ELSEVIER

Interactive CardioVascular and Thoracic Surgery 3 (2004) 470–474

INTERACTIVE CARDIOVASCULAR AND THORACIC SURGERY

www.icvts.org

Institutional report - Congenital

Complete repair of tetralogy of Fallot in infancy

Jeong Ryul Lee[a,*], Jun Sung Kim[a], Hong Gook Lim[a], Ho Young Hwang[a], Yong Jin Kim[a], Joon Ryang Rho[a], Curie Ahn[b]

[a]*Department of Thoracic and Cardiovascular Surgery, Seoul National University Children's Hospital, Seoul National University College of Medicine, Seoul National University Medical Research Institute, Xenotransplantation Research Center, 28 Yongon-dong, Jongro-gu, Seoul 110-744, South Korea*

[b]*Department of Internal Medicine, Seoul National University Children's Hospital, Seoul National University College of Medicine, Seoul National University Medical Research Institute, Xenotransplantation Research Center, 28 Yongon-dong, Jongro-gu, Seoul 110-744, South Korea*

Received 15 October 2003; received in revised form 29 March 2004; accepted 7 April 2004

Abstract

We reviewed our long-term results of complete repair of tetralogy of Fallot (TOF) in infant. One hundred and sixty infants diagnosed as TOF underwent complete repair between January 1990 and April 2002. Mean age at the operation was 8.1 ± 2.6 months. Correction was accomplished through a short right ventriculotomy of less than 30% of the ventricular height in all patients. A transannular patch was used in 78 patients (49%). There were four early deaths and no late death. Follow-up was complete in all survivors. All patients are currently in New York Heart Association functional class I or II. Actuarial freedom from reoperation at 1 and 10 years were 94.0 and 87.5%, respectively. Echocardiographic studies at follow-up showed excellent right ventricular function in most patients. Our results suggest that early complete repair of TOF yielded acceptable results with low mortality and morbidity. Transventricular repair of intracardiac pathology can be safely applied to yield good postoperative right ventricular function.

Keywords: Tetralogy of Fallot; Infancy

1. Introduction

Since 1954, when Lillehei completed the first successful definitive repair of tetralogy of Fallot (TOF), the surgical management of TOF has continued to evolve. Dramatic advances in infant cardiac surgical procedures now allow early (<1 year of age) complete repair of TOF. The optimal management of patients with symptomatic TOF has been the subject of debate over the past several decades. Ideally, the surgical treatment of choice for symptomatic TOF is a one-stage total repair, which ensures that sinus rhythm is preserved, no residual right ventricular outflow tract obstruction is present, the patient's pulmonary valve remains competent, and that the ventricular septal defect (VSD) is completely closed. Moreover mortality should be comparable to that of a two-stage repair. Good early and late results in patients with TOF repaired in infancy have stimulated many centers to perform routine primary repair for symptomatic TOF regardless of the age and weight of the patient [1–6]. Effects of chronic hypoxia on arrhythmias, progressive damage to the right ventricle with fibrous tissue, the incidence of ventricular ectopia and sudden death, and the impairment of alveolar and pulmonary vascular growth are additional factors that promote early repair in infants with symptomatic TOF. We analyze our results of early one-stage repair (at <1 year of age) using short right ventriculotomy to close the VSD and to relieve right ventricular outflow tract obstruction.

2. Material and methods

2.1. Patient profiles

From January 1990 to April 2002, a total of 160 symptomatic infants diagnosed as TOF underwent total correction at our institute. There were 101 males and 59 females. Median age at operation was 8.1 ± 2.6 months (3–12) and mean body weight was 7.9 ± 5.6 kg (2.1–14.0). Echocardiography was used in all patients and cardiac catheterization was indicated when the diagnosis of TOF

* Corresponding author. Tel.: +82-2-760-2877; fax: +82-2-765-7117.
E-mail address: jrl@plaza.snu.ac.kr (J.R. Lee).

1569-9293/$ - see front matter © 2004 Elsevier B.V. All rights reserved.
doi:10.1016/j.icvts.2004.04.002

was doubtful, or there were concerns about pulmonary artery distortion, aortopulmonary collateral arteries, or pulmonary vascular obstructive disease. Thirty-five patients (22%) had a history of hypoxic spell and 94 patients (59%) had a deepening cyanosis. Thirty-one patients (19%) had no symptom except failure to thrive.

Associated cardiovascular anomalies were 36 right aortic arches, 14 atrial septal defects, 12 patent ductus arteriosus, 9 systemic venous anomalies, 7 coronary anomalies, 2 aortic coarctations, and 1 partial anomalous pulmonary venous connection.

