

Repair of Tetralogy of Fallot in Infancy via the Atrioventricular Approach

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Background: Tetralogy of Fallot (TOF) is a well-recognized congenital heart disease. Despite improvements in the outcomes of surgical repair, the optimal timing of surgery and type of surgical management of patients with TOF remains controversial. The purpose of this study was to assess outcomes following the repair of TOF in infants depending on the surgical procedure used. **Methods:** This study involved the retrospective review of 120 patients who underwent TOF repair between 2010 and 2013. Patients were divided into three groups depending on the surgical procedure that they underwent. Corrective surgery was done via the transventricular approach (n=40), the transatrial approach (n=40), or a combined atrioventricular approach (n=40). Demographic data and the outcomes of the surgical procedures were compared among the groups. **Results:** In the atrioventricular group, the incidence of the following complications was found to be significantly lower than in the other groups: complete heart block (p=0.034), right ventricular failure (p=0.027) and mediastinal bleeding (p=0.007). Patients in the atrioventricular group had a better postoperative right ventricular ejection fraction (p=0.001). No statistically significant differences were observed among the three surgical groups in the occurrence of tachycardia, renal failure, and tricuspid incompetence. The one-year survival rates in the three groups were 95%, 90%, and 97.5%, respectively (p=0.395). **Conclusion:** Combined atrioventricular repair of TOF in infancy can be safely performed, with acceptable surgical risk, a low incidence of reoperation, good ventricular function outcomes, and an excellent survival rate.

Key words: 1. Tetralogy of Fallot
2. Cardiopulmonary bypass
3. Congenital abnormalities

INTRODUCTION

Tetralogy of Fallot (TOF) is a well-recognized congenital heart disease involving the combination of ventricular septal defects (VSDs), pulmonary stenosis, and hypertrophy of the right ventricle (RV) [1]. Previous research has suggested that repairing TOF in infancy promotes the normal growth and development of the heart and other organs, the elimination of

hypoxemia and cyanosis, the prevention of right ventricular hypertrophy, the preservation of left ventricular function, and the decreased incidence of late arrhythmias [2]. Earlier studies have reported that the use of traditional ventriculotomy for VSD closure and relief of right ventricular outflow tract (RVOT) obstructions leads to an increased incidence of late RV failure, ventricular arrhythmias, and sudden death. Currently, the right atrial (RA) approach via the tricuspid valve is

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used in the majority of infants undergoing repair of TOF. Atriotomy provides excellent exposure, but is associated with an increased risk of complete heart block (CHB) and tricuspid incompetence (TI) [3]. The purpose of this study was to describe our experiences with the repair of TOF using three techniques to close VSDs, with particular emphasis on the surgical procedure used.

METHODS

1) Patients

Between 2010 and 2013, 135 consecutive children with TOF underwent classic TOF repair in our center. Our study was approved by our local ethics committee and informed consent was obtained from the parents, because the patients were not of the legal age to provide consent. Fifteen patients with pulmonary atresia, coronary anomalies, or who underwent emergency operations were excluded from the study. Therefore, our study population consisted of a total of 120 eligible patients. All patients were diagnosed using two-dimensional and Doppler echocardiography. All patients were operated on by one surgeon, and their demographic and clinical characteristics were obtained retrospectively from their medical records.

During aforementioned time, in our center, the atrial and ventricular approaches were exclusively used for TOF repair according to the surgeon's preference (based on cardiac anatomical characteristics and VSD location). In the present study, the patients were divided into three groups depending on the procedure they underwent: the RA group included patients who underwent TOF repair via atriotomy (n=40), the RV group included patients who underwent TOF repair via ventriculotomy (n=40), and the right atrioventricular valve (RAV) group included patients who underwent TOF repair via a combined atrioventricular technique (n=40). The patients' medical records in the hospital database, including clinical follow-up information, were retrospectively reviewed in the current study.

2) Surgical technique

Standard cardiopulmonary bypass (CPB) with a single injection of cold crystalloid cardioplegia and hypothermia (24°C–

