Strategy for biventricular outflow tract reconstruction: Rastelli, REV, or Nikaidoh procedure?

Sheng-Shou Hu, MD, PhD, Zhi-Gang Liu, MD, PhD, Shou-Jun Li, MD, Xiang-dong Shen, MD, Xu Wang, MD, Jin-ping Liu, MD, Fu-Xia Yan, MD, Li-qing Wang, MD, and Yong-qing Li, MD

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From the Department of Pediatric Cardiovascular Surgery, The National Cardiovascular Institute and Fu Wai Hospital Beijing, Chinese Academy of Medical Science, and Peking Union Medical College, Beijing, China.

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Address for reprints: Sheng-Shou Hu, MD, PhD, Cardiovascular Institute and Fu Wai Hospital, Chinese Academy of Medical Science, Department of Cardiac Surgery, Beilishi Rd 167A, Beijing 100037, China (E-mail: huss@vip.sohu.com or liuzgfw@hotmail.com).

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Objective: Three techniques have been developed as the surgical management for patients with anomalies of ventriculoarterial connection, ventricular septal defect, and pulmonary outflow tract obstruction (stenosis): the Rastelli, Lecompte, (REV), and Nikaidoh procedures. This study was designed to compare these procedures in terms of hemodynamics of the reconstructed biventricular outflow tract, early clinical consequences, and follow-up.

Methods: Between March 2004 and September 2006, a total of 30 consecutive patients underwent double root translocation procedures (modified Nikaidoh $n = 11$, REV $n = 7$, Rastelli $n = 12$). In the Nikaidoh procedure, both aortic and pulmonary roots were translocated. A single-valved bovine jugular vein patch was used to repair the stenotic pulmonary artery in both Nikaidoh and REV procedures. The Senning procedure was added for those with atrioventricular discordance.

Results: The Nikaidoh procedure was the most time-consuming in terms of mean cardiopulmonary bypass and aortic crossclamp times. The average mechanical ventilation time was significantly shorter in the Rastelli group (63.3 ± 89 hours) than that in the Nikaidoh group (188.7 ± 159 hours, $P = .016$), but not different from that in the REV group (76.4 ± 112.5 hours, $P = .395$). Two patients in the REV group and 1 in the Rastelli group died. There were no in-hospital or late deaths in the Nikaidoh group. Postoperative echocardiography demonstrated physiologic hemodynamics in the left ventricular outflow tract and normal heart function in the Nikaidoh group. Abnormal flow pattern in the left ventricular outflow tract was noted in both REV and Rastelli groups. There were no late deaths or reoperations in any group during follow-up.

Conclusion: The modified Nikaidoh procedure is a better surgical option for transposition of the great arteries, ventricular septal defect, and pulmonary stenosis in terms of physiologic cardiac hemodynamics. Its long-term benefits need to be evaluated with a larger number of patients and longer follow-up.

Surgical management for patients with anomalies of ventriculoarterial connection associated with ventricular septal defect (VSD) and pulmonary outflow tract obstruction (pulmonary stenosis [PS]) continues to be a challenge, because the anatomic correction of these lesions requires complete reconstruction of the biventricular outflow tract. Three major surgical techniques have been developed during the past three decades. The Rastelli procedure was first introduced in 1969 and soon became the standard surgical treatment for patients with transposition of the great arteries (TGA), VSD, and PS.^{1,2} Clinical data, however, have revealed the long-term results of the Rastelli procedure to be far from optimal; most importantly,

