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Morbidity of the Arterial Switch Operation

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Abstract

Background—The arterial switch operation (ASO) has become a safe, reproducible surgical procedure with low mortality in experienced centers. We examined morbidity, which remains significant, particularly for complex ASO.

Methods—From 2003 to 2011, 101 consecutive patients underwent ASO, arbitrarily classified as “simple” (n = 52) or “complex” (n = 49). Morbidity was measured in selected complications and postoperative hospitalization. Three outcomes were analyzed: ventilation time, postextubation hospital length of stay, and a composite morbidity index, defined as ventilation time + postextubation hospital length of stay + occurrence of selected major complications. Complexity was measured with the comprehensive Aristotle score.

Results—The operative mortality was zero. Twenty-five major complications occurred in 23 patients: 6 of 25 (12%) in simple ASO and 19 of 49 (39%) in complex ASO ($p = 0.002$). The most frequent complication was unplanned reoperation (15 vs 6, $p = 0.03$). No patients required permanent pacing. The complex group had a significantly higher morbidity index and longer ventilation time and postextubation hospital length of stay. In multivariate analysis, factors independently predicting higher morbidity were the comprehensive Aristotle score, arch repair, bypass time, and malaligned commissures. Myocardial infarction caused one sudden late death at 3 months. Late coronary failure was 2%. Overall survival was 99% at a mean follow-up of 49 ± 27 months.

Conclusions—In this consecutive series without operative mortality, morbidity was significantly higher in complex ASO. The only anatomic incremental risk factors for morbidity were aortic arch repair and malaligned commissures, but not primary diagnosis, weight less than 2.5 kg, or coronary patterns.

The arterial switch operation (ASO) has evolved from a pioneering neonatal procedure to a reproducible technique allowing anatomic repair of transposition of the great arteries (TGA) and selected forms of double-outlet right ventricle (DORV) [1–3]. Between 2005 and 2009, the operative mortality of 1,671 ASOs in The Society of Thoracic Surgeons congenital database was 2.2% for TGA-intact ventricular septum, 5.5% for TGA-ventricular septal defect (VSD), and 7.3% for TGA-VSD with aortic arch obstruction [4].

When the hospital mortality rate is very low, clinical performance is analyzed through surrogate markers of morbidity. An intellectual debate is taking place around general morbidity indicators for congenital cardiac operations [5, 6]. Many agree that the optimal

morbidity indicator is a combination of metrics looking at hospital resources and major complications (Lacour-Gayet and associates, 2011, unpublished data). In this context, we analyzed a consecutive series of ASOs with no operative deaths from a single institution, with a stepwise focus on (1) a comparison between simple and complex cases and (2) the operative morbidity burden of ASO.

Patients and Methods

This study was approved by the Institutional Review Board of the Children's Hospital in Denver, Colorado.

Patients

Between January 2003 and January 2011, 101 consecutive ASOs were performed at Denver Children's Hospital Heart Institute. Patient details are given in Tables 1 and 2. Prospective risk stratification was done using the comprehensive Aristotle score [6]. Balloon atrial septostomy was performed routinely in the run-up to early complete repair, except in patients with an unrestricted septum. Early extubation and enteral feeding were actively encouraged where tolerated [7]. All Taussig-Bing lesions and DORV with noncommitted VSD with 2 viable ventricles were managed by ASO [8]. The final diagnosis was established by preoperative echocardiograms and intraoperative findings.

The technique is described elsewhere [9, 10]. Briefly, one-stage neonatal repair was pursued in all suitable patients. We used full-flow hypothermic (22°C) cardiopulmonary bypass (CPB) and myocardial protection with cold crystalloid cardioplegia with Bretschneider's solution (Custodiol HTK, Newton, PA) reinfused at 40-minute intervals. To avoid circulatory arrest, selective antegrade perfusion of the brachiocephalic artery was used for homograft patch enlargement of the arch [11, 12].

Coronary transfer followed the uniform technique of inserting the right coronary button above the neo-aortic suture line. This occasionally required division of an infundibular branch. Trap-door incisions were not used. In case of side-by-side great vessels, the main pulmonary trunk was translated to the right to reduce the risk of coronary compression. Conventional ultrafiltration was used routinely, without additional modified ultrafiltration.

