Long-term results after the Ross procedure with the decellularized AutoTissue Matrix P® bioprosthesis used for pulmonary valve replacement

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Abstract

OBJECTIVES: Since 1967, the Ross procedure has been performed to treat aortic valve disease using homografts for pulmonary valve replacement. The decellularized Matrix P® prosthesis was developed to overcome (some) limitations of homografts. Until now, the long-term outcome data have been unavailable.

METHODS: Between 2002 and 2010, the Ross procedures using the Matrix P prosthesis were performed in 492 adult patients (mean age 57.2 ± 10.6 years, range 21–73 years) at our institution. Patient data were prospectively collected and analysed (3617.3 patient-years, mean follow-up 7.7 ± 4.3 years). Completeness of follow-up at 1, 5 and 10 years was 98.4%, 94.5% and 91.0%, respectively.
RESULTS: Hospital mortality was 3.9% (n = 19). During follow-up, 121 patients died resulting in a survival rate at 5, 10 and 12.5 years of 82.8 ± 1.7%, 70.4 ± 2.3% and 62.4 ± 2.9%, respectively. Echocardiography revealed a high incidence of relevant dysfunction of the Matrix P prosthesis and subsequent right ventricular failure. Primary reoperation/reintervention was necessary for 150 Matrix P and 48 autografts. Freedom from pulmonary valve reoperation at 5, 10 and 12.5 years was 76.2 ± 2.1%, 58.6 ± 2.9% and 53.4 ± 3.4%, respectively. The autograft function and the left ventricular function showed similar results as previously reported with a freedom from autograft reoperation at 5, 10 and 12.5 years of 91.8 ± 1.4%, 86.1 ± 2.0% and 86.1 ± 2.0%, respectively.

CONCLUSIONS: The Matrix P prosthesis used for the right ventricular outflow tract reconstruction in the Ross procedure showed unfavourable long-term echocardiographic results with a high rate of reoperation/reintervention for structural pulmonary valve failure. As a consequence, long-term survival of this patient cohort was impaired. Based on these findings, the use of the Matrix P prosthesis for pulmonary valve replacement for Ross procedures in adults should not be recommended.

Keywords: Ross procedure • Pulmonary valve replacement • Aortic valve replacement • Heart valve prosthesis • Bioprosthesis

INTRODUCTION

In 1967, Donald Ross introduced the concept of a pulmonary autograft procedure to treat aortic valve disease, which was later termed the Ross procedure [1]. In recent years, the excellent haemodynamic characteristics, a low risk of thromboembolism and the benefits of not requiring anticoagulation in the long term have consistently been reported [2, 3]. The Ross procedure is, therefore, considered as an alternative for aortic valve replacement in younger patients with a contraindication to oral anticoagulation or the desire to avoid oral anticoagulation [4]. In the paediatric population, the growth potential of the viable autograft makes it the procedure of choice [5]. These advantages come at the price of a 2-valve procedure for a simple aortic valve replacement. This does not only increase the operative risk but also potentially doubles the risk of valve reintervention [6]. In the long-term perspective, dysfunction of the pulmonary valve along with the necessity for reintervention has emerged as a major limitation. Homografts were originally and predominantly used for pulmonary valve replacement [1]. Limited availability, the need for reintervention and a potential immunogenic response have triggered the search for alternative substitutes, including different stentless xenografts [7]. The Matrix P bioprosthesis (AutoTissue GmbH, Berlin, Germany) differs from other stentless valves in its fabrication process of decellularization. As a result, in vivo recellularization and regeneration are anticipated. Preclinical tests of this valve [8] and short-term clinical outcomes in adults were promising [9]. The short-term results in children were not that encouraging, showing a high rate of the obstruction [10]. However, long-term results are still lacking.

PATIENTS AND METHODS

Patients

From 2002 to 2012, the Ross procedure using a Matrix P prosthesis was performed in 492 adult patients (mean age 56.7 ± 10.7 years, range 21–73 years) at our institution. Procedures were performed after collecting patient information and written informed consent in accordance with actual guidelines. Patient data were prospectively collected and analysed.

Matrix P prosthesis

Matrix P prostheses are the first in Europe certified decellularized and commercially available porcine heart valves. During the decellularization process, xenogenic cells are eliminated from the extracellular matrix. This leads to intact but cell-free extracellular connective tissue structures. After implantation, the implants attract and homoeautologous cells and, hence, allow for regeneration of the valve. The Matrix P prostheses are available in 3 different formats: (i) Matrix P: full porcine pulmonary root, (ii) Matrix P Plus: full porcine pulmonary root covered with a glutaraldehyde-fixed equine pericardial patch and (iii) Matrix P Plus N: full porcine pulmonary root covered with a decellularized equine pericardial patch (Fig. 1).

