Long-term outcome of right ventricular outflow tract reconstruction with bicuspidalized homografts

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Abstract

Objective: Given the shortage of small-sized cryopreserved homografts for right ventricle (RV) to pulmonary artery (PA) reconstructions, more readily available larger-sized homografts can be used after size reduction by bicuspidalization. The aim of our study was to determine and compare function over time of standard and bicuspidalized homografts in infants younger than 12 months, including patients with a Ross or extended Ross procedure. Methods: All consecutive infants under the age of 1 year, who underwent a surgical procedure in which a homograft was placed in the RV-PA position between January 1994 and April 2009, were included. Prospectively collected data from serial, standardized echocardiography from all patients were extracted from the database, and hospital records were retrospectively reviewed. Results: A total of 40 infants had a valved homograft conduit placed in the RV-PA position. In 20 of those patients, a bicuspidalized homograft was used. Twelve patients underwent a Ross procedure, of whom seven had an additional Konno-type aortic annulus enlargement. Median follow-up was 146 months (interquartile range [IQR], 117–170; total patient years: 178) in the group with standard use of the homograft and 95 months (IQR, 11–104; total patient years: 78) in the group with bicuspidalized conduits. Freedom from re-intervention (re-operation or percutaneous) was not different in the standard and bicuspidalized groups for all and Ross or Konno–Ross procedures (Tarone–Ware, \( p = 0.65 \) and \( p = 0.47 \), respectively). Consecutive echocardiographic maximum velocities in the right ventricular outflow tract were similar in the standard and bicuspidalized groups. Conclusion: When proper sized cryopreserved homografts for placement in the RV-PA position in Ross, Konno–Ross, and other procedures in infants under the age of 1 year are not readily available, bicuspidalized homografts provide an acceptable alternative.

Keywords: Right ventricular outflow tract; Bicuspidalized homograft; Congenital cardiac surgery; Ross procedure

1. Introduction

Cryopreserved aortic and pulmonary valve homografts are widely used as a conduit in right ventricle (RV) to pulmonary artery (PA) reconstructions for different congenital anomalies [1]. Given the shortage of small-sized conduits for these reconstructions in young infants, more readily available larger-sized grafts can be used after size reduction by bicuspidalization [2,3]. The long-term functionality of bicuspidalized grafts in the RV outflow tract (RVOT) has been described by few groups [4–7]. The results in children with Ross or extended Ross (Konno) procedures have only been reported anecdotally [4,7]. The aim of this study was to determine and compare long-term allograft function after surgical procedures in which a standard or bicuspidalized homograft was used in the RV-PA position in infants younger than 12 months, including patients with a Ross or extended Ross procedure.

2. Material and methods

2.1. Patient population

All consecutive infants under the age of 1 year, who underwent a surgical procedure in which a homograft was placed in the RV-PA position at the Erasmus University Medical Center in Rotterdam, the Netherlands, between January 1994 and April 2009, were included. Since 1987, serial, standardized echocardiography has been carried out on all patients, who received human tissue valves [8,9]. The prospective echocardiographic database was frozen on July 2009, and echocardiographic data on all studied patients was extracted. Hospital records were retrospectively reviewed. The Dutch civil registry was consulted for survival data of the patients. Our local ethical committee approved of the study and waived the need for informed consent.

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2.2. Procedure

Two attending surgeons performed all the procedures. The conduits were bicuspidalized by excising a longitudinal strip containing one of the three leaflets, and consecutively reapproximating the free edges. The homograft was proximally implanted on an autologous pericardial patch placed in the defect after ventriculotomy in the RVOT, and distally connected to the PA. The underlying pathology of the infant determined the other steps in the procedure.

Timing of (re-)intervention was determined in a weekly scheduled heart team meeting between the (congenital) cardiologists and cardiac surgeons during which all cases were discussed. The decision to whether to operate or not was based on contemporary clinical practice.

2.3. Definitions

Early mortality was defined as death within 30 days after the operation. In-hospital death was defined as early mortality or mortality within the initial hospitalization. The cause of death was registered and reported according to the guidelines for reporting mortality and morbidity after cardiac valve interventions [10].

