Early results of right ventricular–pulmonary artery conduits in patients under 1 year of age

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Abstract

Objectives: Management strategies for the repair of many complex heart defects require the implantation of a valved conduit between the right ventricle (RV) and the pulmonary artery (PA), often using aortic or pulmonary homograft valves. Their limited availability, however, has led to the development and use of new conduits. We retrospectively compared our experience with small homografts in patients of less than 1 year of age with the TissueMed\textsuperscript{e} bioprosthetic valved conduit.

Methods: From March 1994 to November 1997 29 patients in their first year of life underwent conduit implantation for complex heart defects. These were retrospectively reviewed in order to determine the incidence of death or conduit stenosis. Seventeen patients received homografts and 12 TissueMed\textsuperscript{e} conduits.

Results: Diagnoses and operative details including conduit size were similar in the two groups and in all cases complete repair of the underlying defect was carried out. Early post-operative mortality was 4/17 (23.5%) in the homograft group and 3/12 (25%) in the TissueMed\textsuperscript{e} group. Echo Doppler evaluation within 1 month of operation showed no right ventricular outflow tract (RVOT) obstruction in any of the survivors. In the TissueMed\textsuperscript{e} group 8/9 (77%) survivors have gone on to develop significant RVOT obstruction within 12 months of operation. There have been three late deaths in this group all related to severe RVOT obstruction. Two patients died during an attempt at balloon dilatation and one patient died of progressive right heart failure. Five patients had successful replacement of the TissueMed\textsuperscript{e} conduit. One child remains well with no evidence of RVOT obstruction. At operation to replace conduit, or at autopsy, the stenoses were related to the deposition of fibrous tissue at the anastomotic suture lines. In the homograft group none of the survivors developed RVOT obstruction during the first 12 months post-operatively. There was one late death (non-cardiac in origin) and one child is awaiting conduit replacement 40 months after initial implantation for obstruction.

Conclusions: The homograft is a satisfactory conduit for re-establishment of RV–PA continuity in infancy. Further work needs to be undertaken in order to elucidate the mechanisms of early graft failure in bioprosthetic conduits if these are to be a suitable alternative for RV outflow reconstruction in infants. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Right ventricular outflow tract; Conduit; Homograft; Xenograft; TissueMed\textsuperscript{e}

1. Introduction

Surgical repair for complex congenital heart defects requiring the use of a valved conduit as a substitute for an absent right ventricle (RV) to pulmonary artery (PA) connection is increasingly being performed in early infancy. Types of conduit used include prosthetic valved conduits, homografts, autogenous tissue reconstruction [1], ovine pulmonary valved conduit [2] and equine pulmonary valved conduit [3]. Continuing problems associated with these conduits, low availability of small homografts and difficulties with anticoagulation have led to the development of new conduits for reconstruction of the right ventricular outflow tract (RVOT). We report our recent experience with conduit implantation in patients of less than 1 year of age utilizing both small homografts and the TissueMed\textsuperscript{e} bioprosthetic conduit, a porcine xenograft.

2. Materials and methods

A retrospective study was carried out on 29 consecutive patients undergoing conduit implantation for complex heart defects between March 1994 and November 1997. Seventeen patients received small homografts and 12 received TissueMed\textsuperscript{e} conduits, a glutaraldehyde-preserved porcine valve. The decision to use TissueMed\textsuperscript{e} bioprosthetic
conduits in 12 patients was based solely on the lack of availability of small homografts at that time. Patient follow-up was 100% complete at the end of the study period.

Pre-operative diagnosis, age at operation, operative details and post-operative data (including time to extubation, ITU and post-operative stay, inotropic usage and utilization of delayed sternal closure) were collected. End points for the study were defined as death or freedom from re-intervention for conduit obstruction within the first 12 months following operation. Indications for re-intervention were based on a combination of clinical, echocardiographic and angiographic findings of RVOT obstruction with conduit stenosis. Death was defined as early (occurring within 1 month of operation), late (1 month to 1 year post-operatively) and non-cardiac.

