Optimal timing of pulmonary valve replacement in tetralogy of Fallot

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Right Ventricular Function after Pulmonary Valve Replacement in Patients with Tetralogy of Fallot

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Abstract

Background

To assess the time course of right ventricular (RV) function improvement after pulmonary valve replacement (PVR) in patients 25.2 ± 7.0 years after repair of tetralogy of Fallot (TOF).

Methods

Cardiac magnetic resonance imaging was performed before, at 7 months and at 19 months after PVR in 25 consecutive TOF patients on a Philips 1.5T system. RV function was obtained from gradient echo sequences in the short axis plane and pulmonary flow was assessed using a velocity encoded phase-contrast sequence. The paired t test was used to evaluate follow-up data. The independent samples t test was used to assess differences based on the presence of recurrent pulmonary regurgitation (PR).

Results

Mean indexed RV end-diastolic volume (RV-EDV-I) decreased from 166.9 ± 41.3 ml/m^2 before PVR to 113.5 ± 35.7 ml/m^2 (P<0.001) at 7 months and 111.7 ± 41.1 ml/m^2 (P=NS) at 19 months follow-up. The RV ejection fraction corrected for PR (RV-EF$_{cor}$) improved from 25.0 ± 7.7% before surgery to 44.1 ± 11.9% (P<0.001) and 45.2 ± 11.1% (P=NS), respectively. Recurrent pulmonary regurgitation (RPR) after PVR was found in 11 patients (RPR group), whereas 14 patients had no recurrent PR (NRPR group). Total reduction of RV-EDV-I at 19 months follow-up was more prominent in the NRPR group than in the RPR group (40.1 ± 9.9% versus 25.5 ± 19.9%, P<0.05). Furthermore, in the NRPR group, improvement of RV-EF$_{cor}$ was more marked than in the RPR group (25.2 ± 8.8% to 49.8 ± 5.8% versus 24.6 ± 6.1% to 38.4 ± 13.1%, P<0.05).

Conclusion

In TOF patients RV function improves rapidly after PVR and is sustained at 19 months follow-up in the majority of patients. However, recurrence of pulmonary regurgitation after PVR appears to reduce recovery of right ventricular systolic function.

Introduction

Tetralogy of Fallot (TOF), the most common of all cyanotic congenital heart diseases worldwide, is the combination of an overriding aorta, ventricular septal defect (VSD), pulmonary stenosis and hypertrophy of the right ventricle. The aim of the surgeon at initial repair is to obtain an adequate pulmonary circulation. In order to achieve this, the pulmonary stenosis is relieved and in addition, the ventricular septal defect is closed using a pericardial patch [1]. Although long-term results are good [2-4], most patients have some degree of pulmonary valve incompetence after repair, following the relief of pulmonary stenosis. The deleterious effects of longstanding pulmonary regurgitation (PR) on right ventricular (RV) size and function, resulting in an increased risk for severe arrhythmias and sudden death, have been well documented [5-8]. Furthermore, exercise capacity is often diminished in patients with severe dilatation of the right ventricle [9,10]. Recent studies have shown that RV dysfunction in Fallot patients is also affected by the initial surgical procedure and the formation of aneurysms of the RV outflow tract (RVOT), which commonly occurs after initial repair [11,12].

Pulmonary valve replacement (PVR) is often performed in Fallot patients with longstanding PR in combination with severe RV dilatation and leads to direct volume unloading of the RV. In a recent study by Vliegen et al. the early haemodynamic effects of PVR in adults 24 years after initial repair of TOF were evaluated [13]. A significant decrease of right ventricular dilatation of approximately 30% and an improvement of systolic function and functional class according to the New York Heart Association (NYHA) classification in these patients 7 months after surgery was found. Mid- and long-term outcome in patients after PVR is largely unknown. Several studies have reported residual or recurrent PR after surgery [14,15]. However, the clinical significance of recurrent PR and the time course of RV recovery have not been evaluated systematically.

Accordingly, the purpose of this study was to assess the time course of RV function improvement after pulmonary PVR in patients late after repair of TOF.

