In situ pericardial extracardiac lateral tunnel Fontan operation: Fifteen-year experience

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Background: The study purpose is to evaluate the long-term outcome of the in situ pericardial extracardiac lateral tunnel Fontan operation.

Methods: From June 1994 to August 2009, 160 patients with single ventricle (boys, n = 96, 60%, median age = 39 months, mean weight 15.5 kg) underwent the pedicled pericardial extracardiac lateral tunnel operation. Patients' charts were reviewed for perioperative and long-term follow-up data, outcome, and mortality. The potential growth of these tunnels was evaluated.

Results: The main diagnoses included tricuspid atresia (n = 44, 27%); double-outlet right ventricle (n = 29, 18%), and hypoplastic left heart syndrome (n = 26, 16%). The mean follow-up was 6.5 ± 3.7 years (range: 0.1–15 years). There were 2 (1.3%) operative and 6 (3.7%) late deaths. Actuarial survival at 14 years was 93%. Early complications included prolonged effusions (n = 35, 22%), chylothorax (n = 5, 3.1%), readmissions (n = 35, 22%), cerebrovascular accidents (n = 8, 5%), contralateral phrenic nerve palsy (n = 1, 0.8%), and transient arrhythmias (n = 5, 3.1%). No pacemaker was needed. Late complications included tunnel stenosis (n = 3, 1.8%) managed with balloon dilatation and stenting in 2 patients and surgical revision in 1; tunnel thrombosis (n = 2, 1.2%) causing death in both patients; and protein losing-enteropathy (n = 4, 2.5%). Follow-up echocardiography of 10 patients showed laminar flow, no turbulence/gradient at the inferior vena cava and mid-tunnel levels. The diameter indexed to body surface area showed growth, reduction, or no change depending on flow demands.

Conclusions: The construction of the extracardiac lateral tunnel Fontan conduit using viable pedicled pericardium is a relatively simple, durable, and safe operation. Long-term follow-up confirms low morbidity and mortality. Fenestration is unnecessary in most patients. This viable tunnel adapts to physiologic flow demands. (J Thorac Cardiovasc Surg 2010;140:1076-83)

Since the introduction of the Fontan operation in 1971, dramatic improvements in the management of children with single ventricle physiology have occurred.¹ The separation of the systemic and pulmonary circulations brought oxygen saturation and the volume work of the systemic ventricle to near normal in those patients. The long-term outcomes of this initial palliative operation were not ideal. Accordingly, several modifications to the original atriopulmonary connection were introduced in an attempt to decrease postoperative morbidity.²⁻⁴

The "cavopulmonary anastomosis," also known as the intracardiac or "intra-atrial lateral tunnel" Fontan opera-

tion, was introduced by de Leval and colleagues.⁵ This modification provided more efficient and laminar flow, but it also required cardiac arrest, intracardiac manipulation, and atrial incisions. In 1988, extracardiac prosthetic conduits were introduced in an attempt to decrease the incidence of late atrial arrhythmias.^{6,7} The construction of the cavopulmonary conduit extracardially has decreased the cardiopulmonary bypass time, minimized myocardial ischemia, and resulted in better preservation of ventricular and pulmonary vascular function, lower Fontan circuit pressure, lower postoperative morbidity, and lower incidence of atrial arrhythmias.⁸⁻¹⁰ The disadvantages of these prosthetic conduits revolve largely around the potential for thromboembolism, associated infection, lack of growth potential in length and width, and a fixed (or even decreased) luminal conduit diameter over time.^{11,12}

Our initial report¹³ in 1997 reintroduced the use of a pedicled pericardial tube first reported by Hvass and colleagues¹⁴ in 1992. This technique constructs an extracardiac lateral tunnel (ECLT) and completes the cavopulmonary connection. This report provides the long-term outcomes of the in situ ECLT for the Fontan operation.

Although both intracardiac lateral tunnel conduits and ECLT conduits are widely accepted as standard "Fontan"

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Disclosures: None.

Read at the 90th Annual Meeting of The American Association for Thoracic Surgery, Toronto, Ontario, Canada, May 1–5, 2010.

Received for publication April 29, 2010; revisions received July 10, 2010; accepted for publication July 30, 2010.

