Original Article

Mid-term Results of the Hancock II Valve and Carpentier-Edward Perimount Valve in the Pulmonary Portion in Congenital Heart Disease

Jae Gun Kwak, MD [a], Jeong Ryul Lee, MD [b,*], Woong-Han Kim, MD [b] and Yong Jin Kim, MD [b]

[a] *Department of Thoracic and Cardiovascular Surgery, Sejong General Hospital, Bucheon, Republic of Korea*
[b] *Department of Thoracic and Cardiovascular Surgery, Seoul National University Children's Hospital, 28 Yeongun Dong, Jongno Gu, Seoul, Republic of Korea*

Background: **As the number of cases with artificial pulmonary valve implantation increases for congenital heart disease, the number of young adults with artificial pulmonary valves has also increased.**

Methods: **From 2000 to 2007, 146 artificial valves, such as the Carpentier-Edward Perimount, Hancock II, Biocor, homograft and hand-made valves were implanted for pulmonary valve in 132 patients with various forms of congenital heart disease. Among them, the outcomes of the Carpentier-Edward Perimount ($n = 63$) and the Hancock II ($n = 40$) valves were reviewed retrospectively. The mean age at initial implantation was 12.8 ± 6.6 years. The overall duration of follow up was 36.0 ± 24.2 months.**

Results: **There was an early death due to right ventricular failure with intractable ventricular arrhythmia and 3 late deaths due to progressive right ventricular failure, dilated cardiomyopathy and infective endocarditis. The overall survival and re-operation free rate was 96.3% and 89.8% respectively. Eight out of 63 Carpentier-Edward patients (12.6%) underwent re-replacement at 49.2 ± 25.2 months. The re-operation free rates were 97.7%, 87.7% and 50% at 1, 3 and 5 years respectively. There was no re-operation required for the 40 Hancock II patients over 18.0 ± 10.8 months. There was no statistical significance in the re-operation free rates between these 2 valves (p-value = 0.51).**

Conclusions: **The overall survival rate associated with pulmonary valve bioprosthetic valve implantation was acceptable. However, the re-operation freedom rate was not satisfactory at mid-term for the Carpentier-Edward.**

(Heart, Lung and Circulation 2010;19:243–246)

Keywords. Congenital heart disease; Heart valve, prosthesis; Heart valve, allograft; Pulmonary valve replacement

Introduction

As the long term results of the surgical treatment for congenital heart disease have been improved, the number of adolescent and adult patients with congenital heart disease has increased. Patients with Tetralogy of Fallot or pulmonary atresia especially have shown satisfactory long-term surgical outcomes, although they have persistent right ventricle and pulmonary artery associated problems. A significant number of these patients require one or more re-operations for the right ventricular outflow problems, such as stenosis and/or insufficiency of the pulmonary valve, right ventricular dilatation or aneurysmal changes after total surgical correction of these congenital anomalies [1]. The aim of this study was to review the mid-term results of bioprosthetic pulmonary valve implantation, especially, the Hancock II porcine valve (H) and the Carpentier-Edward Perimount pericardial valve (C) for the patients with congenital heart disease.

Methods and patients

From December 2000 to October 2007, 132 patients underwent pulmonary valve implantation and were enrolled in this retrospective study. Including re-replacement of artificial valve, 146 pulmonary valve implantation procedures were performed on these patients. Carpentier-Edward Perimount pericardial valve ($n = 69$), Hancock II porcine valve ($n = 43$), St. Jude Biocor porcine valve ($n = 29$), Homograft ($n = 4$) and hand-made valve including the Gore-Tex membrane leaflet ($n = 1$) were used. Among these, 63 Carpentier-Edward Perimount pericardial valves and 40 Hancock II porcine valves were used for the initial artificial pulmonary valve. The choice of valves' type was depend

Received 10 March 2009; received in revised form 28 August 2009; accepted 31 October 2009; available online 9 February 2010

* Corresponding author. Tel.: +82 11 9989 1081.
E-mail address: jrl@plaza.snu.ac.kr (J.R. Lee).

1443-9506/04/$36.00
doi:10.1016/j.hlc.2009.10.009

on the surgeons' preference. The medical records of these 103 patients were reviewed retrospectively.

