Intermediate-term outcomes of the arterial switch operation for transposition of great arteries in neonates: Alive but well?

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Objectives: This interprovincial inception cohort study outlines the operative and intermediate outcomes of all neonates at a single institution with a broad referral area who underwent the arterial switch operation for transposition of great arteries, including complex types. Predictors of outcome are explored.

Methods: A total of 88 consecutive neonates underwent the arterial switch operation between 1996 and 2004 with full-flow (150 mg/kg/min) cardiopulmonary bypass with selective deep hypothermic circulatory arrest. Overall and event-free survivals were calculated. Health and neurodevelopment (Bayley Scales of Infant Development II) were assessed at 18 to 24 months of age. Univariate and multivariate analyses, sensitivity, and specificity were determined to identify preoperative, intraoperative, and postoperative factors associated with mental and/or motor delay.

Results: There was 1 operative mortality (1.1%). At the average 4-year follow-up, survival was 98.9% and freedom from reintervention was 93.2%. Eighty-five children were assessed. Three were excluded because of unrelated postoperative diagnoses. For the remaining 82, mean scores were 89 ± 17 (49-118) for mental skills and 92 ± 15 (49-125) for motor skills. Anatomic complexity, cardiopulmonary bypass, and deep hypothermic circulatory arrest times were not associated with developmental outcome. Preoperative variables of low gestational age and high preoperative lactate correctly classified 84.1% of mentally and/or motor-delayed children.

Conclusion: Transposition of great arteries, including complex types, can be corrected with low surgical risk and good intermediate survival; however, neurodevelopmental outcome is a concern. These data suggest that although anatomic complexity may not affect late outcome, there may be potentially modifiable preoperative factors that can be optimized to improve developmental outcomes.

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The surgical therapy of congenital heart disease and perioperative care in the intensive care unit have made great advances so that the outcomes emphasis for most congenital lesions has shifted from operative results to later outcomes including neurodevelopment.[1] The surgical treatment of transposition of great arteries (TGA) has evolved significantly over the past 20 years. Presently, TGA, including complex forms, can be repaired using the arterial switch operation (ASO) with a low operative risk in most high-volume centers.[2-5] On the basis of concerns about the effect of neonatal deep hypothermic circulatory arrest (DHCA) on neurologic development,[6] studies with patient intake between 1988 and 1992 from the United States[7-10] have shown the detrimental effect of DHCA on infant psychomotor development,[7] preschool motor function,[8] and speech apraxia.[8] Low-flow cardiopulmonary bypass (CPB) without[10] or with DHCA[11] has shown school-

Abbreviations and Acronyms

ASO = arterial switch operation
CPB = cardiopulmonary bypass
DHCA = deep hypothermic circulatory arrest
TGA = transposition of great arteries
ECMO = extracorporeal membrane oxygenation
MDI = Mental Developmental Index
PDI = Psychomotor Development Index
SD = standard deviation
VSD = ventricular septal defect

age intelligence test results (intelligence quotient) to be within average range but below population normative data.[10,11] Similar concerns for motor development with study intake between 1988 and 1994 but with full-flow CPB and limited DHCA have been reported from Australia.[1] Understanding the limits for a safe period of DHCA is still evolving,[6] but 41 minutes has been suggested.[9] The standard surgical approach for repair of TGA with intact ventricular septum is shifting toward full-flow CPB with a brief period of DHCA for closure of the atrial septal defect. For more complex cases, longer periods of DHCA may be required.

In addition to the contribution of DHCA, the relative impact of preoperative status on late outcome after complex neonatal cardiac surgery is becoming increasingly recognized and includes lower gestational age,[12] duration of preoperative ventilation,[12] older age at surgery,[1] and preoperative acidosis.[1,11] The prevalence of preexisting brain injury has been found to be high and presumably would contribute to late developmental outcomes.[13] Although antenatal diagnosis may improve the perioperative state, it has not yet been shown to improve neurodevelopmental outcome.[14] Longer hospital stay, a known predictor of adverse outcome, also depends in part on preoperative variables including lower birth weight, abnormal neurologic examination results, intubation, and operative and postoperative variables.[15] In 1996, we initiated a longitudinal, prospective study of all neonates undergoing complex heart surgery at age 6 weeks or less at a single institution that receives referrals from Alberta, Saskatchewan, Manitoba, the Northwest Territories, and parts of British Columbia. We report the outcomes of all children who underwent neonatal ASO and identify variables associated with adverse outcome from operative data as well as preoperative and postoperative periods.