Operation

The procedure was performed according to a technique previously described [1]. In brief, after median sternotomy standard...
cannulation, cardiopulmonary bypass and hyperkalaemic cardioplegic arrest were applied. The pulmonary valve was excised and trimmed. After the excision of the native aortic valve leaflets, the pulmonary autograft was implanted by subcoronary, inclusion cylinder or root replacement technique. The subcoronary technique was used whenever anatomically possible using polypropylene running sutures for the proximal and the distal suture lines. The root replacement technique was infrequently used and was abandoned during the course of the study, as the potential risk for late graft aneurysm formation became evident with this technique. Instead, the inclusion cylinder technique was implemented using polypropylene running sutures for the proximal suture line, the coronary ostia and the distal suture line. In a few cases, the excised pulmonary valve was reinforced with a Dacron patch. Finally, the pulmonary valve was substituted with the Matrix P prosthesis using polypropylene running sutures for both suture lines.

Follow-up

The local ethics committee approved the study (official file number EA1/228/16). Patients’ charts, information of the local residents’ registration office, telephone interviews and physical as well as all available echocardiographic examinations were evaluated. Mean follow-up was 7.7 ± 4.3 years. Total follow-up was 3657.4 patient-years, 3281.3 autograft-years and 2750.6 Matrix P-years. Completeness of follow-up at 1, 5 and 10 years was 98.4%, 94.5% and 91.0%, respectively. Patients requiring reoperation or reintervention were included in the survival analysis of the study.

Echocardiography

Evaluation of cardiac function and valve function was done using transthoracic 2-dimensional echocardiography and Doppler echocardiography with the HP Sonos 5500 (Hewlett Packard, Andover, MA, USA) and later the GE Vivid 7 Dimension (General Electric, Fairfield, CT, USA). The mean values for each measurement were derived from 3 beats in sinus rhythm and averaged from 5 beats in non-sinus rhythm. Transaortic and transpulmonary flow velocities were assessed using the continuous-wave Doppler, whereas flow velocities in the left ventricular outflow tract were assessed using the pulsed-wave Doppler. The pressure gradients were calculated using the Bernoulli equation. The left and the right ventricular ejection fractions were assessed by semiquantitative definitions (normal, moderately impaired and profoundly impaired). Because of death, reoperation, poor echocardiographic conditions or patients’ unavailability, completeness of echocardiographic follow-up declined over time. At discharge, 444 patients underwent echocardiography. At 1, 5 and 10 years, an echocardiogram was available for 350, 210 and 60 patients, respectively. Therefore, after 1, 5 and 10 years, 84.3%, 76.4% and 52.6% of the patients with the originally implanted Matrix valve still in place had an accessible follow-up echocardiogram, respectively.

Statistical analysis

All data were analysed using the SPSS Statistics version 25 (IBM Corporation, Armonk, NY, USA). Descriptive statistics are reported as the mean ± standard deviation for continuous variables and as absolute frequencies and percentages for categorical variables. Morbidity, freedom from reoperation and mortality were evaluated with time-to-event analyses using the Kaplan-Meier method. Univariate curve comparisons were performed using the log-rank test. All P-values were 2-sided. Statistical significance was set at a P-value of less than 0.05. Survival curves were created using Prism version 6 (Graphpad, La Jolla, CA, USA).

RESULTS

Patient baseline characteristics and operative data are listed in Tables 1 and 2.

Hospital outcome

Hospital mortality was 3.9% (n = 19). Relevant bleeding requiring re-exploration was present in 42 patients (8.5%). Stroke occurred in 5 patients (1.0%). A cardiac pacemaker had to be implanted in 7 patients (1.4%).

Echocardiographic outcome

The echocardiographic results (according to the time of follow-up) of the aortic autograft and the left ventricle as well as the pulmonary valve and the right ventricle are shown in Table 3. Notably, the proportion of patients presenting with aortic insufficiency >2 changed from 14% after 1 year to 20% after 5 years and to 8% after 10 years, whereas the frequency of aortic insufficiency (AI) III° was consistently low. Among patients with AI >2, 24.7%
were reoperated on and 27.0% showed stable or declining AI without clinical symptoms. The remaining patients died, were lost to echocardiographic follow-up or had not reached the 10-year echocardiographic follow-up yet.

