The importance of neo-aortic root geometry in the arterial switch operation with the trap-door technique in the subsequent development of aortic valve regurgitation†

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Abstract

OBJECTIVE: Regarding neo-aortic valve regurgitation (neo-AR) after the arterial switch operation (ASO), the ‘trap-door’ technique was supposed to be a risk factor due to a distortion of the sinotubular junction (STJ) geometry. Here we report our results of the ‘trap-door’ technique with a special emphasis on root geometry including the ratio of STJ to annulus.

METHODS: From August 1991 to March 2010, 240 patients with transposition of the great arteries underwent the ASO and who had at least 1 year of follow-up were included in this study. The medical records were retrospectively reviewed.

RESULTS: The median age and body weight at the time of operation were 11 (0–1213) days and 3.4 (1.30–18.75) kg, respectively. The median follow-up duration was 79 months (range 12 months—19.5 years). At the latest echocardiographic follow-up, only six patients had neo-AR greater than Grade II (6 of 240, 2.5%). We found no relationship between neo-AR greater than Grade II and perioperative factors. The actual sizes of the neo-aortic annulus, mid-sinus and STJ were observed as having increased over time. However, most z-scores of STJ at the latest echocardiography varied between −2 and 2 and, more importantly, the ratio of STJ to neo-aortic annulus was 0.93 ± 0.20, which was near normal at the latest echocardiographic follow-up.

CONCLUSIONS: Our results showed a very low incidence of significant neo-AR, which was relatively attributable to the preserved z-score of STJ and the normal range of STJ/annulus ratio. Therefore, we propose that it is important to maintain these factors adequately during the reconstruction of the neo-aortic root in the ASO.

Keywords: Transposition of the great arteries • Arterial switch operation • Aortic regurgitation

INTRODUCTION

The arterial switch operation (ASO) is the most frequently chosen surgical procedure for most types of transposition of the great arteries (TGA). It begins with transecting the native pulmonary trunk and aorta above their respective sinotubular junction (STJ). Then, the root is reconstructed by transferring the coronary arteries. The aorta is connected to the root of the native pulmonary trunk, which becomes the neo-aorta and the pulmonary trunk is connected to the native aortic root, which becomes the new conduit to the pulmonary arteries.

Although the ASO promises low mortality as well as satisfactory early- and mid-term results, it is also widely recognized that the ASO could cause several problems such as coronary insufficiency [1], stenosis of the neo-pulmonary trunk [2] or neo-aortic valve regurgitation (neo-AR). According to previous reports, significant neo-AR, one of the late postoperative complications was observed in ~1.9–25% of patients [3–9]. Nevertheless, the causes of neo-AR have not clearly been explained.

The purpose of the present study was to evaluate the neo-AR after the ASO by focusing on the root geometry, which had been disrupted during the procedure. We investigated several potential risk factors including the ‘trap-door’ technique, which was performed in all our patients and indicated as one of the risk factors for neo-AR through analysing our data.

PATIENTS AND METHODS

Patients

From August 1991 to March 2010, a total of 276 patients with TGA underwent the ASO in the Asan Medical Center. Early mortality

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(death within 30 days of the operation) was 9.1% (25 patients). Late mortality (death after 30 postoperative days) was 2% (five patients) and a further six patients were excluded due to follow-up loss. As a result, 240 patients who had at least 1 year of follow-up were included in our study. We had this criterion because the focus of the present study was on the size and function of the reconstructed arteries during the follow-up. The hospital records were retrospectively reviewed for demographics, morphological and operative details, and postoperative echocardiographic and clinical follow-up data. This study was approved, with waived parental consent, by the ethics committee of the Asan Medical Center, Seoul, South Korea.

Among the 240 patients, 166 patients (69.1%) were male and 74 patients (30.8%) were female. Eighty-five (35.4%) were prenatally diagnosed and 14 (5.8%) were born at a gestational age of <37 weeks. The median age at diagnosis was 1 day (range 0–270). The median age and body weight at the time of operation were 11 days (range 0–1213) and 3.40 kg (range 1.30–18.75), respectively. Of the 240 patients, 41 (17.0%) underwent the ASO out of the neonatal period and 14 (5.8%) weighed <2.5 kg at the time of operation.

