Long-term durability of bioprosthetic valves in pulmonary position: Pericardial versus porcine valves

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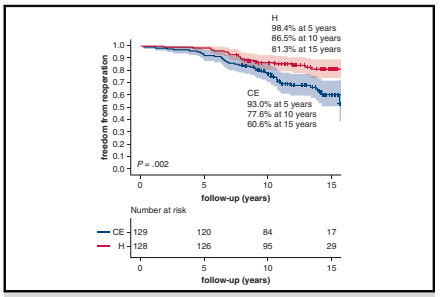
ABSTRACT

Objectives: The long-term durability of the 2 most commonly used types of bioprosthetic valves in the pulmonic position, the porcine and pericardial valves, is unclear. We compared the long-term durability of the pericardial (Carpentier-Edwards PERIMOUNT [CE]) and porcine (Hancock II) valves in the pulmonic position in patients with congenital cardiac anomalies.

Methods: We retrospectively reviewed the medical records of 258 cases (248 patients) of pulmonary valve implantation or replacement using CE (129 cases, group CE) or porcine (129 cases, group H) valves from 2 institutions between 2001 and 2009.

Results: The patients' age at pulmonary valve implantation was 14.9 ± 8.7 years. No significant differences in perioperative characteristics were observed between groups CE and H. Follow-up data were complete in 219 cases (84.9%) and the median follow-up duration was 10.5 (interquartile range, 8.4∼13.0) years. Ten mortalities (3.9%) occurred. Sixty-four patients underwent reoperation for pulmonary valve replacement due to prosthetic valve failure; 10 of these 64 patients underwent reoperation during the study period. Patients in group CE were significantly more likely to undergo reoperation (hazard ratio, 2.17; confidence interval, 1.26-3.72; $P = .005$) than patients in group H. Patients in group CE showed had a greater prosthetic valve dysfunction (moderate-to-severe pulmonary regurgitation or pulmonary stenosis with ≥3.5 m/s peak velocity through the prosthetic pulmonary valve) rate (hazard ratio, 1.83; confidence interval, 1.07-3.14; $P = .027$) than patients in group H.

Conclusions: Compared with the pericardial valve, the porcine valve had long-term advantages in terms of reduced reoperation rate and prosthetic valve dysfunction in the pulmonic position in patients with congenital cardiac anomalies. (J Thorac Cardiovasc Surg 2020;160:476-84)



Reoperation-free rates of porcine and pericardial valve in pulmonary portion.

CENTRAL MESSAGE

We compared long-term results of 2 different types of bioprosthetic valves, porcine and pericardial valve, in pulmonary portion in the patients with congenital heart diseases.

PERSPECTIVE

Our data show a meaningful superiority of the porcine valve in terms of reoperation-free rate (81.3% at 15 years, vs 60.6% at 15 years in pericardial valve, $P = .002$) and prosthetic valve failure-free rate in the pulmonic position (69.4% at 15 years, vs 41.8% at 15 years in pericardial valve, $P = .024$).

See Commentaries on pages 485, 487, and 488.

This study aimed to compare the long-term durability of the pericardial valve (Carpentier-Edwards PERIMOUNT [CE] valve; Edwards Lifesciences, Irvine, Calif) and the porcine valve (Hancock II valve; Medtronic, Minneapolis, Minn) in the pulmonic position in patients with conotruncal anomalies (tetralogy of Fallot, pulmonary atresia [PA] with ventricular septal defect [VSD], and truncus arteriosus) or other congenital cardiac anomalies that are accompanied by pulmonary valve stenosis (PS) or atresia.

METHODS

Patients, Materials, and Surgeries

The medical records of 258 consecutive cases of pulmonary valve implantation or replacement in 248 patients from 2 institutions (Sejong General Hospital and Seoul National University Children's Hospital) between 2001 and 2009 were retrospectively reviewed. These institutions follow similar operative indications and surgical strategies

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Abbreviations and Acronyms

CE = Carpentier-Edwards PERIMOUNT valve
CI = confidence interval
EDVi = end-diastolic volume index
EF = ejection fraction
ESVi = end-systolic volume index
HR = hazard ratio
IQR = interquartile range
LV = left ventricle
MRI = magnetic resonance imaging
PA = pulmonary atresia
PR = pulmonary valve regurgitation or pulmonary insufficiency
PS = pulmonary valve stenosis
PVR = pulmonary valve replacement
RV = right ventricle
RVOT = right ventricular outflow tract
VSD = ventricular septal defect

for pulmonary valve implantation in patients with congenital heart disease. Incidentally, the same numbers of cases were enrolled; CE valves were implanted in 129 cases (group CE) and Hancock II valves were implanted in 129 cases (group H). During the study period, another 21 patients underwent pulmonary valve implantation with Epic Biocor valves (porcine valve; St. Jude Medical, St. Paul, Minn); however, we excluded these patients to minimize any possible bias that was due to the different manufacturers.

