Cardiol Young 2003; 13: 49–52
© Greenwich Medical Media Ltd.
ISSN 1047-9511

Original Article

Adequate left ventricular preparation allows for arterial switch despite late referral

Antonio F. Corno, Michel Hurni, Maurice Payot, Nicole Sekarski, Piergiorgio Tozzi, Ludwig K. von Segesser

Centre Hospitalier Universitaire Vaudois, Lausanne, Switzerland

Abstract *Objective:* To evaluate the feasibility of the arterial switch for surgical repair of transposition, defined as the combination of concordant atrioventricular and discordant ventriculo-arterial connections, after late referral. *Methods:* From March 2000 to August 2001, six children underwent an arterial switch procedure following left ventricular preparation because of late referral. The mean age at referral was 8.3 months, with a range from 3 to 25 months, and mean body weight was 5.3 kg, with a range from 3.7 to 9.3 kg. The mean saturation of oxygen was 57%, with a range from 50 to 72%. Associated defects included a restrictive ventricular septal defect in three patients, aortic coarctation in one, and partially anomalous pulmonary venous connection in one. The mean interval between referral and the arterial switch procedure was 3.7 months, within a range from 1 to 7 months. A mean of 1.5 surgical procedures were undertaken to prepare the left ventricle, the most being 3 procedures, including combinations of creation of an inter-atrial communication in four patients, banding of the pulmonary trunk in five, and creation of a systemic-to-pulmonary arterial shunt in three. We evaluated left ventricle ejection and shortening fractions, left ventricular diastolic diameter and volume, right and left ventricular wall thicknesses, and the ratio of right to left ventricular values by echocardiography at referral, immediately before, and one week after the arterial switch procedure. *Results:* All children are alive and well, with a mean follow-up of 17 months, ranging from 9 to 26 months. Echocardiography showed a statistically significant decrease of the ratio between right and left ventricular wall thicknesses, from 1.33 ± 0.26 at referral to 0.79 ± 0.08 before the switch procedure ($p < 0.005$). Left ventricular function was adequate after arterial switch, with a mean ejection fraction of 79.3%, ranging from 66 to 87%, and a mean shortening fraction of 41.7%, ranging from 30 to 49%. *Conclusions:* Despite late referral, and initially inadequate left ventricular volume and mural thickness, children with transposition can successfully be treated with the arterial switch procedure, provided that the left ventricle is adequately prepared, using echocardiography to monitor left ventricular morphology and function.

Keywords: Congenital cardiac surgery; banding of pulmonary trunk; transposition of the great arteries

In order to utilize the left ventricle as systemic ventricle for the long term in patients with the combination of concordant atrioventricular and discordant ventriculo-arterial connections, or transposition, the recognized standard surgical treatment is now the arterial switch procedure,[1] even in the presence of increased risk factors such as low body weight and a solitary coronary artery.[2] The ability of the left ventricle to sustain the systemic circulation, however, starts slowly to decline when patients with an intact ventricular septum reach the age of two to three weeks. The capability can remain, dependent upon the patency of the arterial duct, the level of pulmonary vascular resistance, the size of the inter-atrial communication, and the presence of obstruction within the left ventricular outflow tract.

There is also the potential, nonetheless, to retrain the left ventricle. This procedure was first reported by Yacoub and his associates in 1977,[3] prior to the era of the neonatal switch procedure,[4] with a rapid

Correspondence to: Antonio F. Corno, MD, FRCS, FETCS, Cardiovascular Surgery, Centre Hospitalier Universitaire Vaudois (CHUV), 46 rue du Bugnon, CH-1011 Lausanne, Switzerland. Tel: +41 21 314 2280; Fax: +41 21 314 2278; E-mail: Antonio.Corno@chuv.hospvd.ch

Presented at the 37th Annual General Meeting of the Association for European Pediatric Cardiology, Porto, May 15–18, 2002

Accepted for publication 16 August 2002

two-stage technique for retraining being reported by Jonas and colleagues in 1989.[5] Subsequent to this, several investigators[6–9] have reported the feasibility of performing the arterial switch procedures in patients with intact ventricular septum immediately after the critical period of 2–3 weeks of age without retraining the left ventricle, with or without the need for postoperative extra-corporeal membrane oxygenation temporarily to support a ventricle not yet ready to sustain the systemic circulation.

Retraining the left ventricle because of late referral has also been reported, but generally in patients within the first stages of infancy.[10–13] Reports of retraining followed by the arterial switch in older patients, excluding those with right ventricular failure after an atrial switch, are anecdotal.[10] We report here our experience with retraining the left ventricle a group of consecutive patients who successfully underwent an arterial switch procedure despite a very late referral, having a mean age of over 8 months.