Results are expressed as the mean ± standard deviation. Univariate analysis was performed using Fisher’s exact test for discrete data and the Mann–Whitney test for continuous data.

3. Results

The diagnoses were similar between the two groups (Table 1). The median age at conduit implantation was 15.5 days (range 1–243 days) in the homograft group and 13 days (range 1–161 days) in the TissueMed™ group (P = 0.4, Table 1). There was no significant difference between the two groups by operative details or conduit size (Table 2). The mean conduit size in the TissueMed™ group was 12.5 ± 1.6 mm as compared to 13.4 ± 1.9 mm for the homografts (P = 0.07). Only one patient in the homograft population underwent implantation with a conduit of less than 10 mm. Early post-operative mortality (less than 30 days) was 23.5% (4/17) in the homograft group and 25% (3/12) in those receiving TissueMed™ conduits (Table 3). Echo Doppler evaluation within 1 month of operation showed no right ventricular outflow obstruction in any patient.

Of the surviving TissueMed™ population 8/9 (77%) developed evidence of RVOT obstruction within 12 months of the initial procedure, with right ventricular pressures of more than 75% of the systemic blood pressure in these cases. Five have undergone re-operation. There have been three late deaths, two related to balloon angioplasty. One child is well. In the homograft population none of the survivors developed RVOT obstruction within 12 months of the initial procedure (P < 0.0001). There was one late death (pneumonia in a patient with Di-George syndrome) and one child is awaiting conduit replacement for RVOT obstruction 40 months after initial implantation.

Of the three late deaths in the TissueMed™ group, post-mortem examination was performed in one case. This patient died following balloon angioplasty for conduit stenosis (Fig. 1) at 144 days following the initial procedure. Histological examination of the in situ conduit demonstrated clinically significant neo-intimal proliferation with evidence of circumferential laminar thrombus formation.

In the five patients requiring re-operation, conduit obstruction was confirmed in all cases at the time of surgery. In two patients the stenosis could be seen macroscopically to involve the area around the proximal (RV) suture line (Fig. 2). In the remaining three cases the stenosis was seen to be generalized throughout the length of the conduit and only one patient showed valvular involvement in the proliferative process. Three patients underwent replacement with a homograft valve and two with aortic monocusp valves. All made uneventful post-operative recoveries. None of the patients received anticoagulants or antiplatelet therapy following the initial procedure.

4. Discussion

Primary reconstruction of many complex congenital cardiac anomalies may require the utilization of valved conduits as part of the operative procedure. Tetralogy of Fallot with pulmonary atresia, persistent arterial trunk

<table>
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<tr>
<th>Table 1</th>
<th>Diagnosis at operation of patients undergoing RV to PA conduit implantation</th>
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<tr>
<td></td>
<td>TissueMed™</td>
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<tr>
<td>Total number</td>
<td>12</td>
</tr>
<tr>
<td>Truncus arteriosus</td>
<td>4</td>
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<tr>
<td>Absent pulmonary valve syndrome</td>
<td>3</td>
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<td>Others</td>
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<tr>
<th>Table 2</th>
<th>Operative details</th>
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<tr>
<td></td>
<td>Homograft</td>
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<tr>
<td>Bypass time (min)</td>
<td>90.6 ± 36.3</td>
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<tr>
<td>Cross-clamp time (min)</td>
<td>87.4 ± 19.3</td>
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<tr>
<td>Arrest time (min)</td>
<td>54.9 ± 27.1</td>
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<td>Conduit size (mm)</td>
<td>12.5 ± 1.6</td>
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<th>Table 3</th>
<th>Post-operative details including duration of hospital stay and early post-operative deaths in the two groups</th>
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<tr>
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<td>TissueMed™ (n = 12)</td>
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<tr>
<td>Days to extubation</td>
<td>4.4 ± 2.8</td>
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<tr>
<td>Days on ITU</td>
<td>5.6 ± 3.2</td>
</tr>
<tr>
<td>Post-operative stay (months)</td>
<td>18.5 ± 11.1</td>
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<tr>
<td>Early deaths*</td>
<td>3</td>
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* Defined as death occurring within 30 days of the initial procedure.
Fig. 1. Right ventricular angiogram in a patient 144 days following implantation of a TissueMed™ bioprosthetic conduit in the PA position demonstrating an area of tight stenosis at the proximal suture line.

