EARLY RESULTS OF THE EXTRACARDIAC CONDUIT FONTAN OPERATION

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Background: **Among the modifications of the Fontan operation, the extracardiac approach may offer the greatest potential for optimizing early postoperative ventricular and pulmonary vascular function, insofar as it can be performed with short periods of normothermic partial cardiopulmonary bypass and without cardioplegic arrest in most cases. In this study, we reviewed our experience with the extracardiac conduit Fontan operation, with a focus on early postoperative outcomes.** ***Methods and results:*** **Between July 1992 and April 1997, 51 patients (median age 4.9 years) underwent an extracardiac conduit Fontan operation. Median cardiopulmonary bypass time was 92 minutes and has decreased significantly over the course of our experience. Intracardiac procedures were performed in only 5 patients (10%), and the aorta was crossclamped in only 11 (22%). Intraoperative fenestration was performed in 24 patients (47%). There were no early deaths. Fontan failure occurred in 1 patient who was a poor candidate for the Fontan procedure. Transient supraventricular tachyarrhythmias occurred in 5 patients (10%). Median duration of chest tube drainage was 8 days. Factors significantly associated with prolonged resource use (mechanical ventilation, inotropic support, intensive care unit stay, and hospital stay) included longer bypass time and higher Fontan pressure. At a median follow-up of 1.9 years, there was 1 death from bleeding at reoperation.** ***Conclusions:*** **The extracardiac conduit Fontan procedure can be performed with minimal mortality and morbidity. Improved results may be related to advantages of the extracardiac approach and improved preservation of ventricular and pulmonary vascular function. (J Thorac Cardiovasc Surg 1999;117:688-96)**

Follow-up studies have shown that although outcomes have improved substantially over time, results of the Fontan operation and its modifications remain suboptimal.[1-4] The instantaneous hazard for Fontan failure is greatest in the first month after the operation,[1,4] a fact that underscores the importance of early results for the overall success of a program for univentricular palliation. For perioperative results to be optimized, it is essential to preserve ventricular and pulmonary vascular function, reduce arrhythmias, and improve flow dynamics in the Fontan circuit. Among the modifications of the Fontan operation currently used, the extracardiac conduit approach may offer the greatest potential for optimizing early postoperative outcomes.

Since 1992, we have used the extracardiac conduit Fontan procedure as our operation of choice for palliation in patients with single ventricle physiology. In this report, we present our initial experience with this technique, with a focus on our early postoperative results.

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Patients and methods

Demographic and diagnostic information. Between July 1992 and April 1997, 51 consecutive patients underwent total cavopulmonary anastomosis with an extracardiac conduit at the University of California, San Francisco (UCSF). Although we currently operate at 3 hospitals, all Fontan operations during the study period were performed at the UCSF Medical Center. This excludes an additional 8 patients who had a previous atriopul-

Table I. *Anatomic diagnoses*

Primary diagnosis	*No. of patients*
Tricuspid atresia	13
Double-inlet left ventricle	13
Atrial isomerism/heterotaxy	6
Pulmonary atresia with intact ventricular septum	4
Hypoplastic left heart syndrome	2
Other complex functional single ventricle	13

monary or atrioventricular Fontan connection revised to an extracardiac conduit Fontan during the same period.[5]

Median age was 4.9 years (1.5-44 years) and median weight was 16 kg (10-68 kg). Primary diagnoses are summarized in Table I. The morphologic characteristics of the dominant ventricle were those of the left venticle in 33 patients, the right ventircle in 11, and indeterminate in 4. Both the right and left ventricles were present in 3 patients. Twenty-five patients (49%) had anatomy other than tricuspid atresia or double-inlet left ventricle. All but 2 patients had undergone prior operations (median 2, range 0-7), which are summarized in Table II. Median age at the time of the first shunt or band procedure was 24 days (1 day–24 years) and at construction of the classic or bidirectional Glenn procedure, 2.5 years (2 months–42 years).