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0022-5223/\$36.00

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doi:10.1016/j.jtcvs.2010.07.068

Abbreviations and Acronyms

ECLT = extracardiac lateral tunnel
IVC = inferior vena cava

operations, the pedicled pericardial ECLT Fontan operation may offer a better late outcome, cost benefit, and potential for growth. The objective of our study was to assess perioperative and late results using this technique.

PATIENTS AND METHODS

Study Population

Between June 1994 and August 2009 the medical records of all patients undergoing a Fontan operation at Loma Linda University Children Hospital were reviewed. Starting in 2000, all data were collected prospectively, creating a database for all these patients. Only patients who had ECLT were reviewed for this study. The Institutional Review Board of the Loma Linda University approved the study. Of 183 patients who underwent total cavopulmonary connection, 160 children underwent the completion Fontan operation, using the autologous in situ pedicled pericardial ECLT. There were 96 (60%) boys and 64 (40%) girls. The median age at operation was 39 months (range, 1.5–15 years) with 72 (45%) patients younger than 24 months. The median patient weight was 15.5 kg (range, 5–70 kg). The median pulmonary artery pressure was 12 mm Hg (range, 5–19). The mean pulmonary resistance was 1.76 ± 0.75 Wood units. The median preoperative oxygen saturation was 84% (range, 60%–89%). Twenty-three patients who had other conduits used were excluded from the study. In these patients other conduits were used if the pericardium was not adequate to construct the tunnel, if the pericardium was stuck to the lung, or if hepatic veins were not confluent and were too far apart. The primary anatomic diagnoses are shown in Table 1. Twenty (13%) patients had heterotaxy and 18 (11%) had dextrocardia or mesocardia with midline inferior vena cava (IVC). All patients underwent prior procedures, which include bidirectional Glenn anastomosis (n = 157, 98.1%), Kawashima operation (n = 3, 1.9%) systemic–pulmonary artery shunt (n = 78, 48.8%), Norwood operation (n = 38, 23.8%), pulmonary artery band (n = 26, 16%), open atrial septectomy with Fontan operation (n = 9, 5.6%) and Damus–Kay–Stansel procedure (n = 9, 5.6%).

Aortic crossclamping was used in 29 (18%) patients only to complete additional procedures. These include atrial septectomy, pulmonary angioplasty, and valve repair.

Early or perioperative complications/mortality were defined as those occurring within 30 days of the operation. This included readmission, reoperation for bleeding, prolonged intubation (>48 hours), the need for reoperation or reintervention, or prolonged chest tube drainage (>14 days).

TABLE 1. Anatomic primary diagnoses

Diagnosis	n (%)
Tricuspid atresia	44 (27)
Double-outlet right ventricle	29 (18)
HLHS	26 (16)
Double-inlet left ventricle	20 (13)
Pulmonary atresia/IVS	16 (10)
Unbalanced AVC	14 (9)
Other CHD	11 (7)

HLHS, Hypoplastic left heart syndrome; IVS, intact ventricular septum; AVC, atrio-ventricular canal; CHD, congenital heart disease.

Operative Technique

Preparations for this operation begin with the initial 1 or 2 operations in this multistaged procedure by preserving and minimizing unnecessary dissection of the right pericardium. All operations were performed through redo median sternotomy, using cardiopulmonary bypass and deep hypothermia that allows low flow and better exposure. The surgical technique was similar to that described in our initial report.¹³ The technique is depicted in Figure 1, A to C. We no longer suture between the pulmonary veins to obliterate severe “valleys.” This posterior floor obliterates spontaneously and becomes smooth with time. In 10 (6.3%) patients the superior part of the pericardium was deficient. To avoid a narrow conduit, we used a small piece of contralateral pericardium (n = 6, 3.8%) or supple bovine pericardium (n = 4, 2.5%) to make up for the deficiency. Fenestration was selectively performed (n = 4, 2.5%) when the conduit pressure was elevated (>18 mm Hg) or when preoperative hemodynamics were suboptimal.

All patients were weaned from cardiopulmonary bypass on low-dose nitroglycerin ($0.25\text{--}0.5 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) with or without dopamine ($3\text{--}5 \mu\text{g} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$). Postoperative management goals were early extubation, placement on a regimen of angiotensin-converting enzyme inhibitors, diuretics, and aspirin, and chest tube retention until drainage was less than 100 mL per day. All patients were discharged home receiving aspirin at 10 mg/kg or 81 mg daily for bigger children.