Methods

Study subjects

At our institution, between 1993 and 2002 a total of 65 patients underwent PVR for PR after correction of TOF. Since 1997, 25 consecutive adult TOF patients, who underwent PVR for right ventricular dilatation and PR 25.2 ± 7.0 years after repair of TOF and had been evaluated preoperatively with cardiac MR, were included. MR imaging was performed in all patients with a median of 5.3 months (range 3.1 – 15.6 months) before PVR and repeated at 7 and 19 months (median 7.2, range 4.3 – 13.6 and 18.6, range 17.2 – 34.9) months after the operation. Patient characteristics are shown in table 6.1.

Table 6.1. *Baseline Characteristics.*

Characteristics	Patients Without Recurrent PR (N=14)	Patients With Recurrent PR (N=11)
Male sex	8 (32%)	7 (28%)
Previous palliation	7 (28%)	4 (16%)
Total repair		
RV patch	3 (12%)	3 (12%)
Transannular patch	5 (20%)	4 (16%)
Arrhythmias	4 (16%)	1 (4%)
QRS duration >180 msec	3 (12%)	4 (16%)
Pulmonary stenosis	2 (8%)	3 (12%)
NYHA (mean ± SD)*	2.0 ± 0.7	2.0 ± 0.6
Age at repair (y)†	5.0 (1.8 – 21.0)	4.9 (2.0 – 9.2)
Age at PVR (y)†	32.8 (18.4 – 45.6)	25.0 (17.0 – 42.1)

Note.—Unless otherwise indicated, data are number of patients, and data in parentheses are percentages.
** Data are mean ± standard deviation. † Data are median values. Data in parentheses are ranges.*

Median age at total repair (closure of VSD in combination with relief of pulmonary stenosis) was 4.9 years (mean 5.7 ± 4.3, range 0.4 to 21.0 years). A palliative procedure, prior to total repair was performed in 11 patients (44%). Nine patients (36%) had received a trans-annular patch. From all patients an electrocardiogram was obtained shortly before PVR. QRS duration was manually measured from the first deflection in any lead to the latest deflection in any lead by the same observer (HWV). This study was approved by the local medical ethical committee and informed consent was obtained from all patients.

Surgical Procedures

PVR was performed at a median age of 28.9 years (range 17.0 to 45.6 years), without peri-operative mortality. Operations were performed by two surgeons with 10 years experience in valve replacements. All patients were operated on with normothermic or moderately hypothermic cardiopulmonary bypass. All pulmonary valve insertions were performed on the beating heart. Aortic cross-clamping was dependent on the surgeon's preference or on concomitant procedures. Recurrent ventricular septal defects (VSD) were closed in 3 patients. All patients received a cryopreserved pulmonary homograft, orthotopically inserted in the pulmonary position. Calcified outflow tract patch material was resected as much as possible. In 4 patients the RVOT diameter was surgically reduced, in 3 of them a pericardial patch was used in order to obtain a better fit between the outflow tract of the right ventricle and the homograft. In 7 other patients a patch was used for the same purpose but without RVOT reduction. In 5 patients, significant pulmonary stenosis was present before PVR. In all 5 patients the stenosis was relieved during surgery for valve replacement.

Magnetic Resonance Imaging

MR studies were performed on a 1.5 Tesla system (NT15 Gyroscan, Philips Medical Systems, Best, The Netherlands). The magnetic resonance (MR) protocol has been described previously [13]. In summary, a multiphase, electrocardiography (ECG) triggered, multishot echoplanar gradient echo technique was used to acquire short axis images. Images were acquired during breath holds. Slice thickness 10 mm with a 0.8 to 1.0 mm section gap. The flip angle was 30 degrees and the echo time was 5 to 10 msec. Eighteen to 25 frames per cycle resulted in a temporal resolution of 22 to 35 msec.

Velocity mapping was performed with the use of a velocity-encoded phase contrast sequence. For velocity mapping of the pulmonary artery, sagittal and coronal spin-echo scout images were used to construct a double oblique plane perpendicular to the vessel. Pulmonary flow measurements were performed halfway between the pulmonary valve and the bifurcation or approximately 2 cm proximal to the bifurcation when no pulmonary valve was present. The sequence was encoded for through-plane velocities of up to 200 cm/s. For velocity mapping of the flow through the tricuspid valve, 2- and 4-chamber gradient echo images were used to construct a parallel plane through the valve. The flip angle was 20 degrees and the echo time was 12 msec. Temporal resolution was between 25 and 35 msec. No sedation was used in any of the patients.