At the time of Fontan completion, pulmonary blood flow was supplied by a Glenn anastomosis only in 13 patients, by a Glenn anastomosis plus another source in 33, and by another source only in 5. All patients had undergone preoperative echocardiography and catheterization. Results of these studies are summarized in Table III. Aortopulmonary collaterals were present at preoperative catheterization in 15 patients, and in 5 they were occluded by coil embolization. No patient had significant semilunar valvular regurgitation, and 2 patients had subvalvular systemic outflow tract obstruction.

Operative techniques. Through a standard median sternotomy, a modified Fontan circulation was completed by connecting the inferior vena cava to the pulmonary arteries with an extracardiac conduit of either expanded polytetrafluoroethylene or aortic allograft. The operative strategy centered on preservation of ventricular and pulmonary vascular function. Unless a concomitant intracardiac procedure was to be performed, aortic crossclamping was avoided. No active cooling was used and the operation was performed on a warm beating heart. Hemodilution was avoided by the use of a blood prime in the cardiopulmonary bypass (CPB) circuit, and the priming solution was supplemented with calcium to optimize cardiac function.

Every effort was made to avoid or minimize the duration of total CPB. If the pulmonary arteries were large enough and did not require extensive augmentation, the pulmonary anastomosis was performed off bypass with the use of vascular clamps so that the Glenn shunt perfused one or both lungs. With this technique the duration of CPB was limited to the time required to perform the inferior cavopulmonary anastomosis only. When bypass was established, it was in the form of partial support with inferior vena cava cannulation alone whenever possible.

Table II. *Previous procedures*

	Patients	
Previous procedure	*No.*	*%*
Bidirectional Glenn anastomosis	42	82*
Systemic–pulmonary arterial shunt	35	69†
Atrial septectomy	26	51
Pulmonary arterial reconstruction	22	43
Ligation of pulmonary trunk	15	29
Relief of systemic outflow tract obstruction	11	22
Pulmonary arterial band	9	18†
Classic Glenn anastomosis	6	12*
Atrioventricular valve repair	4	8

*Two patients had previously undergone both classic and bidirectional Glenn procedures.
†Two patients had previously undergone both systemic–pulmonary arterial shunt and pulmonary arterial band.

Table III. *Preoperative hemodynamics and echocardiographic findings*

Variable	*Value*
Mean systemic arterial blood pressure (mm Hg)	80.0 ± 11.8
Mean pulmonary arterial pressure (mm Hg)	12.1 ± 5.2
Common atrial pressure (mm Hg)	4.3 ± 2.3
Transpulmonary pressure gradient (mm Hg)	7.6 ± 4.8
Ventricular end-diastolic pressure (mm Hg)	6.8 ± 2.7
Pulmonary vascular resistance (Wood units)	2.3 ± 1.2
Pulmonary/systemic blood flow ratio	1.1 ± 0.8
Systemic arterial oxygen saturation (%)	83.1 ± 5.2
Atrioventricular valve regurgitation ≥mild (No. of patients)	6 (12%)

Data are expressed as mean ± standard deviation or number and percent of patients.

After the patients were weaned from CPB, Fontan hemodynamics were evaluated. If the Fontan pressure was 18 mm Hg or more with a transpulmonary gradient of 10 mm Hg or more, consideration was given to placement of a fenestration between the conduit and the right atrial free wall. This was accomplished without return to CPB either with a direct side-to-side anastomosis or with a 4-8 mm polytetrafluoroethylene tube graft along with a snare device. Aprotinin and modified ultrafiltration were not used.

Data analysis. Data were collected on retrospective review of patient records. The early postoperative period was defined as the time period before hospital discharge or as 30 days after the operation if discharge occurred earlier. After discharge, all patients were followed up for at least 6 months. Median follow-up time was 1.9 years (6 months–3.8 years). Continuous variables before and after the Fontan operation or between 2 groups of patients were compared with the use of the paired or independent samples *t* test, respectively. Dichotomous variables were compared by means of Fisher's

exact test or χ^2 analysis. Correlation between 2 continuous variables was assessed with linear regression analysis.