To assess the tunnel growth in 10 patients who had complete echocardiography data, we evaluated the tunnel diameter proximally at the IVC–atrium junction and in the mid zone of the tunnel to assess adaptation of these tunnels to the physiologic flow demands. These measurements were indexed to the body surface area at the time of the measurement.

Data Analysis

Data were collected initially by retrospective review of the patient’s hospital records and later (after 2000) prospectively. Data were expressed as mean $\pm$ standard deviation and median (range) for continuous variables. The primary outcome variable in this study was survival with an intact Fontan circulation. Failure was defined as death or takedown of the Fontan connection or as early failure if death or takedown occurred within 30 days from surgery. Secondary end points were arrhythmias or delayed Fontan tunnel complications requiring in interventional procedures. Survival data and probability of freedom from time-related events were analyzed by the method of Kaplan and Meier.

RESULTS

Postoperative Complications

No inotropic support was used in 73 (46%) patients. Postoperative mean oxygen saturation was $93\% \pm 4.8\%$ (range, 70%–98%). Postoperative mean central venous pressure was 14 mm Hg (range, 11–20 mm Hg).

Among those 160 patients, 107 (67%) were extubated in the operating room, 16 (10%) within 6 hours of surgery, and 25 (16%) were extubated within the first 24 hours. Only 12 (7.5%) patients required more than 24 hours of intubation. Before 2002, 21 of 48 (44%) patients were extubated in the operating room compared with 86 of 112 (77%) patients after 2002.

The mean hospital stay was 4.2 ± 0.6 days (range, 1–66 days). The mean follow-up was 6.5 ± 5.3 years (range, 0.1–15 years). Five patients were lost to follow-up.

A total of 8 (5%) deaths occurred over 15 years. Two (1.25%) were within 30 days of surgery and 6 (3.8%) were late deaths (Table 2). In the last 9 years there were

FIGURE 1. A to C, Surgical technique. ECLT, Extracardiac lateral tunnel; RA, right atrium.

only 2 (1.25%) deaths. The actuarial survival at 14 years was 93% (Figure 2).

Postoperative bleeding complications occurred in 7 (4.4%) patients. Six required reoperation for bleeding ($n = 6$, 3.8%) and 1 had tamponade. One patient required takedown of the Fontan conduit and conversion to the bidirectional Glenn operation owing to hemodynamic failure. One patient had phrenic nerve injury on the contralateral side of the ECLT Fontan conduit.

Pleural effusion was the main cause of readmissions ($n = 25$) and repeated hospital/clinic visits. Prolonged pleural effusion (>14 days) occurred in 36 (22%) patients and chylothorax in 5 (3.1%). One required thoracic duct ligation and 4 were treated successfully with medical treatment. The initial mean hospital stay of 4.2 days was not affected by the tube drainage inasmuch as parents were trained to record output and report it to the treating surgeon in the clinic.

New transient arrhythmias occurred in 5 (3.1%) patients (3 bradycardias and 2 tachycardias). All were treated medically without the need for a pacemaker. All patients were documented to remain in normal sinus rhythm with an adequate rate at their long-term follow-up.

Stroke or neurologic deficit occurred in 8 (5%) patients. Only 2 late-onset strokes were related to the procedure. One happened 4 weeks after the Fontan operation and the patient had a complete recovery. The second patient was admitted with sepsis that was complicated by left middle cerebral artery infarction, multisystem organ failure, and death.

Tunnel complications occurred in 5 (3.1%) patients. Stenosis owing to technical error occurred in 3 (1.9%) patients. Two required balloon dilatation and stenting and 1 underwent correction with surgical revision. All of them did well without further complications. Thrombosis occurred in 2 (1.25%) patients; both were admitted with sepsis that was complicated by Fontan tunnel thrombosis, multisystem organ failure, and death. After 1997, tunnel stenosis happened in

1 patient only and was treated successfully with balloon dilatation and stenting. Protein-losing enteropathy was encountered in 3 (1.9%) patients. All had tunnel complications. Mild compression of the right pulmonary veins was reported in 1 case but did not require any intervention. The majority of the cases were done in the recent era (2002–2009) ($n = 112$, 70%) compared with the early era (1994–2001) ($n = 48$, 30%). The mortality, risk of thromboembolism, and the use of other conduits were 2 (1.2%), 1 (0.6%), and 9 (39%) during the recent era compared with 6 (3.8%), 4 (2.8%), and 14 (61%) during the early era, respectively.

