Mid-term follow-up of the status of Gore-Tex graft after extracardiac conduit Fontan procedure

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Abstract

Objective: Extracardiac conduit Fontan procedure (ECFP) using Gore-Tex graft has been performed with increasing frequency for the patients with functional single ventricle. However, lack of growth potential and longevity of the conduit are consistent concerns and main points of criticism of the ECFP. In this study, we investigated the mid-term status of the Gore-Tex graft used in the ECFP by comparing the internal diameter of the graft with the inferior vena cava (IVC) diameter at 1 month and 5.2 years after the ECFP.

Methods: Of 79 patients who underwent ECFP using Gore-Tex graft between November 1997 and December 2007, 33 patients who had completed cardiac catheterization at 1 month (21—73 days) and 5.2 years (3.3—9.6 years) after the ECFP were included in this study. We measured the internal diameter of the Gore-Tex graft and IVC at both catheterizations retrospectively.

Results: The size of the Gore-Tex graft used in the ECFP was 16 mm in 17 patients, 18 mm in 9 patients, and 20 mm in 7 patients. Laminar flow through the conduits was maintained without any stenosis or kinking of the graft in these 33 patients. No intervention or reoperation related to the extracardiac conduit has been required. There were no significant differences in mean cross-sectional area (CSA) of the conduits at 1 month versus 5.2 years after the ECFP for each conduit size, and no significant changes in the conduit-to-IVC CSA ratio (0.98 ± 0.40 vs 0.82 ± 0.21 for 16 mm, 1.09 ± 0.30 vs 0.92 ± 0.33 for 18 mm, and 1.16 ± 0.55 vs 0.94 ± 0.44 for 20 mm conduit).

Conclusions: The conduit CSA and conduit-to-IVC CSA ratio remained unchanged in small caliber grafts down to 16 mm at 5.2 years after the ECFP. However, further investigation is necessary to evaluate the fate of the Gore-Tex graft and late hemodynamics in the patients with small conduits after they achieve full somatic growth.

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1. Introduction

Reflecting excellent mid-term outcomes and low frequency of early and late postoperative arrhythmias, extracardiac conduit Fontan procedure (ECFP) has been performed with increasing frequency in patients with functional single ventricle [1—8]. The advantages of the ECFP including optimal laminar flow in the systemic venous pathway, avoidance of myocardial ischemia, atriotomy, and intra-atrial suture lines, as well as simplicity of the surgical technique, could contribute to a low incidence of atrial arrhythmia and better ventricular function. Nevertheless, thrombogenicity and lack of growth ability of the prosthetic graft used in the ECFP are potential disadvantages and the main points of criticism of the ECFP. Pedicled autologous pericardium or tissue-engineered graft as an extracardiac conduit is being used at some centers to replace the prosthetic conduit [4,9,10], however, these grafts are not readily available or used universally. Gore-Tex graft (W.L. Gore & Associate Inc., Flagstaff, AZ) has been widely used as a stable conduit due to its minimal peel formation [1,11,12], resistance to calcification [13], its availability in various size, and easy handling. We believe that the rhythm-stabilizing advantages of the ECFP [2,3] outweigh its disadvantages related to the lack of growth potential, and the ECFP using Gore-Tex graft has been our procedure of choice for treatment of functional single ventricle since 1997. For more than a decade following our introduction of the ECFP, we continue to monitor the effects of the lack of growth potential and the longevity of the Gore-Tex graft especially in the small caliber grafts. In this study, we investigated the mid-term status of the Gore-Tex graft used in the ECFP by comparing the internal diameter of the graft with the inferior venous diameter at postoperative 1 month and 5.2 years to evaluate its growth potential.
vena cava (IVC) diameter at 1 month and 5.2 years after the ECFP.

