through December 2018, among all patients who underwent ASO for TGA, those who underwent staged repair or were repaired at an age older than 1 year were excluded because they enhanced the homogeneity of the patient cohort. For a comparison of serial changes in the morphology and function of the neoaortic root, patients who died before discharge and patients who lacked echocardiographic data at discharge that would provide baseline morphological data were also excluded. Propensity score matched data were used to compare the outcomes of early survivors according to the number of pulmonary cusps. Variables used to generate the propensity score included sex, age at operation, ventricular septal defect (VSD), Taussig-Bing anomaly and arch obstruction.

We reviewed the electronic medical records of the study cohort to collect and collate data regarding patient characteristics, anatomical details, operative details, perioperative data and follow-up data. All serial echocardiographic images for individual patients were reviewed to obtain the information about the neoaortic root dimensions, neoaortic valve function and other morphological or functional measurements. Sections that are difficult to identify accurately with echocardiography in neonatal patients, such as commisural orientation and the phenotype of the bicuspid valve, may be obtained with computed tomographic scans or magnetic resonance imaging. Preoperative computed tomography has been used at our institution for all patients undergoing surgery for complex congenital heart disease since 2015.

The data underlying this article cannot be shared publicly to protect the privacy of the individuals who participated in this study.

Definition

Serial measurements of the neoaortic annulus and sinus were taken in the parasternal long-axis view and adjusted for body surface to calculate z-scores by referring to the data from the Cincinnati Children’s Hospital (6). The severity of neoAR was assessed on the basis of Doppler echocardiographic findings following the American Society of Echocardiography guidelines (7); none to trivial, 0; mild, 1; mild to moderate, 2; moderate to
severe, 3; and severe, 4. Significant neoAR was defined as the degree of regurgitation equal to or greater than grade 2.

The outcomes of interest were the composite of all-cause death, major complications within 30 days after surgery and the development of significant neoAR and neoaortic root dilatation. Major complications included unplanned reoperation, cardiac arrest, arrhythmia requiring a permanent pacemaker implant, circulatory instability requiring mechanical support, acute renal failure requiring haemodialysis or haemofiltration, neurological deficit persisting at discharge and deep wound infection or mediastinitis.

Surgical techniques

During the study period, ASO for TGA was performed by 4 surgeons. With standard aortic and bicalval venous cannulation, moderate hypothermic cardiopulmonary bypass was used for repair. Repeated doses of antegrade cold crystalloid or blood cardioplegia were administered indirectly and directly. After transection of the main pulmonary artery, the morphological characteristics of the pulmonary valve were evaluated. None of the pulmonary valves, which were designated as future aortic valves, were ever touched in this study cohort. Decisions regarding coronary reimplantation using trapdoor incisions and before or after neoaortic reconstruction were made at the discretion of the individual surgeons. Deficient neopulmonary arteries were augmented with autologous pericardial patch with or without treatment. The Lecompte manoeuvre was used for all patients. All intracardiac procedures were accomplished before the arterial switch operation.

Statistical analysis

The normality of variables was evaluated with the Shapiro-Wilk test. Categorical variables were presented as frequencies and percentages, and continuous variables were presented as means with standard deviations or medians with interquartile ranges (IQR) according to the distribution of the data. Before matching, with standard deviations or medians with interquartile ranges, and continuous variables were presented as means and the expected probability of each individual was expressed as a probability curve. Statistical analyses were performed using SPSS Statistics version 22 (IBM Corp., Armonk, NY, USA), R software version 3.4.4 (R Foundation for Statistical Computing, Vienna, Austria) and the GraphPad statistical software package version 5 (GraphPad software, San Diego, CA, USA). A P-value less than 0.05 was considered statistically significant.