Among the 248 patients, 10 patients underwent reoperation for pulmonary valve replacement (redo-PVR) because of prosthetic valve failure during the study period; therefore, we had 258 cases of pulmonary valve implantation in this retrospective study. Concomitant procedures such as branch pulmonary artery repair (procedure numbers = 50), tricuspid valve or annuloplasty (n = 17), residual right ventricular outflow tract (RVOT) muscle division or resection (n = 14), antiarrhythmic operation using cryoablation (n = 8), residual VSD (n = 9) or atrial septal defect (n = 4) closure, previously inserted branch pulmonary artery stent removal (n = 4), left-sided outflow tract operation (aortic valve repair [n = 4], ascending aorta reduction [n = 2], subaortic muscle resection and Konno procedure [n = 2]), mitral valve repair (n = 1), patent ductus arteriosus closure (n = 1), bidirectional cavo-pulmonary connection (n = 1), and permanent pacemaker implantation (n = 1) were performed if necessary. All the redo-PVR procedures were performed surgically in this study because PVR through transcatheter intervention has been permitted by Korean government since the mid- 2010s. Because valved homografts (aortic or pulmonary) are not easily available in Korea, we have no cases with homografts. Although the decision of whether to pursue surgical intervention was always made in preoperative conferences in which all the surgeons and pediatric cardiologists attended, the choice of prosthetic valve depended on the surgeons' preferences.

Both valves were evenly used over the study time period. In most cases, we used an additional patch for making a hood in RVOT, including the main pulmonary artery and infundibular area. Postoperatively, the patients received aspirin (Bayer, Leverkusen, Germany) for 3 to 6 months. Over the study period, most patients regularly underwent echocardiographic assessment pre- and postoperatively. We assessed patients' perioperative ventricle volume, volume index of left ventricle (LV) and right ventricle (RV) at systole and diastole, respectively, the fraction of pulmonary valve regurgitation or insufficiency (PR), and ejection fraction (EF) of LV and RV using cardiac magnetic resonance imaging (MRI). Vital statuses were validated using the Korean National Registry of Vital Statistics.

Study End Points and Definition of Prosthetic Valve Failure

Replacement of a previous prosthetic pulmonary valve was considered the end point of this study. Prosthetic valve failure was defined as moderate-to-severe PR of the prosthetic valve or PS with a 3.5 m/s peak velocity through the prosthetic pulmonary valve as assessed by echocardiography.

Statistics and Ethics

The pre- and perioperative continuous variables and categorical variables were compared between the groups using the independent-samples *t* test and the χ^2 test, respectively, except age at the first operation and PVR, cardiopulmonary bypass, and aorta crossclamping times, for which we used the Mann–Whitney *U* test. *P* values $\leq$.05 were considered statistically significant. We tested the proportional hazards assumption using "Cox.zph" function in survival packages "R" (R Foundation is seated in Vienna, Austria). We tested scaled Schoenfeld residuals with time to test for independence between residuals and time. Because the *P* values were .116 for prosthetic valve failure and .39 for reoperation free rate, which are satisfy to assumption of proportional hazard, the Kaplan–Meier and Cox proportional hazards models were used to analyze the effects on the reoperation and prosthetic valve failure rate according to the valve size, valve type, and patients' age and preoperative diagnoses. The Wilcoxon signed-rank test was used to analyze the changes in MRI study parameters in some cases. We used "R (version 3.6.0)" and SPSS (version 23; IBM Corp, Armonk, NY) for statistical analyses. This retrospective study was approved by the institutional review boards of Sejong General Hospital and Seoul National University Children's Hospital.

RESULTS

Patients' Preoperative Characteristics

The patients' median age at pulmonary valve implantation was 12.8 (interquartile range [IQR], 10.3∼16.6) years. No significant differences were observed between groups CE and H in terms of their perioperative clinical features and characteristics (sex, diagnosis, valve size, age at first operation, age at pulmonary valve reoperation, proportion of adult patients [age $\geq$18 years], preoperative functional class, and proportion of patients with arrhythmia and endocarditis) (Table 1). The original diagnoses included tetralogy of Fallot (n = 180, 69.8%), PA with VSD (n = 38, 14.7%), double-outlet right ventricle with PS (n = 15, 5.8%), transposition of great arteries with PS (n = 7, 2.6%), and truncus arteriosus (n = 4, 1.5%); the proportions of the diagnoses did not differ between the groups.

Operative Factors

The sizes of the implanted pulmonary valves were similar in the 2 groups (24.2 ± 0.4 mm in group CE, and 24.2 ± 0.3 mm in group H); however, 27-mm valves were implanted significantly more frequently in group

