

Dacron Conduit for Extracardiac Total Cavopulmonary Anastomosis: A Word of Caution



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Background

The extracardiac conduit technique is a valid option for completing total cavopulmonary anastomosis (TCPC) in patients with a single ventricle. The technique allows for beating heart surgery, optimal flow dynamics, and reduced postoperative atrial arrhythmia. Different types of conduit have been proposed. This study reported a single-centre experience with two different types of conduit.

Methods

Consecutive patients referred for TCPC at the current institution between January 2001 and September 2013 were included. Retrospective extraction of pertinent variables was accomplished through electronic patient chart review. Patients were stratified based on the type of conduit used to perform the TCPC: polytetrafluoroethylene (PTFE) conduit (Group A) and polyethylene-terephthalate (Dacron) conduit (Group B).

Results

The patient population included 105 patients: Group A had 80 patients, and Group B had 25 patients. The two groups were similar in major clinical and procedural variables, including conduit size and Nakata index. Eighteen patients (Group A: one [1.25%]; Group B: 17 [68%]) had conduit occlusion or severe stenosis requiring intervention after a mean 46.9 ± 35 months after the operation. The percentage of patients in Group A who were free of conduit obstruction at 3, 5, and 10 years was 100%, 100%, and 96%, respectively, whereas these figures were 68%, 52%, and 35% in Group B (log-rank <0.000). Conduit re-intervention was associated with an increased risk of overall mortality after primary intervention ($p < 0.004$). Dacron tube was found to be an independent risk factor for mid-term stenosis or obstruction (hazard ratio, 62.9; 95% CI, 8.2–482.2; $p = 0.000$).

Conclusion

Dacron conduit for TCPC surgery was associated with a higher risk of obstruction and need for early re-intervention compared with PTFE conduit. Surgical or percutaneous re-interventions for conduit obstruction increased the risk of late mortality.

Keywords

Fontan • Cyanotic • Extracardiac conduit

Introduction

Since Fontan and Baudet first described, in 1971, “a new operation to treat tricuspid atresia” [1], many modifications

of the technique have been developed and reported for the palliation of almost all types of functionally single-ventricle patients. Surgical variants have been introduced to attain a better quality of circulation after total cavopulmonary

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anastomosis (TCPC), to fit all the anatomic circumstances and make surgery easier and safer.

Total cavopulmonary anastomosis using an extracardiac cavopulmonary connection has a number of theoretical advantages over lateral tunnel TCPC [2]: it avoids extensive atrial suture lines and, hence, arrhythmias and thromboembolism; it can be completed regardless of intracardiac anatomy; it can be performed on a beating heart and even off-pump; and theoretically provides better preservation of kinetic energy in the TCPC circuit [3].

Polytetrafluoroethylene (PTFE) conduits have been widely used to complete TCPC circulation and have proven good long-term patency. In looking for the ideal conduit, some alternatives have been adopted that provide more advantages: aortic homograft tubes were largely used in the early phase because of their ideal increased biocompatibility [2]; Contegra valved conduits were introduced to provide a valve [4]; a pedicled autologous pericardium was suggested for growth potential [5,6]; and a polyethylene terephthalate (Dacron) conduit was introduced, which appeared to be flexible, easily adaptable to anatomic situations, and actually haemostatic. To date, Dacron prostheses have been infrequently used; thus, little information is available on long-term patency.

This study reports experience with 25 patients who underwent extracardiac Fontan with Dacron tube in a short time-span, in comparison with a larger population of patients who underwent extracardiac Fontan with a PTFE tube.

Methods

The present study was conducted as a retrospective single-institution review of all medical records of patients who had undergone extracardiac Fontan operations. Pertinent demographic, clinical, procedural, and cardiovascular imaging data were extracted from a dedicated electronic hospital database. Variables were collected at the time of TCPC completion, and selected variables were longitudinally acquired from the electronic report of clinically driven follow-up. Both informed consent statements and institutional ethical review board approval were obtained in advance.

Patient Population

Consecutive patients referred for TCPC to the current institution between January 2001 and September 2013 formed the primary study population. Patients were stratified based on a nonrandomised assignment to extracardiac PTFE (Gore-Tex WL, Gore & Associates, Newark, DE, USA) conduit TCPC (Group A) or Dacron (Vascutek, Scotland, UK) conduit TCPC (Group B). Patients were excluded if TCPC anastomosis was carried out using the lateral tunnel approach or in the case of TCPC takedown.

A total of 105 extracardiac Fontan patients were not actually consecutive because, over the same period of time, one patient underwent lateral tunnel Fontan due to adverse anatomy to the extracardiac Fontan construction (situs atrialis

inversus and levocardia) and two patients had the Fontan taken down: one for early failure with low cardiac output and high systemic venous pressure, and the other for being unable to close the sternum 4 days after the operation (dextrocardia and situs solitus).