Post-processing

All images were quantitatively analyzed on an IPC workstation (SUN Microsystems Inc., Mountain View, California, USA) using two software packages, which were developed and validated at our institution [16] and can be performed with low inter- and intraobserver variability [17,18]. All contours were drawn manually, by the same observer (AvS). Velocity maps were analyzed using the FLOW analytical software package. Contours were drawn for the main pulmonary artery and flow was obtained from the velocity data of each voxel in all phases. Flow curves were obtained using this method for flow in the main pulmonary artery during a cardiac cycle. The regurgitant fraction was calculated by the formula: (regurgitant flow / systolic forward flow) * 100. PR was considered significant if the regurgitant fraction was more than 5% of the systolic forward flow. In addition, flow curves for flow through the tricuspid valve were assessed using the same method.

The transverse gradient echo sequences of the ventricles were analyzed using the MASS software [16]. RV end-diastolic volume (RV-EDV) and RV end-systolic volume (RV-ESV) were assessed by drawing contours around the lumen of the right ventricle in end-diastole and end-systole in all slices as described previously [19]. Using slice summation, MASS calculated the total RV-EDV and RV-ESV. RV stroke volume (RV-SV) was then calculated by MASS by deducting the RV-ESV from the RV-EDV, RV ejection fraction (RV-EF) was calculated by dividing the RV-SV by the RV-EDV. RV-EF was then corrected for regurgitation of the tricuspid and pulmonary valves by dividing the net pulmonary flow by the RV-EDV, thus $RV\text{-}EF_{cor}$ = net pulmonary flow (pulmonary forward flow – regurgitant flow) / RV-EDV [13]. RV-EDV and RV-ESV were indexed for body surface area (respectively RV-EDV-I and RV-ESV-I).

Statistical Analysis

All data are presented as mean values ± 1 SD, unless stated otherwise. The data were analyzed using SPSS for Windows (version 10.0, SPSS, Chicago, Illinois). The paired samples Student's t-test was used to evaluate post PVR changes in MR parameters and the independent samples Student's t-test was used to identify differences between patients with and without recurrent PR. Statistical significance was considered achieved at the $P<0.05$ level. Repeated measuring of the variables of interest (e.g. end-diastolic volume) was accounted for by a repeated measures model (linear mixed model). Testing for equality of slopes for regression lines of variables of interest versus time was performed for variables RV-EDV-I and EF_{cor}. The latter variable, being a percentage, did not show gross violations of normality in the Kolmogorov-Smirnov test nor by visual inspection.

Results

Mean RV-EDV-I decreased from 166.9 ± 41.3 ml/m^2 before PVR to 113.5 ± 35.7 ml/m^2 ($P<0.001$) at 7 months follow-up and 111.7 ± 41.1 ml/m^2 ($P=0.46$ compared to 7 months) at 19 months follow-up. The improvement of RV dilatation was larger than the decrease in regurgitant volume through the pulmonary valve (figure 6.1).