The chest was left open as part of the operative strategy in patients with cardiac dysfunction and was not considered a complication. Left ventricular (LV) retraining was achieved with moderate pulmonary artery banding associated with a Blalock-Taussig shunt.

The respective characteristics of simple and complex ASOs are given in Tables 1 and 2. The complex ASO group had 49 patients with one or more of the criteria listed in Table 1. The remaining 52 patients formed the simple ASO group. A circumflex artery from the right coronary ($n = 17$), sacrifice of an infundibular artery ($n = 26$), and VSD (other than Taussig-Bing or multiple VSDs) were not considered complex features.

The measurement of postoperative disease burden was studied with a morbidity index (Lacour-Gayet and associates, 2011, unpublished data) that is calculated from the following 3 variables (Table 3) with a total of 5 points: complications (2 points) + ventilation time (VT; 1 point) + postoperative length of stay (LOS) after extubation (2 points) = 5.

Statistical Analysis

Statistical analysis was done with R 2.12.0 software (<http://cran.r-project.org/>). Without binary outcomes such as dead/alive, we aimed to examine morbidity as a continuum. The three outcomes analyzed were VT, post-extubation LOS (peLOS), and the morbidity index.

Results are expressed as mean or median. The *t* test and the Mann-Whitney *U* test were used for normal and skewed continuous variables, respectively, and the Fisher exact test for proportions, followed by multiple linear regression for the outcomes described. Akaike's information criterion (stepAIC in R) was used for model selection in multiple regression analysis. Values of $p < 0.05$ were considered statistically significant.

Results

Preoperative, intraoperative, and postoperative characteristics are reported in Table 2. Complex and simple patients had comparable weight. Four patients had a delayed ASO in the second month of life, after LV retraining. Two other complex ASOs were performed, respectively, at 14 and 20 months in patients with DORV–noncommitted VSD, initially palliated by pulmonary artery banding. There were no differences between the groups for preoperative ventilation or enteral feeding requirements. Cross-clamp and bypass times were significantly higher in the complex ASO group, as was commissure takedown (12 vs 5, $p = 0.06$). The sternum was left open as an operative strategy with coagulopathy or hemodynamic instability in 11 patients (21%) in the simple ASO group vs 17 (35%) in the complex ASO group ($p = 0.19$). In 24 complex patients, the coronaries had the usual anatomic arrangement and the complexity was due to intracardiac factors or aortic arch obstruction, or both ($n = 14$).

Operative Mortality and Complications

The 30-day and discharge mortality was 0 (0%). There were no complications, as defined in Table 3 in 75% of the total cases. Twenty-five complications were seen in 23 patients: 6 of 52 (12%) in the simple ASO group and 19 of 49 (39%) in the complex ASO group ($p = 0.002$). Two patients required extracorporeal membrane oxygenation support for 3 and 5 days in the complex group.

Two complex patients had focal neurologic deficits early postoperatively. In one premature baby, the ASO was delayed due to intracerebral hemorrhage and the LV was retrained. Imaging demonstrated an embolic stroke in the other patient. Both had attenuated clinical signs at discharge and no residual deficit at follow-up.

There were 21 early unplanned reoperations (6 in 6 patients in the simple group and 15 in 13 patients in the complex group, $p = 0.03$), comprising chest reopening for bleeding or cardiovascular instability in 10, diaphragmatic plication in 4, pulmonary artery patch enlargement in 1, and residual VSD and tricuspid regurgitation, mediastinitis, coarctation, recoarctation, chylothorax, and ileal perforation in 1 patient each. No permanent pacemakers were required.

Morbidity Outcomes

As shown in Figure 1, the median VT was 2 days in the simple group vs 4 days for complex patients ($p = 0.006$). The median peLOS was 8 days in simple vs 13 days in complex patients ($p = 0.01$). (At the end of the series we noticed a trend toward reduced peLOS, possibly related to more aggressive preoperative institution of enteral feeding; however, this association was not formally tested.) The morbidity index was higher in complex ASO patients (1.80 vs 1.17, $p < 0.001$).