TABLE 1. Comparison of perioperative variables between the groups

Variables	Total (N = 258)	CE PERIMOUNT (N = 129)	Hancock II (N = 129)	*P* value
Male sex, n %	161 (62.4%)	80 (62.0%)	81 (62.8%)	.898
Age at first operation, y, median (IQR)	1.7 (1.0∼3.3)	1.7 (1.0∼2.9)	1.7 (1.0∼3.8)	.426
Original diagnosis, n %				
TOF	180 (69.8%)	83 (64.3%)	97 (75.2%)	.058
PA with VSD	38 (14.7%)	20 (15.5%)	18 (14.0%)	.725
DORV	15 (5.8%)	9 (7.0%)	6 (4.7%)	.425
TGA with PS	7 (2.6%)	5 (3.9%)	2 (1.6%)	.250
Truncus arteriosus	4 (1.5%)	3 (2.3%)	1 (0.8%)	.314
Age at PVR, y, median, (IQR)	12.8 (10.3∼16.6)	12.6 (10.3∼16.2)	13.3 (10.3∼17.4)	.396
Age ≥18 y	53 (20.5%)	24 (18.6%)	29 (22.5%)	.441
Age <18 y	205 (79.5%)	105 (81.4%)	100 (77.5%)	
NYHA class I, n %	72 (27.9%)	36 (29.3%)	36 (31.6%)	.699
Arrhythmia, n %	23 (8.9%)	14 (11.4%)	9 (7.9%)	.365
Endocarditis, n %	8 (3.1%)	6 (4.8%)	2 (1.8%)	.200
Valve size, mm		24.2 ± 0.4	24.2 ± 0.3	>.99
27	38 (14.7%)	26 (20.2%)	12 (9.3%)	.014
25	126 (48.8%)	55 (42.6%)	71 (55.0%)	.025
23	61 (23.6%)	27 (20.9%)	34 (26.4%)	.464
21	24 (9.3%)	15 (11.6%)	9 (7.0%)	.198
19	9 (3.5%)	6 (4.7%)	3 (2.3%)	.500
CPB time, min, median, (IQR)	152.0 (117.0∼198.0)	148.0 (11.5∼190.5)	162.0 (124.0∼203.0)	.034
ACC time, min, median, (IQR)	8.5 (0.0∼76.0)	25.0 (0.0∼76.0)	0.0 (0∼77.8)	.357

CE, Carpentier-Edwards; *IQR*, interquartile range; *TOF*, tetralogy of Fallot; *PA*, pulmonary atresia; *VSD*, ventricular septal defect; *DORV*, double-outlet right ventricle; *TGA*, transposition of great arteries; *PS*, pulmonary stenosis; *PVR*, pulmonary valve replacement; *NYHA*, New York Heart Association; *CPB*, cardiopulmonary bypass; *ACC*, aorta crossclamping.

CE (n = 26, 20.2%) than in group H (n = 12, 9.3%; $P = .014$, Pearson χ^2 test), and 25-mm valves were implanted significantly more frequently in group H (n = 71, 55.0%) than in group CE (n = 55, 42.6%; $P = .025$, Pearson χ^2 test, Table 1). After dividing the patient groups into 2 subgroups according to the valve size, namely ≤25 mm and ≥25 mm, we observed no significant differences between groups CE and H (81 cases of 25- and 27-mm valve implantation in group CE, 83 cases of 25- and 27-mm valve implantation in group H; $P = .796$, Pearson χ^2 test). The cardiopulmonary bypass time and aorta crossclamping time of group CE and H were similar (Table 1).

Mortality, Reoperation, and Prosthetic Valve Dysfunction

Follow-up data were complete in 219 cases (84.9%) and the median follow-up duration (from operation to last follow-up) was 10.5 (IQR, 8.4∼13.0) years. Mean follow-up duration was 12.7 ± 3.2 years (range, 0.6∼17.3 years). During the follow-up period, 10 patients (3.9%) died. The overall freedom from mortality percentages at 5, 10, and 15 years was 97.1%, 97.1%, and 96.6%, respectively (Figure 1). For overall mortality, both groups of patients showed a similar risk of death (odds ratio, 0.37; 95% confidence interval [CI], 0.08-1.84; $P = .23$). Sixty-four

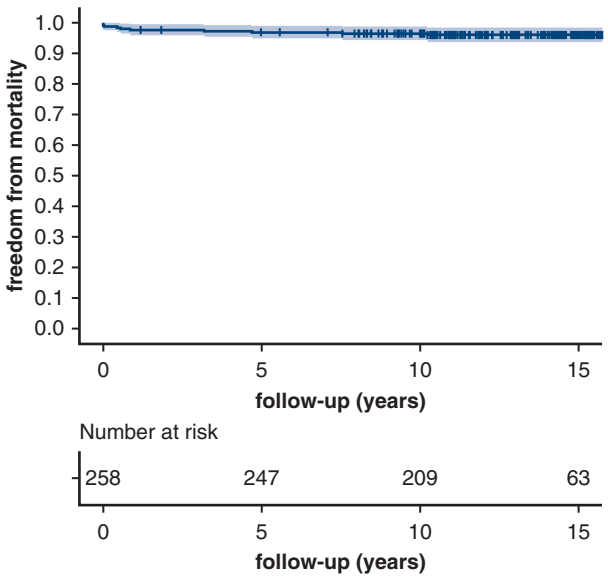

FIGURE 1. Overall freedom from mortality.