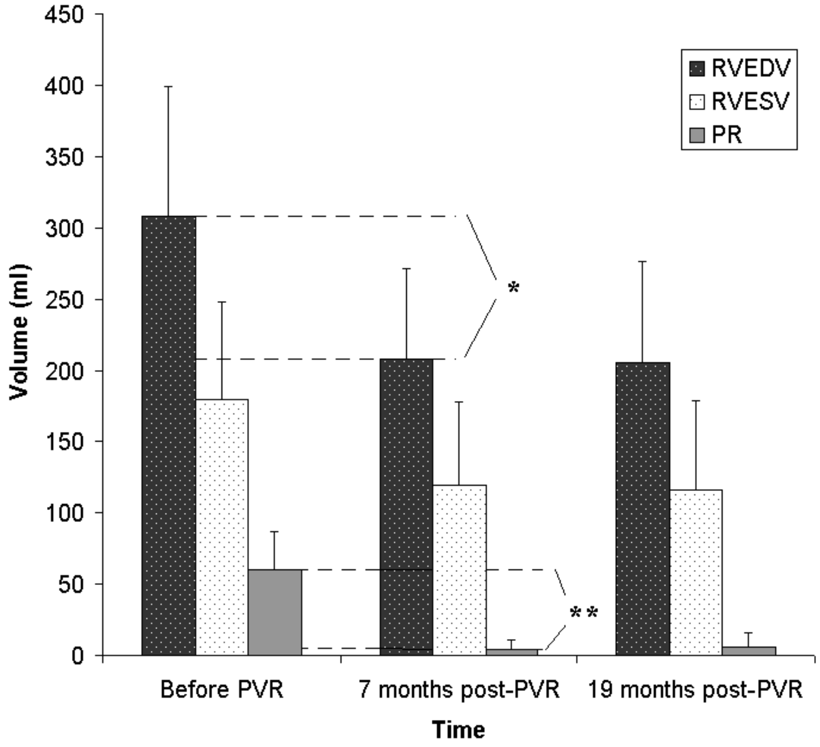

Figure 6.1. *Proportional changes in RV volumes and pulmonary regurgitant volume during follow-up. Pulmonary regurgitation is virtually absent at 7 months follow-up. Note that the change in PR is not proportional to the decrease in RV volumes indicating a non-linear relationship.*

The RV-ESV-I decreased from 98.4 ± 36.7 ml/m^2 preoperative to respectively 65.1 ± 35.5 ml/m^2 (P<0.001) and 63.3 ± 38.5 ml/m^2 (P=0.21) at 7 and 19 months after surgery. The RV-EF did not show a significant change during follow-up. Before valve replacement the RV-EF was 42.6 ± 11.2%, while at 7 months follow-up the RV-EF was essentially unchanged at 44.3 ± 11.0% (P=0.76) and to 46.9 ± 11.4% (P=0.10) at 19 months follow-up. However, after correction for regurgitation, the RV-EF$_{cor}$ improved significantly from 25.0 ± 7.7% to 44.1 ± 11.9% (P<0.001) and 45.2 ± 11.1% (P=0.39 compared to 7 months) at 7 and 19 months after PVR, respectively. Furthermore, functional class according to the NYHA classification improved from 2.0 ± 0.6 to 1.3 ± 0.5 (P<0.001) at 7 months follow-up and 1.3 ± 0.7 (P=0.65 compared to 7 months) at 19 months follow-up.

Recurrent PR

Before PVR, all patients had significant PR of more than 20%. PR decreased from a mean of 45.4 ± 10.4% to 4.2 ± 7.9% at 7 months ($P<0.001$) followed by a slight increase to 6.7 ± 10.9% at 19 months follow-up ($P=0.06$). At the last follow-up, residual or recurrent PR of more than 5% was found in 11 patients (RPR group), whereas 14 patients did not show recurrent PR (NRPR group). Five patients had PR at 7 months (early PR), while in the remaining 6 patients the recurrent PR was newly detected at 19 months post-PVR (late PR). PR was mild (between 5 and 20%) in all but 2 of the patients with recurrent PR who had moderate PR (20-40%).

Baseline characteristics for both groups were similar (table 6.2). Operation techniques, however, were different between NRPR and RPR group patients. Ten patients received a pericardial patch to adapt the homograft to the RVOT, only one of them had early recurrent PR. Surgical reduction of the RVOT in case of aneurysm formation was performed in 4 patients. No early recurrence of PR was seen in these patients. Three patients both underwent surgical reduction of the RVOT as well as insertion of a pericardial patch in the RVOT. In this group, no patient had early recurrent PR. Late recurrent PR, however, was discovered in 4 patients with a pericardial patch and one patient with surgical reduction of the RVOT.

Table 6.2. *Baseline and Surgical Values in Patients without Recurrent PR and Patients with Recurrent PR.*

Variable	Patients Without Recurrent PR (N=14)	Patients With Recurrent PR (N=11)
Baseline		
RV-EDV-I (ml/m^2)	170.5 ± 43.3	162.0 ± 40.5
RV-ESV-I (ml/m^2)	95.2 ± 34.7	102.4 ± 40.7
PR (%)	48.6 ± 11.4	41.6 ± 8.1
RV-EF (%)	45.9 ± 8.9	38.7 ± 11.4
RV-EF_{cor} (%)	25.2 ± 8.8	24.6 ± 6.1
EDFF (ml)	3.4 ± 5.6	5.3 ± 5.1
RVOT (mm)	35.3 ± 5.4	35.9 ± 7.7
Surgery		
Homograft diameter (mm)	25.3 ± 2.0	26.1 ± 1.7
Pericardial patch used (n)	5	5
Reduction of RVOT (n)	3	1