Surgical Technique

Bidirectional cavopulmonary anastomosis (BCPA) was performed in the great majority of patients, usually between 6 and 9 months of age. An accessory pulmonary blood flow source was left in 57 of 97 patients (59%) according to institutional policy. In the presence of persistent left superior vena cava (LSVC; 12 patients) a bilateral BCPA was performed regardless of the LSVC dimension or the presence or absence of the innominate vein. Five (5) patients underwent Fontan operation directly without BCPA as an intermediate step: four after neonatal palliation (Blalock-Taussig [BT] shunt in three and pulmonary artery banding in one) and one as first surgery. Surgical protocols and techniques, as well as the surgeon's team, did not change over the entire time span of this study, regardless of the type of conduit used.

Standard normothermic cardiopulmonary bypass with bicaval and aortic cannulation was achieved in a standard fashion after chest re-entry. A PTFE 0.1-mm thick pericardial membrane has been routinely used for pericardial closure during previous operations to prevent excessive adhesions and protect the heart during chest re-entry. Cardioplegia is never used unless atrioventricular valve repair, atrial septal defect enlargement or Damus–Kaye–Stansel anastomosis is necessary at the time of the Fontan completion.

The inferior vena cava is transected just at its atrial junction after clamp positioning. The atrial segment is oversewn, and the distal end is sutured to an appropriately sized conduit. The extracardiac tube is trimmed in an oblique fashion, and a large anastomosis is carried under the right pulmonary artery wall and extended as far as possible toward the left pulmonary artery. If necessary, fenestration is performed with two side-biting clamps between the atrial appendage and the tube, either directly or with PTFE 5-mm tube interposition. Fenestration is performed either in patients judged to be high-risk Fontan candidates or in patients who have high venous pressure and borderline cardiac output after coming off cardiopulmonary bypass.

Data Analysis

Continuous data were reported as mean \pm standard deviation or median and range when appropriate. Categorical data were expressed as the frequency and percentage.

Endpoints of the study were conduit failure, defined as conduit obstruction or stenosis of $>50\%$ of the initial diameter, and late mortality, defined as mortality at any time after hospital discharge following Fontan operation.

Comparison between the two study groups was obtained with Chi-squared or Fisher's exact test when appropriate for categorical variables, or with Student's *t*-test and Mann-

Whitney test for continuous variables. Kaplan–Meier curves were dotted for temporal outcomes: survival and freedom from conduit failure were compared between groups with a log-rank test. Risk factor analysis for both conduit failure and late mortality was achieved with the univariate model first (Chi-squared or Fisher's exact test when appropriate for categorical variables, or Student's *t*-test for continuous variables). All variables that reached statistical significance in the univariate analysis were entered in a multiple Cox regression model in a forward stepwise fashion. A *p*-value of <0.05 was assumed to be statistically significant. Statistical analysis

was performed using SPSS for Windows version 20.0 (SPSS Inc, Armonk, NY, USA).

Results

During the study period, 105 patients underwent extracardiac TCPC at the current institution. A PTFE conduit was used in 80 patients (Group A) and a Dacron conduit was used in 25 patients (Group B). **Table 1** summarises pertinent demographic, clinical, and surgical history variables of the study population.

Table 1 Demographic data, operation data, ventricular morphology, principal diagnosis, and presence of pulmonary stenosis or atresia between groups.

	Total (n = 105)	PTFE (n = 80)	Dacron (n = 25)	P-value
Age (months)	117.5 ± 78.2	120.6 ± 82.0	116.4 ± 78.5	0.86
Mean conduit diameter (mm)	18.1 ± 2.5	18.4 ± 3.1	18.0 ± 2.2	0.22
Weight (kg)	26.3 ± 12.8	24.9 ± 11.7	30.5 ± 15.4	0.19
Height (cm)	126.5 ± 26.2	136.1 ± 23.0	126.0 ± 26.8	0.6
BSA	27.1 ± 8.9	30.2 ± 9.4	26.2 ± 8.6	0.5
Nakata index	223.3 ± 92.1	186.9 ± 87.4	211.0 ± 112.5	0.2
Sex • Male	54	38	16	0.15
• Female	51	42	9	
Fenestration • Yes	53	41	12	0.8
• No	52	39	13	
Mean pulmonary artery pressure (mmHg)	10.4 ± 2	10.5 ± 2	10.3 ± 2	
BCPA	97	75	22	0.4
Accessory flow	57	43	14	0.8
Bilateral BCPA	12	10	2	0.72
Right isomerism	7	6	1	1
Left isomerism	3	2	1	0.56
Biventricular	18	14	4	1
Right ventricle	30	22	8	0.7
Left ventricle	55	42	13	0.9
Indifferent or unknown	2	2	0	1
Diagnosis				
TA	26	18	8	
DORV	15	12	3	
DILV	23	19	3	
cAVC	3	2	1	
HLHS	24	17	7	
PA + IVS	6	4	2	
DIRV	3	3	0	
cAVC + DORV	4	4	0	
TGA RV H	1	1	0	
Pulmonary stenosis	15	12	3	
Pulmonary atresia	8	6	2	

Abbreviations: TA, tricuspid atresia; DORV, double outlet right ventricle; DILV, double inlet left ventricle; cAVC, complete atrioventricular canal; HLHS, hypoplastic left heart syndrome; PA + IVS, pulmonary atresia with intact interventricular septum; DIRV, double inlet right ventricle; cAVC + DORV, complete atrioventricular canal associated with double outlet right ventricle; TGA RV H, transposition of great arteries with hypoplastic right ventricle; PTFE, polytetrafluoroethylene; BCPA, bidirectional cavopulmonary anastomosis; BSA, body surface area.