28°C) was employed in all patients. The aorta was cannulated with a 12–18-F plastic guided flexible arterial cannula. The superior vena cava was cannulated using a straight venous cannula and the inferior vena cava cannula was inserted through a stab wound at the cavoatrial junction. After establishing CPB, the aorta was cross-clamped with a right-angle cross-clamp and cold crystalloid cardioplegic solution was infused into the aortic root until cardiac arrest. The repair technique used in each patient was chosen based on both the anatomical location of the VSD and the operating surgeon's preference. In the RA group, the VSD was closed using a polytetrafluoroethylene (PTFE) patch via a standard transatrial incision following the relief of the RVOT obstruction. In the RV group, VSD closure was performed using a PTFE patch following the relief of the RVOT obstruction via a longitudinal transventricular incision measuring approximately 2–3 cm. In the third group, after the relief of RVOT obstruction, the anterior portion of the VSD was closed by a PTFE patch via a short atriotomy and minimal retraction of the tricuspid valve. Subsequently, the inferior part of the VSD was closed through a ventriculotomy (limited to 1.5 cm) and minimal manipulation of the RV. In order to verify the full competence of the tricuspid valve, saline solution was injected into the right ventricle. After complete closure of the VSD, pericardium was closed and mediastinal and pleural drainage tubes were placed.

3) Statistical analysis

All statistical analyses were carried out using IBM SPSS ver. 22.0 (IBM Co., Armonk, NY, USA). Continuous variables are presented as mean±standard deviation. One-way analysis of variance (ANOVA) was used to identify statistically significant differences among these data points. Categorical variables are presented as frequency (percentage), and were analyzed using the chi-square test or Fisher's exact test, as appropriate. In order to generate survival curves, we used Kaplan–Meier survival estimates. All p-values <0.05 were considered to indicate statistical significance in all tests.

Table 1. Demographic and clinical data of patients

Variable	Atriotomy (n=40)	Ventriculotomy (n=40)	Atrioventriculotomy (n=40)	p-value
Age (mo)	8.65±2.2	8.48±2.1	8.35±2.5	0.843
Gender				
Female	23 (57.5)	22 (55.0)	28 (70.0)	0.338
Male	17 (42.5)	18 (45.0)	12 (30.0)	
Weight (kg)	7.22±1.9	7.38±1.9	7.67±2.1	0.597
Body surface area (m ²)	0.34±0.91	0.34±0.90	0.34±0.10	0.982
Cardiopulmonary bypass time (min)	126±34	128±32	125±30	0.670
Aortic cross-clamp time (min)	89.32±20.7	91.20±20.6	86.52±19.2	0.584
Intubation time (hr)	23.12±2.6	26.08±2.1	20.75±1.8	0.001
Intensive care unit stay (day)	4.68±0.27	5.78±0.32	3.87±0.16	0.001

Values are presented as mean±standard deviation or number (%). Continuous data are analyzed using one way analysis of variance. Categorical data are analyzed using chi-square test and Fisher's exact test.

RESULTS

1) Demographic and clinical characteristics of the patients

The study participants included 47 males (39%) and 73 females (61%), ranging in age from six to 12 months. Patients who were less than six months of age or underwent initial palliation with a Blalock-Taussig shunt before corrective surgery were excluded from the study. All characteristics of the patients are summarized in Table 1. The mean age of the patients in the RA, RV, and RAV groups was 8.65±2.2 months, 8.48±2.1 months, and 8.35±2.5 months, respectively. The mean weight of the patients at the time of repair in the RA, RV, and RAV groups was 7.22±1.9 kg, 7.38±1.9 kg and 7.67±2.1 kg, respectively. As Table 1 shows, no statistically significant differences were found among the groups with regard to these variables.

The mean aortic cross-clamp time in the RA group was 89.32±20.7 minutes, compared to 91.20±20.6 minutes in the RV group and 86.52±19.2 minutes in the RAV group. The mean duration of CPB was 126±34 minutes in the RA group, versus 128±32 minutes in the RV group and 125±30 minutes in the RAV group. No intraoperative deaths or severe complications involving exposure, cannulation, or bleeding were observed in any of the three groups. The mean duration of intubation was 23.12±2.6 hours in the RA group, 26.08±2.1 hours in the RV group, and 20.75±1.8 hours in the RAV group. The mean length of the stay in the intensive care unit

(ICU) in the RA and RV groups was 4.68±0.27 and 5.78±0.32 days, respectively, in contrast to 3.87±0.16 days in the RAV group. As presented in Table 1, ANOVA showed significant differences in intubation time and ICU stay duration (p=0.001).

