

# Follow-Up of Shelhigh Porcine Pulmonic Valve Conduits

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**Background.** We implanted Shelhigh porcine pulmonic valve conduits because of the limited availability of homografts in our country. The aim of this study was to evaluate the short-term results of SPVC.

**Methods.** From November 2002 to July 2005, the Shelhigh porcine pulmonic valve conduit was implanted in 73 patients (81 procedures) in the right ventricular outflow tract to correct congenital heart diseases. Operative procedures were Rastelli operation in 65, anatomic correction of atrioventricular discordance in 5, and Ross operation in 3. Age at operation was  $6.8 \pm 7.5$  years, including 11 patients under 1 year. The median conduit size was 18 mm (range, 12 to 24 mm).

**Results.** There was no operative mortality and 1 non-conduit-related late death (mean follow-up,  $11.3 \pm 10.7$  months). Ten conduits (12.3%, 7 patients) were removed

at a median of 9.6 months (range, 2.5 to 25.4) owing to obstruction in 9 and pseudoaneurysm in 1. In the explanted conduits, we found a prominent intimal peel at the distal anastomosis without leaflet calcification. Freedom from reoperation at 24 months was  $87\% \pm 11.7\%$  in large-sized conduits ( $\geq 18$  mm) and  $62.8\% \pm 10.6\%$  in small-sized conduits ( $\leq 16$  mm). Especially, 12-mm sized conduit showed 33.3% freedom from reoperation during the first 12 months of follow-up.

**Conclusions.** On the basis of our short-term results, Shelhigh porcine pulmonic valve conduits are not satisfactory. Small-sized conduits ( $\leq 16$  mm) fail earlier; large-sized conduits ( $\geq 18$  mm) fail after 2 years of implantation due to intimal peel formation at the distal segment.

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To reconstruct right ventricular (RV) to pulmonary artery (PA) continuity, several types of conduits have been developed [1]. But the result was not satisfactory for calcific stenosis, fibrointimal peel formation, and lack of growth potential [2–6]. Cryopreserved pulmonic homografts are most commonly used [6, 7], but we implanted Shelhigh No-React (Shelhigh, Millburn, New Jersey) porcine pulmonic valved conduits (SPVC) because of the limited availability of homografts in our country.

In this report, we describe our experience and short-term results with the use of SPVC for patients requiring right ventricular-to-pulmonary artery connection as a part of biventricular complete repair of various congenital heart diseases.

## Material and Methods

### Patients

From November 2002 to July 2005, the SPVC was implanted to 73 patients (81 procedures) in the right ventricular outflow tract to correct congenital heart diseases.

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The average age at operation was  $6.8 \pm 7.5$  years (range, 0.2 to 30.8; median, 4.3), and 11 patients were less than 1 year old. The mean body weight was  $22.0 \pm 19.4$  kg (range, 4.4 to 76.3 kg; median, 14.0 kg). Forty-two patients were boys and 31 were girls.

This study was approved by the Seoul National University Hospital Institutional Review Board (study approval number H-0601-069-167), and the individual consent for the study was waived. The primary diagnoses of the patients are shown in Table 1.

### Surgical Technique

Operative procedures were Rastelli operation in 65 patients, anatomic correction of atrioventricular discordance in 5 patients, and Ross operation in 3 patients. Concomitant pulmonary artery angioplasty was performed in 25 patients, and unifocalization of major aortopulmonary collateral arteries in 6 patients.

The distal anastomosis was performed with a continuous polypropylene suture. After vertical ventriculotomy, the proximal end of SPVC was anastomosed to the ventricle in a same way.

In all, 81 SPVCs ranging from 12 to 24 mm were implanted, including eight conduits for reoperation (Table 2). The average size was  $18.7 \pm 8.5$  mm (median, 18 mm). The choice of conduit size was selected by the patient's body weight, body surface area, and matched pulmonary artery diameter. When the mediastinal space

Table 1. Patient Diagnoses

Diagnosis	Number of Patients
TOF/PA	39
cc-TGA/VSD/PS	15
TGA/VSD/PS	8
Truncus arteriosus	7
Aortic atresia or stenosis	4

cc-TGA = congenitally corrected transposition of great arteries; PA = pulmonary atresia; PS = pulmonary stenosis; TGA = transposition of great arteries; TOF = tetralogy of Fallot; VSD = ventricular septal defect.

allowed, larger conduit was implanted to accommodate the patient's growth.