2.2. Operative technique

Under cardiopulmonary bypass with moderate hypothermia and cardiac arrest using a 4 °C cold potassium blood cardioplegia (20 ml/kg), a short right ventriculotomy less than 30% of the ventricular height in the outflow tract was performed. The VSD was closed using a glutaraldehyde-fixed autologous pericardium using an interrupted pledgetted mattress sutures and the infundibular muscles were resected. Transannular repair was performed when pulmonary valve annulus was checked to be less than one standard deviation than that predicted by Rowlatt's standard charts intraoperatively. Native pericardium tanned in glutaraldehyde or a thin-walled Gore-Tex (W.L. Gore and Associates, Flagstaff, AZ) vascular graft was used as an anterior patch material and was extended distally onto the branch pulmonary arteries if relief of obstruction was required to this level.

Seventy-eight patients underwent transannular repairs and monocuspid pulmonary valve was constructed using either autologous pericardium or a Gore-Tex membrane for preventing postoperative pulmonary insufficiency in 55 of these patients. The mean cardiopulmonary bypass time was 129 ± 70 min (69–354) and the mean aortic cross-clamp time was 62 ± 18 min (36–137). Modified ultrafiltration was routinely performed since 1998 immediately after weaning from cardiopulmonary bypass.

2.3. Follow-up

The family and physician of each infant were contacted to obtain follow-up information between 9 and 143 months postoperatively. The mean follow-up duration was 66 ± 36 (9–143) months. A chest roentgenogram, electrocardiogram, and echocardiogram were obtained in all surviving patients, 24-h Holter recording was performed in 26 patients.

2.4. Statistical methods

Statistical analyses were performed using SPSS version 10.0 software (SPSS, Inc., Chicago, IL, USA). All results were expressed as mean ± standard deviation, and a value of P less than 0.05 was considered statistically significant. Fisher's two-tailed exact test was used to determine risk factors for operative deaths. Actuarial data were analyzed using Kaplan–Meier formulae. Early mortality was defined as death occurring within 30 days of the operation.

3. Results

3.1. Early death and complications

There were four early deaths (2.5%). Three patients died within 1 week of operation due to right heart failure. Their preoperative pulmonary artery indices were 100, 126, and 330 mm^2/m^2, respectively. In these patients, postoperative P_{RV}:P_{LV} ranged between 0.8 and 1.1. One patient died on the 14th postoperative day due to fulminant vancomycin-resistant enterococcus sepsis with multi-organ failure. Risk factors potentially affecting operative mortality were analyzed (Table 1). In multivariate analysis, a pulmonary artery index of less than 150 mm^2/m^2 affected operative mortality ($P = 0.003$). The use of a transannular patch, an age less than 3 months, a weight less than 6.0 kg, and an aortic cross-clamp time more than 60 min did not adversely affect operative mortality. The mean pulmonary artery index (Nakada index) was 145.6 ± 57.9 mm^2/m^2 and the mean right to left ventricular peak systolic pressure ratio measured in the operating room was 0.57 ± 0.17 (0.34–0.77). The median duration of inotropic support was 65 h. Vasodilators were used in 84% of the patients. The mean period of ventilator support was 43.6 h (4–331) and mean intensive care unit stay was 4.6 days (1–60). Postoperative complications included prolonged pleural effusion ($n = 9$), chylothorax ($n = 6$), phrenic nerve palsy ($n = 6$), and mediastinitis ($n = 1$). Early postoperative arrhythmia was noted in seven patients. Five of these showed transient junctional tachyarrhythmia, and the remaining two showed complete atrioventricular block. Permanent pacemaker implantation was required in two patients who showed complete atrioventricular block.

Table 1
Risk factor analysis for operative mortality

Risk factor	P-value
Age (<3 months)	0.7
Body weight (<6.0 kg)	0.5
Year of surgery (<1995)	0.9
ACC time (>60 min)	0.9
PAI (<150 mm^2/m^2)	0.003
Transannular reconstruction	0.4

ACC, aortic cross-clamp; PAI, pulmonary artery index. Fisher's two-tailed exact test was used to demonstrate risk factors for operative deaths. A P-value less than 0.05 was considered statistically significant.

Table 2
Reoperation during follow-up period

Operation name	Number
Peripheral PA angioplasty	10
RV-PA valved conduit	4
Residual PS relief	3
PV replacement	3
Residual VSD closure	2
Permanent PM insertion	2

Reoperation was required in 20 patients (12.5%) during follow-up. No redo-operative mortality occurred. PA, pulmonary artery; RV, right ventricle; PS, pulmonary stenosis; PV, pulmonary valve; VSD, ventricular septal defect; PM, pacemaker.