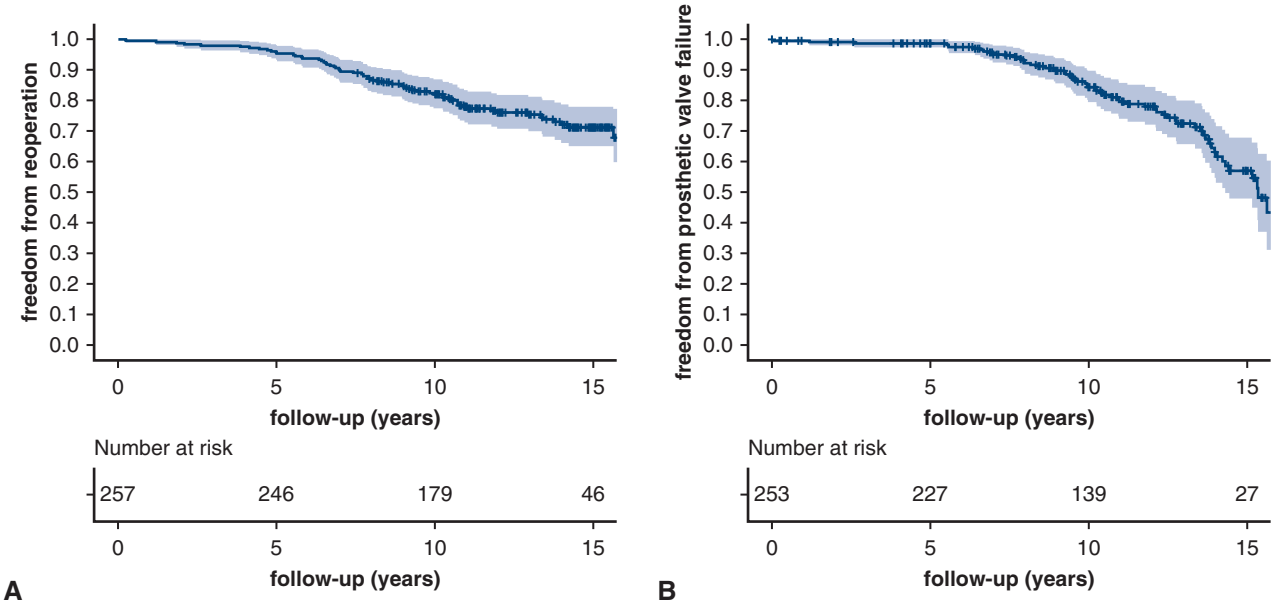

FIGURE 2. Overall freedom from reoperation (A) and prosthetic valve failure (B).

patients underwent reoperation for PVR due to prosthetic valve failure (42 patients in group CE [32.6%] and 22 patients in group H [17.1%]), which was caused by infective endocarditis in 3 patients; 10 of these 64 patients underwent reoperation during the study period. The overall freedom from redo PVR percentages at 5, 10, and 15 years was 95.7%, 82.1%, and 71.3%, respectively (Figure 2, *A*); the corresponding freedom percentages were 98.4%, 86.6%, and 81.3% in group H and 93%, 77.6%, and 60.6% in group CE. A univariate analysis showed that the reoperation rate for PVR after previous pulmonary valve implantation was significantly greater in group CE than in group H ($P = .002$, log-rank test; Figure 3).

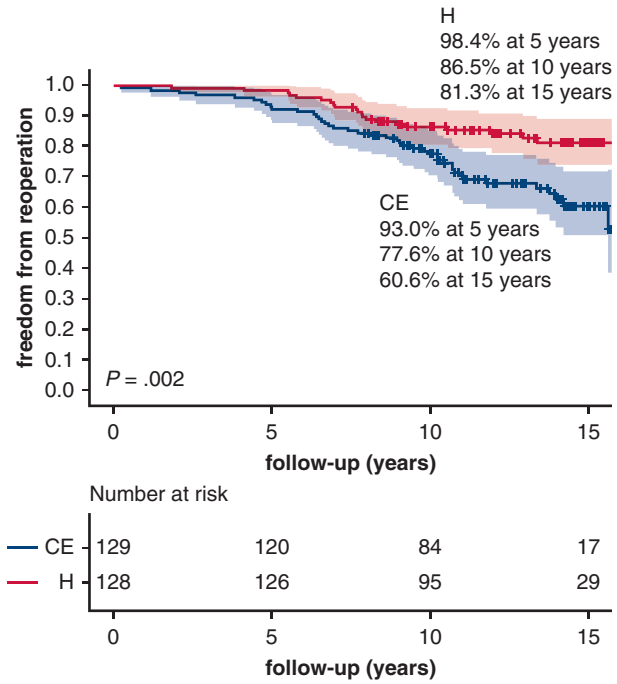

FIGURE 3. Comparison of reoperation-free rates between the Hancock II (H) and Carpentier-Edwards PERIMOUNT (*CE*) valves in the pulmonary position. Patients with Hancock II valves show greater reoperation free rate than patients with Carpentier-Edwards PERIMOUNT valves in long-term follow-up.

In this study, we defined prosthetic valve failure as PS with a peak velocity ≥3.5 m/s through the prosthetic pulmonary valve or moderate-to-severe PR. When a patient's most recent echocardiographic findings presented 1 of these 2 features, we considered it prosthetic valve failure occurrence. According to our definition, overall freedom from the prosthetic valve failure was 98.8% at 5 years, 84.4% at 10 years, and 57.0% at 15 years (Figure 2, *B*). Comparing Figure 2, *A*, and Figure 2, *B*, we can assume that these definitions were not directly used when deciding whether to pursue immediate redo-PVR. That means, we can observe the patients without redo-PVR for a while even after significant prosthetic valve failures were progressed.