Statistical Data

The primary outcome variables for this study were times to death and reoperation. Reoperation included only the reoperation for conduit problems. Probabilities of freedom from reoperation were estimated by means of the Kaplan-Meier method. All statistical analyses were performed using SPSS version 10.0 software (SPSS, Chicago, Illinois). Statistical significance was declared at *p* less than 0.05.

Results

Follow-up was complete in all patients, with a mean duration of 11.3 ± 10.7 months. There was no operative mortality and 1 nonconduit-related late mortality. The late death was related to the patient's previous condition (Alagille syndrome) 2 years after initial Rastelli operation and unifocalization for pulmonary atresia with major aortopulmonary collateral arteries.

In all, 81 SPVC were implanted in 73 patients, and 10 conduits were removed from 7 patients after implantation. Two conduits were removed from a patient with corrected transposition of great arteries. An SPVC of 14 mm was replaced with a 16-mm conduit at 14 months after initial Rastelli operation, and the 16-mm conduit was replaced with same-sized conduit at 15 months after reoperation. Three conduits were removed from a patient with pulmonary atresia with major aortopulmonary collateral arteries. Two 12-mm conduits and one 14-mm

Table 2. Used Conduits

Diameter (mm) <sup>a</sup>	Number	Percent (%)
12	7	8.6
14	16	19.8
16	11	13.6
18	7	8.6
20	10	12.4
22	8	9.8
24	22	27.2
Total	81	100.0

<sup>a</sup> Mean = 18.7 ± 8.49 mm.

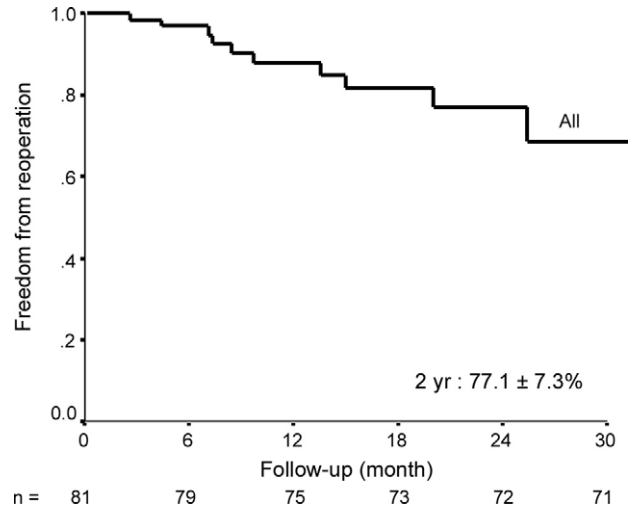


Fig 1. Kaplan-Meier estimates of freedom from reoperation for all grafts over time. The freedom from reoperation at 2 years is 77.1% ± 7.3%.

conduit were removed at 2.6 months, 4.4 months, and 8.4 months interval of the previous operation. In 2 of the 7 patients who underwent reoperation, SPVCs were replaced with nonvalved tube grafts.

The most common indication for conduit replacement was conduit stenosis, which was present in 9 cases. Echocardiographic evaluation at the time of conduit change in all of the patient with conduit stenosis demonstrated that the mean peak gradient across the conduit was 79 ± 18.1 mm Hg (median, 70 mm Hg; range, 60 to 100 mm Hg). The other indication was right ventricular outflow tract pseudoaneurysm formation in 1 case.

The median time to conduit failure in this series was 9.6 months (range, 2.6 to 25.4). The overall freedom from reoperation at 24 months is 77.1% ± 7.3%. Kaplan-Meier

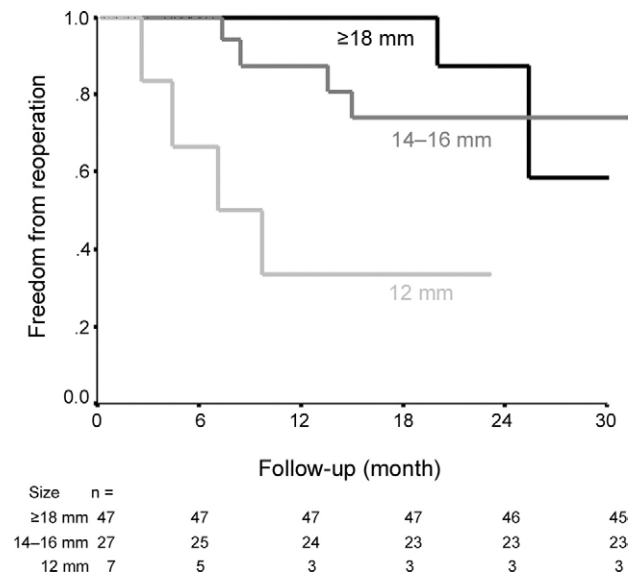


Fig 2. Kaplan-Meier estimates of freedom from reoperation according to conduit size.

