Aortic Root Translocation Plus Arterial Switch for Transposition of the Great Arteries With Left Ventricular Outflow Tract Obstruction

Intermediate-Term Results

Victor Bautista-Hernandez, MD, Gerald R. Marx, MD, Emile A. Bacha, MD, Pedro J. del Nido, MD

Boston, Massachusetts

Objectives
The goal of our study was to report our intermediate-term results with aortic root translocation plus arterial switch for d-transposition of the great arteries with left ventricular outflow tract obstruction.

Background
A d-transposition of the great arteries with left ventricular outflow tract obstruction represents a difficult surgical problem. The Rastelli procedure is the usual approach to this condition. However, recurrent left ventricular outflow tract obstruction and early conduit obstruction as well as arrhythmias and troublesome late mortality are significant limitations.

Methods
From 1993 to 2005, 11 children (8 male, 3 female) ages 1 month to 11 years (median age 7 months) have undergone aortic root autograft translocation plus arterial switch to correct d-transposition of the great arteries with left ventricular outflow tract obstruction. The native aortic root was excised from the right ventricle infundibulum and inserted into the left ventricular outflow, enlarging the outflow tract by resecting the outlet septum and an appropriate-size ventricular septal defect patch. After coronary artery reimplantation, right ventricular outflow reconstruction was achieved with a homograft.

Results
There were no early or late deaths. With a median follow-up of 59 months (range 2 to 137 months), 5 patients required 6 conduit replacement procedures at a median time of 53 months. Two patients required an implantable defibrillator for ventricular arrhythmias. None of the patients have developed left ventricular outflow tract obstruction.

Conclusions
Aortic root autograft plus arterial switch procedure is a good option for the surgical management of infants and children with d-transposition of the great arteries and left ventricular outflow tract obstruction and results in a more anatomic repair compared with Rastelli operation. Intermediate-term results indicate good relief of left ventricular outflow tract obstruction and need for conduit replacement compares favorably with the Rastelli procedure for this lesion. (J Am Coll Cardiol 2007;49:485–90) © 2007 by the American College of Cardiology Foundation

The surgical management of complex forms of d-transposition of the great arteries (d-TGA) with ventricular septal defect (VSD) and left ventricular outflow tract obstruction (LVOTO) continues to present a surgical challenge because of the wide variability in anatomy and the disappointing late results with current approaches (1). For this reason, several techniques for surgical repair have been proposed. To date, the Rastelli operation, which diverts left ventricle (LV) flow through the VSD to the aorta with an extra-anatomical right ventricle (RV) to pulmonary conduit, remains the most widely applied procedure for surgical repair of this lesion. Although several modifications have been described, the procedure itself has remained relatively unchanged since it was first described in 1969 (2,3). The Rastelli procedure can be performed with good early results. However, we and others have reported substantial late morbidity and mortality caused by conduit obstruction, LVOTO, and arrhythmia (4,5). Freedom from an LVOTO reintervention was 88% at 5 years, but shorter for infants <1 year old at the time of the Rastelli procedure. Moreover, overall freedom from death or transplantation at 20 years was 52% (5).

Several alternative procedures to the Rastelli repair have been described with varying results, including Mustard or Senning operations with closure of VSD and resection of LV outflow with or without a conduit (6,7). Atrial level repair techniques, however, have been associated with a very
advantages of this approach over the other mentioned autograft for the same purpose (15,16). The conceptual root, respectively, our procedure uses the aortic root as an autograft to enlarge and replace the LV outflow and aortic valve. Like the Ross-Konno, which uses the pulmonary root as an autograft and the arterial switch procedure (14). Nikaidoh’s major technical principle with the concepts of valvuloplasty; VSD

Like the Ross-Konno and the arterial switch procedure (14). The results because of residual obstruction and a greater hazard for reoperation (10,11). The reparation a l’etage ventriculaire described by Lecompte in 1982 (12) entails resection of infundibular septum along with reconstruction of the pulmonary outflow tract without using a prosthetic conduit by wide mobilization of the pulmonary arteries and reimplantation of the pulmonary trunk to the RV (13). Although for some groups this is the procedure of choice for d-TGA plus LVOTO, free pulmonary regurgitation created by the RV outflow reconstruction has been a concern both in the early as well as the late postoperative period.

