Systemic-to-pulmonary artery shunting using heparin-bonded grafts

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Abstract

OBJECTIVES: Systemic-to-pulmonary artery shunting remains an important palliative procedure in the staged management of complex congenital heart defects. The use of heparin-bonded polytetrafluoroethylene shunts (HBPSs) should enhance graft patency. This study aimed to review the single-centre experience using HBPS in the context of congenital cardiac surgery.

METHODS: The records of 51 patients treated using HBPS between 2010 and 2016 were retrospectively reviewed. The median age and weight of the patients were 8 (range 3–83) days and 3.2 (range 1.8–5.7) kg, respectively. Selected shunt size was 3.5 mm in all patients. Fourteen (27.5%) patients were planned for future biventricular repair and 37 (72.5%) patients underwent univentricular pathway. Shunt modifications included central aortopulmonary shunts (n = 35; 68.6%) and modified Blalock–Taussig shunts (n = 16; 31.4%). Shunt patency and survival until estimated 2nd procedure were calculated using the Kaplan–Meier method.

RESULTS: Shunt patency was 90 ± 4% after a median duration of 133 (range 0–315) days. Early mortality (30 days) was 3.9% (n = 2). Another 3 patients died during their hospital stay. All the deceased patients had univentricular morphology, and the cause of death was not shunt related in all patients. Five patients developed subtotal HBPS thrombosis intraoperatively (n = 3), early postoperatively after 3 days (n = 1, 1.9%) or late after 41 days (n = 1, 1.9%). Treatment of those patients comprised right ventricular outflow tract opening (n = 2, 3.9%) or new shunting (n = 3, 5.9%). Elective shunt takedown was performed during corrective surgery (n = 10, 19.6%), bidirectional Glenn (n = 25, 49%) or shunt replacement (n = 5, 9.8%). At the end of follow-up, 1 (1.9%) patient had still an HBPS in situ. The survival rate until planned 2nd procedure was 87 ± 6% in univentricular patients and 100% in biventricular patients (P = 0.17).

CONCLUSIONS: The use of HBPS in the context of palliative heart surgery is safe and seems to warrant a long-term patency of systemic-to-pulmonary shunts. However, by acting on only 1 site of Virchow’s triad, shunt thrombosis, occurring predominantly early, cannot be totally excluded.

Keywords: Heparin-bonded polytetrafluoroethylene shunts • Blalock–Taussig shunt • Central aortopulmonary shunt • Thrombosis • Graft patency

INTRODUCTION

A systemic-to-pulmonary artery shunt establishes pulmonary blood flow in the context of palliative cardiac surgery. Indications for surgery exist in children with ductal-dependent or decreased pulmonary blood flow, who are not suitable for complete repair or Glenn palliation at this stage. Moreover, children with a single-ventricle physiology and obstructed systemic blood flow need systemic-to-pulmonary artery shunting in the context of ‘classical’ Norwood or Norwood-type operations.

An ideal shunt is expected to have the following attributes: technical simplicity, good functionality, good long-term patency and easy take down during repair [1]. As an alternative to the classic Blalock–Taussig shunt, central aortopulmonary shunts (CAPSs) between the ascending aorta and the main pulmonary artery were introduced by Shumacker and Mandelbaum in 1962 [2]. In 1981, de Leval et al. [3] used polytetrafluoroethylene shunts between the innominate or subclavian artery and the pulmonary artery, which is commonly called as a ‘modified’ Blalock–Taussig shunt (MBTS).

Shunt thrombosis remains a major complication after palliative congenital heart surgery, often resulting in a sudden cardiac arrest and subsequent death without immediate treatment [4, 5]. Heparin-bonded polytetrafluoroethylene shunts (HBPSs) (Propaten® Vascular Graft; W. L. Gore & Associates, Inc., Flagstaff, AZ, USA) offer an intraluminal heparin-active site as a preventive measure against platelet aggregation. It enables the binding of antithrombin III to generate a thrombo-resistant graft surface. Experience on the use of HBPS is referred mainly from vascular surgery and showed less platelet deposition, decreased...
inflammatory response and reduced thrombogenicity. Several groups suggested that HBPS is superior to uncoated grafts or autologous veins, with regard to their probability of thromboembolism [6–8].

So far, limited experience on using HBPS has been published in the context of palliative congenital cardiac surgery [9]. In our institution, HBPS has been used since 2010 in all patients who received MBTS or CAPS for pulmonary perfusion. This study aimed to evaluate the outcome of systemic-to-pulmonary artery shunting using HBPS in patients with different congenital cardiac anomalies. Herein, distinct shunt modifications and cardiac morphology groups were compared regarding shunt patency and survival.