A Fisher exact test showed similar prosthetic valve failure rate between these 2 valves (group CE 27.9% [36/129] vs group H 20.9% [27/129], $P = .164$); however, when we considered time-related events, the freedom from prosthetic valve failure of the Hancock II valve (100% at 5 years, 84.0% at 10 years, and 69.4% at 15 years) showed superiority in the long term compared with the CE valve

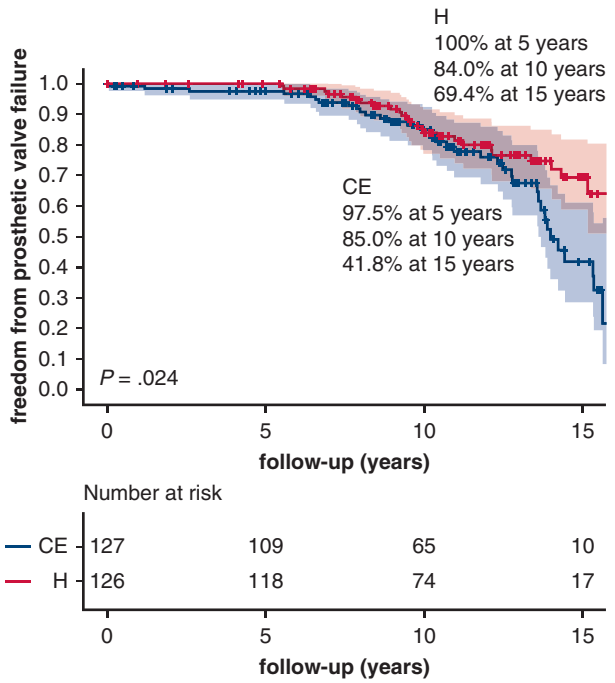

FIGURE 4. Comparison of prosthetic valve failure-free rates (definition of prosthetic valve failure in this study: pulmonary stenosis with more than 3.5 m/s of velocity through prosthetic pulmonary valve "or" pulmonary regurgitation with moderate or severe degree) between the Hancock II (H) and Carpentier-Edwards PERIMOUNT (*CE*) valves in the pulmonary position. Patients with Hancock II valves show greater prosthetic valve failure free rate than patients with Carpentier-Edwards PERIMOUNT valves in long-term follow-up, especially after 10 years.

(97.5% at 5 years, 85.0% at 10 years, and 41.8% at 15 years; $P = .024$, log-rank test, Figure 4). Although most patients showed no significant clinical symptoms or signs associated with prosthetic valve failure in the pulmonic position, some patients' echocardiographic data showed features of prosthetic valve failure with significant PS or moderate-to-severe PR. Both groups showed similar incidences of prosthetic valve failure with PS (15.7% in group CE vs 15.8% in group H, $P = .903$); however, group CE showed a significantly greater incidence of prosthetic valve failure with PR than group H (21.7% vs 8.1%, $P = .014$) upon final echocardiography. The ratio of patients with both significant PS and PR was 27.8% (10/36 patients) in group CE and 11.1% (3/27 patients) in group H.

Consistent with the findings of several previous studies,[1-3] the univariate analysis of the data in the present study showed that young age (≤18 years) and small valve size (<25-mm diameter) were important risk factors for redo-PVR and prosthetic valve failure. Although no preoperative difference was observed between the 2 groups in terms of valve size and the patients' mean age, the Cox proportional hazards model revealed that the valve type (greater reoperation rate in group CE than group H: $P = .005$, hazard ratio [HR], 2.17; CI, 1.26-3.72) and age at time of PVR (greater reoperation rate in patients <18 years old: $P = .009$, HR, 3.90; CI, 1.4-10.86) significantly affected the outcomes in terms of the reoperation rate. Regarding the prosthetic valve failure features assessed by echocardiography, still valve type affected the outcomes in prosthetic valve dysfunction rate (greater prosthetic valve dysfunction rate in group CE than group H: $P = .027$, HR, 1.83; CI, 1.07-3.14). Even though it did not reach statistical significance, valve size (greater prosthetic valve dysfunction rate in patients with valve size <25 mm than valve size ≥25 mm: $P = .085$, HR,1.592; CI, 0.94-2.70) tended to affect prosthetic valve dysfunction.

Different Pathologic Changes Between the 2 Types of Valve in the Pulmonary Position

We found severe structural deterioration in the valves of both groups during redo-PVR (Figure 5) and occasionally even in patients who showed no severe symptoms or signs associated with significant PS or PR or heart failure before the operation. Regarding the porcine valves, the extracted porcine valves tended toward shrinkage or leaflet tearing with a mild calcium deposition and fibrotic change, which was assumed to have progressed gradually after shrinkage or tearing. This deterioration had induced a valve dysfunction, but the leaflet was usually still mobile, even at the time of reoperation for the valve dysfunction. Most of the observed changes seemed to occur at the commissures. In contrast, the extracted pericardial valves mostly showed commissural fusion with much more severe fibrotic changes and calcium deposits without severe shrinkage or tearing defects, along with almost nonmobile leaflets with significant thickness. Their stiff leaflets permitted only a small central opening, which had induced severe stenosis with regurgitation. The pathologic changes in these 2 types of the prosthetic valves in the pulmonary valve position appeared similar to those in the aortic valve position, but the outcomes in terms of durability and mortality were different between these 2 valve types. In our study, acute aggravation of a patients' general condition due to acute deterioration of the prosthetic valve structure has been reported in the left-sided valve position did not happen in the pulmonic position. Microscopically, these 2 valves showed similar pathologic changes, dystrophic calcification, and fibromyxoid changes; however, the CE pericardial valve leaflet usually had a wider and diffuse range of pathologic changes than did the Hancock II porcine valve.