2. Patients and methods

This study was approved by the ethics committee of Kyushu Koseinenkin Hospital, and informed consent was obtained from all patients’ parents. Of 79 patients who underwent ECFP using Gore-Tex graft between November 1997 and December 2007, 33 patients who have completed cardiac catheterization at 1 month and 5.2 years after the ECFP were included in this study. Cases of conversion from an atrioventricular connection Fontan to the ECFP, interruption of IVC and polypsplenia, and using of fenestration were excluded from this study. The primary diagnoses were single right ventricle in eight, hypoplastic left heart syndrome in two, tricuspid atresia in four, pulmonary atresia with intact ventricular septum in five, double outlet right ventricle in seven, and other complex functional single ventricle in seven patients. A total of nine of the patients in this study presented with heterotaxy syndrome. Bidirectional Glenn procedure had been performed prior to completion of the ECFP in 25 out of 33 patients. There were 17 male and 16 female patients. The average age, weight, and height at the ECFP were 4.1 years (32—13 days), 8.0 kg (7.4—49.5 kg), and 122.3 cm (72.5—159.0 cm), respectively.

All data were reviewed retrospectively. The initial postoperative cardiac catheterization was performed at 1 month (32 ± 13 days; 21—73 days) after completion of the ECFP. The mid-term postoperative catheterization was performed at an interval of 5.2 ± 2.9 years (1.8—12.7 years), 13.6 ± 8.0 kg (7.4—49.5 kg), and 94.4 ± 20.2 cm (72.5—159.0 cm), respectively.

All measurements were repeated by three individuals, and the average values were used for analysis to eliminate subjectivity of examiner measurements. Cross-sectional areas (CSAs) of the conduits and IVC were measured at 1 cm after completion of the ECFP. The mid-term postoperative catheterization was performed at an interval of 5.2 years (3.3—9.6 years) after completion of the ECFP. Internal diameters of the conduits and IVC were measured in anteroposterior (AP) and lateral projections at two postoperative cardiac catheterizations (1 month and 5.2 years after the ECFP). Diameters of the conduits were measured at the mid-portion of the conduits, and diameters of the IVC were measured at 1 cm below the anastomotic site between the Gore-Tex graft and IVC (Fig. 1). All measurements were repeated by three individuals, and the average values were used for analysis to eliminate subjectivity of examiner measurements. Cross-sectional areas (CSAs) of the conduits and IVC were calculated as follows; cross-sectional area = 3.14 × (AP diameter/2) × (lateral diameter/2).

Table 1

<table>
<thead>
<tr>
<th>Size (mm)</th>
<th>Age (year)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16 (n = 17)</td>
<td>3.0 ± 1.5</td>
<td>10.8 ± 2.2</td>
<td>86.8 ± 10.2</td>
</tr>
<tr>
<td>18 (n = 9)</td>
<td>3.6 ± 1.5</td>
<td>12.0 ± 2.8</td>
<td>90.2 ± 10.1</td>
</tr>
<tr>
<td>20 (n = 7)</td>
<td>7.2 ± 4.5</td>
<td>22.4 ± 14.2</td>
<td>118.2 ± 30.1</td>
</tr>
</tbody>
</table>

All data were expressed as mean ± standard deviation (range). The differences between the early- and mid-term catheterization data were assessed by paired t-test. Values at different conduit size were compared by Mann—Whitney test. All analyses were performed with SPSS (SPSS 10.0 for Windows, SPSS Inc., Chicago, IL). A p value less than 0.05 was considered significant.

3. Results

3.1. Operative data

The operation was performed through a median sternotomy using cardiopulmonary bypass with mild-to-moderate hypothermia. When cardiac arrest was required for the intracardiac procedures, myocardial protection was achieved with an antegrade infusion of cold crystalloid cardioplegic solution. The size of the Gore-Tex graft used was 16 mm in 17 patients, 18 mm in 9 patients, and 20 mm in 7 patients. In the first seven cases, we used ring enforced Gore-Tex graft (W.L. Gore & Associate Inc., Flagstaff, AZ) in two patients with 16 mm graft and five patients with 20 mm graft. Since 1998, we have routinely used a non-ringed Gore-Tex graft. The relations between the conduit size and age, weight, and height at the ECFP are shown in Table 1. The age, weight, and height in patients with a 20 mm graft were significantly larger than that in patients with 16 mm and 18 mm grafts. There was no significant difference in body size between patients with 16 mm and 18 mm grafts.