RESULTS

Patients characteristics

During the study period, 442 patients underwent ASO for TGA. A total of 90 patients including 15 patients who underwent staged repair, 9 patients who underwent repair who were older than 1 year of age, 46 patients who died before discharge and 20 patients for whom no echocardiographic data were available at discharge were excluded from this study. Among a total of 352 eligible patients, 18 patients (5.1%) had a bicuspid pulmonary valve. After 1:4 matching with propensity scores, 15 patients with bicuspid pulmonary valves (bicuspid group) and 60 patients in the tricuspid PV group were included after 1:4 propensity score matching. Variables used to generate the propensity score included sex, age at operation, VSD, Taussig-Bing anomaly and arch obstruction. ASO: arterial switch operation; PSM: propensity score matching; PV: pulmonary valve; TGA: transposition of the great arteries; VSD: ventricular septal defect.

Table 1 shows the baseline and morphological characteristics that were used as variables for calculating propensity scores. There was no residual imbalance after propensity score matching. Table 2 shows the other baseline and morphological characteristics. There were 36 females and 39 males. Median age and body weight at initial surgical treatment, incidence of low birth weight and prematurity were comparable between the 2 groups. Thirty-six patients (36/75, 48%) were diagnosed prenatally. The relationship of the great vessels was anterior-posterior in 42 patients (56.0%), oblique in 28 patients (37.3%) and side-by-side...
orientation in 5 (6.7%) without significant intergroup differences \( (P = 0.096) \). Coronary artery anatomy was usual in 47 patients \( (47/75, 62.7\%) \) without a significant intergroup difference \( (P = 0.695) \). Forty-five patients \( (45/75, 60.0\%) \) had a VSD, and 13 patients \( (13/75, 17.3\%) \) were diagnosed as having Taussig-Bing anomaly. All patients with an arch obstruction were excluded after the matching process.

### Operative outcomes

The closed technique, which represents coronary reimplantation after neoaortic reconstruction, was used more frequently in the bicuspid group \( [9/15 \ (60\%)] \) in the bicuspid group vs 20/60 \( (33.3\%) \) in the tricuspid group], but the difference did not reach statistical significance \( (P = 0.077) \) (Table 3). For a coronary reimplantation, a trapdoor incision was used in most patients \( [15/15 \ (100\%)] \) in the bicuspid group vs 58/60 \( (96.7\%) \) in the tricuspid group, \( P = 1.000 \) (Table 3). Cardiopulmonary bypass time \( [197 \text{ min (IQR, 167–230 min)}] \) in the bicuspid group vs 161 min \( (\text{IQR, 137–196 min}) \) in the tricuspid group, \( P = 0.063 \) and aortic cross-clamp time \( [121 \text{ min (IQR, 91–157 min)}] \) in the bicuspid group vs 95 min \( (\text{IQR, 81–115}) \) in the tricuspid group, \( P = 0.009 \) were significantly longer in the bicuspid group (Table 3).

Major complications included residual VSD in 3 patients, mediastinal bleeding in 2 patients, residual pulmonary artery stenosis in 1 patient and pericardial effusion requiring pericardiotomy in 1 patient. The median hospital stay was not significantly different between the groups \( [13 \text{ days (IQR, 9–19 days)}] \) in the bicuspid group vs 10 days \( (\text{IQR, 9–15 days}) \) in the tricuspid group, \( P = 0.240 \) (Table 3). NeoAR was absent on the Doppler echocardiographic examination at discharge in most patients \( [86.7\% (13/15)] \) in bicuspid group vs 90\% \( (54/60) \) in tricuspid group]

### Table 1: Covariates used for calculating propensity scores

| Before PSM | After PSM |
|------------|-----------|
| Tricuspid (n = 334) | Bicuspid (n = 18) | ASD* | Tricuspid (n = 60) | Bicuspid (n = 15) | ASD* | P-value |
| Sex (male) | 248 (74.3) | 11 (61.1) | 0.284 | 31 (51.7) | 8 (53.3) | 0.033 | 1.000 |
| Age (days) | 8 (6-13) | 15 (8-23) | 0.753 | 12 (8-17) | 12 (7-20) | 0.061 | 0.827 |
| VSD | 126 (37.7) | 12 (66.7) | 0.605 | 36 (60.0) | 9 (60.0) | 0.000 | 1.000 |
| T-B anomaly | 29 (8.7) | 3 (16.7) | 0.242 | 10 (16.7) | 3 (20.0) | 0.086 | 0.716 |
| Arch obstruction | 37 (11.1) | 0 (0.0) | 0.499 | 0 (0.0) | 0 (0.0) | 0.000 | - |

*An ASD of <0.1 is considered a meaningful imbalance.