The mean age of the patients was 12.8 ± 6.6 years at their first pulmonary valve surgery after a previous total correction of their congenital cardiac anomalies. Eight redo operations for pulmonary valve replacement were performed at 5.3 ± 2.9 years after the first pulmonary valve implantation. The overall follow up duration was 36.0 ± 24.2 months. We were able to follow up all the enrolled patients with regular echocardiography in out-patient clinic. In the cases requiring the additional operation, we further performed cardiac computed tomography (CT) and magnetic resonance imaging (MRI) for the evaluation for pulmonary arteries' status and cardiac function.

Results

The patient diagnoses included Tetralogy of Fallot (76), double outlet right ventricle (7), pulmonary atresia with ventricular septal defect (VSD) (6), transposition of the great arteries with pulmonary stenosis (4), pulmonary atresia with intact ventricular septum (2), isolated pulmonary stenosis (3), truncus arteriosus (2), absent pulmonary valve syndrome (2) and coarctation of aorta with VSD (1) (Table 1). The last patient, with coarctation of aorta, presented the infective endocarditis at the pulmonary valve area after total correction of coarctation of aorta and ventricular septal defect.

There was one early death. This patient had already shown severe right ventricular failure and intractable ventricular arrhythmia before the valve implantation. There were three late mortalities due to progressive right ventricular failure, dilated cardiomyopathy and infective endocarditis, respectively. Overall survival rate was 96.3% and overall re-operation freedom rate was 89.8%.

Since 2004, we have performed the cardiac MRI pre- and postoperatively to evaluate right ventricular function by measuring the end systolic and diastolic dimensions, ejection fraction and status of the myocardial mass in the right and left ventricles as well as echocardiography and cardiac computed tomography. Although we could not perform cardiac MRI on all patients (preoperatively 39 patients, postoperatively 13 patients), there were some meaningful results noted. Among the patients who underwent cardiac MRI both pre- and postoperatively, the right ventricular ejection fraction was improved from $36.35 \pm 8.50\%$ preoperatively to $41.68 \pm 9.30\%$ postoperatively. The end diastolic volume and end systolic volume of the right ventricle were also improved 149.42 ± 25.48 to 103.50 ± 24.60 mL and 91.08 ± 26.71 to 60.84 ± 22.39 mL respectively (Table 2).

Table 1. *Diagnoses of Patients.*

Diagnosis	Number of Patients
Tetralogy of Fallot	76
Double outlet right ventricle	7
Pulmonary atresia with ventricular septal defect	6
Transposition of great arteries with pulmonary stenosis	4
Pulmonary atresia with intact ventricular septum	2
Isolated pulmonary stenosis	3
Truncus arteriosus	2
Absent pulmonary valve syndrome	2
Coarctation of aorta with ventricular septal defect	1
Total	103

Table 2. *Cardiac MRI Findings, Pre- and Postoperatively (n = 13).*

	Preop	Postop
RVEF (%)	36.35 ± 8.50	41.68 ± 9.30
RV EDV (mL)	149.42 ± 25.48	103.50 ± 24.60
RV ESV (mL)	91.08 ± 26.71	60.84 ± 22.39

n: number of patients, RVEF: right ventricular ejection fraction, RV EDV: right ventricular end diastolic volume, RV ESV: right ventricular end systolic volume, preop: preoperative, postop: postoperative.

We divided the patients into two groups, the Carpentier-Edward Perimount pericardial valve group (group C, $n = 63$) and the Hancock II porcine valve group (group H, $n = 40$). For group C, there were 8 re-operations among the 63 patients, all of the re-operations were performed in group C patients at 49.2 ± 25.2 months after the first pulmonary valve implantation. Re-operation freedom rates were 97.7%, 93.4%, 87.7% and 50% at 1, 2, 3 and 5 years respectively. In group H, none of the 40 patients required valve replacement at 18.0 ± 10.8 months after the first valve operation. However, the difference between the two groups with regard to rate of freedom from re-operation was not statistically significant (p-value = 0.51). The implanted valve size was 25.0 ± 1.9 mm (range, 19–27 mm) in group C and 24.1 ± 1.5 mm (range, 21–27 mm) in group H.