3.2. Follow-up

All patients had follow-up assessments with a median duration of 8.8 years (5.5—11.3 years). At follow-up mid-term catheterization, the average age, weight, and height were 9.3 ± 3.8 years (5.0—21.3 years), 24.4 ± 14.3 kg (12.2—84.3 kg), and 122.3 ± 17.3 cm (89.5—175.5 cm), respectively. The age, weight, and height at mid-term catheterization are shown according to the conduit size in Table 2. Hemodynamics obtained at mid-term catheterization showing good Fontan circulation with the following parameters; mean central venous pressure (11.4 ± 2.2 mmHg), mean pulmonary artery pressure (10.7 ± 2.2 mmHg), mean ventricular end-diastolic pressure (6.6 ± 2.2 mmHg), mean cardiac index (4.4 ± 1.4 l/min/M²), mean arterial oxygen saturation (93.8 ± 3.2%), and
pulmonary artery index (Nakata) \((250 \pm 89 \text{ mm}^2/\text{M}^2)\). None of the patients showed significant pressure gradient between the conduit \((11.3 \pm 2.2 \text{ mmHg})\) and IVC \((11.5 \pm 2.6 \text{ mmHg})\). Regarding anticoagulation, aspirin at a daily dose of 5 mg/kg was used in all the patients indefinitely, while warfarin was used for up to 6–12 months after the ECFP to maintain the international normalized ratio between 1.5 and 2.0. For the patients who had a history of thrombosis, warfarin was continued permanently along with the aspirin. In this series, there was no late death. Cerebral infarction occurred in one patient at 5 years after the ECFP; however, there was no thrombus seen in the 18 mm Gore-Tex graft or cardiac lumen.

Interventions during the follow-up period were performed in 13 patients (39%), and included balloon angioplasty for pulmonary artery stenosis \((n=2)\) and coil embolization of the collateral vessels \((n=11)\). There was no intervention or reoperation related to the extracardiac conduit, such as conduit stenosis, kinking, or pulmonary artery distortions.

### 3.3. Gore-Tex graft and IVC diameters

In all patients, laminar flow through the conduit was observed without any stenosis or kinking at both cardiac catheterizations. As shown in Fig. 2A, there was a significant decrease in the lateral diameter of the 16 mm conduits during the follow-up period \((from 13.9 \pm 1.7 \text{ mm} to 13.2 \pm 1.4 \text{ mm}, p < 0.01)\). There were no significant differences in AP diameters of each conduit size during the follow-up period as shown in Fig. 2B. For all 33 patients, the mean ratio of lateral-to-AP diameter of the conduit decreased from 0.96 \pm 0.15 to 0.90 \pm 0.13 \((p = 0.02)\) during the follow-up period, most likely due to gradual compression in lateral direction by the lung and cardiac mass. However, in the 20 mm conduit group, mean ratio of lateral-to-AP diameter did not change during the follow-up period \((from 1.06 \pm 0.15 to 1.04 \pm 0.05, \text{ N.S.})\). Also, mean ratio of lateral-to-AP diameter in the 20 mm conduit group at 5.2 years after the ECFP \((1.04 \pm 0.05)\) was significantly larger than that of 16 mm \((0.88 \pm 0.14, p = 0.01)\) and 18 mm \((0.84 \pm 0.09, p < 0.01)\) conduit groups. In five out of seven patients with 20 mm grafts, we used ringed Gore-Tex grafts, which resist lateral compression forces, and may have helped to maintain close to a 1.0 mean lateral-to-AP diameter ratio and a near circular-shaped cross-section.

Fig. 3A shows the ratio of the conduit-to-IVC lateral diameters at 1 month and 5.2 years after the Fontan procedure according to the conduit size. There were significant decreases in the conduit-to-IVC lateral diameter ratio in each conduit size \((0.93 \pm 0.24 to 0.77 \pm 0.15, p = 0.02, for 16 mm; 1.01 \pm 0.24 to 0.82 \pm 0.14, p = 0.03, for 18 mm; 1.05 \pm 0.27 to 0.87 \pm 0.24, p = 0.01, for 20 mm)\), which were caused by increases in the IVC diameter with somatic growth. In contrast, no significant difference was observed in the ratio of the conduit-to-IVC AP diameter in each conduit size during the follow-up period as shown in Fig. 3B.