*Note. – Data are mean ± standard deviation, unless otherwise indicated. No difference in values between groups was statistically significant. * Data ore number of patients.*

Recurrent PR and RV recovery

Table 6.3 summarizes the haemodynamic and clinical parameters before and after PVR for both groups. Mean RV-EDV-I before PVR was 170.5 ± 43.3 ml/m^2 in the NRPR group. Seven months after PVR, mean RV-EDV-I in this group had decreased to 111.1 ± 19.0 ml/m^2 ($P<0.001$ compared to baseline) and at 19 months follow-up a further decrease to 99.4 ± 19.9 ml/m^2 ($P<0.01$ compared to 7 months after PVR) was found. The patients in the RPR group had a mean RV-EDV-I of 162.0 ± 40.5 ml/m^2 before PVR. At 7 months follow-up, RV-EDV-I had decreased to 116.7 ± 51.0 ml/m^2 ($P<0.01$ compared to baseline) in these patients. At 19 months follow-up RV-EDV-I had slightly increased to 122.6 ± 56.3 ml/m^2 ($P=0.40$ compared to 7 months after PVR).

The time course of recovery of RV function was different between the NRPR and the RPR group. Total reduction of RV-EDV-I in patients in the RPR group was less than that in patients in the NRPR group (-25.5 ± 17.9% versus -40.1 ± 9.9%, P=0.04). Moreover, patients with early recurrent PR showed less reduction of RV-EDV-I in the first 7 months after PVR compared to the patients without early recurrent PR (-19.8 ± 13.6% versus -34.9 ± 12.3%, P=0.03). Late recurrent PR was associated with an increase of RV-EDV-I between 7 and 19 months of +14.7 ± 10.5%, while the patients without early or late recurrent PR showed a further decrease of RV-EDV-I of -9.0 ± 8.9% (P<0.01). Furthermore, the repeated measures analysis (linear mixed model) indicated that the time course of decrease of RV dilatation is different between the NRPR and RPR groups (P=0.02).

Three patients with recurrent PR (2 patients had early, while 1 patient had late recurrent PR) did not show reduction of RV-EDV-I. These three patients neither had an improvement of RV systolic function, nor an improvement of functional class. These observations indicate that recurrent PR has a negative effect on the recovery of RV function. The RV systolic function improved along the same time course as the improvement of RV dilatation. The mean RV-ESV-I before PVR was 95.2 ± 34.7 ml/m^2 in the NRPR group and 102.4 ± 40.7 ml/m^2 in the RPR group. In NRPR group, mean RV-ESV-I had decreased to 58.3 ± 16.3 ml/m^2 (P<0.01 compared to baseline MRI) after 7 months, followed by a further decrease at 19 months to 50.6 ± 12.8 ml/m^2 (P=0.02 compared to 7 months after PVR), while the patients in the RPR group had a mean RV-ESV-I of 73.9 ± 50.7 ml/m^2 at 7 months (P=0.02 compared to baseline) and 75.2 ± 54.4 ml/m^2 at 19 months (P=0.82 compared to 7 months after PVR).

The RV-EF corrected for regurgitation increased from 25.2 ± 8.8% to 48.9 ± 9.3% at 7 months (P<0.01 compared to baseline) to 49.8 ± 5.8% at 19 months (P=0.14 compared to 7 months after PVR) in NRPR group, and from 24.6 ± 6.1% to 38.3 ± 12.5% at 7 months (P=0.03 compared to baseline) to 38.4 ± 13.1% at 19 months (P=0.86 compared to 7 months after PVR) in RPR group. The repeated measures analysis (linear mixed model) showed that the time course of improvement of RV-EF corrected for regurgitation is different (P=0.04).

