The functional status of neoaortic valve and left ventricular outlet tract after arterial switch operation for transposition of great arteries with left ventricular outlet tract obstruction

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Abstract

OBJECTIVES: To assess the function of the left ventricular outlet tract and neoaortic valve after arterial switch operation for patients with transposition of the great arteries and left ventricular outlet tract obstruction.

METHODS: The data of 40 patients, who underwent arterial switch surgery with transposition of the great arteries with left ventricular outlet tract obstruction and a concomitant left ventricular outlet tract obstruction relieving procedure, were retrospectively analysed. Ultrasonic cardiogram and intraoperative findings, surgical methods and early and follow-up results were also summarized.

RESULTS: Early death occurred in one case. One patient died in follow-up stage and 3 patients were lost during follow-up. In all the 35 patients accepting follow-up, 1 patient had a reoccurring left ventricular outlet tract obstruction, 1 patient had mild neoaortic stenosis, whereas mild and moderate neoaortic regurgitation occurred in 11 and 2 patients, respectively. The median pressure gradient across the left ventricular outlet tract was 6.8 mmHg (range: 2–49 mmHg) during follow-up which was statistically significant compared with that before surgery. We defined death, reintervention and rehospitalization for cardiac reasons as a cardiac event; the survival rate of being free from cardiac event for 1 year and 5 years was 92.8 ± 0.04%, respectively.

CONCLUSIONS: Anatomical features and pressure gradient should be used together to evaluate the severity of obstruction, whereas the mid-term outcomes can be satisfied after arterial switch operation for the appropriate candidates.

Keywords: Transposition of great arteries • Left ventricular outlet tract obstruction • Arterial switch operation

INTRODUCTION

The occurrence of left ventricular outlet tract obstruction (LVOTO) of newborn transposition of the great arteries (TGA) ranges from 20 to 33% [1–3]. LVOTO often occurs in combination with a ventricular septum defect (VSD), and a simplex or multifaceted anatomical anomaly can also be found. When the arterial switch operation (ASO) was developed, LVOTO was deemed to be one contraindication for this operation, so the Rastelli procedure, the Réparation à l’Etage Ventriculaire (REV) procedure, the Nikaidoh procedure and double-root translocation (DRT) were recommended for TGAs associated with severe fixed LVOTO [4–7]. The selection criteria for ASO among patients with TGA and LVOTO according to the type and severity of obstruction remain unknown. There are no previous extensive case studies focusing on the outcome of ASO for patients with TGA and LVOTO. The present study attempted to assess the functional status of neoaortic valve and left ventricular outlet tract after ASO, along with surgical relief of LVOTO, for patients with TGA and LVOTO.

MATERIALS AND METHODS

Patients

A cohort of 40 patients with TGA and LVOTO were identified among the 549 patients who underwent ASO from April 2002 to December 2013, and were selected according to the following criteria: (i) TGA; (ii) simultaneous LVOTO; (iii) ASO had been performed. Patients diagnosed with the Taussig–Bing anomaly who had received ASO, and patients with dynamic obstruction attributed to the decline of left ventricle pressure and bulging of the septum were excluded. LVOTO was confirmed by 2D and Doppler ultrasound, as follows: (i) any anatomical anomaly leading to obstruction from outlet tract to pulmonary valve (PV); (ii) a peak...
pressure gradient through the left ventricular outlet tract (LVOT) of 
>16 mmHg, according to our diagnostic echocardiogram criteria.

In our centre, for patients with TGA and LVOTO, the PV and
annulus and the feasibility of LVOTO relief were assessed first
through echocardiogram and intraoperative detection. If the patient
had no obviously hypoplastic PV and annulus (Z-score >−3), then
ASO might be indicated. If not, or the stenosis was unresectable,
either an intraventricular rerouting procedure or aortic translocation
should be considered.