The following factors were selected for multiple linear regression: weight less than 2.5 kg, Aristotle score, primary diagnosis, coronary pattern, arch repair, LV retraining, CPB time, open chest, and malaligned commissures. Table 4 shows the multivariate analysis results for the three morbidity measures defined: VT, peLOS, and the composite morbidity index. Only two anatomic factors independently increased the morbidity index: aortic arch repair and

malaligned commissures. Coronary patterns, primary diagnosis, and weight of less than 2.5 kg were not independently predictive.

Midterm Follow-Up

All but 3 out-of-state patients were seen regularly for an average of 49 ± 27 months. At review, all patients were growing well and required minimal or no cardiac medication. A myocardial infarction caused one late sudden death at 3 months in a patient with Taussig-Bing anomaly and malaligned commissures. Two patients received transplants, respectively, at 4 and 12 months: 1 had a single coronary ostium with shrinking of all 3 coronary branches, the other patient had a new-onset cardiomyopathy in the presence of normal coronary arteries by angiogram. The transplants were uneventful, one of these patients receiving a donation after cardiac death [13].

Late coronary failure, defined as death or a coronary event after ASO, happened in 2 patients (2%), less than in other reports [14]. The 2 patients with late coronary failure had, respectively, malaligned commissures and a single coronary ostium. Control coronary angiograms were not routinely performed, except in the 2 patients whose symptoms suggested coronary ischemia and who subsequently received allografts. There were no late reoperations and three late interventional cardiology procedures (1 recoarctation and 2 pulmonary branch angioplasties). The overall survival was 99%.

Comment

This is one of the first reports to focus on morbidity in a challenging procedure such as ASO. Results have improved dramatically in the last 2 decades, with this series exemplifying that ASO can be performed without operative death, even with 49% complex cases. Limited mortality rates are becoming a reality for many congenital operations. The current assessment of quality of care is primarily based on the operative mortality rate, which is approximately 4% in The Society of Thoracic Surgeons database. This approach does not consider the potential morbidity of the 96% of patients who are operative survivors.

Weight less than 2.5 kg, which was not a significant risk factor for morbidity in this series, is generally seen as an indicator of patient fragility and increased technical complexity. One report indicated weight was only significant in univariate analysis [2], whereas another group found that weight was independently predictive of hospital and intensive care unit LOS, but not VT or inotropic requirement [15]. A multiinstitutional study of 613 patients found weight was almost identical in survivors and nonsurvivors, postoperatively being only predictive of dialysis [1]. Two patients in our series weighed less than 2 kg, both with TGA and an intact septum. One of these patients (1.9 kg) had a VT of 5 days, peLOS of 8 days, and a morbidity index of 1.125. The other (1.8 kg) required a post-ASO laparotomy for bowel perforation, spent 12 days on a ventilator, and another 51 days in the hospital after, with a morbidity index of 3.125. In the absence of extremely low weight or very adverse anatomic or physiologic risk factors, patient size alone is not a surgical contraindication.

Preoperative enteral feeding and extubation were actively pursued, similar to other reports [7, 15]. One series found preoperative ventilation was associated with high resource utilization postoperatively [15]. The proportions of these interventions in our two groups are comparable. We have no indication to believe that preoperative enteral feeding leads to increased morbidity, and our initial experience suggests that atrial septostomy combined with discontinuation of prostaglandin is beneficial in reducing hospital LOS. We have not studied this formally, however.

The diagnostic and coronary categories (Tables 1 and 2) reflect our perception of complexity. Although used to define the complex group as noted, neither diagnostic nor coronary patterns emerged as independent predictors of morbidity in this study. Previous work showed that early complete repair for selected cases of DORV, including noncommitted VSD, is possible [8]. Pasquali and colleagues [16] reviewed nine series containing 1,942 patients with mortality recorded by coronary anatomy. Their meta-analysis forms the basis for the complexity classification used here, where a circumflex artery arising from the right ($n = 23$) was not considered an important risk factor, but double coronary loops, single ostium, and intramural course were.

