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Congenital Heart Disease

Outcomes of Pulmonary Valve Replacement in 170 Patients With Chronic Pulmonary Regurgitation After Relief of Right Ventricular Outflow Tract Obstruction

Implications for Optimal Timing of Pulmonary Valve Replacement

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Objectives The objectives of this study were to evaluate outcomes of pulmonary valve replacement (PVR) in patients with chronic pulmonary regurgitation (PR) and to better define the optimal timing of PVR.

Background Although PVR is effective in reducing right ventricular (RV) volume overload in patients with chronic PR, the optimal timing of PVR is not well defined.

Methods A total of 170 patients who underwent PVR between January 1998 and March 2011 for chronic PR were retrospectively analyzed. To define the optimal timing of PVR, pre-operative and post-operative cardiac magnetic resonance imaging (MRI) data ($n = 67$) were analyzed.

Results The median age at the time of PVR was 16.7 years. Follow-up completeness was 95%, and the median follow-up duration was 5.9 years. Overall and event-free survival at 10 years was 98% and 70%, respectively. Post-operative MRI showed significant reduction in RV volumes and significant improvement in biventricular function. Receiver-operating characteristic curve analysis revealed a cutoff value of 168 ml/m^2 for non-normalization of RV end-diastolic volume index (EDVI) and 80 ml/m^2 for RV end-systolic volume index (ESVI). Cutoff values for optimal outcome (normalized RV volumes and function) were 163 ml/m^2 for RV EDVI and 80 ml/m^2 for RV ESVI. Higher pre-operative RV ESVI was identified as a sole independent risk factor for suboptimal outcome.

Conclusions Midterm outcomes of PVR in patients with chronic PR were acceptable. PVR should be considered before RV EDVI exceeds 163 ml/m^2 or RV ESVI exceeds 80 ml/m^2, with more attention to RV ESVI. (J Am Coll Cardiol 2012;60:1005–14) © 2012 by the American College of Cardiology Foundation

Relief of right ventricular (RV) outflow tract obstruction in tetralogy of Fallot or similar physiology often results in pulmonary regurgitation (PR). The resultant chronic volume overload can lead to RV dilation, biventricular dysfunction, heart failure symptoms, arrhythmias, and sudden death (1–5). Pulmonary valve replacement (PVR) can lead to improvement in functional class and a substantial decrease or normalization of RV volumes (6,7). Other potential benefits of PVR are improvement in exercise capacity (8) and decrease in QRS duration (9). However, benefits of PVR have to be weighed against the risks of this procedure.

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Although operative mortality of PVR is low (6), post-operative morbidities are not negligible (10) and patients are exposed to the risk of repeat PVR (11–13). PVR is indicated when patients become symptomatic or at risk for life-threatening arrhythmias (14). For asymptomatic patients, there have been debates regarding the optimal timing of PVR (15–19). Magnetic resonance imaging (MRI) is a gold standard for evaluating RV volumes and function (20), and these MRI parameters can be used to decide the indications for PVR. Many studies dealing with changes in MRI parameters after PVR have been reported (7–9,21–26). However, most of them have a limitation of small patient

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Abbreviations and Acronyms

EDVI = end-diastolic volume index

EF = ejection fraction

ESVI = end-systolic volume index

LV = left ventricle/ventricular

MRI = magnetic resonance imaging

PR = pulmonary regurgitation

PVR = pulmonary valve replacement

RV = right ventricle/ventricular

VT = ventricular tachycardia

numbers, and there are few studies suggesting the optimal timing of PVR (7–9). The objectives of this study were to evaluate outcomes of PVR performed in patients with chronic PR and to better define the optimal timing of PVR by analyzing MRI parameters.

Methods

Patients. Between January 1998 and March 2011, 170 patients underwent surgical PVR for chronic PR after repair of tetralogy of Fallot or similar physiology. Patients with significant valvular and/or subvalvular pulmonary stenosis, RV to pulmonary artery conduits, and other significant confounding congenital heart diseases were excluded. Indications for PVR were symptoms and signs attributable to RV volume overload, presence of significant associated lesions such as branch pulmonary artery stenosis and tricuspid regurgitation, and sustained tachyarrhythmias. For asymptomatic patients, we prescribed PVR when RV end-diastolic volume index (EDVI) assessed by MRI approached 170 ml/m^2. The institutional review board of Sejong General Hospital approved this retrospective study. Data were obtained by review of medical records and direct telephone contact. Table 1 summarizes the demographic and preoperative characteristics of the study patients.