Of the 240 patients, 137 (57.0%) had TGA with interventricular septum (IVS). The Taussig-Bing anomaly was encountered in 18 patients (7.5%). Ventricular septal defect (VSD) was combined in 100 patients (41.6%). The posterior TGA were diagnosed in one patient (0.4%). Other congenital cardiac anomalies such as arch obstruction (16 patients 6.6%), pulmonary stenosis (nine patients, 3.7%) and bicuspid pulmonary valve (12 patients 5.0%) were combined.

Coronary artery patterns were classified according to the Leiden convention. The arrangement of 1LCx; 2R was the most common type observed in 169 of 240 patients (70.4%), followed by 1AD; 2R, Cx in 28 patients (11.6%), 1R, 2AD, Cx in 12 patients (5%) and 1R, AD; 2R in seven patients (2.9%). A single sinus with double orifice was observed in 11 patients (4.5%). Single coronary artery was present in nine patients (3.7%) and four patients (1.6%) had an intramural course of coronary artery.

Among 109 patients (45.4%) who showed a discrepancy in the aortopulmonary annulus size, 52 (21.6%) showed a severe discrepancy (the size of the pulmonary annulus/aortic annulus >2).

Operative procedures

The operation was conducted with a cardiopulmonary bypass (CPB) at full flow through standard aortic and bicalve cannulae with moderate hypothermic CPB at ~25°C. The main pulmonary artery was transected and dissected through the hilar level. The ‘trap-door’ technique was used for coronary artery reimplantation into the neo-aorta in all the included patients.

The Lecompte procedure was done in 226 patients. In several specific cases, other homograft or graft material was used for avoiding the neo-pulmonary artery stenosis.

The closure of the VSD was mainly performed through the right atrium, but occasionally needed right ventriculotomy in 34 (14.1%) patients or through the pulmonary valve in four (1.6%) patients or through the aortic valve in two (0.8%) patients.

The median CPB time was 145 (93–541) min and the aortic cross-clamp (ACC) time was 78 (35–192) min. One-stage total correction was performed in 229 (95.4%) patients. The staged operation was performed in 11 patients (4.5%). Before the ASO operation, pulmonary artery banding was done in 10 patients (4.1%) and a modified Blalock-Taussig shunt was combined in six patients (2.5%).

Follow-up protocol

Routine clinical and echocardiographic evaluation was performed at 1 and 6 months after surgery, and yearly thereafter. The median follow-up period was 79 months (range 12 months –19.5 years). The echocardiographic examination focused on the neo-aortic valve function and the change in neo-aortic root size. The assessment of neo-AR was done by colour Doppler imaging and quantitatively graded as none (Grade 0), trivial, mild (Grade I), moderate (Grade II), moderate to severe (Grade III) and severe (Grade IV). Serial postoperative measurements of the size of neo-aortic root included the diameter of the valve at the level of basal leaflet attachment, the diameter of root at the widest mid-sinusual level and the diameter of the STJ, which corresponded to distal anastomosis between the neo-aortic root and the ascending aorta.

Data analysis

The echocardiographic measurements of the neo-aortic annulus, mid-sinus and STJ were compared with the expected normal values as determined by the z-scores based on the body surface area of the patient at the time of the echocardiographic control. A significant enlargement of the measured diameter at a level was considered for a z-score >3. Because of their skewed distribution, age, height and weight, data were analysed statistically after natural logarithmic transformation.

Statistical analysis

SPSS software version 14.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. Continuous variables are expressed as medians with ranges or means with standard deviation. Descriptive statistics are described as count and percentage. Univariate and multivariate logistic regression analyses were used to estimate the risk factors for neo-AR of greater than Grade II after the ASO. Kaplan–Meier analysis was used for evaluating the actuarial survival without neo-AR greater than Grade II. Variables with P-value of <0.05 were considered to be statistically significant. SAS 9.1 mixed procedure (random intercept model) was used to evaluate the size change in the neo-aortic root and the changes of the z-scores of the neo-aortic root over time.