We have used an alternative approach that combines Dr. Nikaidoh’s major technical principle with the concepts of the Ross-Konno and the arterial switch procedure (14). Like the Ross–Konno, which uses the pulmonary root as an autograft to enlarge and replace the LV outflow and aortic root, respectively, our procedure uses the aortic root as an autograft for the same purpose (15,16). The conceptual advantages of this approach over the other mentioned procedures are that it can be used in infants as well as in older children, and because it does not require the presence of a VSD, it can be applied to different anatomical variants. Because the aortic root is moved posteriorly, there is ample room for placement of an oversized homograft with little risk of sternal compression. In this article we describe our early and intermediate experience with the aortic root translocation and arterial switch procedure for TGA with LVOTO.

Methods

Patients. From August 1995 to June 2005, 11 patients (8 male, 3 female) underwent repair with this technique. Patient data are summarized in Table 1. Age at operation ranged from 1 month to 11 years (median 7 months). Mean weight at operation was 6.6 kg (range 3.8 to 20 kg). Eight of the patients were under 1 year of age at surgery. The decision not to proceed either with a Rastelli procedure or with an arterial switch was based on review of the conal septal anatomy and the mechanism of LVOTO with 2-dimensional echocardiography and, in the current-era, 3-dimensional echocardiographic imaging. Nine patients had d-TGA with or without VSD, and 2 had double-outlet right ventricle (DORV). All patients but 1 (Patient #2) had a conoventricular VSD and severe LVOTO at the time of operation. An LVOTO caused by annular hypoplasia, thickened and immobile pulmonary leaflets, and subvalvar conal hypertrophy was seen in all patients but 1 (Patient #6), who had abnormalities in the mitral and aortic valves as well as LV hypertrophy and moderately depressed LV function. Patient 11 had parachute mitral valve and hypoplastic LV not precluding biventricular repair. Interestingly, 4 patients presented with a bicuspid pulmonary valve and 3 had straddling tricuspid valve chordae. All patients’ clinical data are summarized in Table 1.

Table 1  Summary of Patient Data

<table>
<thead>
<tr>
<th>Patient</th>
<th>Gender</th>
<th>Previous Operations</th>
<th>Diagnosis</th>
<th>Age (months)</th>
<th>Follow-Up (months)</th>
<th>Outcomes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>Atrial septectomy</td>
<td>d-TGA + LVOTO + VSD</td>
<td>7</td>
<td>137</td>
<td>AICD, no LVOTO, NYHA functional class II</td>
</tr>
<tr>
<td>2</td>
<td>F</td>
<td>Permanent pacemaker Senning + VSD closure TV + PAB</td>
<td>d-TGA + LVOTO</td>
<td>132</td>
<td>121</td>
<td>Bleeding, late CVA, no LVOTO, NYHA functional class I</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>None</td>
<td>d-TGA + LVOTO + VSD</td>
<td>4</td>
<td>103</td>
<td>No LVOTO, NYHA functional class I</td>
</tr>
<tr>
<td>4</td>
<td>M</td>
<td>None</td>
<td>d-TGA + LVOTO + VSD</td>
<td>1</td>
<td>95</td>
<td>Residual VSD (redo), no LVOTO, NYHA functional class I</td>
</tr>
<tr>
<td>5</td>
<td>M</td>
<td>B-T shunt</td>
<td>d-TGA + LVOTO + VSD</td>
<td>20</td>
<td>66</td>
<td>No LVOTO, NYHA functional class I</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>B-T shunt</td>
<td>d-TGA + LVOTO + VSD</td>
<td>5</td>
<td>59</td>
<td>No LVOTO, NYHA functional class I</td>
</tr>
<tr>
<td>7</td>
<td>M</td>
<td>Intraventricular repair of DORV</td>
<td>DORV + LVOTO + VSD + LV dysfunction</td>
<td>11</td>
<td>49</td>
<td>AICD, no LVOTO, NYHA functional class II</td>
</tr>
<tr>
<td>8</td>
<td>F</td>
<td>B-T shunt + PDA ligation</td>
<td>DORV + LVOTO + VSD</td>
<td>4</td>
<td>28</td>
<td>No LVOTO, NYHA functional class I</td>
</tr>
<tr>
<td>9</td>
<td>M</td>
<td>None</td>
<td>d-TGA + LVOTO + VSD</td>
<td>3</td>
<td>23</td>
<td>No LVOTO, NYHA functional class I</td>
</tr>
<tr>
<td>10</td>
<td>M</td>
<td>B-T shunt</td>
<td>d-TGA + LVOTO + VSD</td>
<td>7</td>
<td>4</td>
<td>No LVOTO, NYHA functional class I</td>
</tr>
<tr>
<td>11</td>
<td>M</td>
<td>None</td>
<td>d-TGA + LVOTO + VSD</td>
<td>96</td>
<td>2</td>
<td>No LVOTO, NYHA functional class I</td>
</tr>
</tbody>
</table>