The main reason for re-operation was steno-insufficiency of the artificial pulmonary valve due to severe calcification of the leaflet and cusp retraction due to degeneration. We used two Carpentier-Edward Perimount pericardial valves, two Hancock II pericardial valves and four St. Jude Biocor pericardial valves for the re-operations.

Discussion

In this study, we compared Hancock II porcine valves (Medtronic Heart Valve Division, Irvine, CA, USA) and Carpentier-Edward Perimount pericardial valves (CE valve, Edwards Lifesciences LLC, Irvine, CA, USA) used for pulmonary valve replacement in patients with congenital heart disease. Most of the patients were adolescents. Previous studies have reported on the mid-term and long-term outcomes as well as the pathologic findings after explantation and the causes of failure of these two valves, however, mainly for aortic valves [2–5]. There are few reports on comparison between the porcine and pericardial bioprosthesis used for pulmonary valve replacement with the exception of the study reported by Fiore et al.'s study [6]. Fiore et al. compared the Medtronic

mosaic porcine (Medtronic Inc, Minneapolis, MN, USA), Carpentier-Edwards bovine pericardial valve (Edwards Life-science, Irvine, CA, USA) and the pulmonary homograft (CryoLife Inc., Kennesaw, GA, USA). They reported that these valves showed similar functional outcomes during the three-year study period.

The cusp of Hancock II porcine valve is treated with the detergent sodium dodecyl sulphate (T6) to retard calcification; in addition a low fixation pressure is employed to preserve collagen crimping [7]. Bortolotti et al. [8,9] reported 100% of freedom from structural valvular deterioration at eight years in aortic and mitral position. David et al. [10] reported the results at 15 years with actual freedoms from structural valvular deterioration of 90% in aortic valves and 83% in mitral valves. These results showed the improvement when compared with the first generation of Hancock valve without anti-mineralised treatment, and newly incorporated into the Hancock II valve. David et al. also reported that this valve was more durable in the aortic position than in the mitral position. Bottio et al. [11], in their study on the pathologic features of the explanted Hancock II valve, found that the main cause of structural valve deterioration was lipid insudation rather than calcification. They also reported that T6 treatment not only prevented the mineralisation and calcification but also removed lipid from the porcine valve during the manufacturing process; however, it did not prevent subsequent lipid insudation.

The Carpentier-Edwards Perimount® valve (Edwards Lifesciences LLC, Irvine, CA, USA) is a stented bovine pericardial prosthesis that is glutaraldehyde-fixed under low pressure and anti-calcification treated. Roselli et al. reported the five failure modes of this valve, such as, calcification, non-calcified degeneration, dehiscence, fibrosis and a mixed type [5]. In their study, calcification was the most common cause of failure in 39%, and non-calcified degeneration, such as collagen loss or cusp body perforation, was the second most common in 30%. The mechanism of calcification in bioprosthetic valves is probably related to an inability of the non-viable cells to maintain their normally low intracellular concentration of calcium. As a result, concentrated calcium binds to the phospholipid membranes of non-viable organelles and mineralisation occurs. Collagen, elastin and other interstitial cellular debris provide another nidus for calcification and inflammation. In addition to the above, unbound glutaraldehyde or its polymers used in the fixation process, tissues may become vulnerable to calcification [12,13]. Although the CE Perimount valves are treated with the surfactant polysorbate 80 and ethanol (XenoLogix treatment; Edwards Lifesciences LLC) to reduce calcification by extracting the phospholipids from the pericardial tissue, changing the collagen structure, and controlling residual aldehydes, calcification remains the main cause of failure of the Perimount pericardial valve, and is a time-dependent process [14,15]. Non-calcified degeneration has been a focus of study recently as an important cause of failure of bioprosthetic valves. The Perimount valve is glutaraldehyde-treated using a low-pressure technique (4 mmHg) to maintain cusp compliance. Zero-pressure and dynamic-pressure treatment strategies have improved *in vitro* compliance and mechanical properties [16].