3.2. Follow-up and late death

Follow-up was complete in all survivors. Median follow-up duration was 69 months (9–143), and there was no late death. Reoperation was required in 20 patients (12.5%) during the follow-up (Table 2). Overall reoperation-free rates at 1 and 10 years were 94.0 and 87.5%, respectively (Fig. 1). At the latest follow-up, all patients were at New York Heart Association functional class I or II. All patients except those who received permanent pacemaker implantation due to postoperative complete atrioventricular block were in normal sinus rhythm. At postoperative long-term follow-up echocardiography, no or mild pulmonary regurgitation was found in 91 patients (56.9%) and moderate pulmonary regurgitation in 55 patients (34.4%). Ten patients showed severe pulmonary regurgitation. Among them, seven patients underwent pulmonary valve replacement or conduit interposition. Insertion of monocuspid valve did not affect the degree of late pulmonary regurgitation ($P = 0.36$), and the degree of pulmonary regurgitation was not found to be correlated with the patient's age at operation. In terms of tricuspid regurgitation, 149 patients (93.1%) showed no or mild tricuspid regurgitation, whereas six and one patients showed moderate and severe tricuspid regurgitation, respectively. Echocardiography demonstrated acceptable right ventricular function in all patients except three (Table 3).

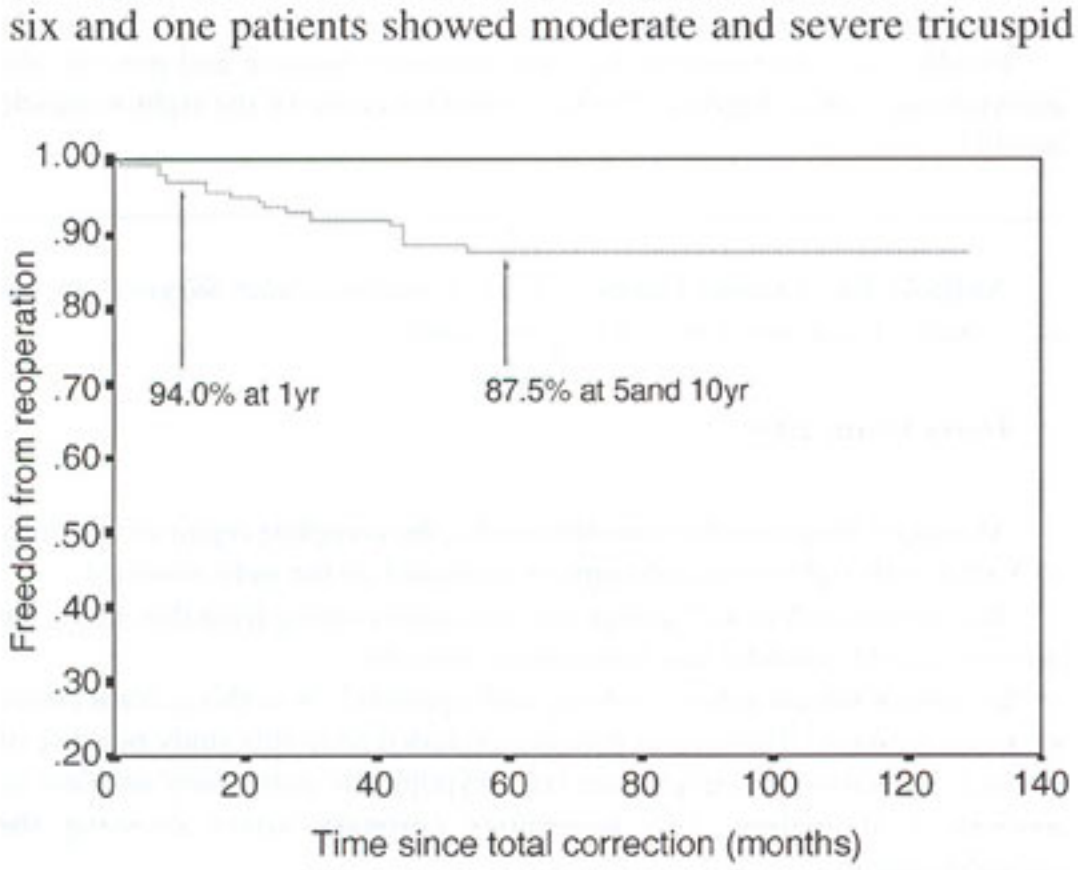

Fig. 1. Freedom from reoperation: results of Kaplan–Meyer actuarial survival analysis.