Abbreviations and Acronyms

ASD	= atrial septal defect
CPB	= cardiopulmonary bypass
CTGA	= congenital corrected transposition of the great arteries
DORV	= double-outlet right ventricle
ECMO	= extracorporeal membrane oxygenation
LVOT	= left ventricular outflow tract
PS	= pulmonary stenosis
RVOT	= right ventricular outflow tract
TGA	= transposition of the great arteries
VSD	= ventricular septal defect

the reported long-term survival is surprisingly low, with a 20-year survival of only 52%.^{3,4} In 1982, Lecompte and colleagues⁵ introduced the Lecompte procedure (REV) technique to reconstruct the pulmonary outflow tract without using prosthetic conduit as an alternative for Rastelli candidates.⁵ Two years later, Nikaidoh⁶ proposed the idea of aortic translocation and biventricular outflow tract reconstruction for the management of TGA with VSD and PS.⁶ For various reasons, this technique has not been widely applied.^{7,8}

Which procedure is the best choice for surgical management of TGA, VSD, and PS in terms of the operative feasibility and long-term results? It has become apparent that the fate of the reconstructed left ventricular outflow tract (LVOT) and RVOT plays an essential role in determination of prognosis. In this sense, there is no ideal surgical procedure for these lesions so far.

With the intent to preserve the competence and growth potential of the pulmonary valve and acquire a better long-term performance of the reconstructed biventricular outflow tract, we proposed the double root translocation technique for biventricular outflow tract reconstruction. This study compares the double root translocation (modified Nikaidoh) technique with modified REV and conventional Rastelli procedures in terms of operative feasibility, postoperative hemodynamics of the LVOT and RVOT, and early-term follow-up. Here we present the experience we gained, the problems we encountered, and lessons we learned.

Materials and Methods**Patient Profile**

Between March 2004 and September 2006, a total of 30 consecutive patients with TGA, VSD, and PS ($n = 19$) or double-outlet right ventricle (DORV) with TGA and PS ($n = 11$) underwent modified Nikaidoh ($n = 11$), modified REV ($n = 7$), and Rastelli ($n = 12$) procedures. The diagnosis was made on the basis of echocardiographic and cardiac angiographic findings. The PS was diagnosed with the transpulmonary annular gradient (systolic) greater than 50 mm Hg in all cases. The patient profile is shown in Table 1.

In the Nikaidoh group, the mean age at operation was 85.9 ± 68.0 months (range 7 months–18 years). The mean weight was

TABLE 1. Patient data

	Nikaidoh	REV	Rastelli
Age (mo, mean $\pm$ SD)	85.9 ± 68.0	72.4 ± 44.9	101.8 ± 104.3
Weight (kg, mean $\pm$ SD)	21.7 ± 14.9	15.9 ± 6.9	23.8 ± 16.6
Sex (male/female)	8:3	3:4	7:5
Diagnosis (No.)			
TGA and VSD, LVOTO	9	3	6
DORV and PS	2	4	5
DOLV and PS			1
Associated anomalies (No.)			
Complete TGA	4	2	1
Multiple VSDs	1	2	3
Pulmonary arterial anomalies	2		1
Atrial septal defect	4	5	2
Coronary anomalies	2		2
Mitral insufficiency			1
Blalock–Taussig shunt	2		1

TGA, Transposition of the great arteries; VSD, ventricular septal defect; LVOTO, left ventricular outflow tract obstruction; DORV, double-outlet right ventricle; DOLV, double-outlet left ventricle; PS, pulmonary stenosis.

21.7 ± 14.9 kg. Nine patients had dextro-TGA, VSD, and PS, among whom 4 patients had atrioventricular discordance (congenital TGA [CTGA]). Associated anomalies were multiple VSDs in 1 patient, atrial septal defect (ASD) in 4, hypoplastic left pulmonary artery in 2, and coronary artery anomalies in 2. DORV with subpulmonary VSD, malposition of the great arteries, and PS were diagnosed in 2 cases. Two patients had previously undergone a palliative procedure (modified Blalock–Taussig shunt).

Among patients treated with a modified REV procedure, the mean age at operation was 72.4 ± 44.9 months (range 19–13.3 years), and the mean weight was 15.9 ± 6.9 kg. Four patients had DORV with subpulmonary VSD, malposition of the great arteries, and PS; the other 3 had dextro-TGA, VSD, and PS, with CTGA in 2 cases. Associated lesions were multiple VSDs in 2 cases and ASD in 5.