Materials and methods

From March 2000 to August 2001, we performed the arterial switch procedure in six consecutive children after left ventricular preparation because of late referral, this sequence representing our overall experience with this protocol. Their mean age at referral was 8.3 months, with a range from 3 to 25 months, and the mean body weight was 5.3 kg, with a range from 3.7 to 9.3 kg. The mean systemic saturation of oxygen, measured percutaneously, was 57%, with a range from 50 to 72%. A restrictive ventricular septal defect was present in three patients, aortic coarctation in one, and partially anomalous pulmonary venous connection in another.

A mean of 1.5, and up to 3, different surgical procedures were performed in each patient to prepare the left ventricle. Enlargement of a restrictive inter-atrial communication, or creation of a new defect, both procedures always performed on cardiopulmonary bypass through median sternotomy, was needed in four patients. Banding of the pulmonary trunk was required in five, along with aortic coarctectomy using an extended end-to-end anastomosis in one, and a modified Blalock-Taussig shunt was constructed in three patients. Re-operation was required to adjust the band placed round the pulmonary trunk in 3 patients, and to adjust the systemic-to-pulmonary arterial shunt in 2 patients.

We evaluated ejection and shortening fraction, left ventricular diastolic diameter and volume, right and left ventricular wall thickness, and the ratio of the right to the left ventricular values by echocardiography at referral, immediately before, and one week after the arterial switch. Results are expressed as mean ± standard deviation, using Student's t test to compare the values at referral with those found before and after the switch procedure. A p value of less than 0.05 was accepted as statistically significant.

The left ventricle was judged to be ready to sustain the systemic circulation when echocardiography revealed reversal of the ratio of the thickness of the right and left ventricular free walls with respect to the value at the time of referral, with concomitant increases in the left ventricular diameter and volume. At this moment, we proceeded to perform the arterial switch procedure.

Results

Within a mean interval of 3.7 months, and a range from 1 to 7 months after referral, all 6 children had undergone an arterial switch procedure. At the same time, we removed all bands placed around the pulmonary trunk, and closed all systemic-to-pulmonary arterial shunts, as well as closing all inter-atrial communications. The restrictive ventricular septal defects present in 3 patients were closed with single suture, and the partially anomalous pulmonary venous connection was repaired in the last patient. No patient required extra-corporeal membrane oxygenation after surgery. There were no early or late deaths, and all children are well at a mean follow-up of 17 months, with a range from 9 to 26 months. Left ventricular function was adequate one week after the arterial switch, with a mean ejection fraction of 79.3%, ranging from 66 to 87%, and a mean shortening fraction of 41.7%, ranging from 30 to 49%. These values remained stable through the follow-up (Table 1).

Table 1. Follow-up for left ventricular function after arterial switch

	Referral	Pre-switch		Post-switch	
RV wall (mm)	5.0 ± 1.6	4.7 ± 0.9	ns	3.9 ± 0.8	ns
LV wall (mm)	4.0 ± 1.7	6.0 ± 1.6	ns	5.4 ± 1.0	ns
RV/LV ratio	1.33 ± 0.26	0.79 ± 0.08	$p < 0.005$	0.72 ± 0.11	$p < 0.005$
LV diameter (mm)	22.6 ± 6.4	25.9 ± 3.4	ns	30.1 ± 3.4	$p < 0.05$
LV volume (cm^3/m^2)	33 ± 17	72 ± 16	$p < 0.01$	71 ± 22	$p < 0.05$

Abbreviations: LV: left ventricle; RV: right ventricle; ns: not significant

Discussion

Despite the fact that potential late problems of the arterial switch still remain mostly unknown, this procedure remains the operation of choice for patients with transposition, since it restores to the morphologically left ventricle its appropriate role of supporting the systemic circulation.[1] When the ventricular septum is intact, however, or when there is a restrictive ventricular septal defect, the left ventricle requires a retraining in patients beyond the neonatal period if it is to be adequate to sustain the systemic circulation. Our knowledge on the remodelling of the left ventricle in young children is still very limited. The main issues to be defined remain the following:

- The criterions that indicate adequate left ventricular retraining.
- The optimal method for retraining.
- The quality of the myocardial tissue generated by retraining.

Several parameters, all obtained by echocardiographic investigation, have been proposed to monitor the remodelling. These include the shape of the ventricular septum, as an indirect index of the ratio of pressures between the right and left ventricles,[14,15] as well as left ventricular ejection and shortening fractions, left ventricular diastolic diameter and volume, left ventricular mass, and left ventricular mural thickness.[11,12,15–17]

The echocardiographic methods currently available, however, have a major limitation. Both the left ventricular volume and mass are calculated using algorithms, considering the left ventricular cavity as an approximation of a sphere.[18] This situation, of course, is far from reality.