ASD: absolute standardized difference; PSM: propensity score matching; T-B: Taussig-Bing; VSD: ventricular septal defect.

### Table 2: Baseline and morphological characteristics

| Number (%) or median (IQR) | Tricuspid (n = 60) | Bicuspid (n = 15) | P-value |
|---------------------------|-------------------|-----------------|---------|
| Body weight (kg) | 3.2 (2.9–3.6) | 3.2 (2.8–3.5) | 0.786 |
| Low birth weight (2.5 kg) | 7 (11.7) | 1 (6.7) | 1.000 |
| Prematurity (37 weeks) | 7 (11.7) | 0 (0.0) | 0.333 |
| Era of surgery | 2001–2003 | 22 (36.7) | 3 (20.0) | 0.096 |
| | 2004–2010 | 20 (33.3) | 3 (20.0) |
| | 2011–2018 | 18 (30.0) | 9 (60.0) |
| Coronary patterns | Usual | 37 (61.7) | 10 (66.7) | 0.695 |
| | Single | 9 (15.0) | 1 (6.7) |
| | Others | 14 (23.3) | 4 (26.7) |
| GA relationship | A-P | 30 (50.0) | 12 (80.0) | 0.096 |
| | Oblique | 25 (41.7) | 3 (20.0) |
| | Side by side | 5 (8.3) | 0 (0.0) |

A-P: anterior-posterior; GA: great artery; IQR, interquartile range.

### Table 3: Operative outcomes

| Number (%) or median (IQR) | Tricuspid (n = 60) | Bicuspid (n = 15) | P |
|---------------------------|-------------------|-----------------|---|
| Order of coronary transfer | Closed | 20 (33.3) | 9 (60.0) | 0.077 |
| | Open | 40 (66.7) | 6 (40.0) |
| Method of coronary transfer | Trapdoor | 58 (96.7) | 15 (100.0) | 1.000 |
| | Buttonhole | 2 (3.3) | 0 (0.0) |
| CPB time (min) | 161 (137–196) | 197 (167–230) | 0.063 |
| ACC time (min) | 95 (81–115) | 121 (91–157) | 0.009 |
| Hospital stay (days) | 10 (9–15) | 13 (9–19) | 0.240 |

ACC: aortic cross-clamping; CPB: cardiopulmonary bypass; IQR: interquartile range.
There was 1 late death (1.3%) in the tricuspid group. A full-term male baby with a birth weight of 3.5 kg who underwent ASO and VSD closure at 2 weeks after birth, died of respiratory arrest at 10.9 months postoperatively. Follow-up was completed for all patients, and the median follow-up duration was 9.9 years (range, 4 months–22.3 years). There was no significant difference in overall transplant-free survival between the groups (100% at 10 years in the bicuspid group vs 98.3% at 10 years in the tricuspid group, \( P = 0.999 \)).

An all-cause reoperation was required in 11 patients (11/75, 14.7%) (Table 4). Freedom from all-cause reoperation at 10 years was 93.3 ± 6.4% in the bicuspid group and 87.0 ± 4.7% in the tricuspid group without a significant intergroup difference (\( P = 0.575 \)). Reoperation for aortic valve or aortic root was required in only 3 patients during the follow-up period (3/75, 4.0%). One patient with a tricuspid pulmonary valve underwent aortic root reduction plasty at 11.9 years after repair. Another 2 patients with bicuspid pulmonary valves needed aortic valve repair for aortic valve stenosis at 10 months and aortic root resection at 19.4 years after ASO, respectively (Table 4).