The Dacron conduits were mainly implanted between April 2007 and October 2008 (21). Two (2) were implanted in 2005 (because they were available in larger diameters of 26 mm and 24 mm), and two were implanted at the very beginning of the study period. Use of Dacron conduit (gelatine sealed) on a regular basis was encouraged due to its easier handling characteristics for sites with less anastomosis bleeding, less compression on the pulmonary veins, less risk of kinking, and better adaptability to distance and angulations for its corrugated wall, which makes it more flexible.

Ninety-seven (97) (92.4%) patients had the Fontan palliation staged by BCPA, which was bilateral in 12 patients and with an accessory pulmonary blood flow in 57. Four (4) patients underwent Fontan directly after neonatal BT shunt, and one had no previous surgery. Three (3) more patients underwent Fontan conversion after Fontan Kreutzer (one) and atriopulmonary direct connection (two) performed at other hospitals (two had a neonatal BT shunt). A modified Damus–Kaye–Stansel procedure, to bypass a subaortic obstruction, was performed in nine patients (one at the time of the Fontan operation, four at the time of the BCPA, and four at the time of neonatal palliation).

The PTFE and the Dacron conduit groups did not differ in terms of age, weight, body surface area, or Nakata index at Fontan completion or initial diagnosis, or in mean conduit size, sex, rate of fenestration, and previous or associated procedures (Table 1).

Hospital Mortality

One patient in Group A died during the operation due to low cardiac output (0.9%).

Follow-up and Late Morbidity

Patient follow-up was 100% complete, with a mean follow-up time of 73.7 ± 38 months.

An anticoagulation or anti-aggregation strategy consisted of heparin intravenous infusion in the immediate postoperative period, which was switched to warfarin on the second or third postoperative day, with a therapeutic international normalised ratio level of 2–3. After 6 months, all patients were routinely switched to aspirin only, regardless of the presence of a patent fenestration, unless atrial fibrillation or atrioventricular valve prostheses were present.

The outpatient visit was scheduled on a 12-month basis and consisted of physical examination, transthoracic echocardiography, and functional oxygen consumption test evaluation when possible.

At the beginning, only patients with signs of clinical deterioration or echocardiographic findings suggesting conduit obstruction underwent computed tomography (CT) scan or magnetic resonance imaging (MRI) and cardiac catheterisation (Figure 1). Because a couple of patients with no symptoms and no echocardiographic signs of conduit obstruction had a completely obstructed or severely stenotic conduit, it was decided to routinely evaluate all patients with either CT scan or MRI unless they were not scheduled for cardiac catheterisation for other reasons. In cases of conduit obstruction or stenosis of >50% of the initial conduit diameter, the patients underwent either percutaneous or surgical treatment, regardless of their clinical symptoms.

During follow-up, 18 patients (17 in Group B (67%) and one in Group A (1.6%); $p = 0.0001$) were found to have severe conduit stenosis (14 patients, Figure 1) or complete occlusion

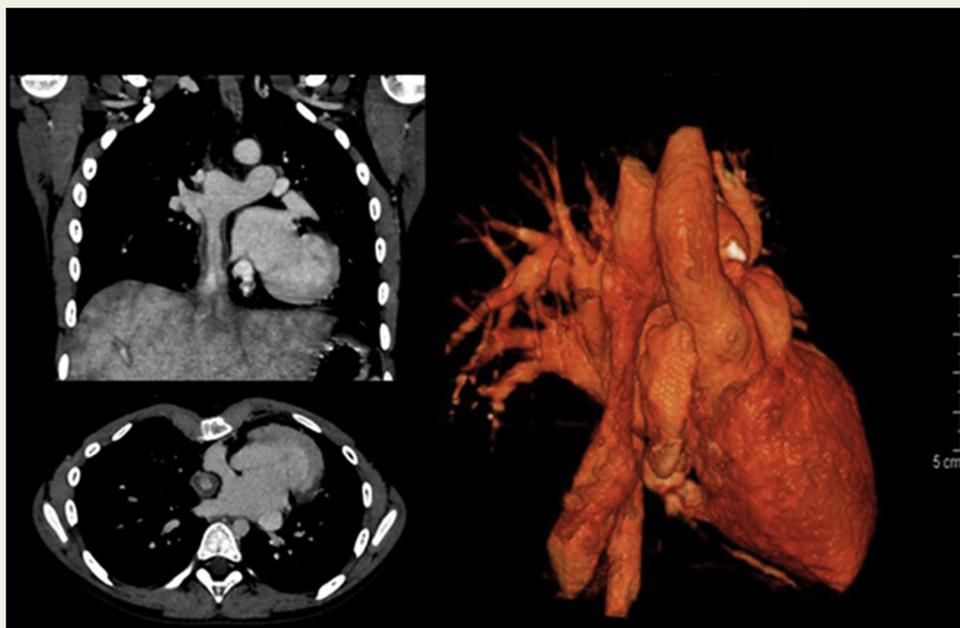


Figure 1 Computed tomography scan of a stenotic Dacron conduit with Volume Rendering (VR) reconstruction. The conduit appears stenotic for its entire length.