Fig. 2. Macroscopic appearance of an explanted TissueMed™ conduit demonstrating formation of a fibrous ‘peel’ at the site of anastomosis to the RV.
[4-6], congenitally corrected transposition of the great vessels (CCTGA) [7-9], and certain forms of double-outlet RV [10] are among the defects in which these conduits are used to create a pathway from the RV to the pulmonary arteries. Such a conduit should ideally have growth potential, be non-thrombogenic, and function indefinitely [11]. In addition, when these conduits are used in the neonate, other characteristics including stiffness, conduit bulk, ease of passing sutures and porosity are critically important in determining the success of a complex reparative operation. So far no conduit used in clinical practice has such a profile.

Although there have been many reports evaluating homograft conduits in the paediatric population [12-17] these mainly report the experience in older children. Stark et al. [18] in a large review of homografts placed in the pulmonary position (656 conduits implanted over 22 years) concluded that they “found no factor intrinsic to the conduit that determines its longevity in the patient”. In their study they found that their 5- and 10-year freedom from conduit failure in patients less than 1 year of age was 91 and 77%, respectively (with this group making up 15% of the total study population). Similar findings are alluded to in a study by Slavik et al. [19] who described 19 patients under 1 year of age treated for persistent arterial trunk and also in a review by Bando et al. [20] of 326 patients receiving homografts in the pulmonary position. In this study a young age at operation (less than 4 years) was a major factor in homograft failure. Chan et al. [13] in a retrospective echocardiographic study of 41 patients also found that cryopreserved homograft dysfunction was frequent and progressive and that a young age at operation (less than 18 months) predicted more rapid deterioration of conduit function. Hawkins et al. [15] found that of 20 patients less than 1 year of age undergoing homograft implantation in the RV-PA position (conduit size averaging 11 mm) six re-operations had to be carried out for conduit dysfunction within 4 years. Conduit failure was similar between pulmonary and aortic allografts.

A number of different non-homograft conduits have been used for reconstruction of the RVOT. Dacron conduits [21] have been shown to be successful, as have glutaraldehyde-preserved ovine pulmonary valves [2]. Valved conduits with cusps prepared from glutaraldehyde-preserved equine pericardium [22] and a valved conduit using bovine jugular vein [23] have also been shown to be promising. Recently, new tissue engineering technology has shown potential in actually being able to grow a ‘living’ PA conduit [24]. Finally, downsizing larger allografts has been shown to give acceptable haemodynamic properties [25].

Recognizing the problem of scarcity of small homografts, development of new conduits has included the use of bioprosthetic materials as in the TissueMed™ conduit used in this study. Although the porcine valve was found to function satisfactorily it is of concern that the mode of conduit failure was neo-intimal proliferation causing obstruction at either the distal suture line or along the length of the conduits in eight out of nine conduits. In one patient who died following balloon angioplasty of an obstructed TissueMed™ conduit, the mode of death was displacement of a circumferential laminated thrombus during the procedure. Histological examination at the time of autopsy demonstrated clinically significant neo-intimal proliferation with evidence of thrombus formation along the length of the conduit.

The retrospective nature of this study and small patient numbers may account for the lack of statistically significant differences in the major parameters such as conduit size and operative details between the two groups. However, these findings lead us to conclude that the homograft conduit remains the preferred option for replacement of the RVOT in children less than 1 year of age. More research is required in order to elucidate the mechanisms of failure of newer bioprosthetic conduits, including prospective and systematic evaluation of conduit performance. Understanding the mechanisms of graft failure may lead to a re-evaluation of conduit design and a change in interventional strategy.

References

[12] Bishop DA, Fullerton DA, Campbell DN, Clarke DR. Conduit reconstruction of the right ventricular outflow tract. Lessons learned in a