Changes in Cardiac MRI Data

In this study, cardiac MRI was performed in 166 cases of 164 patients during either the pre- or

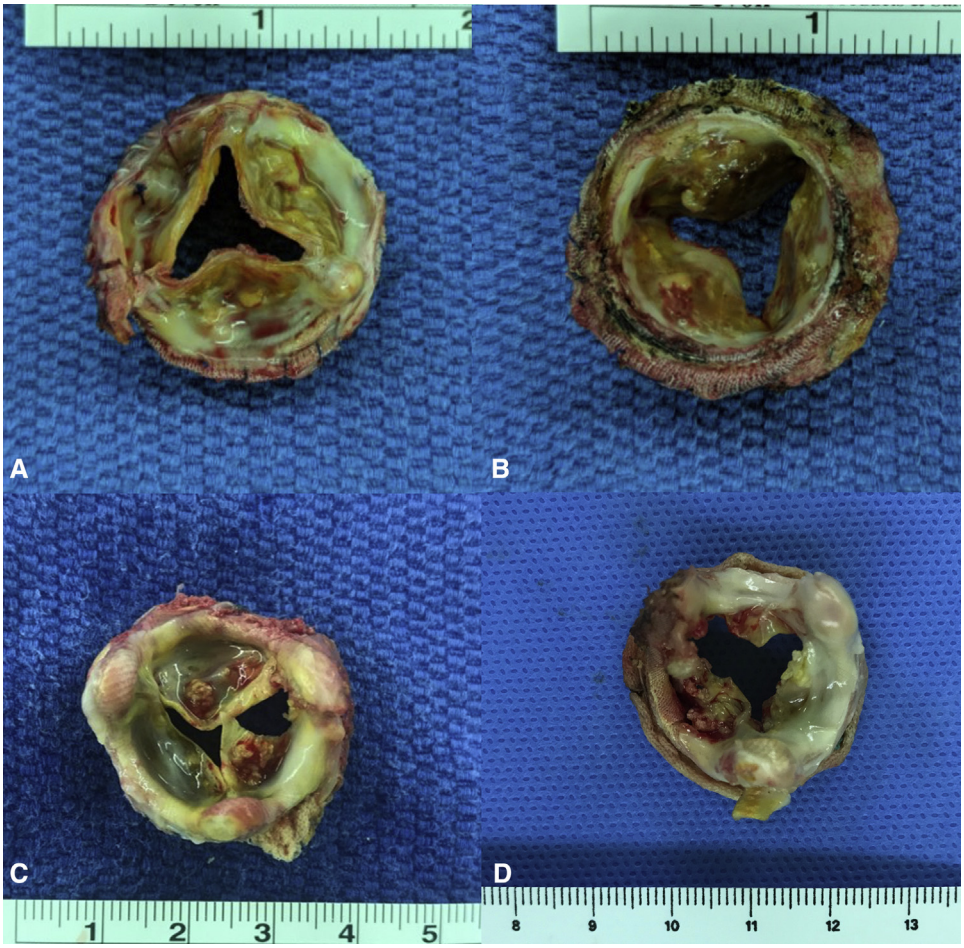

FIGURE 5. A and B, A pericardial Carpentier-Edwards valve extracted 10 years after implantation. C, A porcine Hancock II valve extracted 12 years after implantation. D, A porcine Hancock II valve extracted 18 years after implantation.

postoperative period. Among them, 69 cases of 67 patients were assessed with cardiac MRI in both the pre- and post-PVR periods. The mean duration from the timing of PVR to the timing of the most recent cardiac MRI was 83.9 ± 55.9 months and the mean duration from the timing of the preoperative cardiac MRI to the timing of the most recent cardiac MRI was 86.1 ± 54.9 months. The median with IQR value of the preoperative RV end-diastolic volume index (EDVi), RV end-systolic volume index (ESVi), and RVEF were 160.6 (133.1∼190.0) mL/m^2, 92.8 (70.9∼110.0) mL/m^2, and 43.5 (35.0∼47.9)%, respectively. After PVR, the mean postoperative RVEDVi, RVESVi, and RVEF were 119.0 (87.8∼137.0) mL/m^2, 69.1 (47.0∼86.0) mL/m^2, and 47.0 (40.7∼53.1)%, respectively. Further, the mean preoperative LVEDVi, LVESVi, and LVEF were 76.8 (66.4∼92.5) mL/m^2, 31.5 (25.4∼42.6) mL/m^2, and 59.1 (52.8∼63.6)%, respectively, and the mean post-PVR LVEDVi, LVESVi, and LVEF were 86.0 (73.5∼101.1) mL/m^2, 86.0 (73.5∼101.1) mL/m^2, and 58.0 (52.3∼63.1)%, respectively (Table 2). After dividing these data into 2 groups according to the prosthetic valve types (n = 19 in group CE, n = 50 in group H), we found that the parameters associated with RV were improved after PVR regardless of the valve type. The parameters associated with LV volume were improved only in patients in group H, whereas the LVEF was improved in patients in group CE (Table 2).