(four patients, [Figure 2](#)) at a mean interval of 47 ± 35 months (range, 5–133) from the operation. The mean oxygen saturation before stent implantation or conduit replacement was 85% without statistical significance between the groups ($p = 0.71$). All 14 patients with severe conduit stenosis underwent successful stent implantation, with the exception of one who initially had his conduit stented for an 80% stenosis and after 2 months underwent conduit replacement because of a 40% residual stenosis with persistent exercise tolerance reduction. One (1) patient with complete conduit occlusion was successfully treated with a stent implantation; thus, the conduit was completely reopened with only mild residual stenosis. Four patients had conduit replacement, one shortly after stent implantation and three because of complete conduit occlusion. The four replaced conduits were all Dacron (diameters were 14 mm, 16 mm, 18 mm, and 26 mm), and none underwent histological examination, although the mechanism of obstruction was clearly excessive tissue deposition on the entire inner surface over the full conduit length. All four patients received PTFE conduits (diameters: 20 mm in three patients and 22 mm in one patient). Among the 18 patients diagnosed with conduit obstruction, nine were completely asymptomatic and were fortuitously discovered at catheterisation, MRI, or CT scan; two patients presented with increased cyanosis only, and seven presented with signs of systemic venous hypertension (ascites, hepatomegaly, oedema) or end-reduced exercise tolerance. Moreover, four patients developed protein losing enteropathy.

On univariate analysis, the following variables were regarded as risk factors for conduit obstruction: sex ($p = 0.052$), type of conduit ($p = 0.000$), bilateral BCPA ($p = 0.4$), accessory flow ($p = 0.35$), fenestration ($p = 0.96$), Nakata index ($p = 0.12$), conduit diameter ($p = 0.048$), and

age ($p = 0.63$). Sex, type of conduit, and conduit diameter were entered in a multivariate analysis Cox model with stepwise logistic regression, with results indicating that the type of conduit was the only independent risk factor for obstruction, with a hazard ratio of 62.9 (95% CI, 8.2–482.2; $p = 0.000$; [Table 2](#)). Freedom from conduit obstruction, requiring conduit stenting or replacement at 3 years, 5 years, and 10 years was 100%, 100%, and $96 \pm 3.9\%$ in Group A, and $68 \pm 9.3\%$, $52 \pm 10.7\%$, and $35 \pm 9.8\%$ in Group B, respectively (log rank <0.000 ; [Figure 3](#)).

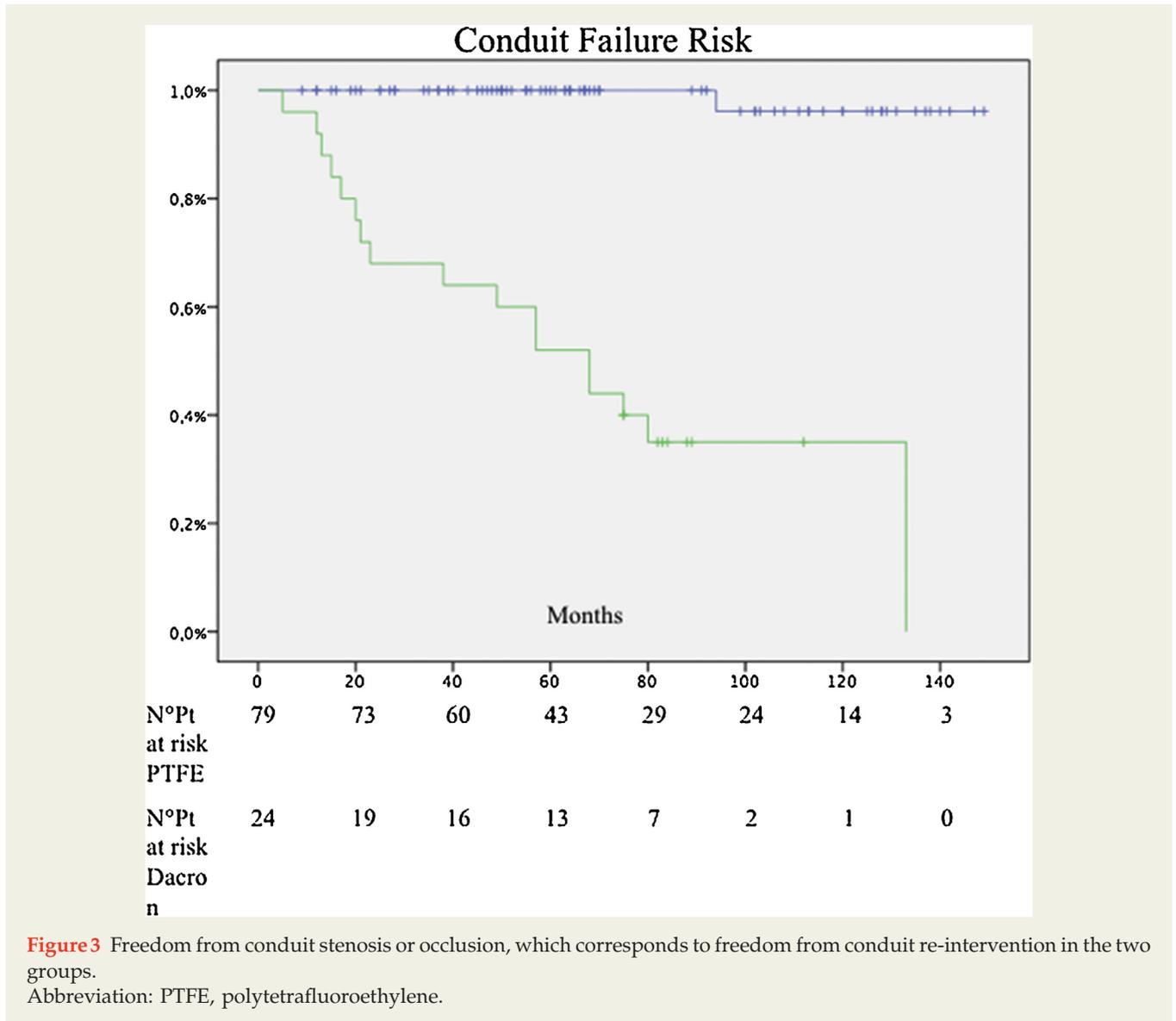
Table 2 Univariate analysis for conduit failure (Dacron vs PTFE).