**Freedom from reoperation**

Overall freedom from reoperation at 5, 10 and 12.5 years was 71.4 ± 2.2%, 54.7 ± 2.9% and 49.7 ± 3.3%, respectively. Freedom from aortic valve reoperation at 5, 10 and 12.5 years was 91.8 ± 1.4%, 86.1 ± 2.0% and 86.1 ± 2.0%, respectively (Fig. 2A). Reoperations were predominantly necessary due to valve insufficiency (98% including 8 cases of endocarditis). The technique of autograft implantation had no significant impact on reoperation (P = 0.56). However, one has to consider the low number of cases with root replacement or a Dacron-reinforced autograft. Freedom from pulmonary valve reoperation at 5, 10 and 12.5 years was 76.2 ± 2.1%, 58.6 ± 2.9% and 53.4 ± 3.4%, respectively (Fig. 2B). Reoperations were almost equally attributed to pulmonary insufficiency or a stenotic distal suture line as the predominant causes of reoperation. However, in most cases, both were present. Nine patients underwent redo surgery due to endocarditis. No statistically significant difference regarding the reoperation rate was observed among the Matrix P, the Matrix P plus and the Matrix P plus N prostheses (log-rank P = 0.85) (Fig. 3). Furthermore, age at the time of the index operation (P = 0.49) and the year of the index operation (P = 0.68) had no impact on the freedom of reoperation. The failed Matrix P valves were replaced using various prostheses and techniques. Reoperations were performed using bioprostheses (Laborcortic Auto-Conduit®, Medtronic Contegra®, Toronto SPV®, Sorin Pericarbon Freedom®, Carpentier Edwards Perimount®, Edwards Prima Plus®, St. Jude Medical Epic®, Medtronic Freestyle®, Vascutek Elan Root® and newer models of the Matrix P prostheses), mechanical prostheses (St. Jude Medical Regent) and patch enlargement of stenotic distal pulmonary anastomoses. Interventional valve procedures were performed using the Edwards SAPIEN® prostheses, Medtronic Melody® prostheses and stent implantation into stenotic distal anastomoses. Because

**Table 2: Operative characteristics**

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Number</th>
<th>Relative frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isolated aortic valve replacement</td>
<td>339</td>
<td>68.9</td>
</tr>
<tr>
<td>Combined procedures</td>
<td>153</td>
<td>31.1</td>
</tr>
<tr>
<td>Coronary artery bypass grafting</td>
<td>72</td>
<td>14.6</td>
</tr>
<tr>
<td>Replacement of the ascending aorta</td>
<td>25</td>
<td>5.1</td>
</tr>
<tr>
<td>Atrial fibrillation ablation</td>
<td>22</td>
<td>4.5</td>
</tr>
<tr>
<td>Aortic annular enlargement</td>
<td>19</td>
<td>3.9</td>
</tr>
<tr>
<td>Mitral valve replacement</td>
<td>9</td>
<td>1.8</td>
</tr>
<tr>
<td>Mitral valve reconstruction</td>
<td>8</td>
<td>1.6</td>
</tr>
<tr>
<td>Tricuspid valve reconstruction</td>
<td>1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**Table 3: The echocardiographic results of the aortic autograft, the left ventricle, the pulmonary valve and the right ventricle according to the time of follow-up**

<table>
<thead>
<tr>
<th>Follow-up</th>
<th>Discharge</th>
<th>1 year</th>
<th>5 years</th>
<th>10 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients</td>
<td>444</td>
<td>350</td>
<td>209</td>
<td>60</td>
</tr>
<tr>
<td>Mean autograft maximum pressure gradient (mmHg), mean ± SD</td>
<td>11.9 ± 4.8</td>
<td>7.2 ± 2.9</td>
<td>7.2 ± 2.9</td>
<td>7.6 ± 3.8</td>
</tr>
<tr>
<td>Aortic insufficiency I (fraction of patients, %)</td>
<td>4.0</td>
<td>12.6</td>
<td>17.6</td>
<td>8.3</td>
</tr>
<tr>
<td>Aortic insufficiency II (fraction of patients, %)</td>
<td>0.9</td>
<td>2.0</td>
<td>2.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Mean left ventricular ejection fraction (%), mean ± SD</td>
<td>55.4 ± 8.3</td>
<td>58.8 ± 7.9</td>
<td>57.4 ± 8.2</td>
<td>57.2 ± 7.7</td>
</tr>
<tr>
<td>Mean left ventricular end-diastolic diameter (mm), mean ± SD</td>
<td>47.9 ± 7.0</td>
<td>47.9 ± 5.6</td>
<td>48.4 ± 5.7</td>
<td>48.4 ± 4.5</td>
</tr>
<tr>
<td>Mean pulmonary valve maximum pressure gradient (mmHg), mean ± SD</td>
<td>6.0 ± 2.8</td>
<td>14.1 ± 9.4</td>
<td>22.7 ± 12.5</td>
<td>23.2 ± 12.0</td>
</tr>
</tbody>
</table>