In our experience, therefore, we decided arbitrarily to monitor the ratio between right and left free ventricular mural thickness, and to proceed with the switch procedure once the ratio with respect to the value at the time of referral was reversed, providing this was concomitant with an increase of the left ventricular diameter and volume. In fact, a substantial change in this ratio was found subsequent to surgical preparation of the left ventricle, from a value of 1.33 ± 0.26 at the moment of referral to one of 0.79 ± 0.08 ($p < 0.005$) at the time we proceeded to perform the arterial switch. The ratio improved still further after the arterial switch.

In terms of the surgical procedures for retraining, we used several operations. The most important step is banding of the pulmonary trunk, associated with creation of a systemic-to-pulmonary arterial shunt.[3,5,10–13,15–17] We also judged it necessary in some of our patients to create an inter-atrial communication, or enlarge an existing restrictive one, because of very low pre-operative systemic arterial saturations, anticipating otherwise a poor tolerance of the necessary banding of the pulmonary trunk.

As an alternative to training the left ventricle before the arterial switch, it is possible to use extra-corporeal membrane oxygenation, or mechanical assistance, to support the left ventricle until it becomes capable of sustaining the systemic circulation.[8,9]

Despite the observation that such mechanical assistance after the arterial switch has the advantage of supporting a left ventricle which is perfused with oxygenated blood, in comparison to the hypoxic myocardium found in the setting of left ventricular retraining with a banded pulmonary trunk, mechanical assistance in children remains a very demanding procedure in terms of technical staff, equipment and disposable materials, and blood products, and suffers a substantial rate of complications,[9,19] probably greater than those that follow banding of the pulmonary trunk.[20]

A limiting factor in banding for left ventricular retraining, nonetheless, is the great difficulty, particularly evident in this group of patients, in appropriately adjusting the band, obtaining the correct balance between the need for an adequate left ventricular afterload and the consequent left ventricular dysfunction. Half of our patients needed a repeated surgical procedure to adjust the band, a feature reported also by others.[10–12] They also required a prolonged stay in the intensive care unit, again as reported by others.[20]

The upper age limit for retraining the left ventricle remains to be defined, even if previous studies demonstrated the possibility of myocardial hyperplasia, that is mitosis with an increased number of myocytes, only within the first few weeks after birth.[21] After this period, the ventricle responds to pressure overload by hypertrophying, this ultimately being a negative process.

In our experience, the oldest patient was referred at 25 months of age, but there are reports of left ventricular retraining because of right ventricular failure years after atrial rerouting, with a subsequent arterial switch proving successful even in adults.[10,22,23]

As to the quality of the myocardium generated, despite the successful clinical results, including our experience with echocardiographic documentation of adequate left ventricular function, so far no information is available on this topic. Recent experimental studies[24,25] have provided new information on the mechanism of myocardial adaptation to the sudden pressure overload, but we have still to clarify the structural and molecular changes induced in myocardium by the acute pressure overload. We still remain uncertain concerning the negative consequences induced by chronic hypoxia on myocardial structure, metabolism and function.[26,27] Clarification of gene expression, nonetheless, will probably provide the molecular bioengineering knowledge needed to modulate the abnormal adaptive responses of the myocardium.