Collectively, they accounted for 19% of our patients, a prevalence close to that seen by others [2, 15]. We successfully switched these complex patterns, confirming that adverse anatomy is neutralized by careful technique. Others reported a higher mortality with intramural coronaries [17]. Redo sternotomy, multiple VSDs, commissure takedown, or sacrifice of an infundibular artery also did not affect postoperative outcomes, similar to other reports [18]. Accurate coronary transfer is paramount. Liberal use of commissural takedown and sacrifice of an infundibular artery when required is key to obtaining large buttons and undistorted coronary trunks. Any ischemia from the occlusion of an infundibular artery resolves in a few hours in neonates in our experience. Reimplantation of the posterior commissure avoids late pulmonary regurgitation.

The only anatomic conditions emerging as risk factors in this series were aortic arch obstruction and malaligned commissures (Table 3). Arch repair, required in 13 patients (13%), was comparable with other series [1, 3, 15]. Here, these factors were associated with prolonged VT and a higher morbidity index, but not with peLOS. One-stage repair using homograft aortic patch enlargement is our preferred technique [11, 12]; it also allows correcting the aortopulmonary mismatch. In 1 patient with TGA-intact ventricular septum, the diagnosis of associated coarctation was missed preoperatively, requiring an emergency second-stage coarctation repair by thoracotomy.

The antegrade cerebral perfusion technique was uniformly used, avoiding circulatory arrest. In the European multiinstitutional report, arch repair was possibly overshadowed by other factors in a heterogeneous population operated on with different techniques [1]. In single institution reviews, however, arch repair is more likely to be separated in proportion to its contribution to the outcome: Gottlieb and colleagues [18] found in 74 complex ASO patients that a distal transverse arch z score of -2.5 or smaller and circulatory arrest time were important predictors of death.

Commissural malalignment is a feature less well described. In an anatomic study with clinical correlates, its prevalence was 12.5%, close to the 14% observed here [19]. In another 13 patients, with the degree of offsetting divided as major and minor, 8 of 28 ASO patients (29%) had major malalignment, this higher prevalence perhaps relating to ethnic variation. One patient died immediately postoperatively from coronary stretching and ischemia [20]. Realignment of the commissures requires subtle degrees of torsion on the great arteries and, occasionally, a higher coronary implantation. This factor was independently responsible for a higher morbidity index in our patients. It most likely contributed directly to complications in 1 patient who required extracorporeal membrane oxygenation support for 3 days. The only late death occurred in a patient with Taussig-Bing, commissural malalignment, and double-loop coronaries. The postoperative course was satisfactory, but myocardial infarction occurred at home 3 months postoperatively. We attributed this to severely malaligned commissures causing suboptimal relocation of the left coronary.

Accurate technique should not be underestimated. In this series, 82 ASO were performed by the same surgeon. In a rigorous analysis of the interaction between institutional management and surgical experience in four complex procedures (Norwood, pulmonary atresia intact septum, interrupted aortic arch, and ASO) the only procedure in which “experience” had a direct positive effect was ASO [21]. This is partly explained by different patient profiles. A well-performed coronary transfer with a limited CPB time is usually followed by a simple postoperative course in most ASO patients. Conversely, even the most technically accurate Norwood has to navigate the vagaries of more complex postoperative physiology. In terms of length of the operation, we used CPB time to examine its interaction with other variables. A long CPB is a surrogate for technical complexity and causes morbidity through its adverse physiologic effects. It approached statistical significance for peLOS but was not retained in the VT model. These data are consistent with other reports in which CPB time is associated with a higher risk of death or complications [2, 15, 18, 22].

The positive contribution of the comprehensive Aristotle score is confirmed by this study, too. Although still based on subjective probability, the Aristotle score is increasingly used in risk estimates and resource planning [5, 23]. In this analysis it was the main factor independently predictive of postoperative LOS along with CPB time. The Aristotle score was not associated with a high morbidity index in this initial analysis, which is likely in relation to the clustering of complications in our cohort. Similarly, the presence of LV retraining as a morbidity predictor has a similar explanation: the 4 patients who required LV retraining had transposition with an intact ventricular septum and a conspicuous absence of other risk factors. However, 3 of 4 patients experienced notable complications: 2 required chest reopening, and preoperative brain hemorrhage occurred in another. Although the mild neurologic deficit was not exacerbated postoperatively, this was still classified as a major neurologic complication. Delayed sternal closure was used liberally in a fifth of the patients. It contributes to increased VT but otherwise is not predictive of increased peLOS or higher morbidity.