	P-value
Age	NS
Sex	NS
Type of conduit	0.000 (HR 48; 95% CI, 12.8–212.7)
Bilateral BCPA	NS
Accessory flow	NS
Fenestration	NS
Nakata index	NS
Conduit diameter	0.048 (HR 1.6; 95% CI, 1.1–5.6)
Multivariate analysis for conduit failure	
Type of conduit (Dacron)	HR 62.9 (95% CI, 8.2–482.2; $p = 0.000$)

Abbreviations: PTFE, polytetrafluoroethylene; BCPA, bidirectional cavopulmonary anastomosis; NS, not significant.



Figure 2 Angiography of an occluded Dacron conduit with venovenous collaterals to both superior venae cavae. Bilateral bidirectional cavopulmonary anastomosis (left). Complete conduit reopening with a double stent (right).



Late Mortality

Three patients died during the follow-up (all Group B). One patient died after conduit replacement (Dacron 26 mm) due to sepsis, and two died after conduit stenting (Dacron 18 mm and Dacron 24 mm) due to low cardiac output, both of whom had moderate ventricular dysfunction after Norwood stage III (one patient) or before and after Fontan conversion (one patient).

Kaplan–Maier survival at 3 years, 5 years, and 10 years was $98.8 \pm 1.2\%$ in Group A and $96 \pm 3.9\%$, $88 \pm 6.5\%$, and $88 \pm 6.5\%$ in Group B, respectively (log rank <0.035 ; Figure 4). Sex ($p = 0.2$), bilateral BCPA ($p = 1.0$), accessory flow ($p = 0.089$), fenestration ($p = 0.24$), Nakata index ($p = 0.213$), conduit diameter ($p = 0.052$), and age ($p = 0.164$) did not influence mortality. The types of conduit and conduit stenosis or conduit re-intervention were associated with increased mortality, with an odds ratio of 24.7 (95%

CI, 12.09–38.12; $p = 0.013$) and 39 (95% CI, 25.45–50.73; $p = 0.004$), respectively (Table 3).

Discussion

The Fontan procedure is the final staged palliation for patients with a functional single ventricle. Since it was first introduced in 1971 it has undergone several modifications.

After having proven, with the first “surgical repair of the tricuspid atresia” [1], that the human pulmonary circulation can work without a subpulmonary ventricular pump [7], all efforts have been focussed on optimising a surgical technique to minimise the frequent complications afflicting Fontan patients. Total cavopulmonary connection or lateral tunnel overcame several complications, such as thromboembolism and arrhythmias, and increased efficiency and longevity of the Fontan circulation by reducing