2) Postoperative morbidity and mortality

A total of 86 patients (71.6%) experienced early postoperative complications. In the RA group, the complications were transient CHB (n=12), supraventricular tachycardia (n=3), RV failure (n=3), mediastinal bleeding requiring reoperation (n=5), tricuspid incompetence (n=5), and renal failure due to low cardiac output syndrome requiring peritoneal dialysis (n=4). The complications in the RV group were transient CHB (n=7), supraventricular tachycardia (8), RV failure (n=8), mediastinal bleeding requiring reoperation (n=12), tricuspid incompetence (n=1), and renal failure due to low cardiac output syndrome (n=6). The postoperative complications in the RAV group were transient CHB (n=3), supraventricular tachycardia (n=3), RV failure (n=1), mediastinal bleeding requiring reoperation (n=2), tricuspid incompetence (n=1), and renal failure due to low cardiac output syndrome (n=2). As Table 2 shows, a significant difference was observed in the incidence of transient CHB, RV failure, and mediastinal bleeding (p≤0.05). Twelve (30%) events of transient CHB occurred in the RA group versus seven (17.5%) in the RV group, whereas three patients (7.5%) in the RAV group experienced transient CHB (p=0.034). Moreover, RV failure took place in three patients

Table 2. Comparison of morbidity and mortality of patients after tetralogy of Fallot repair among tree groups

Variable	Atriotomy (n=40)	Ventriculotomy (n=40)	Atrioventriculotomy (n=40)	p-value
Right ventricular ejection fraction	44.36±0.27	41.28±0.44	49.89±0.50	0.001
Complete heart block	12 (30.0)	7 (17.5)	3 (7.5)	0.0341
Tachycardia	3 (5.0)	8 (20.0)	3 (7.5)	0.132
Right ventricle failure	3 (7.5)	8 (20.0)	1 (2.5)	0.027
Bleeding	5 (12.5)	12 (30.0)	2 (5.0)	0.007
Tricuspid incompetence	5 (12.5)	1 (2.5)	1 (2.5)	0.088
Acute renal failure	4 (10.0)	6 (15.0)	2 (5.0)	0.329
Mortality	2 (5.0)	4 (10.0)	1 (2.5)	0.346

Values are presented as mean±standard deviation or number (%). Continuous data are analyzed using one way analysis of variance. Categorical data are analyzed using chi-square test and Fisher’s exact test, if applicable.

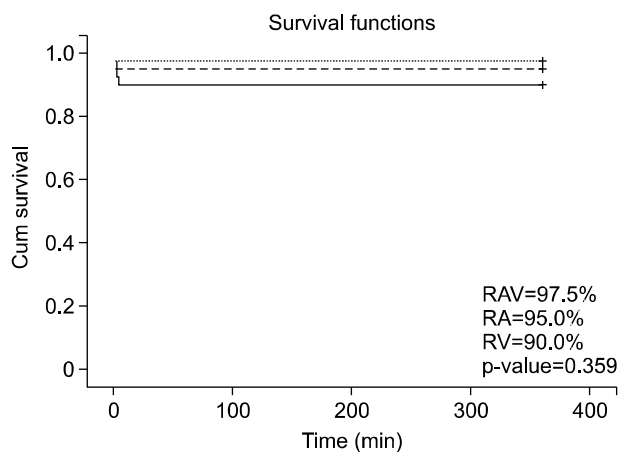


Fig. 1. Kaplan-Meier curves for one-year survival in tree groups. All p-values analyzed by log-rank test. RAV, right atrioventricular valve; RA, right atrial; RV, right ventricle.

(7.5%) patients in the RA group, as compared to eight (20%) in the RV group, whereas only one patient (2.5%) experienced RV failure in the RAV group (p=0.027). Significantly less mediastinal bleeding was observed in the RAV group (5%) than in the RA (12.5%) and RV (30%) groups (p=0.007). Although not significant, other variables showed a trend to be lower in the RAV group compared to the RA and RV groups.

Transthoracic Doppler echocardiography demonstrated significantly better RV function in the RAV group. As Table 2 shows, the mean RV ejection fraction (RVEF) in the RAV group was 49.89%±0.50%. The RVEF in the RA and RV groups was 44.36%±0.27% and 41.28%±0.44%, respectively (p=0.001). The postoperative RV/left ventricle systolic pressure ratio in patients was less than 0.7. As presented in Table 2, two mortality events (5%) took place in the RA group, in

contrast to four events (10%) in the RV group, whereas one mortality event (2.5%) took place in the RAV group. The earliest death in the RAV group was attributed to low cardiac output syndrome (LCOS) on the second postoperative day. Two deaths occurred in the RA group, due to acute respiratory distress syndrome and arrhythmia on the first and second postoperative day, respectively. Four early hospital deaths in the RV group took place, due to RV failure, supraventricular tachycardia, and LCOS in the ICU. The Kaplan-Meier survival curve is presented in Fig. 1. The one-year survival rates in the RA, RV, and RAV groups were 95.0%, 90.0%, and 97.5%, respectively (p=0.395).