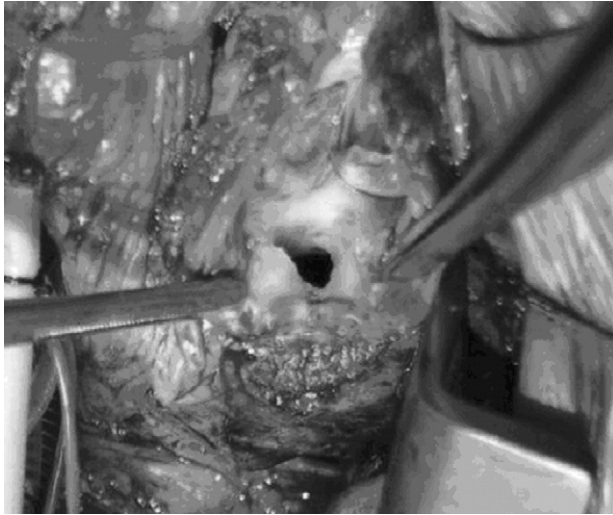


Fig 3. Extensive intimal proliferation at the distal anastomosis.

estimates of freedom from reoperation for all grafts over time is shown in Figure 1. The freedom from reoperation at 24 months was  $87\% \pm 11.7\%$  in large-sized conduit ( $\geq 18$  mm) and  $62.8\% \pm 10.6\%$  in small-sized conduit ( $\leq 16$  mm). In our experiences, early failures occurred in most 12-mm sized conduits within 1 year of implantation, and this resulted in only 33.3% freedom from reoperation at 12 months. This kind of failure pattern also happened in large-sized conduits ( $\geq 18$  mm) after 2 years of operation. So there was no statistical difference in freedom from reoperation rate at more than 2 years after implantation between small- and large-sized conduit ( $p = 0.12$ ). Their Kaplan-Meier estimates of freedom from reoperation are shown in Figure 2.

In the explanted conduits, we found prominent intimal peel formation at the distal anastomosis (Fig 3). All patients who needed reoperation showed distal intimal peel formation except 1 patient who had pseudoaneurysm. Valve leaflet calcification and degenerative change were not found in most reoperation cases (Fig 4). The pathology findings were consistent with chronic inflammation and foreign body reaction with fibrosis. The intimal fibrotic tissue contained multinucleated giant cells, lymphoplasmocytes, and eosinophils.

### Comment

Placement of valved conduit in the right ventricle to pulmonary artery circulation during repair of congenital heart diseases is problematic in that most of these prostheses will eventually require replacement [2]. The main issue is longevity of prosthetic valved conduits and the rate of reoperation. Cryopreserved homograft valved conduits are most commonly used [6-8], but have limited availability especially in small conduit sizes. Therefore, there is great interest in always available alternatives to homograft.

Classical complications of previously used conduits made of synthetic tubes as supportive housing for a

biological valve are focal valvular stenosis, conduit kinking, sternal compression, and diffuse stenosis [4, 7]. Some papers report acceptable results of stentless porcine valved conduits with a bovine pericardium extension, processed with glutaraldehyde and detoxified by the No-React process by Shelhigh [9-12]. We implanted Shelhigh No-React porcine pulmonic valved conduits because of the limited availability of homograft in our country.

The short-term results of SPVC are not favorable. The overall freedom from reoperation at 2 years is 77.1%, and 62.8% in small-sized conduit ( $\leq 16$  mm). In many conferences, including those of pediatric cardiac surgeons, pediatric cardiologists, and radiologists, there has been discussion about the cause of rapid intimal peel formation at distal anastomosis of SPVC. As some studies suggest an intrinsic immunologic response like foreign-body type reaction [13, 14], anti-inflammatory medication was added to anticoagulation drugs postoperatively. And it seems likely that surgical technique related problems play a role. The length of SPVC valvar portion was too long in small infants, and the shape of conduit was relatively straighter than the right ventricular outflow tract of patients. Rheologic factors including pulmonary artery angulation or turbulence at anastomosis site were also problematic. Thus, we thought that modification of surgical technique might be helpful to decrease intimal peel formation at the distal conduit. Finer suture materials and outer-in technique for smooth inner surface were used to prevent turbulence and thrombus formation at the suture line. When we chose the size of conduit and tailored the end of the conduit for anastomosis, more strict matching of the size and length of the conduit to the patient was performed to avoid conduit redundancy or compression to pulmonary artery. But as we could not improve the short-term results of SPVC by technical

