tachycardia is sustained or recurrent, a VSDR using CPB is required. Later-aggravated atrioventricular block and residual shunt can occur, although at a low rate (1.7% in our study).

PDCVSD has been applied for the past decade, but further studies at multiple centers to examine the long-term outcomes are required.

CONCLUSIONS

When VSD is indicated, PDCVSD is a safe modality with an acceptably mild early complication rate and a less severe late complication rate.

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Arterial switch operation for transposition of the great arteries with anomalies of cardiac situs and aortic position

Sachin Talwar, MCh, Aandrei Jivendra Jha, MS, Shiv Kumar Choudhary, MCh, Palleti Rajashekar, MCh, and Balram Airan, MCh, New Delhi, India

Supplemental material is available online.

A prime determinant of successful outcome after the arterial switch operation (ASO) is an accurate transfer of coronary buttons to the neo-aorta.¹ Our experience with the ASO in patients with transposition of the great arteries and unusual relationship of the great arteries (levoposed aorta) and dextrocardia is presented here with details of appropriate modifications in surgical technique.

MATERIALS AND METHODS

Between January 2002 and January 2013, a series of 8 patients with transposition of the great arteries and either dextrocardia or aorta positioned anterior and to the left (levoposed aorta) underwent the ASO (Table 1). Of the 3 patients with dextrocardia, 1 patient had situs inversus totalis and the other 2 had normal visceral situs. Six patients, among them the patient with situs inversus totalis, had a levoposed aorta. Left-sided aortic arch was present in 50%. Two patients had both coronaries arising from a single ostium from sinus 2. Five patients had the usual coronary anatomy for

transposition. Patient 7, who had situs inversus totalis with mirror-image dextrocardia, had a peculiar “double looping” coronary pattern with inverted origins of circumflex and right coronary arteries (a mirror image of the Yacoub type E coronary pattern). The Lecompte maneuver was carried out in 3 patients, including patient 7. Juxtaposed right and left atrial appendages were present in 2 patients and 1 patient, respectively.

All patients underwent aortobicaval cannulation, and standard hypothermic (28°C) cardiopulmonary bypass was instituted. The aorta and pulmonary artery were dissected free, and branch pulmonary arteries were completely mobilized. The ductus arteriosus was isolated, transfixed, and divided. The aorta was crossclamped, cold blood cardioplegia was delivered into the aortic root, and the heart was arrested. Transatrial ventricular septal defect closure was performed wherever needed, except in patients 5 and 7, in whom closure was performed through the proximal neo-aorta. The aorta was transected well above the sinotubular junction. Coronary buttons were harvested, and the main pulmonary artery (MPA) was divided at the confluence.

In all 5 cases of levocardia with levoposed aorta, the proximal right ventricular outflow tract (RVOT) was reconstructed first by suturing autologous pericardium to the margins of the defect created in the proximal aorta (neo-pulmonary artery) after harvesting of the coronary buttons. After RVOT reconstruction, a longitudinal wedge of tissue was excised from the proximal MPA (neo-aorta), well above the sinuses, and the coronary button was sutured in place. Because of the peculiar situation in which the aorta was left-sided, the decision to perform the Lecompte maneuver was always postponed towards the end. Also it was anticipated that, the RVOT might impinge on the transferred coronary artery. To prevent this, the arteriotomy in the distal MPA was extended leftward. Starting from the center of the arteriotomy and up to its rightward end, the distal MPA was closed. The proximal MPA was then anastomosed to the under surface of the left pulmonary artery to shift the RVOT in a leftward direction, thus moving it away from the coronary button. If the Lecompte maneuver was not carried out, both the great arteries would come to lie parallel to each other (Figures 1 and 2).

In patients with dextroposed aorta where the aorta was situated to the right and anterior (patients 1 and 5), coronary buttons were transferred routinely and the Lecompte maneuver was performed.

From the Cardiothoracic Centre, All India Institute of Medical Sciences, New Delhi, India.

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Address for reprints: Sachin Talwar, MCh, Department of Cardiothoracic and Vascular Surgery, All India Institute of Medical Sciences, New Delhi 110029, India (E-mail: sachintalwar@hotmail.com).