Among patients who underwent a Rastelli procedure, the mean age at operation was 101.8 ± 104.3 months (range 19 months–25.3 years), and the mean weight was 23.8 ± 16.6 kg. Six patients had dextro-TGA, VSD, and PS; among them, 1 patient had CTGA. Five patients had DORV with subpulmonary VSD, malposition of the great arteries, and PS. Double-outlet left ventricle was diagnosed in 1 case. Associated lesions were multiple VSDs in 3 patients, ASD in 2, coronary arterial anomalies in 2, mitral insufficiency in 1, and pulmonary atresia in 1. One patient underwent a preliminary modified Blalock–Taussig shunt.

There were no significant differences among the groups in terms of mean age and weight at operation. Patient group was selected by random assignment.

Operative Technique

Median sternotomy and hypothermic cardiopulmonary bypass (CPB) with modified balanced ultrafiltration technique were routinely used. Cold histidine tryptophane ketoglutarat solution crystal

cardioplegia solution (Custodiol; Dr F Köhler Chemie GMBH, Alsbach, Germany) was administered every 2 hours for myocardial protection. The technical modification of Nikaidoh procedure was that both aortic and pulmonary root were completely mobilized and translocated, the double root translocation technique.⁸ If the aorta and pulmonary artery are in anteroposterior relation, the coronary arteries and aortic root can be harvested and translocated en bloc. Otherwise, if the great vessels are side by side, detaching just one or both coronary arteries and reimplanting them at a different site in the aortic sinus during translocation should be considered (Figure 1, A and B). In our series, the coronary arteries were detached and reimplanted in 5 of 11 patients. During pulmonary root harvesting, injury to the conductive tissue and mitral valve apparatus must be avoided. In those patients with CTGA, great care must be taken to avoid damage to the conductive tissue. The anterior portion of pulmonary annulus must be kept intact (not harvested) to avoid injury to the His branch or left bundle branch. Only the posterior portion of the pulmonary root can be dissected and harvested. In this case, one must try to maintain the integrity of the pulmonary leaflets. The orifice of the LVOT was opened anteriorly, and the conal septum was divided completely. The LVOT was reconstructed by anastomosing the aortic root to the opened LVOT orifice posteriorly. The anterior portion of the aortic root was sutured to the upper edge of the polyester fabric (Dacron) VSD patch. The RVOT was reconstructed by anchoring the anteriorly opened pulmonary annulus to the cephalad margin of the right ventriculotomy with 5-0 polypropylene suture in a running fashion (Figure 1, C); thus the posterior wall of the neopulmonary artery was created. A single-valved bovine jugular vein patch was tailored to repair RVOT and enlarge the stenotic main pulmonary artery, taking care that the valve of the bovine jugular vein patch should be in the same plane as the native pulmonary valves for competent neopulmonary valvular function.

In the modified REV procedure, the technique for the RVOT reconstruction is similar to those described in the literature,⁹ as shown in Figure 2. The Lecompte maneuver was routinely performed in our cases. A monovalve bovine jugular vein patch was used to repair the RVOT and enlarge the hypoplastic main pulmonary artery. The Rastelli procedure we applied was a conventional one, and the extracardiac conduits we used were homograft in 5 cases (3 pulmonary and 2 aortic) and bovine jugular vein graft in 7 cases.

Concomitant procedures were as follows: Senning procedure in 7 cases, mitral valve repair in 1 case, left pulmonary arterial

reconstruction in 2 cases, ASD closure in 11 cases, and multiple VSDs repair in 6 cases.