### 3.4. Cross-sectional area of the Gore-Tex graft and IVC

There was no significant difference in mean CSA of the conduits at 1 month and 5.2 years after the ECFP \((195 \pm 53 \text{ mm}^2 vs 191 \pm 45 \text{ mm}^2, \text{ N.S.})\). Also, there were no significant changes in mean CSA of the conduits during the follow-up period \((161 \pm 24 \text{ mm}^2 to 157 \pm 14 \text{ mm}^2, \text{ N.S.}, for 16 mm; 195 \pm 38 \text{ mm}^2 to 203 \pm 16 \text{ mm}^2, \text{ N.S.}, for 18 mm; 271 \pm 35 \text{ mm}^2 to 261 \pm 21 \text{ mm}^2, \text{ N.S.}, for 20 mm)\). We compared the CSA of the conduit to the IVC. Fig. 4 shows the conduit-to-IVC CSA ratio for each conduit size group. This ratio at 5.2 years after the ECFP was 0.82, 0.92, and 0.94 in 16 mm, 18 mm, and 20 mm conduit group, respectively.

| Table 2: Conduit size, age, weight, and height at mid-term catheterization. |
|---|---|---|---|
| Conduit size (mm) | Age (year) | Weight (kg) | Height (cm) |
| 16 \((n=17)\) | 8.0 \(\pm 1.9\) | 19.8 \(\pm 4.7\) | 115.9 \(\pm 11.4\) |
| 18 \((n=9)\) | 8.4 \(\pm 1.7\) | 19.8 \(\pm 2.8\) | 118.1 \(\pm 8.2\) |
| 20 \((n=7)\) | 13.7 \(\pm 5.8\) | 41.4 \(\pm 24.4\) | 143.3 \(\pm 22.3\) |

Values are mean \(\pm SD\).

\(p < 0.05\) compared to the values in patients with 16 mm conduit.

\(p < 0.05\) compared to the values in patients with 18 mm conduit.
which did not differ significantly according to the conduit size. There were no significant changes in the conduit-to-IVC CSA ratio in 16 mm (0.98 ± 0.40 to 0.82 ± 0.21, p = 0.15), 18 mm (1.09 ± 0.30 to 0.92 ± 0.33, p = 0.16), and 20 mm (1.16 ± 0.55 to 0.94 ± 0.44, p = 0.09) conduit group between 1 month and 5.2 years after the ECFP. The amount of change in the conduit-to-IVC CSA ratio was −0.16 (95% confidence interval [CI]; −0.37 to +0.04), −0.17 (95% CI; −0.39 to −0.05), and −0.22 (95% CI; −0.43 to −0.01) in the 16 mm, 18 mm, and 20 mm conduit group, respectively, which did not differ according to the conduit size.

4. Discussion

We investigated the mid-term status of the Gore-Tex graft used in the ECFP by comparing the internal diameter and CSA of the graft with the anastomosed IVC at 1 month and 5.2 years after the ECFP in 33 patients. There were no significant changes in mean CSA at each conduit size in the mid-term. In that the Gore-Tex graft remained dimensionally stable, this result is similar to a previous report [1]. Amodeo et al. [1] evaluated the conduit patency by serial MRI studies and showed that there was no change in conduit internal diameter between the first 6 months and over the following 5 years after the Fontan procedure in 20 patients. We examined a 16 mm Gore-Tex graft explanted from a polysplenia patient who underwent revision of the extracardiac conduit to attain balanced hepatic venous blood flow to the lung at 1 year after the initial Fontan operation [14]. The internal surface of the Gore-Tex graft was completely covered with thin and smooth neointima of 150–250 μm in thickness at the middle of the graft. Theoretically, as long as the laminar flow pattern in the conduit is maintained, it is expected that there will be much less stimulus for further peel formation after the initial peel formation. Because the mechanisms of peel thickening include deposition of platelet-fibrin aggregates and thrombi between the peel itself and the conduit wall, the use of anticoagulant plays an important role to minimize progression of peel thickening. Serial studies using MRI [15] or CT to detect mural thrombi and progression of peel thickening are mandatory to lead better anticoagulation strategy.