The median age and weight at operation were 12 months
(range: 7 days–96 months) and 6.5 kg (range: 3.5–26 kg), respec-
tively. The pulse oxygen saturation ranged from 52 to 85%. The sig-
nificant findings detected on ultrasonic cardiogram (UCG) are
listed as follows: the aorta (AO) to pulmonary artery (PA) diameter
ratio (AO/PA) ranged from 1.08 to 1.2, and two obviously wider
PAs were caused by post-stenotic dilatation. The types of LVOTO
and the respective pressure gradient across LVOT are given in
Table 1. The median pressure gradient of all the sufferers was
38.4 mmHg (range: 16–70.6 mmHg). The median Z-score of PV
annulus measured on UCG and calculated using the Cincinnati
Children’s Hospital formula [8] for 20 patients was −0.31 (range:
−2.05 to 2.05). Fourteen patients had a Z-score of less than zero.
Other cardiac abnormalities included VSD in 39 patients; 3
patients had restrictive VSD and others had non-restrictive VSD.
Perimembranous VSD was found in 8 of these 39 patients, inlet
septal VSD in another 8 patients, muscular VSD in 1 patient, cono-
ventricular VSD in 21 patients and multiple VSD in 1 patient. An
atrial septum defect was present in 14 patients, patent ductus
arteriosus in 8 and cleft anterior leaflet of mitral valve (MV) in 1
patient. Almost all the patients had thickened PVs, among whom
17 individuals suffered from bicuspid PV. Increased pulmonary
blood flow was evident on chest radiographs in 31 cases. Usual
coronary artery pattern was detected during surgery in 29
patients. Unusual coronary patterns included (1R, LAD; 2Cx) in 1,
(1LAD, Cx, R) in 2, (1LAD; 2R, Cx) in 6, (1R, Cx; 2LAD) in 1 and (1R;
2LAD, Cx) in 2, according to Leiden convention [9].

Procedure

All of the patients accepted ASO with moderate hypothermic
 cardiopulmonary bypass. Surgical strategy was decided according
to the type of LVOT abnormality detected via pulmonary
 incision. Doing nothing for isolated thickened PV was advised.
Commissurotomy was performed for commissural fusion of the
PV and pulmonary wall, which should not be incised. The resec-
tion of ridge and muscle was performed for the sub-pulmonary
ridge and muscular tissue, respectively. Partial resection of the
left ventricular outflow septum was performed if necessary, while
the depth of resection should be kept within 3 mm. The removal of
fibromuscular tissue should be as adequate as possible for ring-
form or tunnel-form stenosis.Accessory MV tissue and non-
functional straddling chordae of tricuspid valve (TV) could be also
resected safely, but the contributing chordae of TV responsible for
LVOTO should be reattached after VSD repair. VSD was closed
using a patch technique in 38 patients and direct suture in 1
patient. Reimplantation of coronary arteries and anastomosing of
great arteries were conducted routinely. Other combined malfor-
dations were corrected simultaneously.

Follow-up

A follow-up inquiry about the patients’ situation, daily activity and
reoperation was made by telephone. The morphology of LVOT, pres-
sure gradient and function of neoaortic valve were assessed by UCG.

Statistical analysis

Means ± standard deviation was presented for continuous data,
which were normally distributed, whereas medians were used for
the ones skewly distributed. Wilcoxon signed-rank tests were used
to compare continuous variables skewly distributed. Survival rates
and life curves were obtained by life table methods. All statistical
analyses were performed using SPSS 17.0 software.

RESULTS

The mean cardiopulmonary bypass time and median cross-
clamping time were 192.4 ± 37 and 139 min (range: 109–305 min),
respectively. The median mechanical ventilation time and inten-
sive care unit stay were 36 h (range: 3–960 h) and 4 days (range:
1–48 days), respectively.

Early results

Three patients received extracorporeal membrane oxygenation
(ECMO) support and recovered from circulatory collapse on the

<p>| Table 1: Types of LVOTO, pressure gradient across LVOT and management (n = 42) |
|---------------------------------|------|----------------|----------------|----------------|----------------|</p>
<table>
<thead>
<tr>
<th>Type of LVOTO</th>
<th>No. (%)</th>
<th>Preop. PG</th>
<th>Postop. PG</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV abnormalities</td>
<td>14 (35.9)</td>
<td>36 (17.6–64)</td>
<td>5.8 (2–19.4)</td>
<td>Commissurotomy or no</td>
</tr>
<tr>
<td>Sub-pulmonary ridge</td>
<td>9 (23)</td>
<td>35 (13–57.8)</td>
<td>6.8 (4.8–49)</td>
<td>Resection of ridge</td>
</tr>
<tr>
<td>Tunnel-form obstruction</td>
<td>2 (5)</td>
<td>55 (41–70.6)</td>
<td>24 (13–36)</td>
<td>Resection of fibromuscular tissue</td>
</tr>
<tr>
<td>Accessory MV tissue and straddling chordate of TV</td>
<td>2 (5)</td>
<td>58.4 (46.2–70.6)</td>
<td>5.8 (4.8–6.8)</td>
<td>Resection of accessory tissue and non-functional straddling chordae, reattachment of contributing chordae</td>
</tr>
<tr>
<td>Multiple lesions</td>
<td>13 (33)</td>
<td>36 (31.4–70.6)</td>
<td>13 (11.6–46.2)</td>
<td>Comprehensive management</td>
</tr>
</tbody>
</table>