Table 6.3. *Time Course of Improvement of Hemodynamic Parameters.*

	Baseline		7 months Follow-up		19 months Follow-up	
	Patients Without Recurrent PR	Patients With Recurrent PR	Patients Without Recurrent PR	Patients With Recurrent PR	Patients Without Recurrent PR	Patients With Recurrent PR
MRI						
PR (%)	47.9 ± 11.3*	41.9 ± 8.5*	0.8 ± 2.2*†	8.6 ± 10.3*†‡	0.1 ± 0.5†	15.0 ± 12.3†‡
TR (%)	1.6 ± 3.0†	7.0 ± 9.0†	1.8 ± 2.4	3.0 ± 4.9	3.2 ± 4.0	3.2 ± 5.0
RV-EDV-I	170.5 ± 43.3*	162.0 ± 40.5*	111.1 ± 19.0*§	116.7 ± 51.0*	99.4 ± 19.9§	122.6 ± 56.3
RV-ESV-I	95.2 ± 34.7*	102.4 ± 40.7‖	58.3 ± 16.3*‡	73.9 ± 50.7‖	50.6 ± 12.8‡	75.2 ± 54.4
RV-EF	45.9 ± 8.9	38.7 ± 11.4	47.2 ± 9.7	40.6 ± 11.9	51.4 ± 9.4†	41.6 ± 11.6†
RV-EFcor	25.2 ± 8.8*	24.6 ± 6.1‖	48.9 ± 9.3*†	38.3 ± 12.5†‖	49.8 ± 5.8†	38.4 ± 13.1†
Clinical examination						
NYHA	2.0 ± 0.7	2.0 ± 0.6	1.2 ± 0.3	1.5 ± 0.6	1.1 ± 0.2	1.5 ± 1.0

**a P< 0.01 between baseline and 7-month follow-up.*

†P< 0.05 between patients without recurrent PR and patients with recurrent PR.

‡P< 0.05 between 7 and 19-month follow-up.

§P< 0.01 between 7 and 19-month follow-up.

‖P< 0.05 between baseline and 7-month follow-up.

Discussion

In this study, cardiac MRI was used for follow-up of 25 consecutive adult patients who underwent pulmonary valve replacement late after repair of tetralogy of Fallot. We found a significant decrease of right ventricular volumes at 7 months follow up, followed by sustained benefit at 19 months. However, the individual recovery of RV function varied substantially. Several observations were made that could explain variations in the response of RV function after PVR. Nearly half of the patients had some degree of recurrent PR after surgery. In addition, we observed that the recovery of RV function was hampered by the presence of recurrent PR after valve replacement. The negative effect of PR on RV recovery could not be explained by differences in baseline characteristics between patients with and without recurrent PR. The surgical procedure during PVR, however, was different between both groups. Patients in whom the RVOT volume was reduced and/or a pericardial patch was used had less chance of early recurrent PR. Therefore, we speculate that the surgical procedure might affect the recurrence of PR and subsequently the recovery of RV function.

RV dilatation

We found a significant decrease of RV dilatation after PVR. This observation is in accordance with previous studies, which have shown a decrease of RV dilatation of approximately 30% in Fallot patients following PVR in children [14,20] at follow-up studies up to two years after surgery. These previous studies have suggested that the volume unloading due to elimination of PR may be the most significant factor. However, in these studies, no distinction was made between patients with and without recurrent PR.

In our population, the time course of decrease of RV dilation was influenced by the recurrence of PR. Furthermore, if recurrent PR was detected at early follow-up, decrease of RV volumes was limited and little additional decrease of RV volumes was found at late follow-up. Moreover, the late recurrence of PR coincided with a late increase of RV volumes, although initial decrease of RV volumes was in the normal range. This finding supports the concept that recurrent PR has a detrimental effect on RV function after PVR.

RV systolic function

RV systolic function was measured by the RV ejection fraction and by the RV end-systolic volume. Systolic performance was corrected for the degree of PR as previously reported [13]. In a previous study by Bove et al. in 11 Fallot patients, a significant reduction of RV dilatation after PVR was found, whereas the EF only marginally increased [20], although most patients reported a subjective improvement of exercise tolerance. The improvement of systolic function was possibly obscured in that study, because RV-EF was not corrected for the change in loading conditions.

In the present study, both RV dilatation as well as systolic function improved along the same time course. In case of recurrence of PR after PVR, there is less decrease of RV volumes and subsequently, less improvement of systolic function, compared to patients without recurrence of PR. Therefore, we speculate that the improvement of systolic function is a direct consequence of the volume unloading after valve replacement.

Recurrent PR after PVR

The recurrence of PR after PVR has been reported in several other studies.