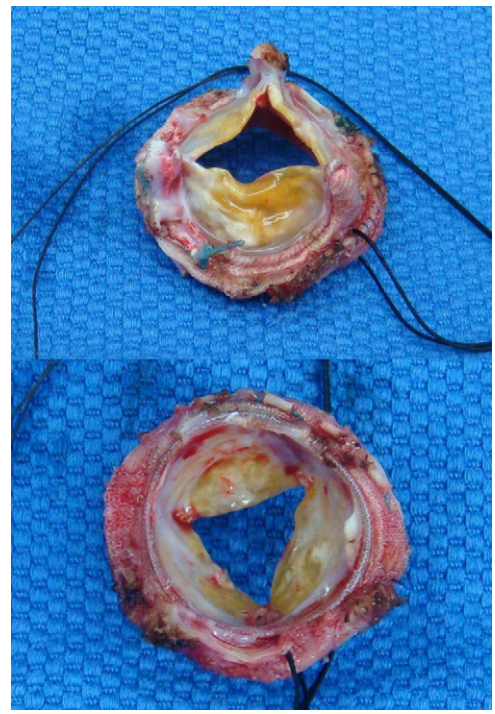

Figure 1. *Explanted previous bioprosthetic valve, Carpentier-Edwards Perimount pericardial valve.*

In our study, re-operation for prosthetic valve failure occurred only in group C at 49.2 ± 25.2 months (2 months to 6.8 years) after the initial valve surgery. Inspection after the explantation of the previously implanted bioprosthetic valves revealed mixed features of calcified degeneration causing stenosis and non-calcified degeneration, such as leaflet retraction, causing insufficiency. Stent deterioration was not detected (Fig. 1). The re-operation freedom rates for the CE Perimount pericardial valve were 97.7%, 93.4%, 87.7% and 50% at one, two, three and five years respectively. This was a poorer outcome when compared to the outcomes with aortic valves in adult patients, although the pulmonary circulation is exposed to lower pressure than the systemic circulation. It is well known that, in pediatric or adolescent patients, bioprosthetic material show more rapid and aggressive calcified degeneration due to the more active and dynamic metabolic process associated with the growth of these age groups. There was no re-operation in group H at 18.0 ± 10.8 months (range, 2 months to 3.8 years). However, the shorter follow up duration for the Hancock II valve might explain the absence of additional surgery in this group. The statistical analysis showed no difference in the freedom from re-operation (p-value = 0.51). And, relatively short term follow duration of H group is limitation in this study.

Because there was no re-operation in the H group, we could not compare the pathological differences between these two valves. However, we could confirm that the

pathological features of the CE Perimount valve at pulmonary position in adolescent patients were not very different from the aortic or mitral valve outcomes of adult patients. However, long-term follow up of Hancock II patients is required.

In addition, appropriate timing of pulmonary valve implantation after total correction of Tetralogy of Fallot and pulmonary atresia needs to be determined. If clinicians wait until the patient complains of symptoms associated with right heart failure such as dyspnea, hepatomegaly or low extremity oedema, the patient might be at risk for a poor outcome even with appropriate pulmonary valve replacement. Since 2004, we have performed cardiac MRI to help to decide on the operation timing and to evaluate the right ventricular function pre- and postoperatively. Although not all patients in this cohort could be evaluated by cardiac MRI, the postoperative MRI findings showed improvement in the right ventricular ejection fraction and right ventricular end diastolic and systolic volume, compared to the preoperative findings (Table 2). Our protocol includes pulmonary valve implantation for patients who underwent the total correction of right ventricular outflow problems such as TOF, PA with VSD or PA with IVS, truncus arteriosus, RV end diastolic volume of 150 mL, RV ejection fraction of 40% by cardiac MRI and progressive tricuspid valve regurgitation in asymptomatic patients, as well as patients who have symptoms of right heart failure. Earlier and more aggressive treatment should help improve the right ventricular function and size after surgical treatment.

Conclusions

The overall survival after bioprosthetic valve implantation at the pulmonary portion was acceptable. However, the reoperation freedom rate was not satisfactory in mid-term results in the Carpentier-Edward valve. Though Hancock II valve showed fewer re-operations, we cannot conclude that it was superior to the Carpentier-Edward pericardial valve because of the shorter follow up duration in the former group. We need a large and long-term follow up for Hancock II valve patients for the comparison with Carpentier-Edward pericardial valve.