**Table 4:** Reintervention or reoperation after the arterial switch operation

| Group | Age (Day) | Cause                                      | Operation                                         | Interval (Year) | Status  |
|-------|-----------|--------------------------------------------|---------------------------------------------------|-----------------|---------|
| 1     | BPV 23    | LAD compression, aortic root aneurysm       | LAD ostial relocation, Aortic root reduction plasty | 19.4            | Alive   |
| 2     | BPV 21    | Valvar AS                                  | 1. Balloon AVP                                    | 0.6             | Alive   |
|        |           |                                            | 2. AVP                                            | 0.8             |         |
| 3     | TPV 19    | VSD, subaortic ridge                       | VSD direct closure, subaortic membrane excision   | 1.0             | Alive   |
| 4     | TPV 14    | Left main bronchus compression              | Aortoectomy                                       | 0.1             | Dead    |
| 5     | TPV 12    | Chylothorax                                 | Thoracic duct mass ligation                       | 0.2             | Alive   |
| 6     | TPV 5     | RVOTO                                      | PV commissurotomy, pulmonary sinus augmentation   | 15.5            | Alive   |
| 7     | TPV 6     | LVOTO                                      | VSD extension, subaortic fibromuscular membrane excision | 1.6             | Alive   |
| 8     | TPV 17    | 1. Supravalvar PS                         | 1. Balloon PVP                                    | 0.7             | Alive   |
|        |           |                                            | 2. Aortic root aneurysm, RVOTO                    | 11.9            |         |
| 9     | TPV 17    | LVOTO                                      | VSD extension, subaortic fibromuscular membrane excision | 6.4             | Alive   |
| 10    | TPV 16    | LVOTO                                      | MPA widening                                      | 0.4             | Alive   |

AS: aortic stenosis; AVP: aortic valve plasty; BPV: bicuspid pulmonary valve; LAD: left anterior descending branch; LPA: left pulmonary artery; LVOTR: left ventricular outflow tract reconstruction; MPA: main pulmonary artery; PS: pulmonary stenosis; PVP: pulmonary valve plasty; RVOTO: right ventricular outflow tract obstruction; RVOTR: right ventricular outflow tract reconstruction; TPV: tricuspid pulmonary valve; VSD: ventricular septal defect.

**Figure 2:** Serial changes in the dimensions of the neoaortic annulus and neoaortic sinus. (A) The indexed neoaortic annulus dimension (\( z \)-score) remained unchanged in both groups (\( \beta = 0.018, P = 0.563 \) in the bicuspid group vs \( \beta = 0.002, P = 0.911 \) in the tricuspid group) without a significant intergroup difference (\( P = 0.575 \)). (B) The indexed neoaortic sinus dimension (\( z \)-score) increased in both groups but the change was significant only in the tricuspid group (\( \beta = 0.026, P = 0.285 \) in the bicuspid group vs \( \beta = 0.037, P = 0.005 \) in the tricuspid group). There was no significant intergroup difference (\( P = 0.691 \)).

**Long-term clinical outcomes of matched early survivors**

There was 1 late death (1.3%) in the tricuspid group. A full-term male baby with a birth weight of 3.5 kg who underwent ASO and VSD closure at 2 weeks after birth, died of respiratory arrest at 10.9 months postoperatively. Follow-up was completed for all patients, and the median follow-up duration was 9.9 years (range, 4 months–22.3 years). There was no significant difference in overall transplant-free survival between the groups (100% at 10 years in the bicuspid group vs 98.3% at 10 years in the tricuspid group, \( P = 0.999 \)).

An all-cause reoperation was required in 11 patients (11/75, 14.7%) (Table 4). Freedom from all-cause reoperation at 10 years was 93.3 ± 6.4% in the bicuspid group and 87.0 ± 4.7% in the tricuspid group without a significant intergroup difference (\( P = 0.575 \)). Reoperation for aortic valve or aortic root was required in only 3 patients during the follow-up period (3/75, 4.0%). One patient with a tricuspid pulmonary valve underwent aortic root reduction plasty at 11.9 years after repair. Another 2 patients with bicuspid pulmonary valves needed aortic valve repair for aortic valve stenosis at 10 months and aortic root resection at 19.4 years after ASO, respectively (Table 4).