DISCUSSION

Because of the structural similarities between the pulmonary and aortic valves, the commercial valves that were originally developed for the aortic valve position have been used in the pulmonic position in patients with congenital heart diseases, especially those patients with RVOT

TABLE 2. Changes in magnetic resonance imaging parameters

	Preoperative	Follow-up	*P* value	Valve	Preoperative	Follow-up	*P* value
RVEDVi, mL/m^2	160.6 (133.1∼190.0)	119.0 (87.8∼137.0)	<.001	CE	170.0 (132.4∼205.3)	120.6 (99.5∼140.9)	.011
				Hancock	158.6 (133.8∼180.4)	119.0 (85.8∼136.8)	< .001
RVESVi, mL/m^2	92.8 (70.9∼110.0)	69.1 (47.0∼86.0)	<.001	CE	96.5 (74.4∼109.7)	67.8 (50.6∼94.5)	.019
				Hancock	90.1 (70.0∼110.1)	64.4 (45.8∼84.1)	<.001
RVEF, %	43.5 (35.0∼47.9)	47.0 (40.7∼53.1)	.001	CE	41.5 (32.7∼46.5)	44.8 (36.5∼54.7)	.031
				Hancock	44.5 (36.9∼47.9)	47.4 (41.9∼52.9)	.013
LVEDVi, mL/m^2	76.8 (66.4∼92.5)	86.0 (73.5∼101.1)	.001	CE	78.4 (59.8∼97.9)	92.0 (80.8∼100.7)	.285
				Hancock	76.8 (67.0∼91.0)	86.0 (72.0∼102.1)	.02
LVESVi, mL/m^2	31.5 (25.4∼42.6)	86.0 (73.5∼101.1)	.037	CE	36.0 (28.0∼63.9)	39.1 (29.1∼52.3)	.285
				Hancock	29.9 (24.4∼41.0)	38.0 (30.5∼46.4)	.003
LVEF, %	59.1 (52.8∼63.6)	58.0 (52.3∼63.1)	.883	CE	52.3 (42.8∼58.5)	57.5 (47.8∼63.1)	.039
				Hancock	60.5 (55.4∼63.9)	58.0 (53.9∼63.0)	.131

Values are shown as median with interquartile range. *RV*, Right ventricle; *EDVi*, indexed end-diastolic volume; *CE*, Carpentier-Edwards valve; *Hancock*, Hancock II valve; *ESVi*, indexed end-systolic volume; *EF*, ejection fraction; *LV*, left ventricle.

problems. Before the introduction of percutaneous pulmonary valve implantation, such as using the Melody valve (Medtronic), Harmony valve (Medtronic), or SAPIEN XT (Edwards Lifesciences, Irvine, Calif), no pulmonary valve–specific commercial valves were available. Therefore, the CE PERIMOUNT pericardial valve and Hancock II porcine xenograft valve have been the most commonly used valves for the pulmonic position. Although many authors have compared the long-term outcomes of these 2 valve types in the aortic and mitral valve positions, only a few studies have reported the mid-term results in the pulmonary valve position, and these studies involved only a small number of cases.[4,5]

Bioprosthetic Valves in Other Valve Positions

Currently, bioprosthetic valves are the most commonly implanted valves in the aortic valve position because of their advantages, namely hemodynamic stability, comparable durability, and being anticoagulant-free.[6] Several studies have compared the surgical results between the pericardial valve and the porcine xenograft valve in the aortic valve position and have shown variable results.[7] Wang and colleagues[8] performed a meta-regression analysis of 4 types of bioprosthetic valves in the aortic valve position and found that the CE pericardial valve and the Hancock porcine valve showed similar mean times to structural valve failure. Ganapathi and colleagues,[9] Hickey and colleagues,[10] and Chan and colleagues[11] also found no significant difference between the bovine pericardial valve and the porcine valve in the aortic position in terms of mid- and long-term survival and the need for reoperation. Although the specific models of bioprosthetic valves were different between our study and other previous studies, Dalmau and colleagues[12] found that the bovine pericardial valve was superior to the porcine valve in the aortic position, whereas other researchers found the opposite.[13] Grunkemeier and colleagues[14] observed a tendency toward a protective effect of the pericardial valve not only in the aortic valve position, but also in the mitral valve position. They also revealed that the main cause of deterioration of the pericardial valve structure was leaflet fibrosis/calcification, whereas that of the porcine valve was leaflet tearing. However, few studies have compared long-term surgical results, and some studies have compared only the mid-term results between these types of bioprosthetic valves in the pulmonary valve position.[4,5]

Failure Modes of Bioprosthetic Valves in the Pulmonary Valve Position

Severe bioprosthetic valve dysfunction in the aortic position has been defined by some committees as ≥40 mm Hg of mean pressure gradient through the prosthetic valve or severe aortic regurgitation[15]; however, there is no widely accepted definition of bioprosthetic valve dysfunction in the pulmonary valve position. In this study, we defined prosthetic valve dysfunction in the pulmonic position as PS with a peak velocity ≥3.5 m/s through the prosthetic pulmonary valve or moderate-to-severe PR upon echocardiography because in our institutions, pulmonary valve implantation was started to be considered if any patients showed any of these findings in addition to the clinical symptoms.