Because only 1 death and only 1 Fontan failure occurred during the study period, these variables could not be used to analyze outcome. Instead, outcome measures assessed included the following variables: duration of mechanical ventilatory support (continuous and longer than/shorter than 24 hours), duration of inotropic support (continuous and longer than/shorter than 3 days), occurrence of arrhythmias, duration of stay in the intensive care unit (continuous and longer than/shorter than 7 days), duration of chest tube drainage (continuous and longer than/shorter than 14 days), and duration of hospital stay (continuous and longer than/shorter than 21 days).

Independent variables analyzed included the following: date of the operation, age, weight, ventricular morphology, morphology other than tricuspid atresia or double-inlet left ventricle, duration of systemic–pulmonary arterial shunting or pulmonary arterial banding, prior bidirectional cavopulmonary anastomosis, duration of cavopulmonary anastomosis, preoperative hemodynamics and atrioventricular valve function, presence of aortopulmonary collateral arteries, duration of CPB, use of cardioplegic arrest, conduit type, conduit size, Fontan fenestration, and additional operative procedures at the time of the Fontan completion.

SPSS for Windows 6.1 (SPSS Inc, Chicago, Ill) was used for statistical analysis. Data are expressed as mean ± standard deviation or median (range). Odds ratios (OR) are presented with 95% confidence intervals (CI).

Results

Perioperative data. A nonringed polytetrafluoroethylene graft was used to complete the extracardiac Fontan operation in 42 patients; a cryopreserved aortic allograft was used in 7 and direct anastomosis between the pulmonary trunk and the inferior vena cava was performed in 2. The median conduit size was 20 mm (16-25 mm). Pulmonary arterial augmentation was performed in 30 patients, ligation of the pulmonary trunk in 21, and bidirectional superior cavopulmonary anastomosis in 5. Intracardiac procedures were performed in 5 patients (10%), all of whom were among the first 25 patients in the series. These procedures included enlargement of the bulboventricular foramen in 2, atrioventricular valvuloplasty in 2, and ablation of an ectopic atrial focus in 1.

Median CPB time (including periods of partial CPB in 14 patients) was 92 minutes (66-247 minutes) and decreased significantly over the course of our experience ($r = –0.38$, $P = .006$). Cardioplegic arrest with aortic crossclamping was used in only 11 patients (22%), all of whom were operated on before 1995. In these 11 patients, crossclamp time ranged from 7 to 66 minutes (median 39 minutes).

A fenestration was performed during the operation in 24 patients (47%). In the early postoperative period, 6 additional patients underwent either placement of a new fenestration or revision of a previous fenestration. Postoperative fenestrations and revisions were performed as closed procedures in the intensive care unit without the need to return to the operating room. Twenty-seven patients (53%) were discharged home with a fenestration. There was a marked decrease in the incidence of fenestration over time, with only 4 of the last 20 patients (20%) undergoing a fenestration compared with 20 of the first 31 patients (65%; $P = .02$).

Early survival and morbidity. There were no early deaths. Fontan failure occurred in 1 patient who was a poor candidate for the Fontan operation. This was a 40-year-old man with tricuspid atresia, severe right pulmonary arterial hypertension, and proximal occlusion caused by complications of previous shunts, systemic hypertension, and scoliosis resulting in ventilatory problems. Owing to limited therapeutic options and severe symptomatic cyanosis, he elected to undergo a one-lung Fontan operation. Systemic hypotension developed as a result of diastolic ventricular dysfunction (atrial pressure of 10 mm Hg) and elevated Fontan pressure of 22 mm Hg. The Fontan conduit was taken down and a systemic–pulmonary artery shunt was re-established.