The initial proximal IVC–tunnel junction diameter in the 10 patients measured 18 to 24 mm compared with 19 to 30 mm at the mid-tunnel area. These measurements increased, decreased, or stayed the same at both the IVC and mid-tunnel over 3 years of follow-up (Figure 3). However, when the diameters were indexed to the patient's body surface area, they remained unchanged at both the IVC end and the mid-tunnel area—8 to 13 mm and 12 to 16 mm, respectively. All uncomplicated tunnels showed laminar flow, no turbulence, and no gradient at both ends of the tunnel.

TABLE 2. Mortality cases

Patient	Age/year at ECLT Fontan	Time to death	Cause of death
1	19 mo/1994	22 d	HF, MSOF, tunnel thrombosis
2	4.5 y/1995	3 mo	IC hemorrhage
3	16 mo/1996	45 d	HF, sepsis
4	2 y/1996	3 y	IC hemorrhage, AV malformation
5	17 y/1997	1 y	Tunnel thrombosis, MSOF, sepsis
6	7 y/2000	2 y	HF, AVVR
7	2 y/2005	3 d	Malignant hyperthermia, shock, MSOF
8	2 y/2008	12 mo	HF

ECLT, Extracardiac lateral tunnel; HF, heart failure; MSOF, multisystem organ failure; IC, intracranial; AV, arteriovenous; AVVR, atrioventricular valve regurgitation.

FIGURE 2. Actuarial survivals after ECLT Fontan operation in 160 patients. Data in parentheses indicate numbers of patients at risk. ECLT, Extracardiac lateral tunnel.

This was confirmed by echocardiography and cardiac angiography. None of these tunnels showed calcification on radiologic studies.

DISCUSSION

Since the inception of the Fontan operation in 1971,¹ its results have steadily improved.¹⁵ Improvements in surgical technique in both extracardiac conduit and lateral tunnel Fontan operations, advances in ICU care, patient selection, and understanding of the physiology of the cavopulmonary circulation in patients with single ventricle physiology have resulted in decreased pleural effusions, shorter hospital stays, and decreased morbidity and mortality.¹⁶ Nevertheless, survivors are still having arrhythmias, conduit stenosis, infections, and thromboembolism.¹⁷⁻²³ The modifications to the original atriopulmonary connection procedure resulted in improved outcome.^{5,24,25}

The lateral intracardiac tunnel introduced by de Leval and colleagues⁵ and its successful clinical application by the Boston Children's Group¹⁵ resulted in widespread acceptance of the technique. However, several drawbacks remain, such as the need for cardiac arrest, atrial suture lines, and hemodynamic and thromboembolic issues related to the intraatrial baffle. The ECLT technique was introduced in search of a simpler operation with better hemodynamics.⁶⁻⁸ Although the initial operation was described using cardioplegia, cooling, and circulatory arrest,⁶ the operation has been simplified and is presently performed by many with a short period of cardiopulmonary bypass and by some without bypass.^{13,26}

The prosthetic material used in the classic ECLT Fontan operation lacks growth potential and decreases in diameter by 18% to 32% within the first 6 months.⁹ Homografts get calcified with time and defeat its hemodynamic purpose. Infection of these prosthetic conduits is rare but is a potential concern.

This procedure is simple and reproducible. Preserving the pericardium and avoiding dissection in the right pericardial area during the preceding staged operations provides adequate pericardium to complete the tunnel in almost all cases. Partial augmentation was used in a few cases using contralateral pericardium or bovine pericardium to successfully complete the tunnel. Adachi and his colleagues²⁷ were able to reconstruct the conduit in only 28 of 202 patients owing to lack of pericardium. This is because they used a slightly different approach of a complete pericardial roll that would require more pericardium than a flap, as in this technique. This technique was feasible to use in patients with dextrocardia or mesocardia with midline IVC. This technique is versatile and can be adopted in most cases regardless of the anatomic substrate.