Table 3
RV function by follow-up echocardiography

RV function	Number of patients (%)
Good RV function	137 (87.8)
Fair RV function	16 (10.3)
Poor RV function	3 (1.9)

All patients were examined after operation or reoperation. Echocardiography demonstrated acceptable right ventricular function in all patients except three. RV, right ventricle.

4. Comment

The outcome after surgical repair of TOF has improved over the last decades and recent studies have reported a mortality rate between 0 and 7% [3]. However, certain issues remain unsolved: (1) the optimal time for repair, (2) early one-stage versus two-stage repair, and (3) transatrial or transventricular approach for closure of VSD [6].

Caspi et al. [6] demonstrated that younger age was associated with a higher incidence of long transannular patching, and also correlated with a greater degree of hypoplasia of the right ventricular-pulmonary arterial junction, the pulmonary valve annulus, and the main pulmonary artery. Kirklin et al. [7] also found that a small ventriculo-pulmonary junction and distal main pulmonary artery or a very young infant of less than 3 months were risk factors for operative mortality. This can be partly explained by the fact that a higher intrinsic pulmonary vascular resistance associated with pulmonary valvar incompetency following transannular patching may be less tolerable in very young infants. Nevertheless, there are many advantages of early repair which include a lesser degree of secondary right ventricular hypertrophy and fibrosis, simple division of the obstructing infundibulum, and a less wide patch resulting in better right ventricular function and few arrhythmias. Early one-stage repair avoids the risks associated with a staged operation; it establishes the normal pulmonary blood flow, which results in improved pulmonary tree and lung parenchymal maturation; and it eliminates potentially serious problems such as branch pulmonary artery stenosis or the distortion associated with palliative shunt operation [1–3,6]. Excellent early and midterm results can be accomplished by adopting routine primary repair of TOF in early infancy regardless of age, symptomatic status, coronary anatomy, and the size of branch pulmonary arteries as long as they normally arborized [8]. Our study shows that right ventricular function was well preserved with no newly developed late arrhythmia during the follow-up period.

Dietl et al. [9] itemized on the advantages of the right atrial approach for intracardiac repair, as follows: (1) The long-term function of the right ventricle is preserved when a ventriculotomy is avoided. (2) The risk of injuring a major ventricular branch of the right coronary artery or an anomalous left coronary artery is minimized. (3) The ventriculotomy site can be the site of origin of serious life-threatening ventricular arrhythmias. (4) The resultant pulmonary regurgitation after limited transannular patching is less severe than that which often occurs after transventricular repair.

However, Pacifico et al. [10] pointed out that approaches to intracardiac repair should depend on right ventricular outflow tract morphology. In his series, transatrial, transpulmonary approach was used in 90% of the patients. In our study, we repaired the intracardiac pathology through a short ventriculotomy, which was not longer than 30% of the height of the right ventricle even in very young infant. We believe that optimal relief of infundibular stenosis and secure closure of VSD are possible using this approach. Only two of our patients had a small residual VSD. Although all patients showed right bundle branch block on the electrocardiogram, this finding is not significant on ventricular function and physical activity of the patient. Postoperative right ventricular function measured by echocardiography remains excellent during the follow-up period. In 49% of the patients, transannular reconstruction was required. However, no difference was observed in the incidence of post-repair pulmonary insufficiency of greater than moderate degree between transannular and non-transannular groups.

Our results suggest that early repair of TOF yields the acceptable results with low mortality and morbidity. Transventricular repair of intracardiac pathology can be safely applied to this patient population, yielding good postoperative right ventricular function. Long-term follow-up is mandatory to demonstrate the definite clinical and functional advantages of this strategy.

References

[1] Castaneda AR, Freed MD, Williams RG, Norwood WI. Repair of tetralogy of Fallot in infancy. J Thorac Cardiovasc Surg 1977;74: 372–81.

[2] Walsh EP, Rockenmacher S, Keane JF, Hougen TJ, Lock JE, Castaneda AR. Late results in patients with tetralogy of Fallot repaired during infancy. Circulation 1988;77:1062–7.

[3] Gustafson RA, Murray GF, Warden HE, Hill RC, Rozar Jr. GE. Early primary repair of tetralogy of Fallot. Ann Thorac Surg 1988;45: 235–41.

[4] Uva MS, Lacour-Gayer F, Komiya T, Serraf A, Bruniaux J, Touchot A, Roux D, Petit J, Planche C. Surgery for tetralogy of Fallot at less than six months of age. J Thorac Cardiovasc Surg 1994;107:1291–300.