Five patients (10%) had new transient early postoperative supraventricular tachyarrhythmias, including junctional ectopic tachycardia in 4 and atrial flutter in 1. In 3 of these patients the tachyarrhythmia was limited to the first 48 hours after the operation, and in 2 it was very brief, lasting less than 10 minutes. None of the patients were discharged on a program of antiarrhythmia medication. After discharge, arrhythmia recurred 20 months later in the patient with atrial flutter. New transient sinus node dysfunction necessitating temporary pacing occurred in 4 patients (8%) in the early postoperative period. None of the patients required a permanent pacer at the time of hospital discharge. In 3 of the patients, sinus rhythm returned within the first 48 hours after the operation. The fourth patient required temporary pacing for several days but eventually returned to normal sinus rhythm. A Holter monitor used before discharge showed no abnormalities. Recurrent sinus node dysfunction eventually developed in this patient, necessitating a permanent pacemaker 3.5 years after discharge. New permanent complete heart block necessitating a pacemaker occurred in 1 patient who underwent enlargement of the bulboventricular foramen ovale. Ventricular tachycardia occurred in 2 patients. In 1 patient it was related to severe hemodynamic compromise caused by mal-

Table IV. *Intraoperative and early postoperative hemodynamics*

	Intraoperative	*Postoperative day 1*
Pulmonary artery/Fontan pressure*	13.7 ± 2.6	12.9 ± 2.8
Transpulmonary pressure gradient	8.3 ± 2.6	7.7 ± 2.4
Common atrial pressure	5.2 ± 2.2	5.3 ± 2.5

*All pressures are expressed in millimeters of mercury ± standard deviation.

Table V. *Early postoperative outcome variables*

Variable	*Value*
Mechanical ventilatory support (h)	16 (1-580)
Inotropic support (d)	1.8 (1-11)
Chest tube drainage (d)	8 (3-210)
Intensive care unit stay (d)	4 (1-46)
Hospital stay (d)	13 (6-59)

Data are presented as median (range).

functioning of a previously placed ventricular pacemaker. The second patient developed nonsustained asymptomatic recurrent ventricular tachycardia. Electrophysiologic study showed no inducibility and he was discharged to his home receiving no medications. He was subsequently readmitted 2 months later with another episode of ventricular tachycardia, which was controlled medically.

Other transient early postoperative complications included elevated liver enzyme levels in 8 patients, renal failure in 4, diaphragmatic paresis without the need for plication in 3, and cardiac tamponade in 2. Forty-two patients (82%) were discharged on a regimen of either oral anticoagulation (n = 24) or antiplatelet (n = 18) medications.

Postoperative hemodynamics and resource use. The median Fontan pressure and transpulmonary gradient were low and did not change significantly between the operating room and the first postoperative day (Table IV). Early postoperative outcome variables are outlined in Table V. Median duration of chest tube drainage was 8 days (range 3-210 days), and prolonged chest tube drainage (>14 days) occurred in 11 patients (21%). Duration of chest tube drainage did not correlate with any hemodynamic or operative variables including preoperative pulmonary vascular resistance, postoperative Fontan pressure, or the incidence of fenestration.

Factors associated with extended resource use are summarized below. Prolonged mechanical ventilatory support (>24 hours) was associated with longer duration of CPB (145 ± 54 vs 107 ± 42 minutes, $P = .02$). Factors associated with prolonged inotropic support (>3 days) included longer duration of CPB (142 ± 61 vs 102 ± 33 minutes, $P = .006$) and higher Fontan pressure (15.0 ± 2.8 vs 13.0 ± 2.2 mm Hg, $P = .01$).

Hemodynamic and operative variables associated with prolonged postoperative stay in the intensive care unit (>7 days) included higher preoperative pulmonary arterial pressure (15.1 ± 6.9 vs 11.1 ± 4.3 mm Hg, $P = .02$), surgery with aortic crossclamping (OR = 3.7, 95% CI = 1.4-9.5, $P = .02$), and higher postoperative Fontan pressure (15.5 ± 2.8 vs 13.2 ± 2.2 mm Hg, $P = .009$). Factors associated with prolonged hospital stay (>21 days) included higher preoperative transpulmonary pressure gradient (10.0 ± 7.0 vs 6.5 ± 3.4 mm Hg, $P = .04$) and higher postoperative Fontan pressure (15.9 ± 2.2 vs 12.8 ± 2.1 mm Hg, $P = .006$).

