Outcomes of the Arterial Switch Operation for Transposition of the Great Arteries: 25 Years of Experience

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Background. **Studies on long-term outcomes of the arterial switch operation (ASO) for transposition of the great arteries (TGA) are uncommon. Thus, we sought to determine the long-term outcomes for patients after ASO performed at a single institution over a 25-year period.**

Methods. **From 1983 to 2009, 618 patients underwent the ASO for TGA and were reviewed retrospectively.**

Results. **Overall early mortality was 2.8%. Risk factors for early death on multivariate analysis were resection of left ventricular outflow tract obstruction at time of ASO ($p = 0.001$), weight less than 2.5 kg at time of ASO ($p < 0.001$), associated aortic arch obstruction ($p = 0.043$), and the need for postoperative extracorporeal membrane oxygenation ($p < 0.001$). Mean follow-up time was 10.6 years (range 2 months to 26.1 years). Late mortality was 0.9%. Reintervention was significantly higher ($p < 0.001$) in patients with ventricular septal defect or arch obstruction versus those without them (25.2% and 23.4% vs 5.9% at 15- year follow-up). Risk factors for late reintervention were left ventricular outflow tract obstruction at time of ASO ($p < 0.001$) and a greater circulatory arrest time ($p < 0.001$). Freedom from at least moderate neoaortic valve regurgitation for the entire cohort was 98.7% (95% confidence interval 96.8 to 99.5%) at 20 years. Mild neoaortic regurgitation was seen in 25.6% of patients at mean follow-up. All patients were free of arrhythmia and heart failure symptoms at last follow-up.**

Conclusions. **The ASO can be performed with good long-term results. Patients with associated ventricular septal defect and aortic arch obstruction warrant close follow-up.**

(Ann Thorac Surg 2012;94:139–45)

A low operative mortality has been achieved with the arterial switch operation (ASO) by most high-volume institutions [1–6]. However, long-term follow-up of these patients is still not well defined and limited to a few studies [2, 4, 7, 8]. The primary ASO is performed in our unit in all children up to 8 weeks of age, irrespective of left ventricular pressure, geometry, or mass [9], and selectively in older children as well. Our technique of medially based rectangular flaps in the neoaortic sinuses for coronary translocation, the so called "Melbourne trapdoor technique," an approach to complex problems and midterm results have been previously described [10–12]. Herein, we sought to determine cardiac outcomes of 618 patients who underwent an ASO for transposition of the great arteries (TGA) over a 25-year period at a single institution, with a focus on long-term results.

Accepted for publication March 9, 2012.

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Material and Methods

Patients

Between May 1983 and January 2009, 720 ASOs were performed at The Royal Children's Hospital. Taussig-Bing anomaly was diagnosed in 57 of them, 21 had double switch operation, 5 had Mustard procedures converted to ASO, 10 had Senning procedures converted to ASO, and the remaining 9 had ASO with univentricular physiology. Therefore, a primary ASO with biventricular repair for simple TGA was done in 618 (86%) patients who were studied retrospectively. This study was approved by The Royal Children's Hospital Human Research Ethics Committee. All data were collected retrospectively. Closing interval, during which the status of each patient was verified, was from October 2009 to January 2010.

Definitions

Early death or reoperation was defined as death or reoperation occurring prior to hospital discharge or within 30 days of ASO. Late death or reoperation was

0003-4975/$36.00
http://dx.doi.org/10.1016/j.athoracsur.2012.03.019

Abbreviation and Acronyms

AAO = aortic arch obstruction
ASO = arterial switch operation
AXCL = aortic cross-clamp
CA = Circulatory arrest
COA = coarctation of aorta
CPB = cardiopulmonary bypass
ECMO = extracorporeal membrane oxygenation
HAA = hypoplastic aortic arch
IAA = interrupted aortic arch
IVS = intact ventricular septum
LVOTO = left ventricular outflow tract obstruction
PS = pulmonary stenosis
RVOTO = right ventricular outflow tract obstruction
TGA = transposition of great arteries
VSD = ventricular septal defect

defined as death or reoperation occurring after discharge and more than 30 days after ASO. Reoperation was defined as an operation on the heart or great vessels performed after the ASO, excluding exploration for bleeding, wound debridement, mechanical circulatory support, and pacemaker replacement. Reintervention encompassed reoperation and catheter reintervention performed after ASO. Abnormal coronary artery anatomy was defined as all patterns of coronary anatomy other than where the left anterior descending and the circumflex coronaries arose from sinus 1 and the right coronary arose from sinus 2.