Selection of an optimal sized-conduit for ECFP is an important issue for growing patients and is related to controversies about the timing of the ECFP with respect to age and weight [7,16]. Regarding the choice of conduit size, this decision is influenced by two competing factors; the desire to insert a large conduit comparable with the size of adult IVC to avoid growth-related obstruction, and the other desire to avoid extremes of conduit—IVC mismatch which may lead to turbulence, stasis, or thrombosis at the anastomotic site. Some reports [17,18] mentioned the upper limit of the conduit size. Lardo et al. [17] reported the maximal ratio of conduit-to-IVC diameter without causing significant hemodynamic energy loss to be 1.5 using an explanted sheep heart flow model. Alexi-Meskishvili et al. [18] reported two patients with the conduit-to-IVC ratio of 2.0 and 1.9 having thrombus in the extracardiac conduits due to oversized conduits, and recommended that conduits more than 20% larger than the IVC size should not be used.

Regarding the small caliber conduits, our concern is that the 16 mm conduits may not accommodate the patients’ future exercise demands or may be stenotic relative to the IVC size as the patients grow. In our 17 patients with 16 mm conduits, at 5.0 ± 0.7 years after the ECFP, the body weight nearly doubled, however they showed good Fontan circulation without significant pressure gradient between the conduit and IVC (10.9 ± 2.1 mmHg vs 10.8 ± 2.4 mmHg). The conduit-to-IVC CSA ratio was getting somewhat smaller (0.98 ± 0.40 to 0.82 ± 0.21), but this difference was not significant at least 5 years after the ECFP. Also, there were no significant differences in the amount of change in the conduit-to-IVC CSA ratio in the 16 mm conduit group compared to that of the 18 mm or 20 mm conduit group. Reviewing the literatures for the use of 16 mm Gore-Tex graft [6,7,11,19], there have been no patients who required conduit replacement owing to size mismatch affecting somatic development. Of course, longer follow-up is necessary to evaluate the late Fontan circulation and the fate of the small artificial conduit with future somatic growth. So far, from this limited follow-up period, the mid-term durable status of the 16 mm conduit with efficient Fontan circulation in our 17 patients is supporting our continued usage of the 16 mm conduit for treatment of a patient of approximately 10 kg body weight.

The other concern for this conduit is the absence of the longitudinal growth potential. It has been reported that, in children at 2–4 years of age, the distance between the IVC orifice and the undersurface of the right pulmonary artery is approximately 60% of that in adults [18]. Therefore, along with the patient somatic growth, some problems such as distortion of the pulmonary artery, compression of the pulmonary vein, or flow disturbance by the conduit might occur. Iwaki et al. observed no distortion of the pulmonary artery in 20 patients who grew more than 10 cm in height after the completion of the ECFP and indicated that the autologous venous tissue was able to compensate for the lack of growth in the artificial graft [20].
There are several limitations in this study. First, this study included a relatively small number of patients with limited follow-up period. Second, we utilized angiography to measure the diameter of the conduits and IVC. In terms of measurement accuracy, MRI or multidetector-row CT might be more suitable than angiography to measure the graft and IVC internal diameters and for evaluation of the configuration of the graft in the chest cavity. Regarding measuring the IVC size, the IVC is an extremely compliant vessel so that its diameter and shape vary greatly with patient body position, volume status, and systemic venous pressure [21]. In some children in whom the hepatic vein enters the IVC near perpendicularly [22], we integrated both veins into one to anastomose the Gore-Tex graft. Therefore, measurement of the IVC size is very difficult.

