High incidence of Dacron conduit stenosis for extracardiac Fontan procedure

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Objectives: Extracardiac conduits are widely used to complete a Fontan circulation in patients with univentricular hearts. Although polytetrafluoroethylene conduits have proven good long-term patency, Dacron (polyethylene terephthalate) prostheses are still infrequently applied, with, as yet, no information on the long-term patency.

Methods: All patients who received an extracardiac Dacron conduit ($n = 12$) were retrospectively studied. The initial conduit size was 16 mm in all recipients. The mean age at Fontan completion was 3.1 ± 0.7 years. Patients with clinical symptoms and/or significant conduit stenosis ($>50\%$ of diameter) underwent reoperation.

Results: Of the 12 patients, 8 underwent reoperation (75%) at a mean interval of 6.5 ± 1.8 years after the Fontan operation. All conduits were replaced by an 18-mm polytetrafluoroethylene graft. The explants showed ubiquitous tissue deposits on the inner surface, with a residual internal diameter from 8 to 11 mm. All patients survived the extracardiac conduit replacement. Recovery was uneventful, except that 1 patient experienced long-lasting pleural fluid drainage. The mean hospital stay was 10.6 ± 12.0 days.

Conclusions: The incidence of extracardiac Dacron conduit stenosis in total cavopulmonary connection patients is high. These data indicate that the use of this type of conduit should be avoided. Vigilant follow-up is advised for those patients who have undergone Fontan completion with a Dacron extracardiac conduit. (J Thorac Cardiovasc Surg 2014;147:1568-72)

The Fontan operation, as a staged procedure for patients born with a univentricular heart, has been successfully modified during the previous years.^{1,2} One of the alternatives to direct systemic venous blood flow from the inferior caval vein to the pulmonary artery is the use of an extracardiac conduit. This conduit has been preferred by many surgeons because of the superior hemodynamics and few postoperative complications.³ The long-term adequacy of the extracardiac conduit cross-sectional area, however, has been a subject of continuous attention.^{4,5} The growth of the child and stenosis of the tube graft has been feared to cause compromised inferior caval vein drainage, significant enough to cause a mismatch to body surface area.⁶

Studies addressing the occurrence of extracardiac total cavopulmonary connection (TCPC) conduit stenosis and its relation with the type of material used are few. Although

most surgeons adhere to polytetrafluoroethylene (PTFE; GORE-TEX, WL Gore & Associates, Newark, Del) to accomplish the TCPC, polyethylene terephthalate (Dacron; DuPont, Wilmington, Del) is still infrequently used as an alternative graft material for this indication.^{2,7,8} The preference for PTFE vascular grafts might have been based on a few early reports of Dacron conduit stenosis and on the more favorable material characteristics of PTFE (less contact activation and less compliance mismatch of PTFE compared with Dacron).⁹ Moreover, the mid- and long-term outcomes with extracardiac PTFE in Fontan patients have shown excellent results without stenosis at a mean follow-up of 5 and 8 years, respectively.^{10,11} In contrast, the long-term follow-up of Dacron conduits has not yet been reported. From 2002 to 2003, a limited number of Dacron extracardiac conduits were implanted in our center by our precedent colleagues. The present study reports our long-term follow-up experience with this type of extracardiac conduit for TCPC.

METHODS

Patient Characteristics

From January 2002 to June 2003, a Dacron tube graft was temporarily used by our former staff for extracardiac Fontan completion in a cohort of 14 patients at the Wilhelmina Children's Hospital, University Medical Center Utrecht (Utrecht, The Netherlands). Since 2004, PTFE conduits have been exclusively used by us for this indication. In 13 patients, a gelatin-impregnated knitted Dacron graft (Vascutek, Scotland, United Kingdom) was used, and in 1 patient, a collagen-impregnated Dacron prosthesis (Hemashield; Meadox Medical, Oakland, NJ) was used.

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Abbreviations and Acronyms

- PLE = protein-losing enteropathy
- PFTE = polytetrafluoroethylene
- TCPC = total cavopulmonary connection

The conduit size was 16 mm in all patients. The age at the TCPC operation ranged from 2.4 to 4.5 years (mean, 3.1 ± 0.7). Fontan completion was performed with cardiopulmonary bypass and a beating heart throughout the whole procedure. All patients received anticoagulants after the operation. These started after extubation with acenocoumarol to achieve an international normalized ratio of 2.0 to 3.0. Because of minor bleeding complications, 2 patients were switched to antiplatelet therapy (acetylsalicylic acid) 5 and 8 months postoperatively.