2nd, 7th and 14th postoperative day separately. There was no delayed sterna closure except for the ECMO receiver. Reintubation was required in 3 patients and high-frequency oscillatory ventilator was applied to 2 patients. Two individuals underwent peritoneal dialysis for renal failure. There was one early death caused by severe pneumonia, repeated gastrointestinal haemorrhage and trachea haemorrhage on the 15th postoperative day.

Results of follow-up

One patient died 6 months after surgery, but the reason was unclear. Three patients lost to follow-up, and 35 completed it with a median follow-up time of 24 months (range: 3–116 months). All of the surviving patients had a satisfactory quality of life. The latest follow-up UCGs showed that a 2-mm residual shunt of the VSD had occurred in 1 patient. Mild and moderate neoaortic regurgitation occurred in 11 and 2 patients, respectively. A reoccurring LVOTO, with 6 mm inner diameter and pressure gradient of 49 mmHg secondary to a proliferative sub-neoaortic membrane that was resected as sub-pulmonary ridge during surgery, led to no symptom and no further measures were taken. One patient who received commissurotomy and resection of the subvalvular muscle had mild neoaortic stenosis with a pressure gradient of 46 mmHg; he had no symptoms or further treatment as well. One patient who received reattachment of tricuspid chordae had good TV function.

The median pressure gradient of LVOT after surgery was 6.8 mmHg (range: 2-49 mmHg). The difference between preoperative and postoperative pressure gradient was statistically significant with a Z-value of −5.444 shown by Wilcoxon signed-rank test. The outcome of each patient’s pressure gradient is shown in Fig. 1. We defined death, reintervention and rehospitalization for cardiac reasons as a cardiac event, whereas the survival rate of being free from cardiac event of 1 year and 5 years was 92.8 ± 0.04%, respectively. The life curve is shown in Fig. 2.

DISCUSSION

In our hospital, the patients came from each province of China and had high mobility. Their contact information often changed. Some patients had no regular follow-up in our centre or community clinic. Therefore, some patients were lost during follow-up.

Although ASO has been used as the standard treatment procedure for TGA, surgical options for patients with TGA and severe fixed LVOTO remain diversified. The Rastelli procedure had once been the optimal choice for many years; the follow-up showed that the recurrence rate of LVOTO was low, but a higher rate of reoperation due to an extra conduit could be found [10, 11]. The REV procedure and the Nikaidoh procedure provided better haemodynamics of LVOT, but a high reoperation rate related to the right ventricular outlet tract and the neopulmonary valve was difficult to avoid [12, 13]. DRT, a modified aortic translocation procedure to translocate the root of the PA and preserve competence and growth potential of PV, had its limits of application, due to complex technique and extensive invasion [7]. Short-term follow-up revealed a high prevalence of neopulmonary regurgitation. Therefore, it is important to select suitable patients suffering from TGA and LVOTO for ASO to avoid surgery that is more complex and relevant complications. Wu et al. [14] described a criterion for determining the severity of LVOTO: when the pulmonary to aortic annulus ratio was less than 0.85 and an LVOT pressure gradient was more than 35 mmHg, the fixed obstruction was unresectable and other surgical options were preferred. Park et al. [15] reported that 8 patients who were possible candidates for aortic translocation underwent ASO and LVOTO relief surgery (including commissurotomy, resection of fibrous tissue and hypertrophic conal septum). By evaluating the haemodynamics and the growth of neoaortic annulus after operation, they discovered that an excellent outcome could be obtained when the Z-score of the PV annulus before surgery was as little as −3.4. In our study, the PV annulus Z-score measured in 20 patients ranged from −2.05 to 2.05; and among them, 14 patients had measured less than zero. Only 2 patients whose PV annulus Z-scores were −1.45 and −0.85 had residual LVOTO (pressure gradients were 46.2 and 49.0 mmHg, respectively), at the subvalvular level. McElhinney et al. [16] proved that the diameter of the hypoplastic aortic annulus could increase to the normal range, and the Z-score could be normal after surgery for the patients who underwent balloon aortic valvuloplasty for aortic stenosis. It can be inferred that hypoplastic PV annulus has growth potential and will catch up.