RESULTS

Neo-aortic valve function

At the time of discharge from the hospital, neo-AR was absent in 117 patients. Echocardiography showed Grade II neo-AR in three patients. No patient had a greater than Grade III neo-AR. The evolution of neo-AR between the immediate postoperative and the most recent follow-up echocardiography is shown in Table 1.
patients, neo-AR was absent in 84, Grade II in five (2.0%) and Grade IV in one (0.4%).

The overall actuarial freedom from greater than Grade II neo-AR was 99.36 ± 0.64% at 5 years (Fig. 1). Two patients required reoperation for neo-AR. One patient had a bicuspid pulmonic valve preoperatively and another patient had progressive left ventricular dysfunction.

**Fate of neo-aortic root**

The sizes of the neo-aortic annulus, mid-sinus and STJ increased over time. Immediately after the ASO, the z-score of >3 was observed in 25 patients at the neo-aortic annulus, 37 at the mid-sinus level and four at the STJ level. At the latest follow-up echocardiography, the z-score of >3 was detected in 44 patients at the neo-aortic annulus, 74 at mid-sinus level and 12 at the STJ level. The ratio of STJ to annulus was plotted in Fig. 2. The ratio at the latest follow-up echocardiography was 0.93 ± 0.20.

**Risk factors for neo-AR greater than Grade II**

In the univariate logistic regression analysis, the following parameters were found to be risk factors for greater than Grade II neo-AR: the last aortic annulus z-score, the last aortic annulus z-score of >3, the last aortic mid-sinus z-score, the last aortic mid-sinus z-score of >3, the last aortic STJ z-score, the last aortic STJ z-score of >3. Among them, the last aortic STJ z-score remained as a predictor of greater than Grade II neo-AR (Table 2) by multivariate analysis.

**DISCUSSION**

In this study, neo-AR greater than Grade II was observed in only six of 240 patients (2.5%) with a median follow-up duration of 79 months (range 12 months—19.5 years). In spite of the small number of patients who had neo-AR greater than Grade II, we tried to search for the risk factors for it on the basis of our results.

Although there are several already-known risk factors for neo-AR such as the Taussig–Bing anomaly, the presence of VSD, the size discrepancy between the aorta and pulmonary artery prior to protective pulmonary artery banding, the complex TGA, aortic arch obstruction and the age at the ASO [5, 7, 8], they did not have any significant impacts on the occurrence of neo-AR in our data, nor did they precisely or reasonably explain why neo-AR occurs. Thus, we shifted our attention to the relevant factors that had been identified and reported in previous research as potential causes of AR such as the aortic valve itself and the aortic root.

As is well known, the valve itself could be problematic in several aspects. The first concern regarding the ASO procedure was the systemic circulation that the native pulmonary valve and root would do when being connected to an ascending aorta. In the previous report, the pulmonary valve was indicated to be inadequate in the systemic position. However, some reports suggested that vascular remodelling occurs in the pulmonary vessel during the natural course of TGA, which is structurally different compared to a normal heart [10]. It was also reported that the pulmonic valve is not a big concern, even in the Ross, Norwood or Damus–Kaye–Stansel procedures, all of which have to do with the systemic circulation [11]. Furthermore, pressure between both ventricles did not differ during the foetal period such that the pulmonic valve was exposed to the systemic pressure. Thus, an abrupt change in pressure after birth is not a critical concern as long as the ASO is performed within a few days of birth.

Another concern regarding the valve problem is the bicuspid neo-aortic valve. According to previous reports, the presence of the bicuspid aortic valve may be associated with a significant valvular dysfunction, which may manifest either as neo-aortic stenosis or as neo-AR in their natural course [12]. However, others reported that the well-functioning bicuspid pulmonary

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**Table 1:** The change in neo-AR grade from the time of discharge to the latest echocardiographic follow-up

<table>
<thead>
<tr>
<th>Neo-AR</th>
<th>At discharge</th>
<th>Latest</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>117</td>
<td>84</td>
</tr>
<tr>
<td>Trivial</td>
<td>102</td>
<td>121</td>
</tr>
<tr>
<td>Grade I</td>
<td>18</td>
<td>29</td>
</tr>
<tr>
<td>Grade II</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Grade IV</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

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**Figure 1:** The overall actuarial freedom from greater than Grade II neo-AR.