Follow-up

All patients discharged from the hospital were followed up to the end date of the study (September 2006). The patients were contacted by telephone or direct interview in our outpatient clinic. Echocardiographic studies were performed at 3 and 6 postoperative months and then once each year. The latest follow-up echocardiograms were available for all survivors. The performance of the heart valves and LVOT and RVOT function were assessed by echocardiography. The severity of the valvular regurgitation was graded according to guidelines published by the American Society of Echocardiography.¹⁰

Statistical Analysis

Statistical analyses were performed with SPSS version 11.5 software (SPSS Inc, Chicago, Ill). All results are expressed as mean $\pm$ SD. The significance of differences between two groups was assessed with the unpaired Student *t* test.

Results

Operative Data

The mean CPB and aortic crossclamp times of the modified Nikaidoh procedure were 342.0 ± 52.1 min and 228.8 ± 42.5 min, respectively. The mean intubation and mechanical ventilation time was 188.7 ± 159 hours. In the REV group, CPB time was 337.3 ± 197.0 min, crossclamp time was 177 ± 40 min, and intubation and ventilation time was 76.4 ± 112.5 hours. For the Rastelli procedure, CPB time was 170.3 ± 40.6 min, crossclamp time was 126.5 ± 31.5 min, and intubation and ventilation time was 43.0 ± 57.4 hours. The modified Nikaidoh procedure was more time-consuming than both REV ($P = .008$) and Rastelli ($P < .001$) procedures in terms of aortic crossclamp time. The mean mechanical ventilation time of the Nikaidoh group was significantly longer than that of the Rastelli group ($P = .016$). There was no difference between Nikaidoh and REV ($P = .15$) groups, nor was there any between REV and Rastelli groups ($P = .395$). Prolonged mechanical

Figure 1. Double root translocation technique. A, Aortic and pulmonary root manipulation. Both the aortic and the pulmonary root are mobilized and excised. The ascending aorta is transected and the coronary arteries are detached from the aortic sinus. B, Lecompte maneuver is performed in most cases. C, Restoration of left ventricle–aorta and right ventricle–pulmonary artery continuity. A single-valved bovine jugular vein patch was used to repair RVOT and enlarge the stenotic main pulmonary artery.

Figure 2. Modified REV procedure: Pulmonary root translocation technique. A, Pulmonary root harvesting. The ascending aorta is transected above the sinus-tubular junction. B, Le-compte maneuver is administered. Restoration of right ventricle-pulmonary artery continuity. A single-valved bovine jugular vein patch is used to repair RVOT, enlarge the stenotic main pulmonary artery, and restore the competence of the neopulmonary valve.

ventilation support (>72 hours) was required by 6 patients in the Nikaidoh group, 1 in the REV group, and 2 in the Rastelli group. The patients who underwent the modified Nikaidoh procedure, which is much more aggressive, needed a longer recovery time (Table 2).

Mortality and Morbidity

All patients in the Nikaidoh group survived. Two patients in the REV group and 1 in the Rastelli group died. Causes of death were small right ventricle and postoperative right ventricular failure in 1 case, severe bleeding in 1 case, and low cardiac output syndrome caused by residual stenosis in the LVOT with a gradient of 45 mm Hg in 1 patient who underwent Rastelli procedure. One patient in the Nikaidoh group required extracorporeal membrane oxygenation (ECMO) support because of acute left heart failure at the fourth postoperative day and was successfully weaned from ECMO 62 hours later. The second patient, who had CTGA

associated with VSD, ASD, and PS, could not be weaned from CPB because of right ventricular dysfunction after modified REV and Senning procedures. He was put on ECMO for 4 days, and then an additional Glenn shunt was performed. This patient could not be weaned from ECMO and died of multiple organ and system failure on the twelfth postoperative day. A patient in the REV group who died of severe bleeding had CTGA, VSD, PS, PDA, and dextrocardia. The bleeding site was on the left atrium (the suture line of the Senning procedure) and could hardly be exposed and controlled, because the atria lie under the ventricles.

More patients in the Nikaidoh group than in the REV and Rastelli groups required prolonged mechanical ventilation support. The causes of prolonged mechanical ventilation support were low cardiac output syndrome, lung infection, stress ulcer, and renal dysfunction.