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TABLE 1. Details of patients who had transposition of the great arteries with dextrocardia or with aorta anterior and to the left

Case	Age	Sex	Weight (kg)	Anatomy	Surgery	Coronary pattern*	CPB (min)	Aoxc (min)	Lecompte	Outcome	Follow-up (mo)
1	1.5 mo	M	3	SS, DC {S, L, D}, TGA, ASD, SP VSD, severe RPA stenosis, valvular PS, JRAA, R arch Ao R/A	ASO, trans RA ASD and VSD closure, RPA plasty	2RLCx (single ostium)	190	126	No	Died POD 2 (PHTN crisis)	—
2	3 d	M	5	SS, LC {S, D, L}, TGA, restrictive ASD, P/BAS, IVS, JRAA, R arch, Ao L/A	ASO, trans RA ASD closure	2R1LCx	116	90	No	Discharged POD 12	89
3	8 mo	F	5	SS, LC {S, D, L}, TGA, SP VSD, L arch, Ao L/A	ASO, trans RA VSD closure	2RLCx (single ostium)	174	123	No	Discharged POD 10	10
4	3 mo	M	4.5	SS, LC {S, D, L}, TGA, VSD, PFO, JLAA, R arch, Ao L/A	ASO, trans RA VSD closure	2R1LCx	116	100	No	Discharged POD 13	79
5	6 mo	F	4.5	SS, DC {S, L, D}, TGA, VSD, L arch, Ao R/A	ASO and VSD closure (through neo-aorta)	2R1LCx	125	106	Yes	Discharged POD 12	68
6	18 mo	M	5	SS, LC {S, D, L} TGA, large ASD, VSD, JRAA, L arch, Ao L/A	ASO, ASD and VSD closure	2R1LCx	138	116	No	Died postop, ECMO, VF on POD2	—
7	5 mo	M	5	SI, DC {I, L, L}, TGA, ASD, VSD, R arch, Ao L/A	ASO, ASD and VSD closure (through neo-aorta)	1LR2Cx	116	96	Yes	Discharged POD 13	64
8	2.5 mo	M	4	SS, LC {S, D, L} TGA, levoposed aorta, VSD, ASD, L arch, Ao L/A	ASO, ASD and trans RA VSD closure, supportive CPB for 30 min (borderline LV)	2R1LCx	167†	84	No	Discharged POD 12	2

CPB, Cardiopulmonary bypass time; Aoxc, aortic crossclamp; SS, situs solitus; DC, dextrocardia; TGA, transposition of the great arteries; ASD, atrial septal defect; SP, subpulmonic; VSD, ventricular septal defect; RPA, right pulmonary artery; PS, pulmonary stenosis; JRAA, juxtaposed right atrial appendages; R, right; Ao, aorta; R/A, right and anterior; ASO, arterial switch operation; RA, right atrium; POD, postoperative day; PHTN, pulmonary hypertension; LC, levocardia; P/BAS, post-balloon atrial septostomy; IVS, intact ventricular septum; L/A, left and anterior; L, left; PFO, patent foramen ovale; JLAA, juxtaposed left atrial appendages; postop, postoperatively; ECMO, extracorporeal membrane oxygenation; VF, ventricular fibrillation; SI, situs inversus; LV, left ventricle; F, female; M, male. *Two patients had both coronaries arising from a single ostium from sinus 2 (2RLCx). Five patients had the usual coronary anatomy for transposition (2R1LCx). Patient 7 had a peculiar “double looping” coronary pattern with inverted origins of circumflex and right coronary artery (1LR2Cx). †Total represents 97 min plus an additional 70 min of supportive bypass.

Patient 7 (case published elsewhere previously²) had an extremely unusual {I, L, L} configuration, with mirror-image dextrocardia with inverted origin of the circumflex and right coronary arteries. A conduit-lengthening procedure was therefore needed. The left coronary button was harvested with a longer “tongue” of native aortic tissue

attached distal to the coronary origin. A flap with dimensions similar to this button was created in the neo-aorta, and the anastomosis was made such that the native aortic flap was placed superior to the neo-aortic flap (Figure E1). The remainder of the operation was as usual.

FIGURE 1. Computed tomographic angiography of patient 3 shows the anterior and left-sided aorta (Ao) with a single coronary artery. A, Maximum intensity projection (MIP) reformatted image in coronal plane. B, MIP reformatted image in axial oblique plane. RCC, Right coronary cusp; LAD, left anterior descending coronary artery; RCA, right coronary artery.

FIGURE 2. Surgical technique adopted in patient 3. A, External cardiac anatomy. B, The coronary button has been transferred. The main pulmonary artery (MPA) is being closed up to the right pulmonary artery (RPA) after extending the arteriotomy into the left pulmonary artery (LPA). C, Final reconstruction. Note that the Lecompte maneuver has not been performed. Ao ARCH, Aortic arch; SVC, superior vena cava; DTA, descending thoracic aorta; Ao, aorta; LCA, left coronary artery; LAA, left atrial appendage; RCA, right coronary artery; LCx, left circumflex coronary artery; LAD, left anterior descending coronary artery; RA, right atrium; RV, right ventricle; IVC, inferior vena cava; DA, ductus arteriosus (divided); NAo, neo-aorta; NPA, neo-pulmonary artery; PDA, patent ductus arteriosus; ASc Ao, ascending aorta.