**Figure 2:** The ratio of the STJ to neo-aortic annulus.
valve is not a contraindication to an ASO [13, 14]. In this study, it was also not associated with significant neo-AR.

The third issue related to the valve itself is iatrogenic cusp damage during the operation. Recently, a report showed that a sub-arterial VSD closure through the pulmonic valve increased the incidence of pulmonary regurgitation [15]. Similarly, we think that the VSD closure through the pulmonic valve could increase the incidence of neo-AR. For instance, in the present research, there was one patient who underwent VSD closure through the pulmonic valve and subsequently had severe neo-AR, which ended up with aortic valvuloplasty. Therefore, we argue that VSD closure through the pulmonic valve should be regarded as an important and relevant issue regarding the incidence of neo-AR. In addition, a more important issue is the VSD type, rather than ‘through where?’ to perform the VSD closure. In case of doubly committed VSD, it is unavoidable to suture at the neo-aortic annulus, which could also result in neo-aortic valve incompetence and regurgitation by limiting the mobility of the involved cusp.

Secondly, it is necessary to consider the neo-aortic root as an important factor for neo-aortic valve function. Originally, the aortic root is a dynamic structure that serves an important role in the maintenance of valve function. The distensibility of the aortic root and complex 3D aortic root deformation, including the asymmetric root expansion, probably help to minimize fatigue stresses on the leaflets by creating the optimal cusp loading condition and minimizing transvalvular turbulence [16–19]. Dilatation of the aortic root can lead to significant increases in regional stresses and strains on the leaflets of the aortic valve. It will displace the valve commissures outwards so that leaflet edges cannot coapt in diastole which possibly leads to regurgitation of the aortic valve [19]. It was also shown by the experiment that aortic root dilatation significantly increased leaflet stress and strain and reduces coaptation in an otherwise normal aortic valve [20].

The essential part of ASO procedures is the manipulation and reconstruction of the neo-aortic root by transferring the coronary arteries. The literature has documented that aortic root dilatation is observed after the ASO in TGA. The neo-aortic root dilatation process occurs predominantly within the first year after the ASO, followed by an active growth with a tendency towards normalization of the root dimension [3, 11]. On the other hand, some found neo-aortic root enlargement for as long as 10 years of follow-up, otherwise normal aortic valve [20].

Our study also showed that the growth of the neo-aortic annulus and sinus are disproportionate to normal body growth. Univariate logistic regression analysis revealed that the last STJ size was associated with greater than Grade II neo-aortic root dilatation to be an ongoing process, disproportionate to normal somatic growth [4]. Some reported gradual neo-aortic root enlargement for as long as 10 years of follow-up, but without further progression thereafter [9]. In addition, severe or rapidly progressive neo-aortic root dilatation was reported as one of the risk factors for neo-AR [3–6, 8, 11].

Table 2: Risk factor analysis for neo-AR greater than Grade II by logistic regression analysis (univariate and multivariate analysis)