Postoperative Echocardiography

Echocardiography was performed for all patients before discharge, at 3 to 6 postoperative months, and then once each year. Postoperative echocardiography showed completely normal anatomy of the reconstructed LVOT after double root translocation in all cases, whereas a bending-shaped LVOT was noted in both REV (1 case of TGA) and Rastelli (6 cases of TGA) groups. Turbulence was also observed in the LVOT tunnel in 3 patients with TGA 18 months after the Rastelli operation. Interestingly, among those patients who had DORV, PS, and subaortic VSD, there were no apparent unfavorable shaped LVOTs or unphysiologic flow patterns in the LVOT tunnel in either the modified REV or Rastelli group. In the Nikaidoh group, 2 patients showed totally normal cardiac hemodynamics: competent aortic and pulmonary valves, physiologic flow pattern in the reconstructed LVOT and RVOT, and good ventricular function.

TABLE 2. Postoperative characteristics

	Nikaidoh	REV	Rastelli
Aortic crossclamp (min, mean $\pm$ SD)	228.8 $\pm$ 42.5	177 $\pm$ 40	126.5 $\pm$ 31.5
CPB (min, mean $\pm$ SD)	342.0 $\pm$ 52.1	337.3 $\pm$ 197	170.3 $\pm$ 40.6
Mechanical ventilation (h, mean $\pm$ SD)	188.7 $\pm$ 159	76.4 $\pm$ 112.5	63.3 $\pm$ 89
Morbidity (No.)			
ECMO support	1*	1†	None
Bleeding	None	1	1
LVOTO	None	None	1
Mortality (No.)	None	2/7	1/12

CPB, Cardiopulmonary bypass; ECMO, extracorporeal membrane oxygenation; LVOTO, left ventricular outflow tract obstruction. *Left heart failure. †Right ventricular failure.

One patient had mild aortic regurgitation, 3 patients had mild pulmonary insufficiency, and 6 had mild to medium pulmonary insufficiency. Five patients in the REV group had mild to medium ($n = 3$) or medium ($n = 2$) pulmonary insufficiency, whereas in the Rastelli group 3 patients showed a mild to medium pulmonary insufficiency and 2 showed severe pulmonary insufficiency.

Follow-up

The mean follow-ups were 7 months (range 2–26 months) in the Nikaidoh group, 6 months (range 2–11 months) in the REV group, and 18 months (range 6–30 months) in the Rastelli group. There were no late deaths, nor was reoperation required in any case.

Discussion

The conventional management for TGA, VSD, and LVOT obstruction has been the Rastelli procedure.^{1,2} Clinical data, however, reveals at least three major limitations of the Rastelli technique. (1) It is not feasible for small children or those with unfavorable intracardiac anatomy. (2) Subsequent reoperation (to change the obstructed conduit) is inevitable. (3) Most importantly, the long-term survival is surprisingly low. Deterioration of the hemodynamic performance of LVOT or RVOT with time may account for these problems.^{3,4,11} To overcome the disadvantages inherent in the Rastelli technique, the REV and Nikaidoh procedures were introduced successively.^{5,6} Although the problem-causing valved conduit for RVOT reconstruction can be avoided in both procedures, the competency of pulmonary valve is sacrificed at the same time. We proposed a new method for biventricular outflow tract reconstruction—the double root translocation technique—as a modification of the Nikaidoh procedure.⁸ We also applied pulmonary root translocation to modify the REV procedure, similar to descriptions in the literature,¹⁰ with the aims of keeping the competence and growth potential of the native pulmonary valve and acquiring a better long-term hemodynamic performance of the reconstructed RVOT.