Follow-up

One patient died early after the operation in cardiac failure, and one patient was lost to follow-up 4.9 years after the Fontan procedure. Therefore, the study group consisted of 12 patients, with a mean follow-up period after the Fontan operation of 9.7 ± 0.8 years (range, 8.6-10.6). The annual follow-up examination included anamnesis, physical examination, and, on indication, transthoracic echocardiography. In the case of clinical or echocardiographic suspicion of conduit stenosis, cardiac catheterization (n = 8) and computed tomography (n = 2) were performed to assess conduit patency, respectively. The patients were scheduled for reoperation when exercise tolerance was reduced (greater than New York Heart Association class II), the noninvasively measured peripheral tissue oxygen saturation was less than 90%, signs of protein-losing enteropathy (PLE) were present, or in the case of dysrhythmias and/or liver dysfunction. Patients without clinical symptoms but with at least a 50% conduit diameter reduction were also scheduled for conduit replacement. One explanted gelatin-sealed Dacron prosthesis was examined histologically.

RESULTS

From August 2007 to November 2012, 8 patients were diagnosed with extracardiac conduit stenosis requiring reoperation at a mean interval of 6.5 ± 1.8 years after the Fontan operation (Table 1). Oral anticoagulants were continuously used by all patients (acenocoumarol in 6 and acetylsalicylic acid in 2). Three patients presented with

decreased exercise tolerance, and 1 patient had PLE. In these 4 symptomatic patients, significant conduit stenosis was diagnosed by angiography (Figure 1). With regard to this high incidence of stenosis, a database search was done to identify all patients with this type of conduit. In all identified patients, conduit patency was assessed using transthoracic echocardiography. Angiography and computed tomography could establish the suspected diagnosis of conduit stenosis of more than 50% in 3 asymptomatic patients. The eighth patient presented with left pulmonary artery stenosis, dysrhythmias and conduit narrowing of 40%. After interventional left pulmonary artery stent placement, he underwent epicardial pacemaker implantation and an extracardiac conduit change concomitantly.

At the latest follow-up examination, the remaining 4 patients had not had an indication for reoperation at 10.0 ± 0.6 years of follow-up. All were in good clinical condition with moderate conduit stenosis (10-12 mm) determined by echocardiography.

Reoperation

The patient weight and length at reoperation was 30 ± 11 kg and 134 ± 18 cm, respectively. The procedure was performed on the beating heart with a standard cardiopulmonary bypass technique and mild hypothermia (32°C). Femoral vein cannulation was performed in 7 patients; however, in 1 patient (14 kg), the femoral vein was too small and inferior caval vein cannulation was performed. In all patients, extracardiac conduits were replaced by an 18-mm PTFE graft. The mean hospital stay after revision was 10.6 ± 12.0 days (range, 4-40). All patients, except for 1, experienced an uneventful postoperative course. The postoperative recovery for the 1 patient was complicated by persistent pleural effusion. All preoperative symptomatic patients improved their exercise tolerance. Two have been able to participate in sports

TABLE 1. Data from patients with surgical intervention

Pt. no.	Preoperative symptoms	Diagnostic tool	Diameter stenosis (mm)	Revision after TCPC (yr)	Weight (kg)	Stenosis (mm)	Mean IVC pressure (mm Hg)	Mean Fontan pressure (mm Hg)
1	Progressive exercise intolerance	Echocardiography, angiography, CT	8	5.6	24	8	11	11
2	PLE	Echocardiography, angiography	6	5.2	24	6	14	14
3	Progressive exercise intolerance	Echocardiography, angiography	6	5.7	15	6	13	12
4	Progressive exercise intolerance	Echocardiography, angiography	10	4.3	20	7	—	—
5	None	Echocardiography, angiography	6	5.7	40	8	17	15
6	None	Echocardiography, angiography	8	7.5	41	9	18	17
7	None	Echocardiography, angiography	8	8.5	42	8	16	16
8	None	Echocardiography, angiography, CT	10	9.3	30	10	—	—

Pt. no., Patient number; TCPC, total cavopulmonary connection; IVC, inferior vena cava; CT, computed tomography; PLE, protein-losing enteropathy.

FIGURE 1. Typical angiographic example of a stenosed extracardiac Dacron conduit. *SVC*, Superior vena cava; *RPA*, right pulmonary artery; *LPA*, left pulmonary artery; *C*, conduit; *IVC*, inferior vena cava.

activities. The PLE had significantly improved in 1 patient, leaving only mild hypoproteinemia.

Explant Analysis

All explanted conduits showed excessive stenosis by tissue deposition (on the entire inner surface) over the full conduit length. The internal explant diameter measured intraoperatively using a Hegar dilator varied from 8 to 11 mm (Figure 2).