Outcomes after hospital discharge. Room air oxygen saturation increased from a preoperative median level of 83% (73%-93%) to 95% (85%-99%) on postoperative follow-up. Patients with lower saturations were those whose fenestration remained open. Five patients underwent elective fenestration closure with the previously implanted snare device an average of 10 months after the Fontan operation. In 3 patients the fenestration was documented to have closed spontaneously. All surviving patients were in New York Heart Association class I (82%) or II (16%) except 1 patient who was in class III. This was a patient who had been converted to a one-lung Fontan circulation after thrombosis and occlusion of the left pulmonary artery. None of the patients showed evidence of conduit stenosis or thrombosis on follow-up echocardiogram. One patient had a cerebrovascular accident 12 months after the operation. This patient had undergone a fenestrated Fontan procedure and was discharged receiving an antiplatelet agent only. His fenestration was found to be occluded on echocardiogram. He was started on a regimen of anticoagulant therapy and the neurologic deficit subsequently cleared. Late atrial dysrhythmias occurred in 2 patients. One patient presented with recurrent atrial flutter 20 months after discharge and he was treated medically. The second patient developed recurrent sinus node dysfunction requiring a permanent pacemaker implantation 3.5 years after the Fontan operation. Recurrent ventricular tachycardia occurred 2 months after discharge in 1 patient who was treated medically. Protein-losing enteropathy developed in 1 patient and was managed effectively with medical therapy. One patient required mitral valve replacement 3.5 years after the Fontan operation for worsening regurgitation. Two patients were readmitted 22 and 54 days after the operation for drainage of recurrent pleural effusions. The second of these patients underwent resternotomy 5 months after the Fontan pro-

cedure for fenestration of the extracardiac conduit for attempted treatment of persistent effusions. Massive bleeding occurred during this procedure, and the patient died of a cardiac arrest. Actuarial freedom from death or Fontan failure was 96%.

Discussion

The Fontan circulation has marginal hemodynamics, and during the vulnerable early postoperative period, it is at greatest risk for Fontan failure and associated complications. Small disturbances in ventricular or pulmonary vascular function, development of arrhythmias, or turbulent flow in the Fontan circuit translate into elevated Fontan pressure and poor outcome. To optimize perioperative results it is essential to preserve ventricular and pulmonary vascular function, reduce arrhythmias, and improve flow dynamics in the Fontan circuit.

Outcomes with the lateral tunnel technique have been improving, and several centers have reported encouraging results.[3,4,6-8] Nevertheless, among the modifications of the Fontan operation currently used, the extracardiac conduit approach may offer the greatest potential for optimizing early postoperative outcomes. The strategy we have used in approaching the Fontan operation has been primarily aimed at optimizing perioperative ventricular and pulmonary vascular function. This requires not only intraoperative and technical measures, but preoperative planning as well.

An important preoperative strategy is to perform early bidirectional Glenn anastomosis to preserve ventricular function by relieving the volume load on the single ventricle.[9-12] Most of the patients included in this study have undergone previous palliation elsewhere, and their preoperative status was not optimized with early staging to a bidirectional Glenn shunt, as is our preferred approach. Whereas the median age among 160 patients undergoing a bidirectional Glenn shunt at our institution since 1990 was 7.8 months, the median age at which our Fontan cohort underwent a bidirectional Glenn shunt was significantly higher at 2.5 years. As more of our patients reach the age for a Fontan procedure after early volume unloading with a bidirectional Glenn anastomosis, we expect to appreciate better the advantages of this strategy on Fontan outcome.

Another important preoperative strategy relates to the use of cardioplegic arrest and the duration of CPB in the Fontan operation. Prolonged cardioplegic arrest and CPB times are associated with increased risk of early postoperative death or failure necessitating takedown of the Fontan conduit.[4,7,13] We therefore make every effort to limit or avoid the use of cardioplegic arrest and to shorten the duration of CPB at the time of the Fontan operation. This is accomplished by performing most ancillary intracardiac procedures (such as atrial septectomy, valve repair, relief of outflow tract obstruction) during the Glenn operation. This ensures that the Fontan operation is limited to placement of the extracardiac conduit alone (along with pulmonary arterioplasty, if necessary). Over the course of our experience, we have become more adamant in this respect, which is reflected by the fact that only 10% of our patients underwent a concomitant intracardiac procedure, all of whom were among the first 25 patients in this series.