![Figure 1: Comparison of preoperative and postoperative pressure gradient (IU: mmHg). Left vertical axis represents pressure gradient before surgery (median value: 37.2 mmHg). Right vertical axis represents pressure gradient after operation (median value: 4 mmHg). The pressure gradient increased after operation in surgery patients.](https://academic.oup.com/icvts/article-abstract/23/1/9/1749996/1163718)
with the growth of the neoaortic annulus. Therefore, a mildly to moderately hypoplastic pulmonary annulus did not preclude ASO. Sohn et al. [17] suggested that anatomical details were more important to assess the severity of LVOTO than the pressure gradient. The stenosis will be overestimated due to the left to right shunt of secondary VSD. Whether LVOTO can be relieved and if ASO is feasible or not depends on the type of lesion. If the lesion can be resected, ASO could offer a good solution, even though PV annulus is insufficient. In our study, the increased pulmonary blood flow shown on the chest radiographs of 31 patients indicated that pulmonary flow was not obviously restricted. Eleven patients whose PVs were thickened with no intervention had a pressure gradient ranging from 17.6 to 64 mmHg; among them, 7 patients had a pressure gradient higher than 30 mmHg, so the severity of LVOTO was apparently overestimated. Pressure gradient is not a precise indicator of LVOTO severity. As for anatomical features, Sohn et al. proposed that the relievable obstructions include PV abnormalities (thickened valve, commissural fusion and hypoplasia), subvalvular ridge, accessory valve tissue and non-functional straddling chordae. Unrelievable anomalies include the bulging of septum, fibrous-muscular tunnel and malattachment of MV. In their study, 26 patients underwent ASO and LVOTO relief and the survival rate free from reoperation for 130 months reached 73.3 ± 10%. Hazekamp et al. [18] believed that sub-pulmonary muscular conus, muscle of Moulaert and protruding outlet septum were resectable, but that LVOTO due to atrioventricular valve malposition (as anterior rotation of MV and malattachment of anterolateral papillary muscle) was difficult to correct and other procedures were required. If the straddling atrioventricular valve prohibits ventricular septation, univentricular palliation would be the only choice.

We can use sound to measure the calibre of PV when PV anomaly is simplex. Commissurotomy can be performed finitely when the commissural fusion reduced the calibre. Excessive commissurotomy should be avoided to prevent neoaortic regurgitation [17, 19]. Bicuspid PV would not progress to neoaortic stenosis, as reported in other literature [17, 20]. In fact, in our study 27 patients had a PV lesion, which were simply a thickened valve and commissural fusion. Valve mobility was good and the annulus was relatively normal (Z-score > −2), so the outcome of ASO for these patients was satisfactory. Sub-pulmonary ridge and ring-form stenosis should be resected thoroughly to prevent recurrence. Hypertrophic muscle or partial outlet septum can be resected when muscular stenosis exists. If the obstruction was created by leftward deviation of the infundibular septum, aortic translocation was preferred over ASO to avoid residual postoperative LVOTO [3, 15]. The fibrous-muscular tunnel can be resected extensively. Accessory valve tissue and non-functional chordae can be removed and the real valve should be distinguished. Single tricuspid chordae straddling VSD can also be reattached after VSD repair. Too many straddling chordae are difficult to manage at any time. Moderate neoaortic regurgitation occurred in 2 patients who did not undergo surgery for the native PV; the mechanism should be researched further with more cases and a longer follow-up time. This study is limited by the lack of Z-score for neoaortic valve annulus, because the body-weights and heights were not clear for when the latest UCGs were performed.

**CONCLUSION**

The mid-term outcome of ASO and surgical relief of LVOTO can be satisfied with low recurrence and reintervention rate for appropriate candidates. The long-term outcome remains to be studied. PG would overestimate the severity of LVOTO when a left to right shunt on the ventricular level exists. The mechanism of neoaortic regurgitation after ASO of patients with LVOTO should be studied more deeply.

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