Technical Concerns

The most important issue of aortic root translocation is coronary artery manipulation. To avoid any kink or distortion imposing on the coronary arteries, complete mobilization of aortic root and coronary arteries is necessary. There must be no tension on or kinking of the coronary arteries after the aortic root is translocated. There should be no hesitation to detach the coronary artery (one or both sides) if the great vessels are in a side-by-side relationship. Otherwise, we agree with Nikaidoh's view¹²; that is, try to translocate the aortic root and coronary arteries en bloc to avoid coronary ostial stenosis caused by coronary reanastomosis. The aortic root should be relocated to the LVOT without any distortion to keep the aortic annulus in a natural geometry. We had a case of postoperative aortic insufficiency (mild

in degree) caused by aortic root distortion. In this case there was tension on the right coronary artery during aortic root reattachment. We had to reroute the suture line to transfer the tension from coronary artery to aortic root to eliminate the tension imposing on right coronary artery, as a result of which the aortic annular was distorted. Another important issue concerning pulmonary root translocation is avoidance of damage to coronary arteries and the conductive tissue, especially in patients with CTGA. Great care must be taken to keep the excision away from the regions occupied by the His bundle and its primary branches.¹³ Usually, we did not resect the right anterior segment of the pulmonary annulus in these cases. There were no cases of complete atrioventricular block in our series, and we have performed 20 modified Nikaidoh procedures and 14 modified REV procedures to date. We routinely perform the Lecompte maneuver during pulmonary root translocation, because the neopulmonary root always lies anterior to the neo-aortic root. In addition, if the ascending aorta is too long after being posteriorly translocated, a tubular segment of aorta can be resected if it is anteriorly compressing the pulmonary artery. The aortic autograft tissue can also be used to repair the hypoplastic pulmonary artery.¹⁴

We recommend using a homograft valved pulmonary patch to repair the RVOT and stenotic main pulmonary artery. Because of the limited availability of the homograft, however, we routinely use a single-valved bovine jugular vein patch. According to unpublished observations at our institution, this kind of single-valved bovine jugular vein patch has been doing well as a material for RVOT reconstruction 5 years after repair of tetralogy of Fallot. Its durability needs to be investigated with long-term follow-up.

Figure 3. Echocardiogram of a patient with TGA, VSD, and PS. Parasternal long-axis view shows completely normal morphology of LVOT after double root translocation procedure. TGA, Transposition of the great arteries; VSD, ventricular septal defect; PS, pulmonary stenosis.

Figure 4. The parasternal short-axis view of the same patient as in **Figure 3** shows the normal anatomy of the reconstructed biventricular outflow tract and great arteries after double root translocation. In this case, the Lecompte maneuver was not applied.

Figure 6. Echocardiogram of a patient with TGA after modified REV procedure. A horse-shoe shaped LVOT can be observed in the parasternal long-axis view. Abbreviations as defined in **Figure 3**.

Hemodynamics of LVOT and RVOT

For patients with TGA, VSD, and LVOT obstruction, the hemodynamic performance of the reconstructed LVOT and RVOT in the Nikaidoh group was more physiologically normal than that of the REV or Rastelli group. There was no abnormal flow pattern observed in the LVOT or RVOT after the modified Nikaidoh procedure. Turbulent blood flow in the LVOT was noticed, however, in both the REV and Rastelli groups. Through translocation of aortic and pulmonary roots, the left ventricle and aorta are aligned anatomically, as shown in the postoperative echocardiogram in **Figures 3 and 4**. The case of the right ventricle and main pulmonary

artery is just the same. In contrast, the LVOT reconstructed with the Rastelli technique is a long and bending tunnel (see **Figure 5**), especially in cases of unfavorable intracardiac anatomy. Likewise, the LVOT after REV procedure does not show normal geometry, even though the conal septum has been widely resected, which makes the left ventricle–aorta connection straighter (see **Figure 6**). Postoperative echocardiography in our series demonstrated this (**Figures 5 and 6**). For patients who had DORV, PS, and subaortic VSD, however, no abnormal flow patterns were detected by echocardiography in the LVOT in both the REV and Rastelli groups, suggesting that the intracardiac tunnel in this subset anatomy is more favorable and less likely to have LVOT obstruction develop late.