MATERIALS AND METHODS

Patients

All patients, who received HBPS between January 2010 and December 2016, were retrospectively reviewed. Inclusion criteria were age younger than 3 months, anterior sternotomy approach and HBPS as initial palliative surgical treatment. In patients with ‘classic’ hypoplastic left heart syndrome, it is our institutional policy to perform Norwood procedures from a right ventricle to pulmonary artery conduit (‘Sano-Shunt’/5-mm non-HBPS). These patients were not included in this analysis. A 4.0-mm graft was implanted in only 1 patient, who was, therefore, excluded from the analysis; 3.0-mm grafts have not been used. Patients were categorized with respect to their distinct cardiac morphology (uni- vs biventricular) and according to the used shunt modifications (MBTS vs CAPS).

Surgical technique

All cardiac procedures were performed via median sternotomy. The pulmonary arteries and ductus arteriosus were dissected and the anatomical structures evaluated. The decision to proceed with an MBTS or CAPS was made according to cardiac morphology and the position, size or anatomical relationship of the pulmonary arteries to the aorta and its branching patterns [10]. Univentricular patients with a morphological left ventricle were palliated using MBTS. For MBTS, an obliquely fashioned end of the HBPS was sutured end-to-side to the innominate artery. The straight distal end of the graft was then anastomosed to the right or left pulmonary artery depending on arch and pulmonary artery anatomy [11] (Fig. 1A). For CAPS, distal end-to-side anastomosis between the shunt and main pulmonary artery and proximal side-to-side anastomosis between the shunt and aorta were performed. The open end of the shunt was trimmed and clipped close to the proximal anastomosis after deairing [12] (Fig. 1B).

Heparinization was carried out, either ‘low dose’ (125 IU/kg) or ‘full dose’ (400 IU/kg), if cardiopulmonary bypass was necessary. Moderate hypothermia (32–35°C) was used for standard shunt operations without additional procedures. Antegrade-modified blood cardioplegia was administered if cardioplegic arrest was necessary. Septectomy in univentricular patients was performed to improve intracardiac mixing at atrial level. The Norwood procedure using MBTS was carried out under moderate hypothermia (25–28°C) with regional cerebral perfusion. Correction of total anomalous pulmonary venous drainage was performed under deep hypothermia (18°C) and a brief period of circulatory arrest. After weaning from bypass, modified ultrafiltration was completed. Protamine was administered at a dose ratio of 1 mg protamine per 10 IU of heparin. Clotting factors were substituted according to rotational thromboelastometry measurements. Aspirin (3 mg/kg) was administered to the patient in the intensive care unit (ICU) and maintained daily until shunt take down.

Follow-up

Follow-up was accomplished using routine control echocardiography or by directly contacting the patient by the referring cardiologist until 31 July 2017. All patients with systemic-to-pulmonary artery shunt were scheduled for cardiac catheterization at the age of 3 months.

Shunt patency was defined as an open graft until estimated next surgical treatment, which was either corrective surgery or bidirectional Glenn procedure. Additionally, in patients who were not
eligible for those 2 procedures despite open graft, elective shunt replacement was scheduled whenever patient outgrowth was suspected.

Shunt thrombosis was managed according to anatomical features by intervention or surgery. The former included balloon dilatation and stent placement if necessary. The latter comprised new shunting with CAPS, MBTS, right ventricular to pulmonary artery conduit or patch enlargement of the right ventricular outflow tract.

Statistical analysis

Data were collected using Microsoft Excel 2010. Analysis was performed using SPSS 21.00 (SPSS Inc., Chicago, IL, USA). Descriptive data for continuous variables are reported as median with ranges or mean ± standard deviation. Categorical variables are presented as numbers or percentages. Risk adjustment was stratified according to the Aristotle and risk adjustment for congenital heart surgery scores. Primary end points included survival and shunt thrombosis are summarized in Table 3.

RESULTS

Patient characteristics and operative data

The patient characteristics are summarized in Table 1 and operative data in Table 2.

Fifty-one patients with a 3.5-mm HBPS were identified. All except 3 patients were operated on cardiopulmonary bypass. Thirty-five patients (68.6%) received CAPS and 16 patients (31.4%) MBTS.

In 2 patients, the decision for further palliation was made during the 2nd step operation due to the straddling mitral valve in 1 patient with corrected transposition and pulmonary atresia originally planned for Senning/Rastelli and due to ‘remote’ ventricular septal defect in another patient with double-outlet right ventricle and malposition of the great arteries. In addition, 1 patient with corrected transposition and pulmonary atresia who received bidirectional Glenn at 2nd step was referred to further ‘1 and 1/2 repair’ and was included to the group of biventricular patients. Thus, in total, 14 (27.5%) patients were stratified to be biventricular and 37 (72.5%) patients to have functionally univentricular morphology.