Ventilation time is arguably a better indication of early morbidity compared with intensive care LOS, which is more institutionally dependent. Likewise, peLOS is a better reflection of second-phase morbidity, even if it also depends on institutional protocol. A myriad of complications can be recorded, but a few selected ones can give a concise indication of the patient’s postoperative journey before discharge.

The morbidity index (Lacour-Gayet and associates, 2011, unpublished data) forms a new metric that draws on the Clavien-Dindo classification of surgical complications [24]. It can be assumed that the low mortality rate observed in some centers is not due to an absence of adverse events but to their better recognition and management [25–27]. When applying the failure to rescue principle to this series [27], good survival in presence of 25% major complications translates into a 0% failure to rescue, a new angle for outcome evaluation.

The current study has several limitations. First, the focus was mainly on hospital events. Second, there was some overlap between the comprehensive Aristotle score and a few of the factors analyzed separately. Finally, our data set was too small for studying multiple predictors, and inherently, the regression analysis has low power.

In summary, this report shows that ASO can be performed with excellent early results, even in patients with high-risk features. Accurate technique is necessary for coronary artery transfer and permits expanding the complexity range of the procedure without an increase in death. Higher morbidity is present in more complex subgroups, particularly in presence of malaligned commissures and arch obstruction. Further work is needed to refine the morbidity analysis framework. The Society of Thoracic Surgeons Congenital Heart Surgery

Database Task Force is currently developing a morbidity score to allow a fair evaluation of the 96% survivors of operations.

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Fig 1. Morbidity comparisons between patients undergoing atrial switch operations. (A) Ventilation time (VT) and postextubation length of stay (peLOS) in patients undergoing simple (gray bars) and (complex (black bars) atrial switch operations. (B) Morbidity index, scale 0 to 5.

Table 1

Definition of Complex Atrial Switch Operation (N = 49) Based on One or Several Associated Lesions

Variable	No.
Diagnosis	
Taussig-Bing	9
DORV noncommitted VSD	2
Coronaries	
Double loop	11
Intramural	6
Single ostium	2
Aortic arch obstruction	13
Multiple VSDs	4
Malaligned commissures	14
Left ventricular retraining	4
Weight<2.5 kg	3
Total lesions in 49 patients	68

DORV = double outlet right ventricle; VSD = ventricular septal defect.

Table 2

Patient Characteristics

Variable	All (n = 101)	Simple (n = 52)	Complex (n = 49)	p Value
Age, days (IQR)	8 (5, 12)	7 (5, 9)	9 (7, 15)	0.002
Weight, mean (SD) kg	3.2 (0.50)	3.4 (0.57)	2.2 (0.22)	0.13
Weight < 2.5 kg, No.	3	0	3	0.25
Primary diagnosis, No.				N/A
TGA-IVS	67	40	27	
TGA-VSD	23	12	11	
Taussig-Bing	9		9	
DORV-noncommitted-VSD	2	...	2	
Coronary patterns ^a				N/A
1	65	41	24	
2	17	11	6	
3	19	...	19	
Arch repair, No. (%)	13 (13)	0	13 (27)	N/A
Multiple VSDs, No. (%)	4 (4)	0	4 (8)	N/A
Malaligned commissures, No. (%)	14 (14)	0	14 (29)	N/A
Comprehensive Aristotle score, mean (SD)	14 (3)	11.7 (1.9)	16.9 (2.6)	<0.001
Preop ventilation, No. (%)	19 (19)	9 (17)	10 (20)	0.89
Preop enteral feeding, No. (%)	58 (58)	32 (62)	26 (53)	0.51
LV retraining, No. (%)	4 (4)	0	4 (8)	n/a
Sacrifice of infundibular artery, No. (%)	26 (26)	11 (21)	15 (31)	0.36
Commissure takedown, No. (%)	17 (17)	5 (10)	12 (24)	0.06
Redo sternotomy, No. (%)	7 (7)	1 (2)	6 (12)	0.09
CPB time, mean (SD) min	184 (49)	165 (33)	206 (56)	<0.001
Cross-clamp time, mean (SD) min	103 (32)	82 (23)	114 (37)	<0.001
Open chest as strategy, No. (%)	21 (21)	8 (15)	13 (26)	0.22
Complications, No. (%)	25 (25)	6 (12)	19 (39)	0.002
Unplanned reoperations	21 (21)	6 (12)	15 (31)	0.03
ECMO	2 (2)	0	2 (4)	0.23
Neurologic complications	2 (2)	0	2 (4)	0.23
VT, median (IQR) days	3 (2, 5)	2 (1, 4)	4 (2, 9)	0.006
LOS, median (IQR) days				
Postextubation	11 (7, 15)	8 (6, 13)	13 (8, 19)	0.01
Total hospital	15 (9, 20)	12 (8, 17)	17 (13, 26)	<0.001
Morbidity index, mean (SD)	1.48 (0.9)	1.17 (0.6)	1.8 (1.05)	<0.001
Late death, No.	1	0	1	0.48
Secondary heart transplant, No.	2	0	2	0.23
Coronary failure, No.	2	0	2	0.23
Operative death, No.	0	0	0	N/A