In addition to these preoperative strategies, intraoperative and technical features of the extracardiac Fontan procedure offer advantages for preserving ventricular and pulmonary vascular function. The operation is performed entirely as an extracardiac procedure without the use of cardioplegic arrest. Aortic crossclamping was not used in 78% of our patients and in only 1 of our last 30 patients. In patients who do not require extensive pulmonary arterioplasty, CPB time can be reduced by performing the pulmonary anastomosis off bypass. Over the course of our experience we have seen our CPB times decrease significantly, and recently we have achieved CPB times as low as 9 minutes (data not included in the current series). At an extreme, the extracardiac Fontan operation can be performed entirely without CPB, as reported by Burke and associates.[14] We have recently experimented with this technique and believe it is a viable alternative in appropriate candidates.[15]

Because we do not have an internal control group of patients undergoing Fontan completion with other techniques, we cannot determine whether the extracardiac conduit technique confers an early survival benefit. Although the low failure rate prevented assessment of factors associated with death or Fontan takedown, our analysis did reveal several interesting findings relating to postoperative hemodynamics and resource use. Fontan pressure was significantly higher in patients who required prolonged inotropic support, prolonged stay in the intensive care unit, and prolonged hospitalization. The strongest predictor of prolonged inotropic and ventilatory support, factors that may be considered markers of cardiopulmonary dysfunction, was longer duration of CPB. This lends support to our contention that the shorter duration of CPB required for the extracardiac Fontan operation may help optimize early postoperative outcome.

The ability to perform the extracardiac Fontan operation without the need to enter the heart poses a new question regarding the role of routine fenestration. We acknowledge that improved results have been reported using fenestration with the lateral tunnel Fontan opera-

tion.[4,16,17] In this setting, the purpose of the fenestration is to optimize Fontan hemodynamics in the early postoperative period. Inasmuch as most of our patients undergo the Fontan operation without cardioplegic arrest and with a short duration of partial CPB, their postbypass Fontan hemodynamics may be more favorable than those of patients who undergo the lateral tunnel operation without a fenestration.

We have therefore refrained from routine fenestration, instead concentrating on performing fenestration only in those patients who demonstrated objective evidence of poor or marginal postpump hemodynamics. This approach is especially suitable with the extracardiac technique, because the fenestration can be conveniently performed as a closed procedure without resuming CPB, either in the operating room or in the intensive care unit. By limiting fenestration to those patients who will derive a hemodynamic benefit from a postoperative right-to-left shunt, we hope to avoid the potential morbidities associated with fenestration, including systemic desaturation, systemic embolization, and the need for an additional procedure to close the fenestration. Overall, we have performed fenestration in about half of our patients, and with improvements in our perioperative strategies for preserving ventricular and pulmonary vascular function, we have seen the incidence of fenestration decrease significantly over time (from 65% in the first 31 patients to 20% in the last 20 patients).

One of the most promising advantages of the extracardiac Fontan operation may be its potential to reduce supraventricular arrhythmias, which are a persistent source of morbidity and mortality after the Fontan operation.[18-22] The extracardiac conduit approach avoids or minimizes all 4 of the factors thought to be important potential contributors to arrhythmias after the Fontan procedure: (1) exposure of the right atrium to the elevated systemic venous pressure, (2) extensive atrial incisions and suture lines,[23] (3) surgery in the vicinity of the sinus node,[22] and (4) ventricular dysfunction resulting from ischemic arrest and long CPB times.