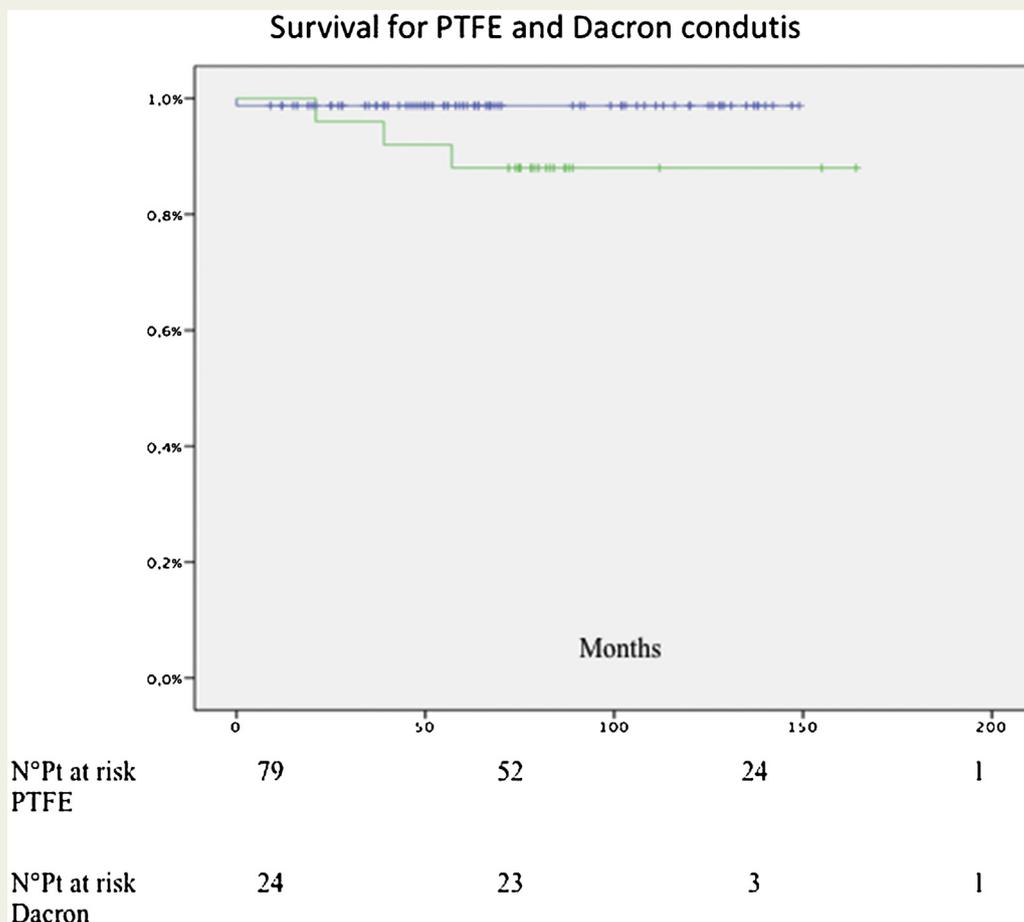


Figure 4 Overall survival between Dacron and polytetrafluoroethylene conduit groups. Abbreviation: PTFE, polytetrafluoroethylene.

flow energy dissipation into a more regular venous pathway [8].

The extracardiac Fontan procedure, initially proposed in 1992 to overcome the technical problems of complex intra-atrial anatomy [9], has gained acceptance, and nowadays is the most used technique due to its simplicity, reproducibility, and possibility of being performed on a beating heart. Nevertheless, thromboembolism risk and the lack of growth potential of the prosthetic conduit, particularly in younger patients, have encouraged surgeons to consider some conduit alternatives. Homograft, used initially, is less prone to intraconduit thrombosis because of its biological nature but has a tendency to calcify and degenerate [10]. Bovine jugular vein has been proposed with the aim of maintaining a better forward flow, when gravity is thought to be responsible for reverse flow observed in the inferior vena cava and suprahepatic veins [4,11]. Autologous pericardial roll conduit has been proven to grow along with small patients' somatic development, although its construction appears rather intricate [5,12]. Extracardiac lateral tunnel with bovine pericardium offers both potential to grow and low thrombogenicity [13]; however, it entails long suture lines on the outer atrial wall and a less than perfect 'energy-preserving' shape. The

most used conduit is PTFE, and long-term results have been encouraging [14,15]. Dacron conduit has been used as alternative since the beginning but little is known regarding its mid-term to long-term performance [10,16]. Very few isolated case reports have been published reporting acute thrombosis of the Dacron conduit [17–19]. However, a recent single-institution report showed alarming results, with a 75% incidence of severe stenosis in 12 Dacron conduits implanted and replaced after a mean time of 6.5 years and, for the first time, Dacron conduit has been indicated as a risk factor for early extracardiac Fontan conduit obstruction [20]. Dacron conduit inadequacy has been reported in the past but the few reports presented in the literature were actually about valved or non-valved Dacron conduit used as an atrioventricular conduit in the Fontan Bjork procedure [21]. Furthermore, the Dacron conduit was also collagen sealed and not gelatine sealed. From present experience, between April 2007 and October 2008, 21 Dacron conduits were consecutively implanted until a high incidence of early obstruction was suspected, and PTFE conduit became the only one used.

Four conduits (all Dacron) were replaced: one after ineffective stenting for severe stenosis and three after complete occlusion. None were histologically examined, but the

Table 3 Univariate analysis for mortality (Dacron vs PTFE).