**Neoaortic root morphology and function**

Baseline neoaortic root dimensions measured before discharge after ASO were similar between the groups. The indexed neoaortic annulus diameter (\( z \)-score) remained unchanged in both groups (\( \beta = 0.018, P = 0.563 \) in the bicuspid group vs \( \beta = 0.002, P = 0.911 \) in the tricuspid group) without a significant intergroup difference (\( P = 0.575 \)) (Fig. 2A). The indexed neoaortic sinus diameter (\( z \)-score) increased in both groups, but the change was statistically significant only in the tricuspid group (\( \beta = 0.026, P = 0.285 \) in the bicuspid group vs \( \beta = 0.037, P = 0.005 \) in the tricuspid group).
for neoAR was rarely required (11). In contrast, van der Palen seemed not to be progressive and that, in their report, surgery significant neoAR. It is interesting that neoaortic root dilatation pair and the presence of a VSD as risk factors for development of artery band as a risk factor for the development of neoaortic root long term (11). The authors identified a previous pulmonary societ et al. noted that neoaortic root dilatation was progressive and as- sociated with the progression of neoAR (14). McMahon and colleagues from Boston demonstrated that post-ASO is among the major concerns following ASO (11–16). Schwartz NeoAR, which might be associated with neoaortic root dilatation, though reports about long-term concerns are still lacking. TGA have consistently noted low operative mortality (2, 3, 10), al- though reports about long-term concerns are still lacking.

Neoar stenosis was developed in 1 patient in the bicuspid group, and reintervention was required at 7 months and 10 months after ASO (Table 4).

DISCUSSION

The ASO is among the greatest success stories in the field of paedia tricentric cardiac surgery. Since its first documented success in 1975 (1), it has become a standard surgical treatment for TGA. Knowledge and improved techniques were amassed by leading groups in the late 1980s (8, 9). Recent reports covering ASO for TGA have consistently noted low operative mortality (2, 3, 10), although reports about long-term concerns are still lacking. Neoaortic root dilation, which might be associated with neoar root dilatation, is among the major concerns following ASO (11–16). Schwartz and colleagues from Boston demonstrated that post-ASO patients were at risk of neoar root dilatation and neoAR in the long term (11). The authors identified a previous pulmonary artery band as a risk factor for the development of neoar root dilatation and a previous pulmonary artery band, older age at repair and the presence of a VSD as risk factors for development of significant neoAR. It is interesting that neoar root dilatation seemed not to be progressive and that, in their report, surgery for neoAR was rarely required (11). In contrast, van der Palen et al. noted that neoar root dilatation was progressive and associated with the progression of neoAR (14). McMahon and colleagues (13) indicated that neoar root dilatation was a risk factor for the development of significant neoAR. They also identified the factors associated with neoar root enlargement, including previous pulmonary artery banding, the presence of VSD and Taussig-Bing anatomy.

In our study, neoar sinus dimensions seemed to increase over time, although only the tricuspid group showed statistical significance in this regard. Given that the bicuspid aortic valves are frequently associated with aortic dilatation partially attributable to the effect secondary to flow dynamics (17), our findings tell a different story in switched neoar bicuspid valves compared to the bicuspid aortic valves in the normal position; a bicuspid neoar valve might not have an additional effect on the neoar root through flow dynamics. The presence of a bicus- pid pulmonary valve might render coronary artery reimplanta- tion and aortic root reconstruction difficult; consequently, the neoar root could become more damaged; however, we did not observe any negative effects on aortic root morphology or function associated with technical difficulties in coronary implan- tation or neoar root manipulation. Our study also demonstrated that the growth of the neoar valve annulus was proportional to the somatic growth regardless of pulmonary valve morphology. Because the Leiden group noted that the growth of the neoar valve annulus was stabilized from 2 years to 18 years of age but started to increase again at 15 years of age (14), longer follow-up might be mandatory to draw solid conclusions.