Lemler and colleagues²⁸ showed significant reduction in chest tube drainage with fenestrations. Fenestration, on the other hand, is associated with potential complications including thromboembolic phenomena with neurologic sequelae.^{29,30} We rarely attempt fenestration and believe that fenestration defeats the purpose of this operation of maintaining near normal saturation. The ECLT, as seen in other series, improves hemodynamics, hence making fenestration unnecessary.^{31,32}

The pericardium has been routinely used in surgery for congenital cardiac disease as a graft substitute. The free surface of the pericardium is neither immunogenic nor thrombogenic.¹² Owing to lack of thrombogenicity, all patients in this report were maintained on an aspirin regimen without full anticoagulation with minimal risk of thromboembolism. The risks of thromboembolism of 1.25% in this series are comparable with the 2.5% to 25% rates reported after different types of Fontan operations.^{20-22,29} Left-sided emboli (in the absence of fenestration) should be eliminated in extracardiac tunnels inasmuch as no foreign material exists within the heart.

As a vascularized live pedicle, pericardial tissue should theoretically grow with the heart and mediastinal structures as it does normally. In our early report, we¹³ showed that autologous viable pericardium has the potential for growth but long-term follow-up was not available. The intrinsic adjustability of the viable pericardial tunnel, which has the ability to vary its own shape in response to the flow volume passing through it relative to body size, was shown in this study using echocardiography (Figure 3). Similar findings were reported angiographically by Adachi and colleagues.²⁷

Our echocardiographic and angiographic data showed no evidence of narrowing, obstruction, or dilatation during the follow-up period.

Arrhythmias and the need for a pacemaker were not a concern in this series after long-term follow-up although the tunnel was sutured to the outside of the right atrium. Although it appears that sinus node dysfunction and arrhythmias are potential risks with this technique, this was not

FIGURE 3. A, Echocardiographic measurement of the mid-tunnel diameter (cm). B, Indexed to body surface area. C, Echocardiographic measurement of the proximal tunnel diameter (cm). D, Indexed to body surface area.

a concern on the long run inasmuch as the pericardial flap to the atrial suture line was performed away from the sinus node.

Although we had no phrenic nerve injury on the side of the Fontan tunnel, it remains a major concern in this approach and carries an increased morbidity after Fontan operation.³³ Close attention to the phrenic nerve and its blood supply while preparing the baffle is important to avoid injury to the nerve.

The theoretical concern of right pulmonary vein compression has not manifested itself clinically in this study. The concern of anterior compression of the right pulmonary veins by the enlarged right atrium seen in the “classic” Fontan procedure was not encountered in this series by either echocardiography or angiography over long-term follow-up.

The overall survival in this series is 93% at 10 and 14 years, comparable with those reported by other techniques (Table 3).

TABLE 3. Ten-year survival after Fontan operation

No. of patients					Years of operation	Survival (%)
Fontan et al ³⁴	1990	334		1975–1988	69%	
Driscoll et al ³⁵	1992	352		1973–1984	70%	
Cetta et al ³⁶	1992	339		1987–1992	81%	
Gentles et al ¹⁵	1997	500		1973–1991	79%	
Stamm et al ³⁷	2001	220		1987–1991	91%	
Weipert et al ²³	2004	162		1978–1995	83%	
Giannico et al ³⁸	2006	221		1988–2003	85%	
Present study	2009	160		1994–2009	93%	

Chowdhury and colleagues³⁹ have shown in their small series that this technique reduces arrhythmias, requires no anticoagulation, and provides the potential for tunnel growth.

The cost of a homograft in the United States is around \$7000 to \$9000. The cost of the polytetrafluoroethylene graft (Gore-Tex graft; W. L. Gore & Associates, Inc, Flagstaff, Ariz) used to reconstruct the ECLT is around \$400 to \$500. The pericardial conduit costs zero dollars. This adds another advantage to this technique during this time when cost is a major concern in health care.

CONCLUSIONS

The construction of the ECLT Fontan conduit using viable pedicled pericardium is a relatively simple, durable, and safe operation. Long-term follow-up confirms low morbidity and mortality. Fenestration is unnecessary in most patients. This viable tunnel adapts to physiologic flow demands.

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Discussion

Dr Erle H. Austin III (Louisville, Ky). I have no disclosures.

I congratulate Dr Hasaniya on an excellent presentation and thank him for providing me with the manuscript and slides to help me prepare these comments. I also thank Dr Bailey and his colleagues for introducing this technique back in the mid-1990s. Although I am aware that Dr Hvass should be credited with the pedicle pericardial tube concept, the Loma Linda group modified the technique to use the atrial epicardium as the medial wall of the extracardiac pathway and began to apply this technique to the vast majority of their Fontan candidates.