2.4. Statistical analysis

Continuous data are presented as mean with standard deviation or median with range or interquartile range (25th—75th percentile), and comparison between groups was done using the unpaired t-test. Categorical data are presented as proportions, and comparison was done using the chi-square test or the Fisher’s exact test, where appropriate. All tests were two-sided, with an $\alpha$-level of 0.05. Gradients over the RVOT were calculated from the maximum velocity ($V_{\text{max}}$). $V_{\text{max}}$ in the RVOT was plotted against days after the initial operation for both patients with bicuspidalized and non-bicuspidalized homografts in two different panels. To assess the possible association between bicuspidalization and $V_{\text{max}}$ over time, a linear mixed model for longitudinal data was constructed with random effects for slopes. This model has proven in the past to provide an appropriate fit for the type of data that we have analyzed in the present study [11]. Based on the linear mixed model for both groups, a mean regression line was calculated and plotted. Freedom from re-intervention and freedom from death were calculated using the Kaplan–Meier method. The Tarone-Ware test was used to compare Kaplan–Meier curves between surgical techniques (correcting for the differences in follow-up time between the groups). All statistical tests were two-sided, and tests with $p$ value of 0.05 or lower were considered significant. All statistical analyses were done using Statistical Package for Social Sciences (SPSS) for Windows version 15 (SPSS Inc.; Chicago, IL, USA).

3. Results

3.1. Population and procedures

In the study period, a total of 40 infants under the age of 1 year had a valved homograft conduit placed in the RV-PA position. In 20 of those patients, a bicuspidalized homograft was used; the other 20 patients received a non-bicuspidalized homograft. The preoperative diagnoses are shown in Table 1.

Patient demographics and intra-operative data are shown in Table 2. The use of pulmonary grafts was more frequent in the bicuspidalized group. No bicuspidalized allografts were implanted before the year 2000. Other described intra-operative data and demographics were similar in both groups.

The mean diameter of the bicuspidalized conduits was 14.6 mm (median 14 mm, range 14–16 mm). The conduits were constructed from homografts with a mean diameter of 22.6 mm (median 23 mm, range 19–24 mm). The bicuspidalized grafts were relatively undersized with an indexed size of 54 compared with 65 mm m$^{-0.5}$ in the non-bicuspidalized group ($p = 0.030$).

3.2. Follow-up

Early death occurred in nine patients. One patient died during initial hospital stay 125 days post-operatively. There were five in-hospital deaths in both groups ($p = 1.00$). No deaths were directly related to homograft dysfunction. Follow-up was complete in 29 of 30 survivors. One patient was lost to follow-up due to emigration. Median follow-up was 146 months (IQR, 117–170; total patient years: 178) in the group with standard use of the homograft and 95 months (IQR, 11–104; total patient years: 78) in the group with bicuspidalized conduits. No late deaths occurred.

A total of 214 serial echocardiographic measurements of homograft valve function were available in 30 patients (mean seven echocardiographic measurements per patient; range 1–13). Initial overall $V_{\text{max}}$ was 1.7 m s$^{-1}$ (standard error (SE) 0.13) and overall $V_{\text{max}}$ progression was 0.21 m s$^{-1}$ year$^{-1}$ (SE 0.02). The linear mixed model fitted best and was used. There was a trend toward a smaller initial $V_{\text{max}}$ in bicuspidalized patients versus non-bicuspidalized patients (1.5 vs 2.0 m s$^{-1}$, respectively; $p = 0.07$) while there was no significant difference in annual progression rates (0.23 vs 0.21 m s$^{-1}$ year$^{-1}$, respectively; $p = 0.61$). Echocardiographic $V_{\text{max}}$ in the RVOT for each consecutive investigation for patients with non-bicuspidalized and bicuspidalized homografts is shown in Fig. 1(A) and (B). No significant difference between both groups could be found.

Two patients in the bicuspidalized group versus six patients in the standard group underwent a re-operation or percutaneous balloon dilatation for homograft failure due to stenosis. No endocarditis occurred. Freedom from re-intervention was not different between the standard and bicuspidalized group (Tarone-Ware test, $p = 0.653$) (Fig. 2).

<table>
<thead>
<tr>
<th>Table 1. Preoperative diagnosis.</th>
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<tbody>
<tr>
<td>Type of homograft conduit</td>
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<tr>
<td></td>
</tr>
<tr>
<td>Bicuspidalized</td>
</tr>
<tr>
<td>Truncus arteriosus</td>
</tr>
<tr>
<td>Aortic stenosis/regurgitation</td>
</tr>
<tr>
<td>Tetralogy of Fallot/DORV</td>
</tr>
<tr>
<td>Pulmonary atresia with VSD</td>
</tr>
<tr>
<td>Aortic atresia with VSD</td>
</tr>
</tbody>
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DORV: double outlet right ventricle; VSD: ventricle septum defect.
3.3. Ross group

Twelve patients underwent a Ross procedure [12], of whom seven had an additional Konno-type aortic annulus enlargement. Ten out of 12 infants received a bicuspidized prosthesis. One of the patients from the Ross group died in hospital (8%). This patient concomitantly underwent a mitral valve replacement because of severe mitral valve regurgitation and stenosis. This was a redo procedure, after a previously performed mitral valve repair. Median follow-up in the Ross group was 80 months (IQR, 9—109 months). Two of the survivors (18%) were re-operated because of homograft failure at 82 and 106 months after the first procedure. Both patients had a bicuspidized conduit.