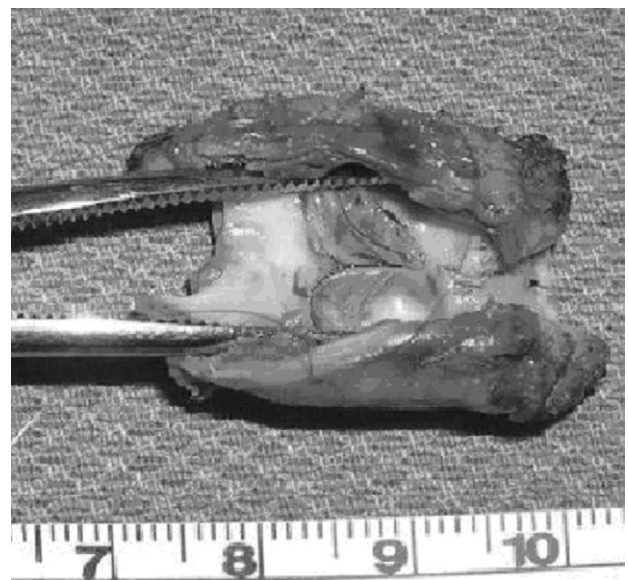


Fig 4. Explanted Shelhigh porcine pulmonic valve conduits without leaflet calcification or degenerative change.



modification or medications, we have to find other alternative valved conduits for right ventricle to pulmonary artery reconstruction.

In conclusion, on the basis of our short-term results, SPVC are not satisfactory. Small-sized conduit ( $\leq 16$  mm) failure occurred earlier, and large-sized conduit ( $\geq 18$  mm) failure occurred after 2 years of implantation owing to intimal peel formation at distal conduit.

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## INVITED COMMENTARY

Favorable early and mid-term outcomes after corrective congenital surgery (including reconstruction of the right ventricular outflow tract) have led to an increasing demand for right ventricular-pulmonary artery (RV-PA) conduits in children, adolescents, and even in adult patients. Unfortunately there still is no ideal conduit that fulfills all the expectations (eg, autologous material, unrestricted and immediate availability, growth potential, resistance to infection, and, last but not least, excellent long-term durability and low rate of structural degeneration).

Because the successful introduction of cryopreservation in the 1980s, pulmonary homografts have been considered as the conduit of choice by a large number of surgeons. However, the expanding use for homografts has led to an increasing mismatch between demand and supply and has made availability a limiting factor for the use of homografts, mostly in small sizes. With the advent of the Contegra bovine jugular vein graft (Medtronic Inc, Minneapolis, MN) and the new generation of Shelhigh pulmonic porcine xenograft (NR-4000PA, Shelhigh Inc, Union, NJ) there was reasonable hope to overcome this lack of homograft availability. However, despite favorable immediate hemodynamic results, these new grafts raised several questions regarding durability.

Kim and co-workers [1] report their experience with 81 Shelhigh pulmonic xenografts (median size, 18 mm

(Shelhigh Inc), mainly in tetralogy of Fallot patients who required RV-PA conduit implantation.

This article has several weaknesses that make general statements regarding the performance of the conduit difficult if not questionable. Follow-up is rather short with a median of 8 months, but freedom from reoperation is only 58% in the group who received larger conduits ( $>18$  mm) and drops to 33% in patients with small-sized conduits (12 mm).

The primary mechanisms of RV-PA conduit failure generally include stenosis, especially at the level of the distal anastomosis, multi-level stenosis, intimal peel, embolism, thrombosis, and calcification with or without valvular dysfunction.

Excessive intimal peel is a major problem, especially with the Shelhigh pulmonic graft. Although the authors do not comment, it seems at least from previous publications that some degree of anticoagulation (ie, platelet inhibitor or coumadin) can be recommended.

In neonates and infants, immunologic mechanisms should not be overlooked. In some individuals, a rise in B cells to 150% of the normal value may be observed 3 to 6 months postoperatively and is associated with T-lymphocyte activation, CD69+, and CD71+ cells. Cellular remnants in the xenograft may be responsible for such reactions. Another important issue in the younger age group is the differentiation between effective pre-