New-onset transient supraventricular tachyarrhythmias occurred in 10% of our patients in the early postoperative period. Most of these were either extremely short-lived (<10 minutes), or they occurred within the first 48 hours after the operation when the patients were under the influence of endogenous (pain) and exogenous (inotropic agents) catecholamines. None of the patients were discharged on a program of antiarrhythmia medication. Transient sinus node dysfunction occurred in 8% of the patients in the early postoperative period. Most of these episodes resolved within 48 hours after the operation, and none of the patients required a permanent pacemaker at the time of discharge. The figures above compare favorably with the 14% to 32% incidence of atrial arrhythmias (including supraventricular tachycardia and sinus node dysfunction) reported recently for other types of Fontan operation.[3,7,21,22] Moreover, late atrial rhythm abnormalities occurred in only 2 patients at a median follow-up time of 1.9 years. Although these results are encouraging, longer follow-up will be necessary to confirm the advantages of the extracardiac approach in decreasing the incidence of late postoperative atrial arrhythmias.

Another feature of the extracardiac conduit approach that may play a role in improving early postoperative outcome is the improved laminar flow patterns, which can theoretically be achieved in the Fontan circuit. The importance of avoiding turbulence and stasis has been demonstrated convincingly by hydrodynamic and computational modeling studies.[24-26] The extracardiac Fontan conduit is made of a smoothly contoured circumferential tube that can potentially optimize flow dynamics. The conduit can also be conveniently incorporated into a pulmonary arterioplasty both medially toward the pulmonary trunk and laterally toward the right lower lobe pulmonary artery. Clinical and experimental hydrodynamic and imaging studies will be necessary to validate the hemodynamic advantages of the extracardiac Fontan operation.

Median duration of chest tube drainage was 8 days, and prolonged drainage (more than 2 weeks) occurred in 21% of the patients. These figures are similar to the 13% to 39% incidence of prolonged drainage reported recently for other types of Fontan operation.[3,4,6,16,17] Our approach to removing chest tubes in patients who undergo a Fontan operation is extremely conservative. Chest tubes are not removed unless the drainage is less than 1 mL/kg per day for at least 2 days. Although this approach prolongs the time before chest tubes are removed, it decreases the incidence of readmission for recurrent effusions (only 2 patients in our series). We recognize the reported role of fenestration in decreasing postoperative effusions[4]; however, because we have no control group, we cannot draw inferences regarding the need for fenestration on the basis of our effusion data. Our analysis nonetheless did not show any significant difference in the duration of chest tube drainage between patients with and without fenestration.

The extracardiac Fontan operation has potential disadvantages that relate to the use of a conduit, including lack of growth potential, conduit stenosis, and thromboembolism. By waiting until the patient weighs at least 15 kg (approximately 3 years of age) before per-

forming the operation, we expect to avoid reoperation by using an adult-sized conduit (20-22 mm), which should accommodate the patient's future growth and exercise demands. None of our patients has had evidence of conduit stenosis or obstruction, but we nevertheless recommend periodic imaging to monitor conduit patency. In view of the reported 18% to 20% risk of postoperative thromboembolism after different types of Fontan procedures,[27,28] a majority of our patients were discharged from the hospital on a regimen of acetylsalicylic acid or warfarin. Our current recommendation is warfarin therapy for the first 3 postoperative months and acetylsalicylic acid thereafter.

In conclusion, our approach to the extracardiac conduit Fontan operation has evolved over the course of our experience. With a strategy that centers increasingly on preservation of ventricular and pulmonary vascular function, in both the preoperative and intraoperative periods, we have been able to perform the operation with minimal early postoperative morbidity and mortality. By avoiding concomitant intracardiac procedures, we have seen our CPB times decrease, our incidence of aortic crossclamping and fenestration decline, and many of the potential advantages of the extracardiac approach realized. Long-term benefits of the extracardiac conduit Fontan operation remain to be determined in future follow-up studies.

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Commentary

The original description of the Fontan procedure included placement of an extracardiac conduit from the right atrium to the left pulmonary artery. When Fontan and Kirklin[1] reviewed the late outcome of an early cohort of patients surviving the Fontan procedure, they concluded that much of the late morbidity could be attributed to problems associated with conduit use. Why is it, then, that Petrossian and associates, as well as other groups, are once again promoting use of an extracardiac conduit for this procedure?