[5] Hennein HA, Mosca RS, Urcelay G, Dennis CC, Edward LB. Intermediate results after complete repair of tetralogy of Fallot in neonates. J Thorac Cardiovasc Surg 1999;109:332–44.

[6] Caspi J, Zalstein E, Zucker N, Applebaum A, Harrison Jr. LH, Munfakh NA, Heck Jr. HA, Ferguson Jr. TB, Stopa A, White M, Fontenot EE. Surgical management of tetralogy of Fallot in the first year of life. Ann Thorac Surg 1999;68:1344–9.

[7] Kirklin JW, Blackstone EH, Colvin EV, McConnell ME. Early primary correction of tetralogy of Fallot. Ann Thorac Surg 1988;45: 231–3.

[8] Reddy VM, Liddicoat JR, McElhinney DB, Brook MM, Stanger P, Hanley FL. Routine primary repair of tetralogy of Fallot in neonates and infants less than three months of age. Ann Thorac Surg 1995;60: S592–6.

[9] Dietl CA, Cazzaniga ME, Dubuer SJ, Perez-Balino NA, Torres AR, Favaloro RG. Life threatening arrhythmias and RV dysfunction after surgical repair of tetralogy of Fallot. Comparison between transventricular and transatrial approaches. Circulation 1994;90:II7–II12.

[10] Pacifico AD, Sand ME, Bargeron LM, Colvin EC. Transatrial–transpulmonary repair of tetralogy of Fallot. J Thorac Cardiovasc Surg 1987;93:919–24.

Appendix A. ICVTS on-line discussion

Author: ***Mr. Adrian Ooi***, *Wessex Cardiac Centre, Department of Cardiothoracic Surgery, Southampton University Hospital, Tremona Road, Southampton SO 16 6YD, UK*

Date: 22-Jun-2004

Message: I read with interest this article which concluded that transventricular repair can be safely applied to patients under the age of 12 months old.

In this study only the transventricular approach is shown. I wonder if Jeong Ryul Lee and colleagues have any data or practice with other approaches to this repair. Certainly it would be very interesting to see:
(1) If these results (transventricular approach) are to be compared with transatrial or transpulmonary approach in repairing TOF.
(2) Do they recommend the routine use of transventricular approach?
(3) 1 in 8 patients required re-operation and most are associated with RVOT obstruction or pulmonary anomaly. Would these outcomes be of any difference if they were repaired via the transpulmonary approach?

Furthermore, in this study, do they have any data or the outcome of patients under the age of 1 month/3 months/6 months with transventricular approach? What are the morbidity and mortality or how are they compared in each of those sub-age group?

I gather from the patient selection that most of them are simple Fallot of Tetralogy. Does the author exclude Fallot with major cardiac anomalies such as absent pulmonary valve, double outlet right ventricle, multiple VSD's and complete AV canal defect? I just wonder if different approaches were used in these conditions.

Finally, so as to preserve the right ventricle function and prevent any arrhythmias, why a figure of "30%" ventriculotomy of the right ventricle height?

Author: ***Dr. Antonio Corno***, *CHUV, Cardiovascular Surgery, 46 rue du Bugnon, Lausanne, CH-1011, Switzerland*

Date: 19-Jul-2004

Message: Based on the reported results, the complete repair of tetralogy of Fallot with right ventriculotomy is proposed as the gold standard.

Before the readers will accept the indication coming from this study, the authors should consider the following comments:
– the patient selection has not been well specified. Was this a consecutive series of patients? There were patients excluded from this study because of either risk factors for early repair (i.e.: hypoplastic pulmonary arteries) or associated anomalies (i.e.: anomalous coronary artery crossing the infundibulum)?
– how have been treated the infants with anomalous coronary artery (7 in the reported series)?

– the Authors should provide the readers with more precise criteria on their indication for a monocusp pulmonary valve (used on 55/78 patients), as well as their surgical tricks to prevent/reducing the chance of having a pulmonary valve regurgitation after repair.
– what are the frequency and the indication for the tests utilized during the follow-up to monitor the presence of arrhythmias, pulmonary valve regurgitation, right ventricular function?
– what are the indications for re-operation in the presence of pulmonary valve regurgitation? With this regard, the incidence of re-operation can vary substantially depending upon the threshold for valve implantation.
– what are the elements to indicate that the pulmonary valve and right ventricular function will remain stable, since it is well recognized that deterioration of both increases after 10–15 years follow-up.