DISCUSSION

Despite improvements in the outcomes of surgical repair of TOF over the last decades, certain issues remain under debate, such as the optimal timing of surgery and the use of a transatrial or a transventricular approach for the closure of the VSD [4]. The location of the defects, clinical symptoms, and the coexistence of cardiac malformations affect the timing of corrective surgery. Hence, the morbidity and mortality associated with the complete repair of TOF depend on the existence of major cardiac lesions and the complexity of the cardiac deficit. The primary clinical sign of children with TOF depends on the degree of RVOT obstruction. Generally, cyanosis is moderate at birth and slowly progresses with growth. However, some children have a remarkable degree cyanosis and RVOT obstruction at or shortly after birth, as a result of the hypoplastic pulmonary valve annulus with or

without severe right ventricular infundibular obstruction or hypoplasia [5,6].

Numerous studies have demonstrated the advantages of early TOF repair, including the promotion of normal growth and organ development, the relief of cyanosis, a decreased occurrence of dysrhythmias, the need for little or no extensive right ventricular muscle excision, and improved left ventricular function [2,4,7]. Seliem et al. [8] demonstrated that, among patients who underwent TOF repair before six months of age, both right ventricular wall thickness and right ventricular hemodynamic function decreased significantly. In opposition, infants who underwent TOF repair after six months of age showed no significant changes in these parameters. It was clear that long-standing right ventricular hypertension in older patients resulted in hypertrophy of the ventricular septum [8]. Thus, more extensive incision in the right ventricle was required due to difficult exposure, which may have adversely affected postoperative ventricular function. Nonetheless, some concerns have been raised regarding the safety of primary repair in infancy [9].

The present study is a descriptive report of the survival and clinical outcomes of 120 patients who underwent TOF repair. Better surgical outcomes were demonstrated after TOF repair using an atrioventricular approach in comparison to routine atriotomy and ventriculotomy, in terms of mortality and morbidity. Transatrial and transventricular approaches have been previously investigated at several institutions. The transatrial repair of TOF can be performed at any age, even in infants [3]. Dietl et al. [10] described the advantages of right atriotomy for intracardiac repair, including the preservation of long-term function of the right ventricle, minimal injuries to the ventricular branch of the right coronary artery, and a decreased incidence of life-threatening arrhythmias. Moreover, the severity of pulmonary regurgitation after transannular patching is less than that observed when the ventricular approach is used [10,11]. However, atrial incisions are associated with the disadvantages of CHB and TI. The traditional approach of ventriculotomy provides superior exposure through a right ventricular incision for the closure of the VSD and relief of the RVOT obstruction. Nevertheless, right ventricular hypertrophy and fibrosis are concerns, since these conditions may increase the occurrence of arrhythmias and

sudden death. Importantly, pathophysiologically, the impairment of right ventricular function due to RV wall rupture and disruption of the RV geometry is associated with extensive incisions on the body of the RV in ventriculotomy [12].

In our study, we repaired cardiac malformations via a combined atrioventricular incision, which was limited to less than 20% of the length of the RA and RV. The mortality rate was low (2.5%), which was similar to that reported in other studies assessing the outcomes of transventricular and/or transatrial repair in neonates and infants [3]. One early death occurred related to LCOS following surgery. This surgical approach enabled the optimal closure of VSDs was achieved with no late residual VSDs. The low occurrence of late arrhythmias and the absence of sudden cardiac death in our study correspond to the results of previous investigations reporting no late arrhythmias or sudden deaths following atriotomy or ventriculotomy incisions for TOF repair in infancy [10]. Nevertheless, three patients (7.5%) showed transient CHB that returned to a sinus rhythm after 48 hours. Postoperative RV function assessment by regular echocardiography demonstrated a trend toward improvement of RV hemodynamic function in the RAV group.

The present study had some limitations. This retrospective study included a small number of patients who underwent surgical repair of TOF in a single center. Hence, the statistical analyses may not have sufficient power to support any definitive conclusions. Similarly to previous studies, a longer follow-up duration would be also warranted.

In conclusion, the combined atrioventricular approach to the repair of TOF in children seems to be a superior procedure, yielding acceptable results with low mortality and morbidity. This approach can be safely performed with a low operative risk, a low incidence of late arrhythmias, better preservation of RV function, and excellent survival. Moreover, the occurrence of RV disruption, TR, and CHB was low due to the minimal retraction and manipulation of the RA and RV. Therefore, we believe that the atrioventricular approach yields acceptable results and successful repair of TOF in infants.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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