	P-value
Age	NS
Sex	NS
Type of conduit	0.015 (OR 10.5; 95% CI, 6.52–25.65)
Conduit failure	0.041 (OR 18.1; 95% CI, 9.03–38.89)
Bilateral BCPA	NS
Accessory flow	NS
Fenestration	NS
Nakata index	NS
Conduit diameter	NS
Multivariate analysis for mortality	
Type of conduit (Dacron)	OR 24.7 (95% CI, 12.09–38.12; $p = 0.013$)
Conduit failure (Dacron)	OR 39 (95% CI, 25.45–50.73; $p = 0.004$)

Abbreviations: PTFE, polytetrafluoroethylene; BCPA, bidirectional cavopulmonary anastomosis; NS, not significant.

mechanism of obstruction was pretty evident upon gross examination. There was excessive tissue deposition on the entire inner surface over the full conduit length; this sort of hyperplastic “pseudointima” looked like a thick and weakly adherent layer. There were no signs of clot apposition, conduit thrombosis, or pulmonary emboli.

The current study adds solid, alarming evidence about the differential long-term performance of Dacron over PTFE conduits in TCPC surgery. It confirms the excellent durability of PTFE conduit in terms of patency, and an 18–20-mm diameter can be considered a definitive conduit. On the other hand, Dacron conduit showed a clear propensity to become stenotic over time. Excessive “pseudointima” formation lead to an unacceptable rate of re-intervention. On univariate analysis, the conduit diameter was identified as an obvious risk factor for conduit failure as well, but when entered in the multivariate analysis, the type of conduit was the only independent risk factor for conduit failure and need for re-intervention. The current institution tried to accommodate the largest conduit diameter based on contingency anatomy, but for the smaller patients it was obliged in some cases to use conduits with a diameter of <18 mm (with no differences between Group A and Group B). Unsurprisingly, a smaller conduit diameter was associated with a higher incidence of conduit failure; however, failure occurred only in the Dacron conduit group.

Generally, patients with extracardiac Fontan conduit may come across two different occlusion situations: (1) thrombosis and or thromboembolism, which is usually an acute problem that more commonly presents with dramatic

symptoms of abdominal pain, low cardiac output, sudden cyanosis, or collapse; and (2) stenosis due to hyperplastic pseudointima or excessive tissue apposition, which is a chronic problem, frequently well tolerated with mild or no symptoms at all, and often underestimated with low or no gradient across severe conduit obstruction or occlusion in the presence of important collaterals. In the case of thrombosis or thromboembolism, an erroneous anticoagulation strategy can be somehow responsible; on the contrary, in the case of stenosis due to hyperplastic pseudointima or excessive tissue apposition, anticoagulation therapy has nothing to do with it.

Among the 18 patients diagnosed with conduit obstruction, nine were completely asymptomatic and two only presented with increased cyanosis; thus, clinical status may not be specific or suggestive for conduit failure, which of course could be underestimated. Routine echocardiography control may also be rather inconstant and bear little sensibility in detecting extracardiac conduit failure; thus, a more accurate examination may be required.

Among the asymptomatic patients or those who only presented with increased cyanosis, no patient died after conduit stenting or replacement. On the contrary, three of the seven patients who presented with venous congestion symptoms (ascites, hepatomegaly, lower limb oedema, and reduced exercise tolerance) died after conduit replacement (one patient) or stenting (two patients). The presence of venous congestion symptoms suggests that late diagnosis and consequently late intervention may somehow affect mortality. However, two of the three patients who died also had a pre-existing moderate dysfunction of the systemic ventricle, which might, of course, have played a major role in the adverse outcome.

Ultrasound has been demonstrated to not be sensitive enough to screen patients for conduit stenosis. In the current series, two patients with severe conduit stenosis or complete occlusion, both clearly visualised at MRI, failed to be diagnosed at the routine follow-up echocardiography; therefore, all patients were screened with CT scan, MRI, or cardiac catheterisation and angiography. A CT scan, MRI, or cardiac catheterisation are mandatory for detecting the patency of extracardiac Fontan conduits, particularly if Dacron conduits have been implanted.

Study Limits

The findings of the present study are quite evident and indisputable. Nevertheless, there were several obvious limitations due to the relatively small number of enrolled patients and the retrospective and nonrandomised nature of the study. The time distribution of the two different implanted conduits was also relatively unusual; nevertheless, the mean follow-up period was not statistically different between the two groups, even though most Dacron conduits were implanted mainly in a relatively short period of time (between 2007 and the end of 2008) and the PTFE conduits were implanted in a wider time period. The choice of conduit

implanted can also be questionable and of course was not randomised; however, it hardly could have biased the sample and evident results of the present study.

Conclusions

Current experience suggests that Dacron conduit is not suitable for extracardiac Fontan operation because of the high risk of obstruction and need for early re-intervention. The mechanism of obstruction is excessive peel formation rather than clot apposition. Instead, PTFE conduit confirms excellent long-term patency. Surgical or percutaneous re-interventions for conduit obstruction may increase the risk of late mortality. Angio-CT or MRI rather than ultrasound only are recommended to detect conduit obstruction for patients undergoing Fontan completion with extracardiac Dacron conduits.