Survival

A flow chart until next surgical treatment including take down of HBPS is shown in Fig. 2.

Early mortality (30 days) was 3.9% (n = 2). Another 3 patients died during their hospital stay. All of the deceased patients had univentricular morphology and died with patent HBPS. Causes of death were heart failure (n = 4) and sepsis (n = 1). Following hospital discharge, there was no inter-stage mortality until next planned surgical treatment.

Median duration until next palliative or corrective surgical procedure was 141 (range 0–463) days. At the end of follow-up, 1 patient had HBPS still in situ. Estimated 2nd procedure included corrective surgery (n = 10, 19.6%), bidirectional Glenn (n = 25, 49%) and shunt replacement (n = 5, 9.8%). Reasons for new shunting despite open HBPS (univentricular n = 4, 7.8%, biventricular n = 1, 1.9%) were intraoperative haemodynamic instability (n = 1, 1.9%), non-eligibility for biventricular repair (n = 1, 1.9%) or biventricular Glenn (n = 1, 1.9%), pulmonary artery distortion (n = 1, 1.9%) and bronchial obstruction (n = 1, 1.9%).

Survival until planned 2nd procedure was 100% in patients with biventricular morphology when compared with 87 ± 6% in patients with univentricular morphology (P = 0.17) (Fig. 3A).

When comparing between distinct types of shunt modification, survival until planned 2nd procedure was 94 ± 6% in patients with MBTS when compared with 88 ± 6% in patients with CAPS (P = 0.56) (Fig. 3B).

Shunt patency

Data regarding the incidence and management of shunt thrombosis are summarized in Table 3.
Shunt patency was 90 ± 4% after a median duration of 133 (range 0–315) days. Incidences of early shunt thrombosis and late shunt thrombosis were 7.8% (n = 4) and 1.9% (n = 1), respectively, and occurred exclusively during the initial hospital stay. Shunt revision due to subtotal occlusion was performed either intraoperatively (n = 3), early postoperatively (n = 1), after 3 days in the ICU or late (n = 1) after 32 days. Subtotal graft occlusion was treated with shunt resection and patch enlargement of the right ventricular outflow tract in biventricular patients (n = 2) and shunt revision in univentricular patients (n = 3). All patients were managed successfully and survived until scheduled next step of the surgery.

There was no significant difference regarding the freedom from total shunt thrombosis between uni- and biventricular patients (92 ± 5% vs 85 ± 1%; P = 0.5) (Fig. 4A).

When discriminating between CAPS and MBTS, incidence of early shunt thrombosis was 8.6% (n = 3) and 6.3% (n = 1), respectively. Late thrombosis was rare and occurred in 1 patient with CAPS. There was no significant difference regarding shunt patency between CAPS and MBTS (88 ± 6% vs 94 ± 6%; P = 0.57) (Fig. 4B).

A resected and opened graft with thrombotic material is shown in Fig. 5.

**DISCUSSION**

This study demonstrates outcomes after the placement of HBPS as 1st palliative procedure in the management of complex congenital heart disease. Cardiac morphology included patients with univentricular and biventricular cardiac pathology, both eligible for further corrective or palliative surgery.

**Survival**

Survival until the next elective procedure in biventricular patients was excellent (100%). However, in patients with univentricular morphology, outcome was significantly less promising (87%). Patient attrition was not shunt related and mainly influenced by the underlying disease including hypoplastic left heart complex/syndrome and heterotaxy [13].

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**Figure 2:** A flow chart on treatment algorithm. CAPS: central aortopulmonary shunt; MTBS: modified Blalock-Taussig shunt; RVOT: right ventricular outflow tract.

**Figure 3:** The Kaplan–Meier survivals until next planned surgical treatment. (A) A comparison between uni- and biventricular cardiac morphology. (B) A comparison between distinct shunt modifications. CAPS: central aortopulmonary shunt; MTBS: modified Blalock-Taussig shunt.
Palliative shunt surgery is reported with early mortalities between 0% and 18.2% [2, 11, 12, 14–20] and late mortalities between 3.8% and 19% [2, 21]. Early mortality and late mortality after shunt operations are significant, although the surgical procedure itself is rather non-complex. Reasons for unfavourable outcome are excessive pulmonary flow, arrhythmia or shunt thrombosis [2, 21]. Bove et al. [22] reported an in-hospital mortality of 8.7% and later inter-stage mortality of 5.1% among 150 MBTS patients operated between 1995 and 2013. Fenton et al. [21] reported an inter-stage mortality of 7.1% in biventricular patients and 19% in patients with univentricular morphology. The authors pointed out that autopsy-proven shunt thrombosis was one of the leading causes of interim sudden death. To reduce the risk of shunt thrombosis, biological material such as saphenous venous homograft has been introduced by Erez et al. [16] in 17 infants less than 3 kg in weight. Hospital mortality for the entire cohort was 6.3%, and survival rate until shunt take down was 58% in the univentricular group and 90% in the biventricular group. Alsoufi et al. [19] reported significantly higher hospital mortality in univentricular patients but comparable survival until next elective procedure when compared with biventricular patients. Other groups were not able to show a significant effect for univentricular morphology as a predictor of death or shunt dysfunction [11].