In conclusion, during the mean follow-up period of 5.2 years, no intervention or reoperation related to the extracardiac conduit was required, and the conduit CSA and conduit-to-IVC CSA ratio were maintained with efficient Fontan circulation even in the small caliber 16 mm graft. Long-term Fontan circulation and late incidence of conduit-related complications especially in small caliber grafts remain to be elucidated in future follow-up studies.

Acknowledgement

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References


Appendix A. Conference discussion

Dr H. Kurosawa (Tokyo, Japan): I have three questions. You clearly demonstrated that extracardiac Fontan by using Gore-Tex graft could maintain good shape and adequate internal diameter of not only graft but also IVC. With somatic growth, however, graft might become too small, which might increase venous pressure of abdominal organ resulting in PLE or even hepatic failure. I would think that 5 or 8 years follow-up is still too short for the patients with 13 kg of average weight. My first question is, do you think that some patients must require replacement of the graft in the future? The second, despite a wishful expectancy, atrial arrhythmia has been reported after extracardiac Fontan. I would think that detachment of IVC from the right atrium may occasionally damage atrophicventricular node itself or transitional cell zone surrounding the node in the setting of a posterior atrioventricular conduction axis such as Holmes heart or discordant atrioventricular connections with overriding of the mitral valve. You didn’t mention about arrhythmia in your paper. My second question is, did you find atrial or supraventricular arrhythmia in your patients? If so, how would you think the reasons of arrhythmia after your procedure? Finally, I would believe the freedom from anticoagulant therapy is beneficial for the long life of children. You described in your manuscript that aspirin was used in all patients while warfarin was used only up to 6—12 months after surgery. Although you didn’t find peel formation in Gore-Tex graft despite interruption of warfarin, you didn’t mention about pulmonary embolism. My final question is, are you concerned about microembolism in peripheral pulmonary artery long after extracardiac Fontan by using Gore-Tex graft without warfarin?

Dr Ochiai: Regarding replacement of the conduit, I wish it might not occur. As Dr Kurosawa suggested, our follow-up period is still short. However, according to the report from Fukuoka Children’s Hospital and Bambino Gesu Children’s Hospital in Rome, with more than 10-year experience, no patient required replacement of the extracardiac conduit due to patient’s somatic growth. I think if we encounter reoperation, the operation to exchange the
extracardiac conduit is not so risky for the patient who has established Fontan circulation.

For the second question regarding arrhythmia, we have very few patients suffering from postoperative arrhythmia. Most of them are heterotaxy patients, right atriotomy for intracardiac procedure and the damage to the sinus node due to repeated surgery might be the cause of their arrhythmia.

For the final question regarding embolism in pulmonary artery, fortunately, we have not experienced major pulmonary embolism so far. Coagulation abnormality after the Fontan operation regardless of the usage of the extracardiac conduit is now well known. We still don’t know if our current anticoagulation regimen is appropriate or not. I think further studies using MRI or CT to detect mural thrombus in the venous pathway would be useful to lead to better anticoagulation strategy.

Dr T. Ebels (Groningen, The Netherlands): I noticed you did not take the body size or length of the patients into account, because obviously in a larger patient you would need a larger conduit. Do you use a certain relationship between the size of the conduit and the size of the patient? The anticipated size, or how tall somebody is going to be?

Dr Ochiai: Can I move back to my slides?

Dr Spray (Philadelphia, United States): I don’t think there is time. I think really the question is, how do you select the conduit size and do you try to predict how big the patient will become when you select the conduit size.

Dr Ochiai: We choose 18 mm conduit for 10–15 kg patients of 3–5 years old and 20 mm conduit for 20 kg patients. Practically, the graft size is a little bit bigger than the patient’s IVC size. At surgery, we do not take the patient’s future growth into account.

Dr Sano (Okayama, Japan): From the slide, I think that they selected 16 mm graft in average 10 kg.

Dr Ebels: I mean, the anticipated body size. I mean, you can calculate how large somebody will become.

Dr Sano: I think that most of the Japanese are very small compared to Europe.

Dr Ebels: But even then, the relationship must be the same.

Dr Sano: I think that if the parents are very big, then we probably select bigger conduit. But most of the patients are like 50 or 60 kilos.