References

1. de Leval MR. Lessons from the arterial switch operation. Lancet 2001; 357: 1814.
2. Corno AF, von Segesser LK. Transposition of great arteries and single coronary artery: a new surgical technique for the arterial switch operation. Swiss Med Wkly 2001; 131: 47–49.
3. Yacoub M, Radley-Smith R, Maclaurin R. Two stage operation for anatomical correction of transposition of the great arteries with intact ventricular septum. Lancet 1977; 1: 1275–1278.
4. Castaneda AR, Norwood WI, Jonas RA, Colan SD, Sanders SP, Lang P. Transposition of the great arteries with intact ventricular septum: anatomical repair in neonates. Ann Thorac Surg 1984; 38: 438–443.
5. Jonas RA, Giglia TM, Sanders SP, Wernovski G, Castaneda AR. Rapid two stage arterial switch for transposition of the great arteries with intact ventricular septum beyond the neonatal period. Circulation 1989; 80(Suppl I): 203–208.
6. Davis AM, Wilkinson JL, Karl TR, Mee RB. Transposition of the great arteries with intact ventricular septum. Arterial switch repair in patients 21 days of age or older. J Thorac Cardiovasc Surg 1993; 106: 111–115.
7. Foran JP, Sullivan ID, Elliott MJ, de Leval MR. Primary arterial switch operation for transposition of the great arteries with intact ventricular septum in infants older than 21 days. J Am Coll Cardiol 1998; 31: 883–889.
8. Mee RB, Harada Y. Retraining of the left ventricle with a left ventricular assist device (Bio-Medicus) after the arterial switch operation. J Thorac Cardiovasc Surg 1991; 101: 171–173.
9. Naughton P, Mossad E. Retraining the left ventricle after arterial switch operation: emerging uses for the left ventricular assist device in pediatric cardiac surgery. J Cardiothorac Vasc Anesth 2000; 14: 454–456.
10. Helvind MH, McCarthy JF, Imamura M, et al. Ventriculo-arterial discordance: switching the morphologically left ventricle into the systemic circulation after 3 months of age. Eur J Cardiothorac Surg 1998; 14: 173–178.
11. Iyer KS, Sharma R, Kumar K, et al. Serial echocardiography for decision making in rapid two-stage arterial switch operation. Ann Thorac Surg 1995; 60: 658–664.
12. Lacour-Gayet F, Piot D, Zoghbi J, et al. Surgical management and indication of left ventricular retraining in arterial switch for transposition of the great arteries with intact ventricular septum. Eur J Cardiothorac Surg 2001; 20: 824–829.
13. Laohaprasitiporn D, Nana A, Soongswang J, et al. Results of rapid two-stage arterial switch operation in patients with transposition of the great arteries: one-year postoperation. J Med Assoc Thai 1998; 81: 866–871.
14. Sidi D, Planché C, Kachaner J, Villain E, Lacour-Gayet F. Anatomic correction of simple transposition of the great arteries in 50 neonates. Circulation 1987; 75: 429–435.
15. Nakazawa M, Oyama K, Imai Y, et al. Criteria for two-staged arterial switch operation for simple transposition of great arteries. Circulation 1988; 78: 124–131.
16. Boutin C, Wernovsky G, Sanders SP, Jonas RA, Castaneda AR, Colan SD. Rapid two-stage arterial switch operation. Evaluation of left ventricular systolic mechanics late after an acute pressure overload stimulus in infancy. Circulation 1994; 90: 1294–1303.
17. Boutin C, Jonas RA, Sanders SP, Wernovsky G, Mone SM, Colan SD. Rapid two-stage arterial switch operation. Acquisition of left ventricular mass after pulmonary artery banding in infants with transposition of the great arteries. Circulation 1994; 90: 1304–1309.
18. Devereux RB, Alonso DR, Lutas EM, et al. Echocardiography assessment of left ventricular hypertrophy: comparison to necropsy findings. Am J Cardiol 1986; 57: 450–458.
19. Corno AF, Horisberger J, Boone Y, et al. Assistance cardiaque mécanique pédiatrique. Rev Med Suisse Romande 2002; 122: 137–140.
20. Wernovsky G, Giglia TM, Jonas RA, Mone SM, Colan SD, Wessel DL. Course in the intensive care unit after "preparatory" pulmonary artery banding and aortopulmonary shunt placement for transposition of the great arteries with low left ventricular pressure. Circulation 1992; 86(Suppl II): 33–39.
21. di Donato RM, Fujii AM, Jonas RA, Castaneda AR. Age-dependent ventricular response to pressure overload. Considerations for the arterial switch operation. J Thorac Cardiovasc Surg 1992; 104: 713–722.
22. McLeod KA, De Giovanni J, Silove E, Alton H, Poyner R, Brawn WJ. Myocardial perfusion scanning in patients considered for late arterial switch. Cardiol Young 2000; 10: 21–26.
23. Padalino MA, Stellin G, Brawn WJ, et al. Arterial switch operation after left ventricular retraining in the adult. Ann Thorac Surg 2000; 70: 1753–1757.
24. Hon JK, Steendijk P, Khan H, Wong K, Yacoub M. Acute effects of pulmonary artery banding in sheep on right ventricle pressure-volume relations: relevance to the arterial switch operation. Acta Physiol Scand 2001; 172: 97–106.
25. Wong K, Boheler KR, Petrou M, Yacoub M. Pharmacological modulation of pressure-overload cardiac hypertrophy: changes in ventricular function, extra-cellular matrix, and gene expression. Circulation 1997; 96: 2239–2246.
26. Corno AF, Milano G, Samaja M, Tozzi P, von Segesser LK. Chronic hypoxia: a model for cyanotic heart defects. J Thorac Cardiovasc Surg 2002; 124: 105–112.
27. Milano G, Corno AF, von Segesser LK, Samaja M. Chronic and intermittent hypoxia induce different degrees of myocardial tolerance to hypoxia-induced dysfunction. Exper Biol Med 2002; 227: 389–397.