Aortic crossclamp time ranged from 84 to 126 minutes (median, 103 minutes). Total cardiopulmonary bypass time ranged from 97 to 190 minutes (median, 131 minutes).

RESULTS

There were two early deaths. Patient 1 died on the second postoperative day, 2 hours after extubation because of a refractory pulmonary hypertensive crisis. His postoperative echocardiogram before extubation had demonstrated normal biventricular function and normal flow into the coronary arteries. Patient 6 had low cardiac output in the immediate postoperative period. Transthoracic echocardiography showed a poorly contracting left ventricle, normal flow into the proximal coronaries, and no residual defect. Electrocardiography showed no evidence of ischemia. Extracorporeal membrane oxygenation was promptly instituted; however, he could not be successfully weaned. Parents of both patients were counseled regarding autopsy, but they denied consent.

Patient 8 had a borderline left ventricle and required supportive cardiopulmonary bypass for an extra 70 minutes. Subsequent recovery was normal. The median hospital stay of the 6 survivors was 12 days. Postoperative echocardiography at discharge showed normal biventricular function and normally flowing coronary arteries.

Follow-up of the 6 survivors ranged from 2 to 89 months (median, 66 months). At last follow-up, these patients are receiving no cardiac medication and have normal biventricular function on echocardiography.

DISCUSSION

In viscerotransposition with complete transposition, the aorta is right-sided and anterior, whereas an anterior and left-sided aorta occurs in corrected transposition. A rare but important exception to this rule occurs when in patients with viscerotransposition and complete transposition the aorta lies to the left and anterior, described

as complete transposition {S, D, L} instead of the usual expected form of complete transposition {S, D, D}. Houyel and colleagues³ studied 26 such patients (16 surgical and 10 postmortem studies) and found that increasing degrees of levorotation of the subaortic infundibulum and aortic valve in these cases increased the probability of other associated anomalies: subaortic ventricular septal defect, pulmonary outflow tract stenosis, and conal septal hypoplasia.

In many of these patients {S, D, L}, the great arteries may not be side to side, and the leftward position of the aorta may be minimal. It is also extremely rare for the aortic annulus to be located completely to the left of the pulmonary annulus, and more often than not the anomaly is just an abnormal course of the aorta and the pulmonary artery trunks. In such situations, the coronary artery anatomy may be complex and require surgical innovation to achieve a successful coronary transfer.

While performing the ASO in such situations, we have found the following to be helpful: (1) High aortic transection, well above the sinotubular junctions, allows a longer coronary button and coronary prolongation. (2) Transection of the MPA right at the bifurcation is helpful for a similar reason and also allows the coronary button to be placed well above the sinotubular junction, thus avoiding distortion of the neo-aortic root. (3) Reconstruction of the proximal

RVOT before coronary button transfer is often helpful, because the right and to some extent the anterior aspects of this suture line often lie under the implanted coronary buttons, making suturing in this area difficult after reimplantation of the coronary buttons. (4) Shifting of the RVOT on one of the pulmonary arteries while closing the MPA directly or with a patch minimizes the risk of coronary artery compression by a dilated pulmonary artery. (5) Individually assessing the need for a Lecompte maneuver in each patient and performing this maneuver as a final step helps to assess the final positioning of the coronaries and great arteries with respect to each other. In our experience, in patients with levoposed aorta, it may be best to avoid the Lecompte maneuver.

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FIGURE E1. Anatomic and technical details of patient 7, previously published elsewhere.² A, This drawing of the external cardiac anatomy shows dextrocardia, transposition of the great arteries, and the origin and distribution of the coronary arteries. Note that the left coronary artery, arising from the right- and anterior-facing sinus, bifurcates into an anterior descending coronary artery (AD) and a right coronary artery (RCA). The right coronary artery then loops in front of the right ventricular outflow tract to descend into the atrioventricular groove on the left side. The circumflex coronary artery (Cx) originates from the left anterior sinus and takes a posterior and leftward course before finally turning to the right and looping behind the pulmonary artery (PA) to reach the right side of the atrioventricular groove. B, Steps of coronary artery transfer: (1) Coronary buttons are harvested. Note that the button bearing the left coronary artery—which bifurcates into the anterior descending coronary artery and the right coronary artery—has been harvested together with a segment of aortic (Ao) wall that extends well above the ostium. (2) A flap is created from the neo-aorta. (3) Flaps are sutured in preparation for anastomosis of the neo-aorta to the distal aorta, which will complete the coronary transfer. Reproduced with permission from Talwar S, Shivaprasad BM, Kothari SS, Choudhary SK. A novel conduit-lengthening technique to facilitate the arterial switch operation in an infant with a problematic combination of coronary anomalies. *Tex Heart Inst J.* 2009;36:234-7. Copyright 2009, Texas Heart Institute, Houston, Tex.