**Pulmonary insufficiency (fraction of patients, %)**

<table>
<thead>
<tr>
<th></th>
<th>None</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge</td>
<td>87.3</td>
<td>55.9</td>
<td>25.0</td>
<td>10.7</td>
</tr>
<tr>
<td>1 year</td>
<td>11.5</td>
<td>31.2</td>
<td>36.3</td>
<td>44.6</td>
</tr>
<tr>
<td>5 years</td>
<td>1.0</td>
<td>12.1</td>
<td>30.4</td>
<td>30.4</td>
</tr>
<tr>
<td>10 years</td>
<td>0.2</td>
<td>0.6</td>
<td>6.4</td>
<td>10.7</td>
</tr>
</tbody>
</table>

**Right ventricular function (fraction of patients, %)**

<table>
<thead>
<tr>
<th></th>
<th>Normal</th>
<th>Moderately impaired</th>
<th>Highly impaired</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge</td>
<td>71.2</td>
<td>68.9</td>
<td>62.6</td>
</tr>
<tr>
<td>1 year</td>
<td>19.7</td>
<td>25.6</td>
<td>31.8</td>
</tr>
<tr>
<td>5 years</td>
<td>9.2</td>
<td>5.2</td>
<td>5.6</td>
</tr>
<tr>
<td>10 years</td>
<td>26.3 ± 8.5</td>
<td>34.6 ± 5.1</td>
<td>36.7 ± 6.4</td>
</tr>
</tbody>
</table>

**Tricuspid insufficiency (fraction of patients, %)**

<table>
<thead>
<tr>
<th></th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discharge</td>
<td>29.6</td>
<td>46.2</td>
<td>53.7</td>
</tr>
<tr>
<td>1 year</td>
<td>10.8</td>
<td>19.6</td>
<td>21.0</td>
</tr>
<tr>
<td>5 years</td>
<td>25.1 ± 8.6</td>
<td>35.2 ± 12.0</td>
<td>39.4 ± 13.6</td>
</tr>
</tbody>
</table>

**SD:** standard deviation.
of these multiple methods of treatment, no meaningful statistical analyses could be undertaken.

Survival

Survival rate at 5, 10 and 12.5 years was 82.8 ± 1.7%, 70.4 ± 2.3% and 62.4 ± 2.9%, respectively (Fig. 4). Overall, 141 patients died during follow-up (including hospital mortality). The main causes of death were multiorgan failure (n = 28), heart failure (n = 17), malignant diseases (n = 16), others (n = 11) and unknown (n = 69).

The technique of autograft implantation had no significant impact on survival (P = 0.36). On univariate analysis, patients with Matrix P plus N showed a higher survival than patients with the Matrix P, and these patients showed a higher survival than patients with Matrix P plus (P = 0.014). Noteworthy, patients with Matrix P plus N had a mean age of 49.3 ± 8.9 years; patients with the Matrix P had a mean age of 56.3 ± 9.7 years; and patients with Matrix P plus had a mean age of 57.7 ± 10.3 years. Survival rate of reoperated patients at 5, 10 and 12.5 years was 91.9 ± 2.2%, 84.0 ± 3.1% and 75.3 ± 4.4%, respectively (Fig. 5). Reoperated patients had a significantly better survival (P < 0.001, Fig. 5). This aspect was not affected by patient age (P = 0.49), year of operation (P = 0.51) or type of the Matrix P prosthesis (P = 0.63).

DISCUSSION

For more than 50 years, the Ross procedure has been used to treat aortic valve disease mainly in younger patients. Initial concerns about the excess risk by expanding a simple valve replacement to a double-valve root procedure have prevented its application in a larger population. The potential advantages such as the potential for growth and an excellent haemodynamic profile without the need for anticoagulation have led to an increasing use despite a higher surgical complexity. The problems of (the originally used) homografts such as calcification and degeneration as well as their limited availability have resulted in an extensive search for a more suitable alternative for pulmonary valve replacement. Among others, decellularized grafts such as the Matrix P prostheses, which showed encouraging short-term results have been a promising option [9].