The major advantage of aortic root translocation is that the native aortic valve is returned to the systemic circulation, unlike the arterial switch procedure, in which the pulmonary valve is exposed to a high-pressure environment. Thus the long-term competency of the aortic valve is maintained. The major advantage of pulmonary root translocation is that the growth potential of pulmonary artery annulus is kept. In addition, the goal of true—meaning anatomic—repair of biventricular outflow tract can be achieved by restoration of the neopulmonary valvular competency, especially with a relatively well-developed pulmonary valve. In 3 of our recent cases of double root translocation, postoperative echocardiography showed completely normal hemodynamic performance of the reconstructed LVOT and RVOT, with competent aortic and pulmonary valves, normal flow pattern of intracardiac blood flow, and good ventricular ejection fraction (**Figure 4**).

Patient Selection

The double root translocation technique should be applied in patients with anomalies of ventriculoarterial connection

Figure 5. Echocardiogram of a patient with TGA, VSD, and PS, who had undergone the Rastelli procedure. The parasternal long-axis view shows a right-angle-shaped bending tunnel that connected the left ventricle and aorta. Abbreviations as defined in **Figure 3**.

associated with VSD and PS, including complex TGA with VSD and PS and DORV with malposition of great arteries and PS. This technique can also be applied for patients who have contraindications for the Rastelli procedure because of unfavorable intracardiac anatomy, such as small right ventricle, inlet VSD, straddling tricuspid valve, or anomalous coronary anatomy. The modified REV technique is a good alternative treatment for patients with DORV, PS, and subaortic VSD. The Rastelli operation is better used for adult patients or large children with DORV, PS, subaortic VSD, and a large right ventricular cavity. In our institution, the modified REV technique is gaining in prevalence, whereas the Rastelli procedure is only used for patients with pulmonary atresia.

We suggest the modified Nikaidoh procedure for patients with anatomic contraindications to the Rastelli procedure, such as small right ventricle or remote VSD. For those with a large subpulmonary defect (absent conal septum), it is not feasible to resect both aortic and pulmonary roots, because the aortic and pulmonary annuli join together closely; in such cases, the modified REV procedure is a better alternative. Because it is an aggressive and delicate procedure, the optimal timing of double root translocation procedure is 6 months to 1 year of age. In contrast, the modified REV procedure is less aggressive and can be used in small infants.

Conclusions

Double root translocation is a feasible and better surgical option for the management of patients with TGA, VSD, and PS. The modified REV technique is a better alternative for patients with DORV, PS, and subaortic VSD. The superior long-term benefits of our double root translocation and modified REV techniques need to be demonstrated with a larger number of patients and longer follow-up.

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Discussion

Dr Marshall L. Jacobs (Philadelphia, Pa). I thank the Association for the privilege of discussing this unique presentation by the surgical team from the Fu Wai Hospital in Beijing. My compliments on this fine presentation demonstrating the feasibility of a new and technically challenging approach to the repair of hearts with ventriculoarterial discordance and subpulmonary obstruction, the double root translocation procedure.

This new operation combines features of the aortic translocation procedure, which was introduced by Nikaidoh, the REV procedure, which was introduced by Lecompte, and pulmonary root translocation, which as best I can tell was first done in Sao Paulo in 1994 by da Silva but has been advocated by many people.

To give you an idea of the staggering degree of clinical activity and productivity at this center, if you looked carefully, you would notice that more than half of this series of patients have undergone operations since the time of abstract submission and that the number of these double root translocations has gone from 11 to 20 in less than a year. I think that's positively amazing.

Of the 20 patients who have undergone double root translocation, all survived the operation, although, as we were told, 2 required ECMO support to achieve recovery. In 5 of the 20 patients, the coronary arteries were excised, mobilized, and reimplanted in the translocated aortic root.