Functional status was described according to the New York Heart Association (NYHA) classification. Follow-up was defined as concurrent if the patient was seen in the last 3 years before the end of data collection.

Statistical Analysis

Data were imported into Stata Version 10 (Stata Corp, College Station, TX). Continuous variables were reported as a mean or median with an accompanying range. Kaplan-Meier curves were constructed to display freedom from the study's outcomes. Risk factors for an outcome were identified using logistic regression analysis. A p value of less than 0.05 was considered significant. The Wald test was used to compare between groups for variables that were multicategorical.

Results

Early Outcomes

Preoperative and operative data are summarized in Table 1. While translocation technique remained consistent since the first ASO, periods of circulatory arrest were part of the technique during the first 15 years. This has been minimized over the last decade. Periods of circulatory arrest were used in 118 (91.4%) patients between 1983 and 1989 (median 10 minutes, mean 16.3 minutes, range 3 to 67 minutes), 148 (55.6%) patients between 1990 and 1999 (median 5 minutes, mean 9.2 minutes, range 1 to 63 minutes), and in 9 (4%) patients between 2000 and 2009 (median 10 minutes, mean 12.2 minutes, range 1 to 33 minutes). Overall median circulatory arrest time was 6 minutes (mean 12.4 minutes, range 1 to 67 minutes).

Early Mortality

There were 17 early deaths, resulting in an overall early mortality of 2.8% (95% CI 1.4% to 4.0%) between 1983 and 2009. Early mortality remained low during the study interval (Table 2). Early mortality was higher in patients with ventricular septal defect (VSD) or aortic arch obstruction (AAO) compared with patients with an intact ventricular septum (IVS) (3.8% and 7.9% vs 1.8%, respectively, Table 2). Myocardial ischemia was the most common cause of early death. There were no deaths after the ASO in the last 18 of 38 children with AAO.

By multiple logistic regression, the following variables were significant risk factors for early mortality: left ventricular outflow tract obstruction (LVOTO) resection at time of ASO ($p = 0.001$; odds ratio [OR] 19.0; 95% confidence interval [CI] 3.3 to 111.1), a weight of less than 2.5 kg at time of ASO ($p < 0.001$; OR 22.5; 95% CI 5.5 to 91.4), the presence of AAO ($p = 0.043$; OR 5.3; 95% CI 1.1 to 26.9), and the need for extracorporeal membrane oxygenation [ECMO] ($p < 0.001$; OR 126.1; 95% CI 26.6 to 598.0). All patterns of coronary artery anomalies (Table 1) were analyzed separately. No anomaly of the coronary arteries was a risk factor for early mortality in our patients. There were 6 (2.9%) early deaths in 209 patients with abnormal coronary anatomy. In particular, there were no early deaths in 28 patients with intramural coronary arteries. Early mortality was higher for those older than 14 days (Table 3); however, small numbers of those patients did not allow adequate statistical comparison. One (4.3%) early death occurred in 23 patients who had an ASO more than 30 days after birth. Early mortality was higher (19.2%) in children who weighed less than 2.5 kg at time of ASO.

Early Reintervention

There were 24 early reoperations performed in 20 (3.3%, 95% CI 1.2% to 3.7%) patients. The most common early reoperation was pacemaker implantation (n = 7, 1.1%) followed by repair of pulmonary stenosis (PS) (n = 3, 0.5%) and revision of the coronary anastomosis (n = 3, 0.5%). No early catheter reinterventions were necessary.

Late Outcomes

Of 601 survivors, 39 patients were international patients who returned to their native country and were excluded from long-term analysis. There were 25 local patients lost to follow-up, resulting in 537 Australian patients with long-term follow-up of 95.6% (537 of 562). Concurrent follow-up was 74.1% (398 of 537) for Australian patients and 66% (398 of 601) for all patients. Concurrent follow-up was 63.5% (216 of 340) for Australian patients operated before the year 2000 and 92.4% (182 of 197) for patients operated 2000 and beyond. Mean follow-up time