In 113 of 131 cases of Donald Ross’ pioneer series, a homograft was used. Long-term data of this seminal series showed a
The mean age, profile of comorbidities and the pulmonary valve replacement and our patients' data were not registry, in which homografts were predominantly used for pulmonary position homografts of 89% and 80%, respectively [2]. In comparison with our study, only the freedom from autograft replacement is similar. Survival and freedom from pulmonary homograft replacement were clearly superior in the pioneer series, which can be largely attributed to the fact that the patient cohort was substantially different from our contemporary series. The mean age of the patients was less than 25 years, and patients had fewer comorbidities. These demographic differences do not allow for a meaningful comparison of long-term survival data. However, freedom from pulmonary valve replacement, like freedom from autograft replacement, should be less affected by these differences, indicating an inferior long-term durability of the Matrix P prosthesis.

A more fitting comparison was made with the German Ross registry, in which homografts were predominantly used for pulmonary valve replacement and our patients' data were not included [12]. The mean age, profile of comorbidities and the year of the index procedure were more similar, and the study cohort was much larger (n = 1339). However, the mean age was still 12 years younger (44.7 ± 11.6 years) than that of our cohort. As a consequence, relevant comorbidities were also less common. Therefore, without a propensity match (that was not possible due to the lack of access to the original data from the Ross registry), a comparison to our study cohort in terms of survival is again not useful. The overall freedom from reoperation at 5, 10 and 15 years in the registry was 94.9%, 91.1% and 82.7%, respectively. Freedom from autograft reoperation was 96.8%, 94.7% and 86.7%, respectively, whereas freedom from homograft reoperation was 97.6%, 95.5% and 92.3%, respectively. Thus, in this large and important registry, the autograft also showed comparable results, whereas the homograft showed an obviously better durability. Long-term comparison between stentless xenografts and homografts for pulmonary valve replacement in the Ross procedure also indicated significantly better results in homografts [13]. The Contegra bioprosthesis (valved heterologous bovine jugular vein) is predominantly used in children for the reconstruction of the right ventricular outflow tract. Data from adults after the Ross procedure are rare. One group published the midterm results of a small cohort (n = 22) with acceptable results after 9 years (survival 93 ± 3.4% and freedom from reoperation 91 ± 3.9%) [14]. However, 2 cases of conduit stenosis occurred in the first 16 months after implantation, and the long-term results are not available. Another option is the Hancock porcine-valved Dacron conduit. Data after Ross procedures in adults for this device are also rare. Data from a mixed cohort (aged 4 months to 64 years) with mainly paediatric patients revealed a freedom from conduit failure at 5 years of 83% [15]. After comparison of these different devices, homografts should be the prostheses of choice for pulmonary valve replacement in adults.

When evaluating long-term survival, a comparison with the general population can be more appropriate. The study cohort of the German Ross Registry had a comparable survival to the gender- and age-matched general population. A gender- and age-matched general population for our study cohort would have had a 10-year life expectancy of approximately 90% [16]. The observed 10-year outcome in our study population of approximately 70% is clearly inferior but mainly due to the high number of comorbidities present in our cohort.

An interesting finding was the improved long-term survival in patients who were reoperated on. Baseline and operative characteristics, including age and year of the index operation or type of the Matrix P prosthesis used, were not identified as confounders. One possible explanation could be a diagnostic and treatment delay in some patients with a failing pulmonary valve with the consequence of right heart failure. Failure to perform or delaying a reoperation could, therefore, lead to an impaired outcome. The indication for reintervention of failed pulmonary valve prostheses was defined by a combination of echocardiographic data (pulmonary insufficiency III or pulmonary stenosis III, and right ventricular dysfunction) and clinical status (New York Heart Association III–IV) used. Because of diagnostics and treatment in other facilities, the indication for reoperation varied. After the evaluation of the poor outcome of the non-reoperated patients, a more aggressive indication could be helpful to prevent further right ventricular failure. On account of the variety of pulmonary valve replacement therapies [16 different valves (surgical and interventional) and stents/patches], subgroups were small, and therefore, analyses were not meaningful.

