

Right Ventricular Hemodynamic Alteration after Pulmonary Valve Replacement in Children with Congenital Heart Disease

Hamid Bigdelian¹, Mohsen Sedighi^{2*}, Davoud Mardani³

¹ Pediatric Cardiac Surgeon, Department of Cardiovascular Surgery, School of Medicine, Isfahan Medical University, Isfahan, Iran

² M.Sc of Physiology, Cardiac Surgery Department, Chamran Heart Center, Isfahan University of Medical Sciences, Isfahan, Iran

³ M.Sc of Nursing, Cardiac Surgery Department, Chamran Heart Center, Isfahan University of Medical Sciences, Isfahan, Iran

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ABSTRACT

Introduction: In patients who underwent surgery to repair Tetralogy of Fallot, right ventricular dilation from pulmonary regurgitation may be result in right ventricular failure, arrhythmias, and cardiac arrest. Hence, pulmonary valve replacement may be necessary to reduce right ventricular volume overload. The aim of present study was to assess the effects of pulmonary valve replacement on right ventricular function after repair of Tetralogy of Fallot.

Materials and Methods: This retrospective study was carried out between July 2011 and October 2013 on 21 consecutive patients in Chamran Heart Center (Isfahan, Iran). The study included 13 male (61.9%) and 8 female (38.1%). Cardiac magnetic resonance was performed before, 6 and 12 months after pulmonary valve replacement in all patients (Babak Imaging Center, Tehran) with the 1.5 Tesla system. The main reason for surgery at Tetralogy of Fallot repaired time was Tetralogy of Fallot + Pulmonary insufficiency (17 cases) and Tetralogy of Fallot + Pulmonary atresia (4 cases). Right ventricular function was assessed before and after pulmonary valve replacement with Two-dimensional echocardiography and T-test was used to evaluate follow-up data.

Results: Right ventricular end-diastolic volume and right ventricular end-systolic volume were significantly decreased (P value<0.05). Right ventricular ejection fraction had a significant increase (P value<0.05). Right ventricular mass substantially shrank after pulmonary valve replacement. Moreover, pulmonary regurgitation noticeably decreased in patients. The other hemodynamic parameter such as left ventricular ejection fraction improved but was not significant (P value=0.79).

Conclusion: Pulmonary valve replacement can successfully restores the impaired hemodynamic function of right ventricle which is caused by direct consequence of volume unloading in patient. Pulmonary valve surgery in children with Tetralogy of Fallot who have moderate to severe pulmonary regurgitation leads to an improvement of right ventricular function.

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Introduction

Tetralogy of Fallot (TOF), the most common form of cyanotic congenital heart disease (CHD) with a prevalence of 0.26 to 0.8 per 1000 live births, is the combination of an overriding aorta, ventricular septal defects (VSD), pulmonary stenosis (PS), and hypertrophy of the right ventricle (RV). The aim of the surgeon is initially

obtain adequate pulmonary circulation via relieving pulmonary stenosis and closing ventricular septal defects. Despite the fact that long-term results are good, pulmonary incompetence (PI), RV dilation from pulmonary regurgitation (PR), residual atrial and/or ventricular septal defect, right ventricular outflow

*Corresponding author: Mohsen Sedighi, Cardiac Surgery Department, Chamran Heart Center, Isfahan University of Medical Sciences, Isfahan, Iran. Tell/Fax: 09131065680; E-mail: sedighi1984@yahoo.com

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tract (RVOT) aneurysm, pulmonary stenosis, and tachyarrhythmia are some of the abnormal consequences frequently encountered in patients with repaired TOF (1, 2). Although the hemodynamic burden associated with these abnormalities is often tolerated well, severe long standing PR has a deleterious effect on RV size and function resulting in an increased risk for severe arrhythmias and sudden death. Pulmonary valve replacement (PVR) is often performed in patients with TOF who have long-standing PR and severe RV dilatation that leads to direct volume unloading of the RV (3, 4).

Nowadays, cardiac magnetic resonance (CMR) is a valuable and noninvasive modality used in the assessment of biventricular volumes, morphological details of chambers, septum, defects, anomalous connections, and quantification of degree of heart valve regurgitation. Accordingly, the purpose of this study was to evaluate hemodynamic effects of PVR on RV function in children late after repair of TOF.

Materials & Methods

This was a retrospective study of 21 consecutive patients with repaired TOF who underwent PVR for severe pulmonary incompetence in Chamran Heart Center, Isfahan Medical University from July 2011 to October 2013. The study included 13 male and 8 female. The diagnosis of patients at TOF repair time was TOF+ Pulmonary insufficiency (PI) in 17 cases and TOF+ Pulmonary atresia (PA) in 4 cases. Clinical followed up at the time of PVR was performed daily during hospitalization and monthly after discharge by pediatric cardiologists for symptom assessment. All patients also underwent standard conventional transthoracic echocardiography and tissue Doppler imaging (TDI) echocardiography in the standard apical and parasternal two- and four-chamber views using an EKO 7 instrument (Samsung Medison, Korea) with 3–8MHz and 2–4MHz transducers. For more assessment, CMR imaging was performed in Babak Imaging Center (Tehran) with a Siemens 1.5T Avanto MRI scanner (Siemens Medical, Erlangen, Germany) before PVR to estimate flow information across valves,

Table 1. Characteristics of the patients

Variable	at TOF repair time	at PVR time
Age (year)	2.58±2.03*	11.7 ±2.89*
Female	13	% 61.9
Male	8	% 38.1
Total	21	% 100
Weight	10.2±4.5*	33.5±8.8*
Time from complete repair to date of PVR (year)	9.08±3.04	

Table 1 shows Characteristics of the 21 patients. *Data are mean ± SD.