4. Discussion

In most institutions, cryopreserved homografts are the first choice for implantation in the RV-PA position in many surgical procedures for congenital heart defects. Shortage of small-sized homografts for implantation in infants has initiated the search for more readily available alternatives, such as bovine jugular vein grafts [13—16] and bicuspidization of homografts [2,3]. Especially infants, with inherent

Table 2. Patient demographics and intra-operative data.

<table>
<thead>
<tr>
<th>Type of homograft conduit</th>
<th>Bicuspid (n = 20)</th>
<th>Standard (n = 20)</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male:female</td>
<td>14:6</td>
<td>13:7</td>
<td>0.74</td>
</tr>
<tr>
<td>Age, days (range)</td>
<td>144 (20—347)</td>
<td>104 (7—333)</td>
<td>0.24</td>
</tr>
<tr>
<td>Weight, kg</td>
<td>5.3 ± 2.1</td>
<td>4.2 ± 1.8</td>
<td>0.08</td>
</tr>
<tr>
<td>BSA, m²</td>
<td>0.29 ± 0.08</td>
<td>0.25 ± 0.07</td>
<td>0.067</td>
</tr>
<tr>
<td>CPB time, min</td>
<td>153 ± 49</td>
<td>185 ± 100</td>
<td>0.21</td>
</tr>
<tr>
<td>Cross-clamp time, min</td>
<td>104 ± 33</td>
<td>100 ± 26</td>
<td>0.69</td>
</tr>
<tr>
<td>Type of homograft</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pulmonary:aortic</td>
<td>19:1</td>
<td>8:12</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Allograft size, mm (range)</td>
<td>14 (14—16)</td>
<td>16 (13—19)</td>
<td>0.16</td>
</tr>
<tr>
<td>Indexed allograft size, mm m⁻² (range)</td>
<td>54 (35—86)</td>
<td>65 (42—94)</td>
<td>0.030</td>
</tr>
<tr>
<td>Operation before the year 2000</td>
<td>0</td>
<td>18</td>
<td>&lt;0.001</td>
</tr>
</tbody>
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BSA: body surface area; CPB: cardio-pulmonary bypass.

Fig. 1. Maximum velocity ($V_{max}$) at echocardiographic examinations in patients with bicuspidized homografts (panel A) and standard (non-bicuspidalized) homografts (panel B).

Fig. 2. Freedom from re-intervention for graft failure.
small diameter of the conduit, are prone to conduit stenosis [17], eventually necessitating re-intervention [18]. To our knowledge, the performance of bicuspidized homografts in infants <1 year in whom a Ross or extended Ross procedure is performed is only reported anecdotally.

The results of present study show that stenosis in bicuspidized homografts in the RV-PA position in infants younger than a year does not progress faster than in non-bicuspidized homografts. In addition, no difference could be found in freedom from re-intervention between these groups of patients.

Heterogeneity in confounding factors necessitates careful interpretation of the data: more pulmonary graft use and more Ross patients in the bicuspidized group could favor the results in that group, whereas, on the other hand, relative undersized conduits could be a potential disadvantage in the same group.

Results of the use of bicuspidized valves in the RV-PA position in infants <1 year are described by few other groups. McMullan et al. [5] show no difference in freedom from re-intervention in 13 infants with bicuspidized and 21 infants with standard used homografts in surgical repair for truncus arteriosus with a median follow-up of 66 months. Koiraia et al. [4] describe a group of 21 children up to 2.5 years of age compared with a matched group of children aged up to 5.1 years in which the use of a bicuspidized graft does not have a worse freedom from re-intervention compared with the matched group. Mean follow-up was 54 months and the patients underwent various procedures; four of these patients (two in both groups) underwent surgery for aortic regurgitation or stenosis.

The results of present study show that the bicuspidalization technique is an adequate solution, beside the use of bovine jugular vein grafts, to circumvent the shortage of small conduits for Ross or extended Ross procedures in infants.

5. Conclusion

When proper sized cryopreserved homografts for placement in the RV-PA position in Ross, Konno—Ross, and other procedures in infants are not readily available, bicuspidized homografts provide an acceptable alternative. Structural deterioration of the conduit over time is comparable to non-bicuspidized valves as are re-interventions for graft failure.

References