The presence of a bicuspid pulmonary valve in TGA has not been considered an absolute contraindication for ASO unless an unrelievable left ventricular outflow tract obstruction exists (18–21). In our series, the prevalence of the bicuspid pulmonary valve among repaired TGAs was 5.1%, which is compatible with previous reports, with a prevalence ranging from 4% to 7% (4, 5, 14). Previous studies have reported that the presence of a bicuspid pulmonary valve might not be associated with additional risk for the development of significant neoAR after ASO for TGA (4, 5). However, most such studies analysed the data from small samples using simple methods, precluding a fair, comparative analy- sis with patients having normal tricuspid pulmonary valves. In contrast with the previous reports, we directly compared the outcomes relevant to repaired TGA among groups divided by the pulmonary valve morphology. Additionally, in our study, propensity score matching could further strengthen the power of comparison between groups with different pulmonary valve morphologies.

Even though surgery for neoAR in patients who have under- gone ASO for TGA has been consistently uncommon in previous studies (11, 13), likewise in our study, the occurrence of neoAR might increase if the follow-up period were extended. As previ- ously mentioned, the neoar sinus growth seemed more prominent in the tricuspid group, although an increasing trend was also observed in the bicuspid group. Unlike the findings from previous studies (14, 16), in our study, the progression of neoAR was more prominent in the bicuspid group, in which the outgrowth of the neoar sinus was less prominent. This finding suggests that the neoar valve function might be affected by the neoar valve itself rather than by the neoar root pa- thology. Technically speaking, aortic manipulation, such as a trapdoor incision or aortic reconstruction before a coronary im- plant, was known to be a possible factor associated with neoAR attributed to more prominent distortion of the sinotubular junc- tion geometry. In our study, the trapdoor incision was used in most patients (74/75, 98.7%), and aortic reconstruction was per- formed before a coronary implant with similar incidence in both

![Figure 3: Probability of neoar regurgitation grade ≥2 during follow-up. The grade of neoar regurgitation worsened in both groups (common odds ratio 1.40, 95% confidence interval 1.17–1.69, P < 0.001 in the bicuspid group vs common odds ratio 1.12, 95% confidence interval 1.01–1.23, P = 0.029). The worsening of neoar regurgitation was more prominent in the bicuspid group (P = 0.028). AR: aortic regurgitation.](image-url)
CONCLUSIONS

The neoaortic sinus might outgrow the norm regardless of the number of neoaortic valve cusps, whereas the neoaortic annulus remained unchanged. Deterioration of aortic valve function was more prominent in the bicuspid group, which suggests that a bicuspid pulmonary valve might play a significant role in deteriorating neoaortic valve function, without an additional effect on neoaortic root pathology.

FUNDING STATEMENT

No funding was provided for this study.

CONFLICT OF INTEREST STATEMENT

None declared.

AUTHOR CONTRIBUTIONS STATEMENT

Conception and design of the research and writing of the manuscript: Bobae Jeon, Chun Soo Park; Analysis and interpretation of the data: Bobae Jeon, Chun Soo Park, Eun Seok Choi, Tae-Jin Yun; Statistical analysis: Bobae Jeon, Chun Soo Park; Critical revision of the manuscript: all authors. All authors approved the final version of the manuscript.