AICD = automatic implantable cardioverter-defibrillator; B-T shunt = Blalock-Taussing shunt; CVA = cerebrovascular accident; DORV = double-outlet right ventricle; d-TGA = d-transposition of the great arteries; F = female; LVOTO = left ventricular outflow tract obstruction; M = male; NYHA = New York Heart Association; PAB = pulmonary artery banding; PDA = permanent ductus arteriosus; TV = tricuspid valvuloplasty; VSD = ventricular septal defect.
Preoperative procedures. Patient 1 had an atrial septectomy in the neonatal period. Patients 5, 6, 8, and 10 received a systemic pulmonary shunt. Patient 7 had an intraventricular baffle procedure for repair of DORV and normally related great vessels. Along with a residual VSD, he subsequently developed severe LVOTO and LV dysfunction. Patient #2 had received an atrial switch operation (Senning procedure), and closure of VSD was performed in the newborn period. She subsequently developed RV dysfunction and severe tricuspid regurgitation. Tricuspid De Vega–type valvuloplasty plus commissuroplasty and pulmonary artery banding were carried out to prepare her LV for arterial switch at 11 years of age. Three patients had no preoperative procedures.

Surgical technique. Complete anatomical repair was achieved in all patients using moderate to deep hypothermia. Cannulation was achieved with an arterial cannula placed distally at the level of the innominate artery or beyond to permit wide mobilization of the ascending aorta. In most cases the procedure was performed without a period of circulatory arrest other than for closure of the interatrial communication. Intraoperative and postoperative data are shown in Table 2. Once the ascending aorta was cross-clamped and the heart arrested with cardioplegia, the ascending aorta was transected above the level of the commissures. Similarly, access to the LV outflow tract was accomplished through a right ventriculotomy that was slightly oblique in orientation just below the aortic root aiming to resect the aortic root including the infundibular muscle. This technique is similar to that done for pulmonary autograft in normally related great vessels (Fig. 1). Unlike the more common technique for arterial switch in neonates, the coronary arteries were then excised as circular buttons from the respective sinuses of Valsalva.

Once the coronaries were mobilized, as in the arterial switch procedure, the aortic root was then excised by completing the circumferential incision in the right ventricular infundibulum (Fig. 2). The main pulmonary artery was then transected above the level of the pulmonary valve, and an incision was then made across the anterior portion of the pulmonary annulus extending toward the ventricular septal defect, if present, or toward the anterior septum similar to a Konno procedure. This permitted enlargement of the LV outflow tract by insertion of a triangular shaped VSD Dacron patch to accommodate the larger aortic root. The aortic root autograft was then rotated 180° so that the defects from the coronary buttons faced anteriorly. The subvalvular portion of the autograft was sewn to the LV outflow by attaching it directly to the pulmonary valve annulus posteriorly and to the distal edge of the VSD patch anteriorly. The distal orifice of the aortic autograft was then sewn to the ascending aorta after the branch pulmonary arteries were mobilized anterior to the aorta (Lecompte maneuver) similar to an arterial switch procedure (Fig. 3). Reimplantation of the coronary vessels was performed into the neo-aortic root, at the site of the coronary button defects, or more distally in the aorta if the defects were too low into the base of the LV. The RV to pulmonary artery (PA) continuity was then established by inserting an interposition homograft sewn directly from the RV infundibulum to the distal pulmonary trunk (Fig. 4).