**Shunt patency**

Incidences of shunt thrombosis in this study are in accordance with the experience of other studies, where early shunt thrombosis and late shunt thrombosis after systemic-to-pulmonary shunting ranged 0–15% [5, 11, 12, 14, 18, 20, 23] and 0–5.3% [5, 12, 23, 24], respectively. However, the occurrence of late shunt thrombosis in only 1 complex patient with prolonged hospital stay and the absence of both shunt occlusion and attrition of discharged

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**Table 3:** Shunt thrombosis

<table>
<thead>
<tr>
<th>Group</th>
<th>Weight (kg)</th>
<th>Age (days)</th>
<th>Shunt size (mm)</th>
<th>Secondary procedure</th>
<th>Onset of thrombosis (days)</th>
<th>Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intraoperative shunt thrombosis after</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAPS</td>
<td>Single ventricle</td>
<td>3.7</td>
<td>18</td>
<td>3.5</td>
<td>CAPS</td>
<td>0</td>
</tr>
<tr>
<td>MTBS + septectomy</td>
<td>Single ventricle</td>
<td>2.6</td>
<td>5</td>
<td>3.5</td>
<td>CAPS</td>
<td>0</td>
</tr>
<tr>
<td>CAPS</td>
<td>Biventricular</td>
<td>2.4</td>
<td>8</td>
<td>3.5</td>
<td>RVOT-opening</td>
<td>0</td>
</tr>
<tr>
<td>Postoperative shunt thrombosis after</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CAPS</td>
<td>Biventricular</td>
<td>3.6</td>
<td>9</td>
<td>3.5</td>
<td>RVOT-opening</td>
<td>3</td>
</tr>
<tr>
<td>Late shunt thrombosis</td>
<td>CAPS + TAPVD correction</td>
<td>3.2</td>
<td>14</td>
<td>3.5</td>
<td>CAPS</td>
<td>41</td>
</tr>
</tbody>
</table>

CAPS: central aortopulmonary shunt; MTBS: modified Blalock-Taussig shunt; RVOT: right ventricular outflow tract; TAPVD: total anomaly venous drainage.

**Figure 4:** The Kaplan–Meier freedom from shunt thrombosis. (A) A comparison between uni- and biventricular cardiac morphology. (B) A comparison between distinct shunt modifications. CAPS: central aortopulmonary shunt; MTBS: modified Blalock-Taussig shunt.
Heparin-bonded polytetrafluoroethylene shunt in the context of the literature

Studies on vascular surgery reported that heparin-bonded vascular grafts provided improved patency rates and limb salvage in patients with peripheral vascular disease [6]. Daenens et al. [7] reported a similar 1–2-year patency rate when comparing heparin-bonded grafts with autologous saphenous vein grafts. Kirkwood et al. [8] suggested that heparin-bonded vascular grafts should be the conduit of choice for all prosthetic bypasses.

A limited number of reports are available in the literature regarding the use of HBPS in the palliative setting of congenital heart surgery for newborns. In a small cohort, Hörer et al. [9] compared HBPS with classic polytetrafluoroethylene shunts with 13 patients and revealed equally good clinical outcomes for patients with both types of shunts. The histopathological workup revealed a faster process of endothelialization with HBPS within the 1st 30 days, which may prevent the patient from shunt thrombosis in the early interim period. However, the process of intimal proliferation was not affected by HBPS, still exposing the patient to the risk of late shunt thrombosis [9].

Limitations

Limitations of the study are inherent to the retrospective nature of data retrieval. Historical influences on patient outcome related to improvements in surgical techniques and intensive care protocols over the study period cannot be excluded. This article lacks a comprehensive risk analysis for graft occlusion including administered clotting factors. The role of protamine binding to the covalently bonded heparin in the shunt surface remains unclear.

CONCLUSION

The use of HBPS is safe and seems to warrant systemic-to-pulmonary perfusion sufficiently. Despite the covalent binding of heparin in the HBPS inner layer, shunt thrombosis cannot be excluded totally and occurs predominantly early. However, those patients can be considered relatively safe to further palliative treatment, indicating a delay in the process of shunt occlusion using HBPS.

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Conflict of interest: none declared.

REFERENCES