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Univariate analysis</th>
<th>Multivariate analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>0.429</td>
<td>0.308</td>
</tr>
<tr>
<td>Age at diagnosis</td>
<td>0.875</td>
<td>0.889</td>
</tr>
<tr>
<td>Age at operation</td>
<td>0.589</td>
<td>0.604</td>
</tr>
<tr>
<td>Weight at operation</td>
<td>3.592</td>
<td>0.857</td>
</tr>
<tr>
<td>Height at operation</td>
<td>0.837</td>
<td>0.992</td>
</tr>
<tr>
<td>Prematurity</td>
<td>3.400</td>
<td>0.280</td>
</tr>
<tr>
<td>Foetal diagnosis</td>
<td>0.000</td>
<td>0.997</td>
</tr>
<tr>
<td>TGA with IVS</td>
<td>2.727</td>
<td>0.252</td>
</tr>
<tr>
<td>Coronary type</td>
<td>0.569</td>
<td>0.542</td>
</tr>
<tr>
<td>Aorto-pulmonary discrepancy</td>
<td>0.916</td>
<td>0.714</td>
</tr>
<tr>
<td>Arch obstruction</td>
<td>2.920</td>
<td>0.342</td>
</tr>
<tr>
<td>VSD</td>
<td>2.875</td>
<td>0.167</td>
</tr>
<tr>
<td>Bicuspid pulmonic valve</td>
<td>4.0550</td>
<td>0.219</td>
</tr>
<tr>
<td>Staged operation</td>
<td>0.223</td>
<td>0.189</td>
</tr>
<tr>
<td>PAB</td>
<td>5.000</td>
<td>0.161</td>
</tr>
<tr>
<td>CPB time</td>
<td>1.007</td>
<td>0.122</td>
</tr>
<tr>
<td>ACC time</td>
<td>1.015</td>
<td>0.234</td>
</tr>
<tr>
<td>Last AoV annulus z-score</td>
<td>1.636</td>
<td>0.014</td>
</tr>
<tr>
<td>Last AoV annulus z-score &gt;3</td>
<td>9.300</td>
<td>0.012</td>
</tr>
<tr>
<td>Last mid-sinus z-score</td>
<td>2.026</td>
<td>0.003</td>
</tr>
<tr>
<td>Last mid-sinus z-score &gt;3</td>
<td>10.725</td>
<td>0.032</td>
</tr>
<tr>
<td>Last STJ size z-score</td>
<td>2.996</td>
<td>0.001</td>
</tr>
<tr>
<td>Last STJ z-score &gt;3</td>
<td>9.150</td>
<td>0.017</td>
</tr>
<tr>
<td>Last STJ/AoV ratio</td>
<td>2.328</td>
<td>0.310</td>
</tr>
</tbody>
</table>

PAB: pulmonary artery banding; AoV: aortic valve. Bold values are statistically significant.
STJ was disrupted by coronary transfers such as the trap-door technique, preservation of the STJ tissue of the coronary cuff to the original STJ. This suggests that, in ASO, the STJ at the latest echocardiography was 0.93 ± 0.20, which is rather than the STJ (1.16). Therefore, we believe that it is the STJ rather than the STJ ratio of neo-AR. In the present study, the ratio of STJ-annulus at the latest follow-up echocardiography was close to normal (i.e. 0.93 ± 0.20). Combined with a low incidence of neo-AR, this result suggests that neo-AR could be prohibited in the face of unavoidable size augmentation of the neo-aortic annulus or sinus as long as the ratio of STJ-annulus remains close to normal. Taken together, the results of the present study suggest that maintaining the STJ ratio and the STJ-annulus can be a more critical factor than other perioperative factors in preventing neo-AR.

**CONCLUSIONS**

In our data, both the incidence of neo-AR greater than Grade II (6 of 240, 2.5%) and the need for reoperation (2 of 240, 0.8%) were very low. This study showed that neither the bicuspid pulmonary valve nor the trap-door technique has to do with the incidence of neo-AR. However, direct valve cuff damage could be a risk factor for neo-AR. In the present study, the ratio of STJ-annulus at the latest follow-up echocardiography was close to normal (i.e. 0.93 ± 0.20). Combined with a low incidence of neo-AR, this result suggests that neo-AR could be prohibited in the face of unavoidable size augmentation of the neo-aortic annulus or sinus as long as the ratio of STJ-annulus remains close to normal. Taken together, the results of the present study suggest that maintaining the STJ ratio at the annulus could prevent neo-AR. As shown in Fig. 3, the usual trap-door technique will add the tissue of the coronary cuff to the original STJ and obviously increase the z-score of the STJ. Whereas, we made the modification as the ‘inclusion trap-door technique’ by simply trimming the coronary cuff as shown in Fig. 4. It helped us to avoid unnecessary enlargement of the STJ and neo-AR.

**Limitations**

Several limitations are noteworthy. First, when it comes to statistical power for the risk factors, we have to admit that our evaluative power is very low because of the very low incidence of significant neo-AR (six patients 240, 2.5%). Secondly, the present study is a retrospective study with many missing observations in the echocardiographic follow-up data, which prevents us from drawing a definitive conclusion. Nevertheless, we argue that the present study not only provides a new insight into significant neo-AR by shedding light on the importance of maintaining the STJ and the ratio of STJ-annulus but also calls for another centre's re-investigation of this issue.