In cases in which the PA and aorta were side by side, mobilization of the pulmonary branches was not necessary and the RV-to-PA homograft conduit was positioned either to the right or to the left of the aorta.

### Results

All patients survived the operative procedure and had relief of LVOTO as determined by direct pressure measurements intraoperatively and postoperative echocardiography. One patient (Patient #2) required reoperation for bleeding. This patient had received tricuspid annuloplasty and pulmonary banding 9 days before the Senning takedown and anatomical repair. Early postoperative echocardiography detected a resid-

### Table 2 Operative Data

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Median</th>
</tr>
</thead>
<tbody>
<tr>
<td>CCT (min)</td>
<td>118</td>
<td>120</td>
</tr>
<tr>
<td>CPB (min)</td>
<td>243</td>
<td>209</td>
</tr>
<tr>
<td>ICU stay (days)</td>
<td>10</td>
<td>6</td>
</tr>
<tr>
<td>In-hospital stay (days)</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Conduit size (mm)</td>
<td>15.4</td>
<td>17</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>9.97</td>
<td>6.6</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>0.49</td>
<td>0.34</td>
</tr>
</tbody>
</table>

BSA = body surface area; CCT = cross-clamping time; CPB = cardiopulmonary bypass; ICU = intensive care unit.
ual VSD in 1 patient who required reoperation for VSD closure.

Follow-up information was obtained for all 11 patients. For a median follow-up of 59 months (range 2 to 137 months), all patients were alive and without evidence of LVOTO by echocardiography. Five children had developed RV-to-PA conduit obstruction and free regurgitation, requiring reoperation to change a total of 6 conduits. Median time for conduit replacement was 53 months (range 24 to 84 months) postoperatively. One patient has moderate AR that was seen in the early postoperative period and has not progressed in over 5 years of follow-up, and has normal LV volume. Patients #1 and #7 had moderately depressed LV function by echocardiography. Patient #1 developed LV dysfunction immediately after operation, and Patient #7 had abnormal ventricular function before repair because of the previous attempt at intraventricular repair of DORV. Both patients developed ventricular arrhythmias, received an automatic implantable cardioverter-defibrillator, and are in New York Heart Association functional class II.

Discussion

An important feature of all forms of TGA and some forms of double-outlet RV is the presence of an infundibulum supporting the anterior positioned aorta. The subaortic infundibulum is analogous to the subpulmonary infundibulum in normally related great vessels. This feature is important when considering translocation of the aortic root into the left ventricular outflow tract in that the entire aortic root can be excised similar to a pulmonary autograft in a heart with normally related great vessels. In this report we describe good early and intermediate-term results with an operative procedure that takes advantage of this anatomy to achieve a more anatomical repair of TGA and LVOTO compared with the more commonly performed Rastelli operation. In summary, the addition of the arterial switch, the Lecompte maneuver, and the autograft rotation are the 3 primary technical features that differentiate our approach from the Nikaidoh procedure.

As with the Ross procedure performed in infants, concern exists with late development of neo-aortic root dilatation and neo-aortic valve regurgitation (17,18). The mechanism for neo-aortic root dilatation remains controversial; however, distensibility of the pulmonary root at higher pressures is likely to play a role. Unlike the Ross procedure, in transposition, autograft translocation is done using the native aortic root, which has been exposed to systemic pressures and likely has normal aortic wall architecture. Further support for this hypothesis is provided by the lack of aortic root dilatation and regurgitation late after the Rastelli operation. However, neo-aortic root dilatation and regurgitation have been reported to occur during follow-up after arterial switch operation (16–18). Schwartz et al. (19)
reported that persistent LVOTO was a risk factor for at least moderate aortic regurgitation and a predictor of early neo-aortic valve or root surgery late after arterial switch.