One explanted gelatin-sealed Dacron prosthesis was examined histologically. The explant was fixed in 4%

formalin and embedded in paraffin. Sections of 4 μ m were stained with hematoxylin, eosin, and Sirius red for evaluation of the collagen depositions and with antibodies against CD31 to evaluate the presence of an endothelial lining. The inner lining of the explant consisted of a thick layer of collagen (Figure 3, A and B) covered with an intact continuous layer of endothelial cells (Figure 3, C). Some ingrowth of vessels was present in the intima layer (Figure 3, C). In the wall of the Dacron prosthesis, collagen depositions were observed, with an occasional foreign body giant cell (Figure 3, D).

DISCUSSION

A variety of factors, including arrhythmias, atrioventricular valve regurgitation, cyanosis, and ventricular dysfunction, can impair the Fontan circulation and prompt reintervention.¹² A failing Fontan circulation can also be caused by obstruction of the extracardiac conduit itself. Since the 1990s, most centers have abandoned collagen-sealed Dacron conduits because of increasing experience and reports of graft stenosis.⁷ However, for gelatin-sealed grafts, this complication has not yet been reported. The present study is the first to report extensive intima hyperplasia in all explants. The data showed that a gelatin coating does not prevent Dacron venous conduits from narrowing, as was probably thought by our former colleagues. With the current policy introduced in 2004 of using only PTFE conduits of at least 18 mm in diameter without postoperative anticoagulant treatment except for aspirin, we have not encountered this particular problem in any of our extracardiac Fontan patients ($n = 85$, follow-up, 7.4 ± 1.6 years; range, 0-10). Therefore, we have attributed this complication to the nature of the Dacron conduit.

In our cohort, the first 4 reoperations for conduit narrowing were performed in symptomatic patients with

FIGURE 2. *Left*, Vascutek graft after explantation with neointima proliferation covering the entire inner surface of the conduit. *Right*, The graft luminal diameter is depicted by the 8-mm Hegar dilator.

FIGURE 3. Histologic examination of explanted Dacron conduit. A, Fibrotic neointima, collagen richness of neointima. B, Sirius red vital intact endothelium, C, CD31 stain, and D, fibrosis between the Dacron.

progressive exercise intolerance and PLE in 1 patient. Angiography, however, could only detect a mean gradient of 1 mm Hg between the inferior vena cava and extracardiac conduit in 2 patients and of 2 mm Hg in 1 patient. Also, all other patients showed no gradient, with a mean pressure of the Fontan circulation of 11 to 17 mm Hg. Despite the discrepancy between the clinical symptoms and verifiable hemodynamic relevance, angiography has remained our preferred diagnostic tool. Exclusion of many other possible reasons for failing Fontan can be best accomplished with this technique. With increased experience and the observation that conduit replacement can be performed safely and successfully, we have extended the indication for reoperation to asymptomatic patients with only a significant conduit narrowing (>50%). Patients with moderate (<50%) narrowing remain under vigilant observation, because reoperation in these patients is expected to be unavoidable at or before adolescence. The additional growth of these patients to at least 20 to 25 kg is preferred to facilitate easy femoral venous cannulation and thereby offer a safe procedure to these asymptomatic patients.

Little is known about the technical difficulties and risks of reoperation in patients with an extracardiac conduit stenosis, because this problem has not been reported in patients with a PTFE conduit.^{4,10,11} All adhesions, which were very dense, especially around the Dacron graft, had to be totally freed. The risk of damage to the right phrenic nerve and medially located atrial chamber is substantial. The risk of damage to the conduit itself, however, is relatively low, because the inner surface peel of 3 to

4 mm serves as protection against unintentional bleeding. We, therefore, have preferred sharp dissection on the surface of the conduit, instead of dissecting between the different structures. Once the conduit has been completely dissected free, a Glover spoon clamp can be placed on the inferior caval vein–conduit transition. This provides just enough tissue cuff for the new anastomosis but leaves little or no space for inferior caval vein cannulation. Femoral vein cannulation is therefore key for a safe procedure. In only 1 patient was bicaval cannulation performed because of a too small femoral vein. Furthermore, we found a relatively fixed size of the dissected inferior caval vein owing to the 16-mm primary implanted Dacron conduit and obvious shrinkage of the atrial cuff, which restricted us to using an 18-mm conduit.

The main limitation of the present study was that it remains unclear why the Dacron conduit had been chosen. The easier handling characteristics of the Dacron graft at the side of the anastomosis with fewer anastomotic bleeding sites or the assumption of better flow properties of a gelatin-coated graft were probably the reasons. Additionally, in all patients, a 16-mm Dacron graft was used, which currently is considered quite small for patients aged 2 to 4 years. The contribution of this small size to the development of the pannus inside the graft also could not be answered, because we have no experience with the 16-mm PTFE conduit.

CONCLUSIONS

The extracardiac Dacron conduits applied for TCPC in the Fontan circulation demonstrated a high incidence of

stenosis, requiring replacement. These data indicate that the use of this type of conduit should be avoided. For patients who have received a Dacron graft in the past, vigilant follow-up is advised.

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