**REFERENCES**


APPENDIX. CONFERENCE DISCUSSION

Dr K. Sakamoto (Shizuoka City, Japan): Basically I agree with your consideration that maintaining the normal balance of the neo-aortic root can be a critical factor for reducing neo-aortic regurgitation. In the previous paper that you cited, Dr Formigari said that patients with neo-aortic regurgitation usually have an elongated neo-aortic root with a flattened and distally-displaced ST junction, and many of them had the trap-door technique in their studied cohort. They concluded that the trap-door technique is a risk factor for neo-aortic regurgitation, possibly because of distortion of the ST junction geometry. You said that.

In another report from the Boston group, Dr Schwartz commented that two surgeons in an earlier time period had a lower risk than others in a later time period. This finding may be attributable to a change in surgical technique, perhaps using larger buttons for coronary transfer. Undoubtedly, the surgical technique for coronary transfer must be a key factor in reducing neo-aortic regurgitation. By the way, I usually transfer the coronary buttons to the suprasinus position, not to cut the line of the ST junction, even using the trap-door technique, not to deform the ST junction and aortic geometry. However, every technique can have both merits and demerits. So I would like to ask you about surgical techniques and related issues.

First, could you tell us the technical points in your arterial switch operation which seem to be effective for maintaining the ratio of the ST-junction/annulus using the trap-door technique, together with cutting the line of the ST junction? That’s the first question.

Dr Seo: I understood two points in your question. One is about my idea of above-commissure transfer in coronary transfer and another one is about my technique for maintaining the ST junction and the ratio in a more normal range. For the second, I prepared an answer slide. I would like to remind you that in Dr Kunzelman’s paper he stressed that the size of the ST junction and base should follow the normalized root dimensions. So this is my suggestion. The left side is the usual trap-door technique. It will increase the sinus and ST junction. But I prefer inclusion. We don’t enlarge the ST junction circumference and we hope there is less dilatation of the sinus. This is my usual technique. Another one is that many surgeons will adapt the posterior sinus, I mean noncoronary sinus at the neoaosd and aorta, and we can reduce the noncoronary sinus a little bit if a very large circumference. About your first question, above-commissure transfer is a very important technical option for a congenital cardiac surgeon to manage TGA, especially for very unfavourable coronary artery management. It is very useful. But we can guess from normal anatomy that the aortic valve and sinus can protect the coronary ostium from high pressure during systole, but if we make a supra-commisural ostium, it will lose the normal protective effects from the valve and sinus. I don’t know. We’ll have to follow the long-term results with that technique. Anyway, it’s a very good option.

Dr Sakamoto: Then your technique is almost between the usual trap-door technique and punched out. The second question, please tell us about the outcomes of supra-aortic stenosis and coronary events in your studied cohort.

Dr Seo: In this cohort I had 10 reoperations. It was mainly right-sided obstructive lesions, and, as I showed, 2 cases of aortic valve replacement and plasty. Another one was mitral cleft repair. I am lucky not to have had any supra-coronary stenosis or coronary events.

Dr F. Lacour-Gayet (New York, NY, USA): I have a question for you. I belong to this group of people who question the usefulness and the safety of the trap-door. I personally never do a trap-door. I stopped 10 years ago. I belong to this group of people who question the usefulness and the safety of the trap-door. I personally never do a trap-door. I stopped 10 years ago. I have done several hundred of the switch without the trap-door and I didn’t find any difference. What do you answer to this group of people who don’t do trap-door and have good results?

Dr Seo: I agree that with a very large size discrepancy between the ascending aorta and the main pulmonary artery, in those situations the punch technique would be a good option. Why I prefer the trap-door is that during the punch technique you may damage the valve itself. If the punched-out size is not exactly the same with the cuff, you may augment the sinus.

Dr Lacour-Gayet: I don’t do the punch technique.

Dr Seo: Do you just make a sleeve on there?

Dr Lacour-Gayet: No. What I do is to resect a piece of the wall of the neoaorta and replace it with a button of exactly the same size.

Dr Seo: Okay.