Therrien et al. [15] studied 70 patients before and after PVR using echocardiography. In their study 92% of the patients had at least moderate PR before operation. In 11 (20%) of the patients after PVR at least moderate recurrent PR was found. Warner et al. [14] studied 16 Fallot patients who underwent PVR for moderate to severe PR. After PVR, 4 patients suffered from moderate recurrent PR. All 4 patients had a unilateral or bilateral stenosis of the pulmonary artery branches as indicated by postoperative pulmonary artery pressure gradients of more than 20 mmHg, indicating that residual pulmonary stenosis after surgery might induce the recurrence of PR. In our group, 5 patients had significant pulmonary stenosis before PVR, but all were treated during subsequent surgery. Therefore, pulmonary stenosis does not contribute to the recurrence of PR in our study.

Causes for recurrent PR are largely unknown. Different mechanisms could play a role in the early and late recurrence of PR. We believe that early recurrent PR is likely due to surgical technical factors such as distortion of the homograft at implantation. Distortion may be caused by an imperfect fit of the graft when the RVOT diameter and homograft diameter show a significant discrepancy in size. We propose the hypothesis that failure to reduce a grossly enlarged RVOT may result in lack of central leaflet coaptation and subsequent regurgitation. The detrimental role of akinesia or aneurysm formation of the RVOT on RV dilatation and systolic function, independent of the presence of PR, has recently been shown by Davlouros et al [11]. By using a small RVOT patch (autologous or xenopericardium) the adaptation of the homograft may be improved in some cases. The fact that peri-operative reduction of the RVOT was performed in 4 of our patients and none of them had residual, or early recurrent PR, supports this hypothesis. Furthermore, of the 10 patients who received a pericardial patch to obtain a better fit between the RVOT and the homograft, early recurrent PR was found in only one of them.

In our study, one patient showed deterioration of RV function and functional class after PVR. In this patient a mismatch between the grossly enlarged RVOT and the homograft had led to severe recurrent PR shortly after PVR. During re-PVR, 2 years after the first

PVR, the RVOT volume was significantly reduced. In the first 6 months after re-PVR, recurrent PR was not found and RV function improved significantly in this patient.

The mechanism of late recurrent PR might be different from that in early recurrence. Oei et al. [21] recently reported that the insertion of allograft valve conduits in both children and adults leads to an increase of T-lymphocytes precursor cells with a potentially damaging effect towards the heart valve homograft. Immunologic mechanisms of homograft dysfunction seem to occur mainly in small infants whereas degenerative processes in homografts of adult patients are less related to immunologically mediated inflammatory responses. Slow calcific graft degeneration due to fibre rupture and infiltration of several blood components and calcium seems to be the predominant mechanism in adults [22,23].

Limitations of the study

Since patients were not randomized before surgery, definite conclusions on the relationship between operation technique and the recurrence of PR cannot be made. Furthermore, longer follow up is needed to evaluate the long-term effects of recurrent PR on RV function and overall functional class and the possible need for reoperations. A multicentre study with a large patient group and long follow-up could provide more insight into the factors that influence the recovery of RV function after PVR.

Conclusion

Pulmonary valve replacement in adult Fallot patients with moderate to severe pulmonary regurgitation leads to a rapid recovery of RV function. At medium-term follow-up up to 19 months after surgery, the RV function recovery is sustained in the majority of patients. However, recurrence of pulmonary regurgitation after PVR appears to reduce recovery of right ventricular systolic function. Baseline characteristics do not predict recovery RV function, whereas, operation techniques appear to be relevant to prevent recurrence of PR and thereby may affect recovery of RV function.

References

1 Lillehei CW, Varco RL, Cohen M, et al. The first open heart corrections of tetralogy of Fallot. A 26-31 year follow-up of 106 patients. Ann Surg 1986;204:490-502.

2 Murphy JG, Gersh BJ, Mair DD, et al. Long-term outcome in patients undergoing surgical repair of tetralogy of Fallot. N Engl J Med 1993;329:593-9.

3 Waien SA, Liu PP, Ross BL, Williams WG, Webb GD, McLaughlin PR. Serial follow-up of adults with repaired tetralogy of Fallot. J Am Coll Cardiol. 1992;20:295-300.

4 Nollert G, Fischlein T, Bouterwek S, Bohmer C, Klinner W, Reichart B. Long-term survival in patients with repair of tetralogy of Fallot: 36- year follow-up of 490 survivors of the first year after surgical repair. J Am Coll Cardiol 1997;30:1374-83.