Grunkemeier and colleagues[14] found that the main causes of dysfunction of the 2 types of bioprosthetic valves, namely the pericardial valve and the porcine xenograft valve, were different between the aortic and mitral valve positions. According to their findings, the pericardial valve showed gradually progressed calcification and fibrotic changes, which mainly induced chronic stenoinsufficiency of the prosthetic valve, whereas the porcine valve mainly showed leaflet tearing, which induced acute valvular insufficiency. The authors explained that the greater mortality rate in elderly patients with porcine valves in the left-sided heart was mainly due to acute valve leaflet tearing, resulting in acute valvular insufficiency.

Indeed, we usually found calcified fibrotic leaflets with a fixed opening and a small effective orifice area and stiff movement from the extracted valves of the pulmonic position in the patients with the CE PERIMOUNT valve; this is similar to findings in the aortic valve position in other reports. In such a situation, a mixed lesion of stenosis and regurgitation, namely pulmonary stenoinsufficiency of the bioprosthetic valve, can be expected. However, in our study, the main reason for prosthetic valve failure in the Hancock II porcine valve was PS rather than PR. In the present study, 17 cases of 27 patients with prosthetic valve dysfunction (63.0%) had PS without significant PR and 3 cases had pulmonary stenoinsufficiency, indicating that 74.1% (20 cases of 27 patients) of the overall prosthetic valve failures were due to the stenotic component. These findings were different from the previously reported failure mode of the porcine bioprosthetic valves in the aortic valve position. This stenosis-dominant prosthetic valve dysfunction in the pulmonary position in patients with Hancock II valves, coupled with the young age of our patients, may explain the noninferior mortality rate to the patients receiving CE valves because acute valvular insufficiency by tearing, which might lead to significant deterioration of hemodynamics, seems to rarely occur in the pulmonic position. We do not know the exact reasons for the different outcomes of the same bioprosthetic valve from different positions, namely the aortic and pulmonic positions; however, it seems plausible to attribute this difference to the different pressure profiles between the systemic and pulmonary circulation systems. It is known the systemic pressure is greater than the pulmonary pressure, even in patients with PA and major aortopulmonary collateral arteries; therefore, the lower pulmonary pressure has rarely caused acute deterioration of the bioprosthetic valve structure.

Risk Factors for Prosthetic Valve Failure

We analyzed the risk factors for reoperation and prosthetic valve dysfunction using a Cox regression model. We expected that patients with greater RV pressures, such as those with PA with VSD or PA with major aortopulmonary collateral arteries, would show greater rates of early reoperation or early valve dysfunction because high pulmonary pressure can induce early deterioration of the valve structure. However, contrary to our expectation, the original diagnoses did not affect the rates of reoperation or prosthetic valve dysfunction. The only risk factors for early reoperation and prosthetic valve dysfunction were the patients' age (young age at the time of prosthetic valve implantation) and the prosthetic valve type (CE valve). Young age is a well-known risk factor for earlier reoperation for valve replacement in the pulmonary position[1-5,16,17]; however, not only have long-term outcomes according to the types of bioprosthetic valve in the pulmonic position been rarely reported, but also the reasons for the differences in durability between porcine and pericardial valves in the pulmonic position have been rarely explained. Presumably, the thicker leaflet of the pericardial valve of the CE valve, which was originally designed and manufactured to be opened and closed by high aortic pressure, may become stiff more easily over time with the much lower pressure of pulmonary circulation, which seems insufficient to maintain ideal opening and closure of the pericardial valve leaflet. In contrast to this, we guess that the thin porcine valve leaflets of the Hancock II valve may maintain the desired configuration and mobility, even with the lower-pressure system. Further investigation and in vivo experimentation about flow dynamics are needed to reveal the reasons for the different changes in these 2 valve types under low-pressure circulation.

Because of the recent technical development of percutaneous transcatheter pulmonary valve implantation, the number of cases of pulmonary valve implantation using the open-chest maneuver is predicted to decrease gradually. However, the findings of our study can contribute to the future development of transcatheter pulmonary valves.

Limitations of Study

This study has limitations inherent to its retrospective and observational aspects. There might be a selection bias due to individual surgeons choosing a valve type because more than 5 surgeons were involved in our study, even though these 2 types of valves were evenly used in same era and had almost same postoperative follow-up duration. There are several different types of bioprosthetic valves that are available internationally, but we compared only 2 types of pulmonary valves that were available during the study period in Korea because of our small market.

CONCLUSIONS

The porcine valve (Hancock II) has a greater reoperation-free rate and better valve function than the pericardial valve (CE valve) in the pulmonic position in patients with various

types of congenital cardiac anomalies accompanied by RVOT stenosis or atresia. We confirmed our impression of the superiority of the porcine valve in the pulmonic position through this research and have used a porcine valve in the pulmonic position recently, if surgical implantation was required.

Conflict of Interest Statement

Authors have nothing to disclose with regard to commercial support.

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