In our series, only 1 patient developed moderate aortic regurgitation, and aortic root dilation was not seen. This may be because the neo-aorta was placed as an autograft root in the LV outflow tract and during coronary button harvest great care was taken to keep the ring of the sino-tubular junction intact, preventing distortion of the aortic root and minimizing the risk of dilation. Interestingly, Nikaidoh and Leonard (20) did not report any incidence of aortic regurgitation in their series, and their technique also maintained the sino-tubular junction intact. In the 1 patient in our series who had aortic valve regurgitation, the regurgitation was detected early after surgery, suggesting distortion of the aortic root or valve leaflet at the time of autograft implantation as the cause. Morell et al. (21) have recently reported a 25% incidence (3 patients) of moderate aortic insufficiency in a series of 12 patients with TGA, VSD, and LVOTO operated on using a similar approach to ours and that of Nikaidoh and Leonard (20).

Unusual coronary anatomy in the past has been considered a risk factor for mortality in patients undergoing an arterial switch (22). In describing results with a similar approach to ours, Morell et al. (21) considered unusual coronary anatomy as a relative contraindication for the performance of aortic translocation. With current techniques of detachment and mobilization of coronary artery ostia, we believe that, similar to the experience with arterial switch in simple transposition, coronary anatomy should not be considered a risk factor for coronary transfer (23). In fact, in our series 2 patients had unusual coronary anatomy (single coronary ostium and circumflex artery arising from the right) and 5 patients required a trap-door flap approach to re-implant 7 coronary buttons. Although 1 patient in our series has shown a decrease in postoperative LV function, the coronary arteries have been confirmed to be patent and free of proximal obstruction in all patients in this series.

Timing of repair in patients with TGA and LVOTO remains controversial, with some arguing for repair after infancy because of the high risk of need for reoperation for conduit replacement in this age group. Although conduit change will likely be inevitable in patients having anatomical repair for this defect in infancy with a Rastelli type of procedure, regardless there will likely be a need for surgical intervention in infancy because of progressive cyanosis in these patients. The advantage of the technique described in this article over the Rastelli procedure is that with the aortic root moved posteriorly, there is more room for the RV-to-PA connection, independent of the type of reconstruction method used, whether valved or nonvalved, homograft or autologous tissue reconstruction. Thus, primary repair can be performed in infancy, potentially avoiding the need for a systemic to pulmonary artery shunt in most patients. In fact, 4 of our patients did not receive any palliative procedure and 8 of them were <1 year of age at the time of translocation plus arterial switch. Furthermore, the fact that conduit replacement was not required for an average of 53 months after anatomical repair compares favorably with our experience with the Rastelli procedure. Although Kreutzer et al. (5) reported 56% of freedom from reintervention at 5 years, time for LVOTO reintervention was significantly shorter for patients <1 year of age at the time of Rastelli operation (p < 0.01). These findings, along with the absence of LVOTO at a median of 62 months of follow-up, show a significant improvement over our Rastelli experience, indicating that the aortic root translocation plus arterial switch procedure for TGA and LVOTO is an excellent alternative to the Rastelli operation.

In conclusion, aortic root translocation plus arterial switch operation for d-TGA and related anomalies with LVOTO can be achieved with low morbidity and mortality and good relief of LVOTO and RV outflow tract obstruction in intermediate-term follow-up. This approach is especially advocated in cases in which the pulmonary valve is severely dysplastic or even bicuspid, the pulmonary annulus is abnormally small, unresectable subpulmonary stenosis is present, and/or the association of a straddling tricuspid valve with a small and malalignment RV precludes the performance of a straight arterial switch.

Reprint requests and correspondence: Dr. Pedro J. del Nido, Department of Cardiovascular Surgery, Children’s Hospital Boston, 300 Longwood Avenue, Bader 273, Boston, Massachusetts 02115. E-mail: pedro.delnido@tch.harvard.edu.
REFERENCES