Conflict of interest

We have no financial or other interest in the product in this paper and have no relationship with the manufacturer or distributor of the product.

References

[1] de Ruijter FTH, Weenink I, Hitchcock FJ, Meijboom EJ, Bennink GBWE. Right ventricular dysfunction and pulmonary valve replacement after correction of Tetralogy of Fallot. Ann Thorac Surg 2002;73:1794–800.

[2] Butany J, Leong SW, Cunningham KS, D'Cruz G, Carmichael K, Yau TM. A 10-year comparison of explanted Hancock II and Carpentier-Edwards supraannular bioprostheses. Cardiovasc Pathol 2007;16:4–13.

[3] Borger MA, Franka Nette A, Maganti M, Feindel CM. Carpentier-Edwards Perimount magna valve versus Medtronic Hancock II: a matched hemodynamic comparison. Ann Thorac Surg 2007;83:2054–9.

[4] BorgerF M.A., Ivanov J, Armstrong S, Christie-Hrybinsky D, Feindel CM, David TE. Twenty-year results of the Hancock II bioprosthesis. J Heart Valve Dis 2006;15:49–56.

[5] Roselli EE, Smedira NG, Blackstone EH. Failure modes of the Carpentier-Edwards pericardial bioprosthesis in the aortic position. J Heart Valve Dis 2006;15:421–8.

[6] Fiore AC, Rodefeld M, Turrentine M, Vijay P, Reynolds T, Standeven J, Hill K, Bost J, Carpenter D, Tobin C, Brown JW. Pulmonary valve replacement: a comparison of three biological valves. Ann Thorac Surg 2008;85:1712–8.

[7] Wright JTM, Eberhardt CE, Gibbs ML, Saul T, Gilpin CB. Hancock II-An improved bioprosthesis, cardiac bioprostheses. In: Cohn LH, Gallucci V, editors. Proceedings of the 2nd International Symposium. New York: Yorke Medical Books; 1982. p. 425–44.

[8] Bortolotti U, Milano A, Mazzaro E, Thiene G, Talenti E, Casarotto D. Hancock II porcine bioprosthesis: excellent durability at intermediate term follow-up. J Am Coll Cardiol 1994;24:676–82.

[9] Bortolotti U, Milano A, Mossuto E, Mazzaro E, Thiene G, Casarotto D. Porcine valve durability: a comparison between Hancock Standard and Hancock II bioprostheses. Ann Thorac Surg 1995;60:S216–20.

[10] David TE, Armstrong S, Sun Z. Clinical and hemodynamic assessment of the Hancock II bioprosthesis. Ann Thorac Surg 1992;54:661–7.

[11] Bottio T, Thiene G, Pettenazzo E, Ius P, Bortolotti U, Rizzoli G, Valfreĭ C, Casarotto D, Valente M. Hancock II bioprosthesis: a glance at the microscope in mid-long-term explants. J Thorac Cardiovasc Surg 2003;126:99–105.

[12] Schoen FJ, Harasaki H, Kim KM, Anderson HC, Levy RJ. Biomaterial-associated calcification: pathology, mechanisms, and strategies for prevention. J Biomed Mater Res 1988;22:11–36.

[13] Jamieson E. Update on new tissue valves. In: Franco KL, editor. Advanced therapy in cardiac surgery. Hamilton, Ontario: BC Decker; 2003. p. 177–95.

[14] Shen M, Kara-Mostefa A, Chen L, Daudon M, Thevenin M, Lacour B, Carpentier A. Effect of ethanol and ether in the prevention of calcification of bioprostheses. Ann Thorac Surg 2001;71:S413–6.

[15] Cunanan CM, Cabiling CM, Dinh TT, Shen SH, Tran-Hata P, Rutledge III JH, Fishbein MC. Tissue characterization and calcification potential of commercial bioprosthetic heart valves. Ann Thorac Surg 2001;71:S417–21.

[16] Duncan AC, Boughner D, Vesely I. Dynamic glutaraldehyde fixation of a porcine aortic valve xenograft. I. Effect of fixation conditions on the final tissue viscoelastic properties. Biomaterials 1996;17:1849–56.