REFERENCES

[1] Jatene AD, Fontes VF, Paulista PP, Souza LC, Neger F, Galantier M et al. Anatomic correction of transposition of the great vessels. J Thorac Cardiovasc Surg 1976;72:364–70.
[2] Pretre R, Tamisier D, Bonhoeffer P, Mauriat P, Pount D, Sidi D et al. Results of the arterial switch operation in neonates with transposed great arteries. Lancet 2001;357:1826–30.
[3] Losay J, Touchot A, Serraf A, Livinova A, Lambert V, Piot JD et al. Late outcome after arterial switch operation for transposition of the great arteries. Circulation 2001;104:1121–6.
[4] Khan SM, Sallehuddin AB, Al-Bulbul ZR, Al-Halees ZY. Neoaortic bicuspid valve in arterial switch operation: mid-term follow-up. Ann Thorac Surg 2008;85:179–84.
[5] Angeli E, Gerelli S, Beyer C, Lamerain M, Rochas B, Bonnet D et al. Bicuspid pulmonary valve in transposition of the great arteries: impact on outcome. Eur J Cardiothorac Surg 2012;41:248–55.
[6] Zilberman MV, Khoury PR, Kimball RT. Two-dimensional echocardiographic valve measurements in healthy children: gender-specific differences. Pediatr Cardiol 2005;26:356–60.
[7] Zhigbi WA, Enriquez-Sarano M, Foster E, Grayburn PA, Kraft CD, Levine RA. American Society of Echocardiography et al. Recommendations for evaluation of the severity of native valvular regurgitation: two-dimensional and Doppler echocardiography. J Am Soc Echocardiogr 2003;16:777–802.
[8] Bical O, Hazan E, Lecompte Y, Fernmont L, Karam J, Jarreau MM et al. Anatomic correction of transposition of the great arteries associated with ventricular septal defect: mid-term results in 50 patients. Circulation 1984;70:891–7.
[9] Van Praagh R, Jung WK. The arterial switch operation in transposition of the great arteries: anatomic indications and contraindications. Thorac Cardiovasc Surg 1991;39:138–50.
[10] Fricke TA, d’Udekem Y, Richardson M, Thuys C, Dronavalli M, Ramsay JM et al. Outcomes of the arterial switch operation for transposition of the great arteries: 25 years of experience. Ann Thorac Surg 2012;94:139–45.
[11] Schwartz ML, Gauvreau K, del Nido P, Mayer JE, Colan SD. Long-term predictors of aortic root dilation and aortic regurgitation after arterial switch operation. Circulation 2004;110:128–32.
[12] Koolbergen DR, Manshanden JS, Yazdanbakhsh AP, Bouma BJ, Blom NA, de Mol BA et al. Reoperation for neoaortic root pathology after the arterial switch operation. Eur J Cardiothorac Surg 2014;46:474–9.
[13] McMahon CJ, Ravekes WJ, Smith EO, Denfield SW, Pignatelli RH, Altman CA et al. Risk factors for neo-aortic root enlargement and aortic regurgitation following arterial switch operation. Pediatr Cardiol 2004;25:329–35.
[14] van der Palen RLF, van der Bom T, Dekker A, Tsonaka R, van Geloven N, Kuipers IM et al. Progression of aortic root dilation and aortic valve regurgitation after the arterial switch operation. Heart 2019;105:1752–40.
[15] Martins CN, Gontijo Filho B, Lopes RM, Silva F. Mid- and Long-term Neo-Aortic Valve Regurgitation after Jatene Surgery: prevalence and Risk Factors. Arq Bras Cardiol 2018;111:21–8.
[16] Michalak KW, Sobczak-Budlewska K, Moll JJ, Szmyczyk K, Moll JA, Lubisz M et al. Neoaortic Regurgitation in Patients with Transposition Long Term After an Arterial Switch Operation and Its Relation to the Root Diameters and Surgical Technique Used. Pediatr Cardiol 2020;41:31–7.
[17] Sui SC, Silversides CK. Bicuspid aortic valve disease. J Am Coll Cardiol 2010;55:2789–800.
[18] Sohn YS, Brizard CP, Cochrane AD, Wilkinson JL, Mas C, Karl TR. Arterial switch in hearts with left ventricular outflow and pulmonary valve abnormalities. Ann Thorac Surg 1998;66:842–8.
[19] Uemura H, Yagihara T, Kawashima Y, Yamamoto F, Nishigaki K, Matsuki O et al. A bicuspid pulmonary valve is not a contraindication for the arterial switch operation. Ann Thorac Surg 1995;59:473–6.
[20] Wernovsky G, Jonas RA, Colan SD, Sanders SP, Wessel DL, Castaneda AR et al. Results of the arterial switch operation in patients with transposition of the great arteries and abnormalities of the mitral valve or left ventricular outflow tract. J Am Coll Cardiol 1990;16:1446–54.
[21] Park CS, Seo DM, Park JJ, Kim YH, Park IS. The significance of pulmonary annulus size in the surgical management of transposition of the great arteries with ventricular septal defect and pulmonary stenosis. J Thorac Cardiovasc Surg 2010;139:135–8.