Petrossian and others argue that the technique of conduit insertion originally described by Fontan involved anterior placement of a valved homograft that was subject to compression by the sternum, as well as calcification of the homograft valve. They believe that a nonvalved polytetrafluoroethylene conduit will be less likely to become obstructed, both because of its posterior location in the mediastinum and because of the nature of the conduit itself.

It is the hope of those promoting the conduit technique that by not exposing any atrial tissue to high pressure and by markedly reducing the atrial suture load, they can reduce the late incidence of atrial flutter. Flutter has emerged as probably the most common late complication after the Fontan procedure in the present era. Predisposing factors include the high pressure to which the wall of the systemic venous chamber is exposed with the lateral tunnel and other nonconduit techniques. Furthermore, Rodefeld and coworkers[2] have demonstrated in an animal model that the lateral tunnel technique predisposes to flutter through its distribution of suture load in critical areas.

Another theoretic advantage of the extracardiac conduit in performing the Fontan procedure is that it can be done with a shorter crossclamp time or possibly no myocardial ischemia. Petrossian and associates suggest that this will reduce the need for fenestration and the incidence and duration of pleural effusions. Median duration of chest tube drainage in their series of 51 patients was 8 days, with 21% of their patients having prolonged drainage of greater than 2 weeks. Median hospital stay was 13 days.

Not all groups have accepted the current enthusiasm for routinely applying a conduit in performing the Fontan procedure. Certainly justification must be provided for any procedure in growing children that violates the fundamental principle of incorporating growth potential in the design of a congenital cardiac repair. There are other serious concerns that must be carefully assessed before this approach is embraced widely. Apart from atrial flutter, other late complications of the Fontan procedure include the development of cirrhosis[3] and protein-losing enteropathy.[4] These problems surely have some relation to the cumulative impact of raised systemic venous pressure. Thus even an apparently functionally insignificant gradient of 2 or 3 mm Hg across a conduit over many years is likely to increase the probability of development of these very serious untreatable complications (unlike atrial flutter, for which a number of treatment options are available). Petrossian and colleagues suggest that the age at which the Fontan procedure should be performed should be increased to reduce the probability that conduit replacement will be necessary.

Other studies have suggested that there is an increased thrombotic tendency in patients after the Fontan procedure.[5] This risk has led most groups to institute at least aspirin therapy, and some are even recommending permanent warfarin sodium (Coumadin) treatment. Prosthetic material in human beings rarely becomes endothelialized beyond the first 5 to 10 mm. Although this may permit full endothelialization of a baffle as is used in the lateral tunnel technique, it means that a complete conduit will never become fully endothelialized. In the setting of a prothombotic state, this may increase the risk of multiple pulmonary emboli and, if a fenestration is placed, systemic emboli. On the other hand, proponents of the conduit technique can rightfully argue that the lateral tunnel technique places a large amount of prosthetic material in the pulmonary venous atrium with therefore an increased risk of systemic emboli.

It remains unclear from the study by Petrossian and coworkers whether the reduction in myocardial ischemia afforded by the conduit technique does truly reduce the need for fenestration. A recent review of 55 consecutive patients having Fontan procedures between October 1997 and September 1998 at Children's Hospital, Boston (unpublished data), revealed a median duration of hospitalization (including the day of surgery) of 9 days versus 13 days in the Petrossian series. Only 5 of 55 patients (9%) in the Boston series had pleural effusions in excess of 2 weeks versus 21% in Petrossian's series. One patient in Petrossian's series died at reoperation for attempted late placement of a fenestration. Previous analyses of the Fontan experi-

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ence in Boston have not identified fenestration placement as being associated with an increased risk of neurologic injury either early or late. Most fenestrations will probably close spontaneously over a year or two if allowed. Alternatively, they can be closed in the catheterization laboratory a year or so after the operation when appropriate hemodynamics are demonstrated by temporary balloon occlusion.

Many questions remain unanswered about both the optimal technique and optimal staging and timing of the Fontan procedure in the palliation of single ventricle.[6] It is important that information now be collected carefully, ideally as a randomized prospective trial, to demonstrate that the advantages of the conduit technique outweigh its many potential disadvantages before the technique is more widely applied.

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