TOF: Tetralogy of Fallot, PVR: Pulmonary valve replacement

chambers, RVOT and RV thickness that repeated 6 and 12 months after PVR. Main indications for PVR based on TDE and CMR approach were RV dilatation, RV volume decrease, RV thickness decrease and severe PI. The medical records of all patients were reviewed, and all patients gave written informed consents and the study was approved by our local ethics committee in medical center.

PVR was performed in all patients through a median sternotomy using standard cardiopulmonary bypass and mild systemic hypothermia (30°C). We chose the size of the valve according to the patient's body surface area (BSA). Cryo preserved pulmonary homografts were inserted in the orthotopic pulmonary position with 1 proximal and 1 distal end-to-end running suture after longitudinally opening the proximal pulmonary artery and slightly extending this incision if necessary across the former pulmonary annulus. In 17 patients, significant pulmonary insufficiency was present before PVR.

Statistical Analysis

Data were collected and analyzed using SPSS software (version 16, SPSS Inc, Chicago, IL, USA) and described as frequency, mean with standard deviation, or median with interquartile range. Differences between parameters before and after surgery were analyzed with paired Student *t* test. We considered situations in that surgery was performed when preoperative PR was low and did normalize after surgery (low specificity) or performing surgery when preoperative PR was severe and did not normalize after surgery (low sensitivity). Therefore, we selected the point at which sensitivity and specificity were equal. A probability value of <0.05 was considered statistically significant. Therefore, we selected the point at which sensitivity and specificity were equal. probability value of <0.05 was considered statistically significant.

Result

Twenty-one patients who underwent PVR were studied. The average age at PVR time was 11.7 years (range from 7-17 years). All characteristics of patients are listed in Table 1. Descriptive analysis of preoperative and outcomes of patients after PVR surgery was summarized in Table 2. As the table shows, right ventricular indexes significantly decreased after PVR surgery. Right ventricular end-diastolic volume (RVEDV) showed significant reduction in follow-up measures (P value<0.01), Right ventricular end-systolic volume (RVESV) significantly decreased after surgery (P value<0.01). Moreover, right ventricular ejection fraction (RVEF) improved after valve replacement, but was not meaningful (P

Table 2. Comparison of CMRI characteristics of patients before and after PVR

Variable *	Subjects (n=21)		P value
	Before PVR	After PVR	
RVEDV (ml/m ²)	184.70±15.55	112.11±22.02	<0.01
RVESV (ml/m ²)	99.88±17.51	57.88±12.65	<0.01
RV EF (%)	46.00±13.33	49.17±6.67	0.05
RV mass (g/m ²)	47.35±6.66	32.29±8.78	<0.01
LVEDV (ml/m ²)	76.05±27.28	88.17±20.23	<0.01
LVESV (ml/m ²)	35.82±7.35	40.23±5.97	0.06
LV EF (%)	53.76±7.74	54.29±5.54	0.79
PR (%)	48.29±1.49	12.58±5.24	<0.01

* Continues data are presented as Mean ± Standard Deviation and analyzed using t-student test. CMRI=Cardiac magnetic resonance imaging; PVR= pulmonary valve replacement; RVEDV=Right ventricular end-diastolic volume; RVESV=Right ventricular end-systolic volume; RVEF=Right ventricular ejection fraction; RV mass=Right ventricular mass; LVEDV= Left ventricular end-diastolic volume; LVESV= Left ventricular end-systolic volume; LVEF=Left ventricular ejection fraction; PR=Pulmonary regurgitation.

value=0.05). Also, the CMR result showed that right ventricular mass considerably shrank after PVR (P. value<0.01).The trend of left ventricular indexes presented favorable effect of PVR on left ventricle function. Pulmonary valve replacement significantly increased quantities of left ventricular end-diastolic volume (LVEDV) (P value<0.01). Left ventricular end-systolic volume (LVESV) (P value=0.06), and left ventricular ejection fraction (LVEF) (P value=0.79) were not difference meaningfully. In addition, PVR surgery resulted in significant reduction of pulmonary regurgitation (P value<0.01) (Figure 1).