Surgical procedures. PVR was performed through median sternotomy on cardiopulmonary bypass with mild hypothermia. Aortic cross-clamping was dependent on the surgeon's preference or on concomitant procedures. Choice of prosthetic pulmonary valves was at the discretion of the surgeon. When deemed necessary, RV reduction (aneurysm resection/plication/exclusion or RV remodeling) was performed according to the surgeon's preference. Table 2 summarizes the surgical data.

Cardiac MRI. Since 2002, we have performed cardiac MRI as a part of routine pre-operative evaluation for PVR, and 118 patients (69%) have undergone the procedure. Among these, 67 patients (57%) underwent post-operative MRI at a median of 9.7 months (1.1 months to 7.1 years) after PVR. Six patients underwent only post-operative MRI without pre-operative MRI. Therefore, post-operative MRI data were available in 73 patients.

Studies were performed with a 1.5-T Gyroscan Intera CV system (Philips Medical Systems, Best, the Netherlands). A multiphase acquisition was obtained using a steady-state free precession pulse sequence in 2- and 4-chamber planes. From these images, 10 to 12 contiguous short-axis slabs perpendicular to the long axis of the left ventricle (LV) were obtained (slice thickness 6 to 8 mm; interslice gap 0 to 2 mm). Biventricular volumetric analysis was performed using Extended MR Workspace software (Philips Medical Systems). For the evaluation of PR, through-plane velocity imaging perpendicular to the main pulmonary artery was performed using a breath-holding, electrocardiogram-triggered, cine phase contrast pulse sequence. Forward and regurgitant pulmonary volume flow was measured from the velocity-encoded images by manually tracing the main pulmonary artery contour. Flow volumes were calculated by multiplying contour area by average flow velocity within the contour. Flow volumes were summed to give total forward flow and total regurgitant flow per cardiac cycle. When significant artifacts by prosthetic valves made direct

Table 1 Demographic and Pre-Operative Characteristics of the Patients

Male/female	103/67
Fundamental diagnosis	
TOF	139 (82)
PA with VSD	15 (9)
DORV (TOF type)	14 (8)
APVS	2 (1)
Age at repair, yrs	2.0 (0.2–44.1)
Type of RVOT reconstruction	
Transannular patch	124 (73)
Pulmonary valvotomy	26 (15)
Monocusp valve	20 (12)
No. of prior operations before PVR	1.4 ± 0.6
Age at PVR, yrs	16.7 (4.6–60.2)
Interval between repair and PVR, yrs	13.8 (4.0–27.5)
NYHA functional class*	
I	65 (38)
II	91 (54)
III	12 (7)
IV	1 (1)
TR grade*	
None	9 (5)
Trivial	60 (35)
Mild	83 (49)
Moderate	13 (8)
Severe	4 (2)
QRS duration (n = 79), ms†	147 (85–203)
Arrhythmia	
AFL	4 (2)
AF	3 (2)
VT	3 (2)
AV block	3 (2)
SA node dysfunction	3 (2)
Others	4 (2)
Cardiopulmonary exercise test (n = 42)	
Peak VO_2, ml/kg/min	30 (11–40)
% Predicted peak VO_2, %	75 (21–115)

Values are n, n (%), median (range), or mean ± SD. *Data not available for 1 patient. †QRS ≥180 ms in 7 patients.

AF = atrial fibrillation; AFL = atrial flutter; APVS = absent pulmonary valve syndrome; AV = atrioventricular; DORV = double outlet right ventricle; NYHA = New York Heart Association; PA = pulmonary atresia; PVR = pulmonary valve replacement; RVOT = right ventricular outflow tract; SA = sinoatrial; TOF = tetralogy of Fallot; TR = tricuspid regurgitation; VO_2 = oxygen consumption; VSD = ventricular septal defect; VT = ventricular tachycardia.