5 Therrien J, Siu SC, McLaughlin PR, Liu PP, Williams WG, Webb GD. Pulmonary valve replacement in adults late after repair of tetralogy of Fallot: are we operating too late? J Am Coll Cardiol 2000;36:1670-5.

6 Zahka KG, Horneffer PJ, Rowe SA, et al. Long-term valvular function after total repair of tetralogy of Fallot. Relation to ventricular arrhythmias. Circulation 1988;78:14-19.

7 Ebert PA. Second operations for pulmonary stenosis or insufficiency after repair of tetralogy of Fallot. Am J Cardiol. 1982;50:637-40.

8 Marie PY, Marcon F, Brunotte F, et al. Right ventricular overload and induced sustained ventricular tachycardia in operatively "repaired" tetralogy of Fallot. Am J Cardiol 1992;69:785-9.

9 Wessel HU, Cunningham WJ, Paul MH, Bastanier CK, Muster AJ, Idriss FS. Exercise performance in tetralogy of Fallot after intracardiac repair. J Thorac Cardiovasc Surg 1980;80:582-93.

10 Rowe SA, Zahka KG, Manolio TA, Horneffer PJ, Kidd L. Lung function and pulmonary regurgitation limit exercise capacity in postoperative tetralogy of Fallot. J Am Coll Cardiol. 1991;17:461-6.

11 Davlouros PA, Kilner PJ, Hornung TS, et al. Right ventricular function in adults with repaired tetralogy of Fallot assessed with cardiovascular magnetic resonance imaging: detrimental role of right ventricular outflow aneurysms or akinesia and adverse right-to-left ventricular interaction. J Am Coll Cardiol 2002;40:2044-52.

12 d'Udekem Y, Ovaert C, Grandjean F, et al. Tetralogy of Fallot: transannular and right ventricular patching equally affect late functional status. Circulation 2000;102:116-22.

13 Vliegen HW, Van Straten A, de Roos A., et al. Magnetic resonance imaging to assess the hemodynamic effects of pulmonary valve replacement in adults late after repair of tetralogy of Fallot. Circulation 2002;106:1703-7.

14 Warner KG, Anderson JE, Fulton DR, Payne DD, Geggel RL, Marx GR. Restoration of the pulmonary valve reduces right ventricular volume overload after previous repair of tetralogy of Fallot. Circulation 1993;88:189-97.

15 Therrien J, Siu SC, Harris L, et al. Impact of pulmonary valve replacement on arrhythmia propensity late after repair of tetralogy of Fallot. Circulation 2001;103:2489-94.

16 van der Geest RJ, Reiber JH. Quantification in cardiac MRI. J Magn Reson Imaging 1999;10:602-8.

17 Pattynama PM, de Roos A, van der Wall EE, Van Voorthuisen AE. Evaluation of cardiac function with magnetic resonance imaging. Am Heart J 1994;128:595-607.

18 Pattynama PM, Lamb HJ, Van der Velde EA, van der Geest RJ, van der Wall EE, de Roos A. Reproducibility of MRI-derived measurements of right ventricular volumes and myocardial mass. Magn Reson Imaging 1995;13:53-3.

19 van der Geest RJ, de Roos A, van der Wall EE, Reiber JH. Quantitative analysis of cardiovascular MR images. Int J Card Imaging 1997;13:247-58.

20 Bove EL, Kavey RE, Byrum CJ, et al. Improved right ventricular function following late pulmonary valve replacement for residual pulmonary insufficiency or stenosis. J.Thorac.Cardiovasc.Surg. 1985;90:50-5.

21 Oei FB, Welters MJ, Knoop CJ, et al. Circulating donor-specific cytotoxic T lymphocytes with high avidity for donor human leukocyte antigens in pediatric and adult cardiac allograft valved conduit recipients. Eur J Cardiothorac Surg 2000;18:466-72.

22 Koolbergen DR, Hazekamp MG, de Heer E, et al. The pathology of fresh and cryopreserved homograft heart valves: an analysis of forty explanted homograft valves. J Thorac Cardiovasc Surg 2002; 124:689-97.

23 Mitchell RN, Jonas RA, Schoen FJ. Structure-function correlations in cryopreserved allograft cardiac valves. Ann Thorac Surg 1995;60:S108-S12.