Patients and Methods

The methods of this interprovincial inception cohort follow-up study of all neonates undergoing complex cardiac surgery have been published.[12] Acute care data on 88 consecutive neonates undergoing ASO were entered into a database prospectively from September 1996 to August 2004. Children were divided into 3 groups according to the complexity of their cardiac anomalies: Group A, simple TGA with intact ventricular septum (n = 52); Group B, TGA with ventricular septal defect (VSD) (n = 22); and Group C, complex TGA (n = 14). Additional anatomic diagnoses in Group C included double outlet right ventricle (Taussig-Bing anomaly), single coronary artery, interrupted aortic arch, aortic coarctation or hypoplastic aortic arch, pulmonary artery anomalies, and left ventricular outflow tract obstruction or aortic stenosis. All surgery was performed at the Stollery Children's Hospital, Edmonton, Alberta, Canada. Surgery was completed with predominantly full-flow CPB and moderate hypothermia with selective use of DHCA. A modified pH-stat strategy was used for cooling.

Acute care variables recorded prospectively at our institution for the preoperative, early postoperative (24-hour), and later postoperative periods included measures of illness acuity: highest dopamine used; epinephrine used; lowest base deficit, P_{AO_2}, and arterial pH; and highest creatinine, plasma lactate, and oxygenation index. Plasma lactate levels were taken as part of clinical management, regularly ordered twice daily, plus obtained routinely with blood gases. The predictive value of plasma lactate at this institution has been published.[16] Other preoperative variables included out-of-region referral, age at surgery, 5-minute Apgar score, birth gestation and weight, gender, duration of ventilation, antenatal diagnosis, chromosomal abnormality, and socioeconomic index.[17] Additional variables included overall days of ventilation and hospitalization, need for extracorporeal membrane oxygenation (ECMO) or dialysis, clinical convulsions, cardiopulmonary resuscitation, sepsis, and surgical reintervention. Cranial imaging and electroencephalography testing were not performed except as clinically indicated. Collected intraoperative variables included the following: CPB time with lowest flow for more than 10 minutes and lowest mean arterial pressure for more than 10 minutes on CPB, lowest temperature, crossclamp time, DHCA use, duration of DHCA (not included in CPB time) with lowest temperature during DHCA, and need for repeat CPB.

The 88 children (64% were boys, 49% were referred from out of region, and 8% had an antenatal diagnosis) had a mean gestational age of 38.8 ± 1.9 weeks and birth weight of 3.74 ± 0.62 kg, 5-minute Apgar score of 7.8 ± 1.4, age at surgery of 9.9 ± 6.5 days, and socioeconomic level of 40.5 ± 13. None had microcephaly or known chromosomal abnormality.

At 18 to 24 months of age, a nurse research assistant recorded history of hospitalizations, medication use, and physical measurements. Each child was examined by a pediatrician experienced in neurodevelopmental follow-up, as previously described.[12,16] Motor or sensory disability was determined if a child had cerebral palsy,[18] visual impairment (corrected visual acuity in the better eye < 20/60), or binaural/bilateral sensorineural hearing loss greater than 40 dB at any frequency from 250 to 4000 Hz. The Bayley Scales of Infant Development-II[19] were chosen as the main standardized outcome measure because of their widely accepted use in neonatal follow-up clinics and their separate mental (Mental Developmental Index [MDI]) and motor (Psychomotor Development Index [PDI]) scales. Examiners were experienced pediatric psychologists or psychologic assistants certified for reliability. Developmental indices of less than 70 (2 standard deviation [SD] below mean) indicated mental or motor delay or both.