The RVOT reconstruction both in the 20 double root translocation cases and in the 14 modified REV cases included mobilization of the stenotic or hypoplastic pulmonary valve and implantation of this valve on the RVOT together with patch augmentation with a monocusp-bearing patch of bovine jugular vein.

I have three questions. First, in previously published reports of aortic translocation procedures by other authors, a common concern has been the development of aortic valve insufficiency. In a recently published update of Nikaidoh's series, half of the patients at intermediate term follow-up had mild aortic insufficiency. In the 2005 report by Morell, 3 patients had at least moderate aortic valve insufficiency, and 1 eventually required aortic valve replacement.

In the 2007 report by del Nido, 1 patient had moderate aortic insufficiency at the time of the operation, but this did not progress during 5 years of follow-up.

The follow-up in your series for the first 11 patients is only 28 months; and nearly half the cases, as we saw, were done in the past year. Yet you concluded that the long-term competence of the aortic valve is a major advantage of this technique. This optimism, of course, is shared by those who have used the pulmonary autograft in the aortic position for other lesions, but obviously there is concern over time as to whether this optimism is justified.

Are there specific technical innovations associated with your method of aortic root transfer that make you feel confident that the aortic valve will be durable after translocation?

Dr Hu. That is an important issue. We only have early follow-up results. In our series, there has been only 1 patient with mild aortic competence. Technically, there are three issues we should notice. First, we reserve more muscles of the aortic root to support the aortic annulus and hold the stitches. Second, before we translocate the aortic root, we define three points where the three aortic commissures should be located, making sure that there is no tension on the coronary arteries. Another important issue is that we use interrupted stitches to ensure that the aortic root is translocated in a natural geometry. I think this is an important technical tip.

I agree, we need a long-term follow-up study to demonstrate how well these procedures work in the long run.

Dr Jacobs. My second question pertains to the issue of coronary transfer. The guideline that you presented in your presentation is that when the great arteries share an anteroposterior relationship, coronary transfer is not necessary; when they are side by side, coronary transfer is necessary. Did coronary ischemia factor into the 2 cases of required ECMO support, or were revisions of coronary implantations or a secondary change of strategy to coronary excision and implantation required in any of the cases? Did any of the patients

have important ventricular arrhythmias after the operation, as in some earlier series of aortic translocation?

Dr Hu. In our group, we did not find any patients with myocardial ischemia. There were 2 patients who required ECMO support. In 1 case, the right ventricle was not well developed. The other patient with ECMO had an extremely large VSD. I believe left ventricular function was influenced by the large VSD patch.

Dr Jacobs. My final question pertains to your innovation for RVOT obstruction. The long-term function depends not only on the durability of the bovine monocusp but on the fate of the native pulmonary valve leaflets. These are often stenotic, and often even dysplastic. Your early postoperative data reveal mild or moderate pulmonary insufficiency in 9 of the 11 patients undergoing double root translocation and in all 5 of those undergoing the REV procedure.

Does this justify the potential problems associated with excision of the pulmonary root, which in this already complex operation I think potentially puts the left coronary or the mitral anterior leaflet at risk of injury? If there are going to be problems with the durability of the native pulmonary valve leaflets or the monocusp, then perhaps this elegant pulmonary translocation adds risk but not functional durability to the procedure.

That was my final question. I enjoyed your presentation tremendously and I congratulate you and your associates on this unprecedented technical success.

Dr Hu. Thank you. I am aiming to preserve the pulmonary valve, to improve the pulmonary competence, and, most importantly, to preserve the growth potential of the native pulmonary annulus. In our group, we found that in more than 90% of the cases we can preserve at least one or two pulmonary leaflets. And we are using a monovalved bovine jugular vein patch to reconstruct the RVOT and pulmonary artery and have acquired at least better early results. Yet I think it is necessary to do follow-up studies, which is the only way to show what will happen down the road.