The failure pattern of the Matrix P prostheses included valvular regurgitation due to leaflet destruction, stenotic lesions of the distal suture line and a combination of both. The patterns occurred in almost the same proportion. It is important to note that in stenotic lesions, pulmonary insufficiency is difficult to quantify due to the overload of the right ventricle. It is, therefore, possible that the number of insufficient Matrix P bioprostheses necessitating reoperation may have likely been underestimated. Echocardiographic follow-up at 10 years showed that only approximately 10% of the patients had a pulmonary regurgitation of less than grade 1, and the maximum pressure gradient was 23.2 mmHg (despite the reoperation rate after 10 years of 41.4%). A comparison with the German Ross Registry, in which approximately 82% of the patients had a pulmonary regurgitation of less than grade 1 and a maximum pressure gradient of ~13 mmHg after 10 years, confirms the poor long-term haemodynamic profile of the Matrix P prostheses. The modifications of the valve over time did little to improve its haemodynamic properties and durability.

A possible cause for the high failure rate of the pulmonary valve could be due to the manufacturing process. Instead of traditionally used chemicals, such as glutaraldehyde, which are cytotoxic and inhibit tissue recellularization, a non-toxic decellularization method was used. The aim of decellularization is the
preservation of the extracellular matrix to create scaffolds, which can be repopulated with autologous cells in vivo, with the goal to create a viable valve. This process of autoregeneration is based on the application of deoxycholic acid for decellularization. Cell fragments and detergent residues are removed by extensively washing with saline solution. Finally, the tissue is sterilized with ethanol. Successful autoregeneration and growth potential have been shown in animal models [8]. In vivo recellularization of the decellularized pulmonary valve was also shown in a human subject [17]. Short-term echocardiographic follow-up showed promising results [9]. The long-term results presented here show that even a successful recellularization does not prevent structural deterioration. The results reported by other groups applying different approaches for decellularization are more promising. For the SynerGraft technology, mid-term follow-up showed no difference with cryopreserved allografts [18]. Long-term follow-up showed a freedom from conduit dysfunction after 10 years of 83%, which was significantly better (P < 0.001) than for cryopreserved allografts (58%) [19]. Another group used Trypsin/Ethylendiaminetetraacetic acid (EDTA) to produce fresh decellularized pulmonary allografts and has shown comparable short- and mid-term results as with cryopreserved homografts in a paediatric population and in addition, even a lower reoperation rate [20]. Currently, the focus is on a biodegradable synthetic material for the in vivo creation of living autologous tissue-engineered heart valves [21]. These valves are in preclinical testing and show promising results [21]. Although it is almost impossible to compare the results from these different approaches, the Matrix P prostheses showed an undoubtedly inferior long-term outcome.

Because of the improvement of aortic bioprostheses over the last decades, their use in younger patients has become more popular [22–24]. Cardiopulmonary bypass and cross-clamp times are shorter for stented and stentless valves as compared to the Ross procedure, and hospital outcomes are excellent [25, 26]. Freedom from reoperation in younger patients is approximately 60–70% after 15 years for the stented Medtronic Hancock II® or the stentless Edwards Prima Plus® [25–27]. Repeat isolated aortic valve surgery is associated with good outcomes, and operative mortality is only slightly higher than that with the first operation [26–28]. Additionally, the implementation of valve-in-valve percutaneous aortic valve procedures avoids possible high-risk reoperations [29]. In line with these findings, aortic bioprostheses are not only exclusively recommended for older patients but can also be used in younger patients as per the patient’s request according to the 2017 European Society of Cardiology/European Association for Cardio-Thoracic Surgery guidelines for the management of valvular heart disease [4]. In Germany, these facts have led to a decreasing number of Ross procedures in adults from a peak of 261 in 2007 to only 72 in 2016 [30].

Limitations

The main limitation of this study is the lack of a control group. Besides this, as in every study performed over a longer period, changes in staff, medical equipment and routines along with the learning curve lead to bias. This includes slight changes in operative technique, postoperative care and echocardiographic follow-up involving various physicians and different cardiovascular ultrasound systems. Even though we could not find significant differences in long-term outcome according to the year of operation, a bias cannot be excluded. Moreover, cases of missed echocardiographic and/or clinical follow-up could skew the results.

Conflict of interest: none declared.

REFERENCES

[11] Akins CW, Miller DC, Turina M, Acuña V, Pachler M, S湖北 JW, Ohye RG. The Ross procedure: long-term clinical and echocardiographic follow-up involving various physicians and different cardiovascular ultrasound systems. Even though we could not find significant differences in long-term outcome according to the year of operation, a bias cannot be excluded. Moreover, cases of missed echocardiographic and/or clinical follow-up could skew the results.

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