^aCoronary pattern categories: 1 = usual arrangement, 2 = circumflex off right coronary artery, 3 = double loop, single ostium, or intramural.

CPB = cardiopulmonary bypass; DORV = double outlet right ventricle; ECMO = extracorporeal membrane oxygenation; IQR = interquartile range; IVS = intact ventricular septum; LOS = length of stay; LV = left ventricle; N/A = not applicable; Preop = preoperative; SD = standard deviation; TGA = transposition of the great arteries; VSD = ventricular septal defect; VT = ventilation time.

Table 3**The Components of the Morbidity Index**

Variable	Points
Listing of complications ^a	
Neurologic deficit persisting at discharge	2
Renal failure requiring dialysis at hospital discharge	2
Respiratory failure requiring tracheostomy	1.5
Postoperative ECMO, IABP, or VAD	1.5
Arrhythmia necessitating permanent pacemaker	1.5
Unplanned cardiac reoperation with CPB	1.5
Phrenic nerve palsy requiring diaphragmatic plication	1
Mediastinitis requiring sternum reopening	1
Unplanned cardiac reoperation without CPB	1
Unplanned noncardiac reoperation	0.5
Ventilation time ranking ^b	
0	0
Hours	
<6	0.125
7–24	0.25
Days	
1–3	0.375
4–6	0.5
7–14	0.625
15–21	0.75
22–30	0.875
>30	
Postoperative length of stay after extubation	
Hours	
<24	0.10
Days	
1–2	0.125
2–3	0.25
4–6	0.375
7–9	0.5
10–12	0.625
13–15	0.75
16–18	1
19–21	1.25
21–25	1.50
26–29	1.75
>30	2

^aCumulative and capped at 2.

^bVentilation time starts in the intensive care unit and includes the total ventilation time in cumulating reintubations.

CPB = cardiopulmonary bypass; ECMO = extracorporeal circulation membrane oxygenation; IABP = intraaortic balloon pump; VAD = ventricular assist device.

Table 4

Effect of Preoperative and Intraoperative Variables on Three Morbidity Outcomes

	β -Coefficient Estimate	SE	<i>p</i> Value
Ventilation time			
Arch repair	0.79	0.21	<0.001
Comprehensive score ^a	0.07	0.02	0.005
Open chest	0.73	0.16	<0.001
Postextubation LOS			
Comprehensive score ^b	0.07	0.02	<0.001
Bypass time, min ^{a,b}	0.002	0.001	0.07
Morbidity index			
Left ventricle retraining	1.29	0.38	<0.001
Malaligned commissures	0.49	0.23	0.03
Bypass time, min ^b	0.006	0.002	0.006
Arch repair ^a	0.53	0.28	0.06

^aBordering significance.^bIncrease per unit of measurement (ie, points for comprehensive score and minutes for bypass time).

LOS = length of stay; SE = standard error.