Conflict of Interest

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

- [1] Fontan F, Baudet E. Surgical repair of tricuspid atresia. *Thorax* 1971;26(3):240–8.
- [2] Azakie A, McCrindle BW, Van Arsdell G, Benson LN, Coles J, Hamilton R, et al. Extracardiac conduit versus lateral tunnel cavopulmonary connections at a single institution: impact on outcomes. *J Thorac Cardiovasc Surg* 2001;122(6):1219–28.
- [3] Amodeo A, Grigioni M, Oppido G, Daniele C, D'Avenio G, Pedrizzetti G, et al. The beneficial vortex and best spatial arrangement in total extracardiac cavopulmonary connection. *J Thorac Cardiovasc Surg* 2002;124(3):471–8.
- [4] Baslaim G. Bovine valved xenograft (Contegra) conduit in the extracardiac Fontan procedure: the preliminary experience. *J Card Surg* 2008;23(2):146–9.
- [5] Adachi I, Yagihara T, Kagisaki K, Hagino I, Ishizaka T, Koh M, et al. Fontan operation with a viable and growing conduit using pedicled autologous pericardial roll: serial changes in conduit geometry. *J Thorac Cardiovasc Surg* 2005;130(6):1517–22.
- [6] Okabe H, Nagata N, Kaneko Y, Kobayashi J, Kanemoto S, Takaoka T. Extracardiac cavopulmonary connection of Fontan procedure with autologous pedicled pericardium without cardiopulmonary bypass. *J Thorac Cardiovasc Surg* 1998;116(6):1073–5.
- [7] Sade RM, Castaneda AR. The dispensable right ventricle. *Surgery* 1975;77(5):624–31.
- [8] de Leval MR, Kilner P, Gewillig M, Bull C. Total cavopulmonary connection: a logical alternative to atriopulmonary connection for complex Fontan operations. Experimental studies and early clinical experience. *J Thorac Cardiovasc Surg* 1988;96(5):682–95.
- [9] Marcelletti C, Corno A, Giannico S, Marino B. Inferior vena cava-pulmonary artery extracardiac conduit. A new form of right heart bypass. *J Thorac Cardiovasc Surg* 1990;100(2):228–32.
- [10] Amodeo A, Galletti L, Marianeschi S, Picardo S, Giannico S, Di Renzi P, et al. Extracardiac Fontan operation for complex cardiac anomalies: seven years' experience. *J Thorac Cardiovasc Surg* 1997;114(6):1020–30. discussion 30–1.
- [11] Hsia TY, Khambadkone S, Redington AN, Migliavacca F, Deanfield JE, de Leval MR. Effects of respiration and gravity on infradiaphragmatic venous flow in normal and Fontan patients. *Circulation* 2000;102(Suppl 3):III148–53.
- [12] Hvass U, Pansard Y, Bohm G, Depoix JP, Enguerrand D, Worms AM. Bicaval pulmonary connection in tricuspid atresia using an extracardiac tube of autologous pediculated pericardium to bridge inferior vena cava. *Eur J Cardiothorac Surg* 1992;6(1):49–51.
- [13] Lemler MS, Ramaciotti C, Stromberg D, Scott WA, Leonard SR. The extracardiac lateral tunnel Fontan, constructed with bovine pericardium: comparison with the extracardiac conduit Fontan. *Am Heart J* 2006;151(4):928–33.
- [14] Nakano T, Kado H, Tachibana T, Hinokiyama K, Shiose A, Kajimoto M, et al. Excellent midterm outcome of extracardiac conduit total cavopulmonary connection: results of 126 cases. *Ann Thorac Surg* 2007;84(5):1619–25. discussion 25–6.
- [15] Ochiai Y, Imoto Y, Sakamoto M, Kajiwara T, Sese A, Watanabe M, et al. Mid-term follow-up of the status of Gore-Tex graft after extracardiac conduit Fontan procedure. *Eur J Cardiothorac Surg* 2009;36(1):63–7. discussion 7–8.
- [16] Robbers-Visser D, Miedema M, Nijveld A, Boersma E, Bogers AJ, Haas F, et al. Results of staged total cavopulmonary connection for functionally univentricular hearts; comparison of intra-atrial lateral tunnel and extracardiac conduit. *Eur J Cardiothorac Surg* 2010;37(4):934–41.
- [17] Benito Bartolome F, Prada Martinez F, Bret Zurita M. Pulmonary thromboembolism after Fontan operation. *Rev Esp Cardiol* 2002;55(4):449–51.
- [18] Seckeler MD, D'Souza MD, Gangemi JJ, Hoyer AW, Jayakumar KA. Thrombotic occlusion of extracardiac conduit 4 months after Fontan surgery. *Tex Heart Inst J* 2013;40(3):360–1.
- [19] Kammeraad JA, Sreeram N. Acute thrombosis of an extracardiac Fontan conduit. *Heart* 2004;90(1):76.
- [20] van Brakel TJ, Schoof PH, de Roo F, Nikkels PG, Evens FC, Haas F. High incidence of Dacron conduit stenosis for extracardiac Fontan procedure. *J Thorac Cardiovasc Surg* 2014;147(5):1568–72.
- [21] Jonas RA, Mayer JE, Castaneda AR. Unsatisfactory clinical experience with a collagen-sealed knitted Dacron extracardiac conduit. *J Card Surg* 1987;2(2):257–64.