Discussion

In this study, by means of CMR imaging in the follow-up of 21 consecutive patients who underwent PVR, we found a significant decrease in RV volumes during 6-12 month follow-up. In fact, elimination of PR is the most important factor lead to RV volume unloading and resulted in improvement of RV function. The reduction of volume of the dilated right ventricle is in conformity with the results of several previous studies that investigated the effect of PVR. Additionally, our data indicates that RVEDV and RVESV decrease as compared with their preoperative values, significantly (Figure 1). On average, global RV systolic function, measured as ejection fraction (RVEF), was improved which is not in accordance with Bove et al and Vliegen et al findings (5, 6). LVEDV increases meaningfully, whereas global LV systolic function, measured as ejection fraction (LVEF) remains unchanged (Table 2). This finding suggests that while PVR can reduce RV size, the impact on RV function might have been affected by pre-existing scarring and fibrosis.

CMR is a valuable and accurate technique used in the assessment of both structure and function of the heart. Use of CMR, as Gold standard method,

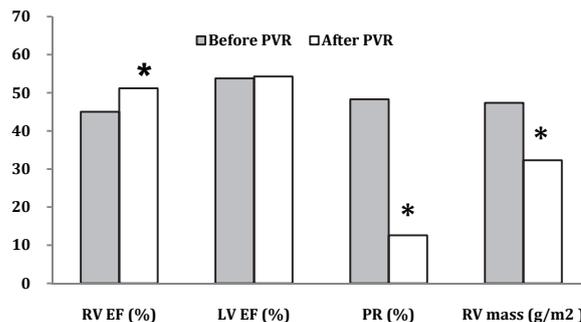


Figure 1. Comparison of ventricular indexes before/after pulmonary valve replacement. The figure shows proportional changes in RVEF and LVEF and PR volume before and after PVR in 21 patients. Note the significant decrease of PR volume and RV mass (* P<0.05) whereas RVEF and LVEF changes is not proportional. RVEF: right ventricular ejection fraction; LVEF: left ventricular ejection fraction; PR: pulmonary regurgitation; RV: right ventricle

has become established for acquisition quantitative information on biventricular size and function, blood flow measurements, myocardial viability, and cardiovascular anatomy. Moreover, CMR supports clinical decision making in patients with congenital heart disease by providing comprehensive clinical and functional information on cardiovascular abnormalities (6-8).

There is a close relationship between the degree of PR and RV diastolic dimensions and stroke volume. PR enhances right ventricular preload and eventually leads to right ventricular dilatation. In chronic PR, RV systolic function is initially preserved that may last for years, but the compensatory mechanisms begin to fail, RV mass-to-volume ratio decreases, end-systolic volume increases, and ejection fraction decreases (9, 10). Bernheim first in 1910 recognized interdependence between LV and RV function. He assumed that alterations in the size and function of the LV adversely affect the geometry and function of the RV, a phenomenon named 'Bernheim effect' (11-13).

There are strong evidences that elimination or reduction of PR is associated with symptomatic improvement, significant decrease in RVESV and RVEDV, and no significant change in RV ejection fraction. Moreover, there is some evidence that indices of exercise tolerance improve (14). We found a significant decrease in RV dilatation after PVR (P value<0.05). This observation is in accordance with previous investigation, who has found a decrease in RV dilatation of approximately 30% in patients with TOF after PVR (15, 16). RV systolic function was measured with the RV ejection fraction (RVEF) and the RVESV. Systolic performance was corrected for the degree of PR. In a previous study by Bove et al (17), a significant reduction of RV dilatation after PVR was found in patients with TOF; only a slight increase in the RVEF was found, although most patients reported a

subjective improvement in exercise tolerance. In contrast, in another report by van Straten et al, both RV dilatation and systolic function improved along the same time course. In case of recurrence of PR after PVR, there is less decrease of RV volume and subsequently, less improvement of systolic function (RVEF) when compared with that in patients who did not experience recurrence of PR. Patient's symptom and most patients with symptoms before surgery were now symptom free which is in agreement with previous studies (16, 18). Clinical experiences have been shown that children may develop clinical symptoms lately whereas the ventricular function is already seriously impaired. Additional arguments support the strategy of predisposition of moderate to severe PR for ventricular dys rhythmias and cardiac arrest, whereas PVR may not have led to reduce the incidence of tachyarrhythmia or death (19).

PVR may cause to a reduction in RV dilatation, improved exercise tolerance and decreased tachyarrhythmia's. There is noticeable difficulty in comparing surgical series: patients may be referred for surgery at different stages in the disease stage; there is considerable heterogeneity in the basic anatomy; many patients have additional lesions that are addressed at the time of pulmonary valve replacement (20). This was a retrospective design and the main limitation of this study was the small patient sample. Larger study populations might enable demonstration of statistically significant improvement in cardiopulmonary exercise capacity and RVEF postoperatively. Furthermore, longer follow-up time is needed to assess the long-term effects of PR on RV function before and after PVR.

Conclusion

In conclusion, in patients late after total correction for TOF who undergo PVR for moderate to severe PI and RV dilatation, CMR imaging measurements showed remarkable hemodynamic improvement in RVEDV and RVESV which is caused by direct consequence of volume unloading in RV after PVR and RVEF was improved significantly. The diminish in RVEDV was compensated by reduction in RVESV after correction of PR. PVR in children with TOF who have moderate to severe PR leads to an improvement of RV function.

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Conflict of Interest

The authors declare no conflicts of interest.

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