Back in 1995, when the extracardiac conduit idea was beginning to catch on, I began to convert to the polytetrafluoroethylene tube technique. My enthusiasm for that approach, however, significantly waned when I almost lost a patient on the second postoperative day when the polytetrafluoroethylene conduit acutely thrombosed. After that unsettling experience, I was seriously considering reverting to the lateral tunnel when I heard Dr Steve Gundry, who was Len Bailey's associate at the time, describe this idea of using the patient's own viable vascularized in situ pericardium to construct the Fontan pathway. As this seemed to me at the time to be much less likely to pose a thrombosis risk, I soon tried the approach myself, and it has been the technique I have used most commonly ever since. My experience is somewhat more modest in terms of numbers and length of follow-up, having reported our 7-year experience back in 2004, but it has essentially matched the excellent results that you have presented today. I am especially pleased to see that your 10-year overall survival is as good as any other reported series of Fontan operations. However, as suggested in Sunday morning's congenital symposium, we may need at least

another 15 years of follow-up to determine whether any one of the currently applied Fontan techniques proves to be the superior one.

Like you, with the extracardiac pedicle pericardial approach, I have rarely found it necessary to perform fenestration in these patients. I have learned that in some cases it is necessary to augment the pericardial flap with some bovine pericardium to avoid any narrowing of the pathway, especially over the pulmonary veins. Unlike you, however, I have not felt the need to cool substantially on bypass and have thus usually been able to complete the construction of the pathway in less than an hour of bypass time. The excellent early postoperative course in your patients, however, suggests that extra time on bypass had minimal if any adverse effect.

Despite what we consider to be enviable results, you did have a few problems, specifically with the created extracardiac tunnel. You indicated in the presentation and in the manuscript that 3 patients had pathway stenosis that was attributed to technical error. I do think that this technique is slightly more technically demanding than simply sewing in 2 ends of a tube graft and that may explain why relatively few surgeons have tried this technique.

My first question, therefore, is this: Can you describe the technical errors that were encountered and what technical pitfalls your mentors may have taught you to avoid when you perform this novel technique?

Dr Hasaniya. Thank you, Dr Austin, for taking the time to review our manuscript and thank you for your questions.

Of course, I joined the team at Loma Linda approximately 5 years ago, and so I avoided these pitfalls. There are a few important points: We are operating close to the phrenic nerve, but it really is not necessary to dissect close to the phrenic nerve, except sometimes inferiorly, and that must be done carefully to release the pericardium. As I showed, we did not have any nerve injury on the side of Fontan.

The other important point is not to make the tunnel really big. If you need to trim the pericardium, you need to do so to make the tunnel diameter equal or slightly bigger than the diameter of the IVC.

Most of these technical errors happened in our early experience; they happened mainly in the IVC junction. However, we have not experienced any of these in the last probably 7 to 9 years. This could be attributed to Dr Bailey's modification of suturing the pericardial flap to the diaphragm (not to the IVC edge) to avoid stenosis at that anastomosis.

Dr Austin. In my own learning experience, the IVC area was the area that was of greatest concern. I did find that if you are not careful, you can create a twist in the pathway when you place the clamp to oversee the atrial side of the IVC–atrial junction. If you do not place the clamp in a straight anteroposterior orientation, you can get a twist and narrowing at that particular point.

Dr Hasaniya. That is probably the advantage of hypothermia because that allows us not to use any clamps on the IVC; we just use a flexible sucker in the IVC and everything is wide open. We usually match the medial part with a stay suture before we complete the anterior anastomosis.

Dr Austin. My second question relates to fenestration. I know that it was rarely performed in your experience, but you do need to be prepared to perform it. If you find yourself in that situation, how exactly would you perform it?

Dr Hasaniya. Intraoperatively, you can use a punch before closing the tunnel into the side of the right atrial wall to create

the fenestration. The advantage of this technique is you can do it after surgery as well. This technique allows you to take the patient to the cardiac catheterization laboratory and pass a guidewire puncture through the right atrium and then create the fenestration.

Dr Austin. Did you ever do that?

Dr Hasaniya. Yes, we have done it in 1 patient.

Dr Austin. Just to add to your response, we had a patient in whom protein-losing enteropathy developed within a year of this operation. Echocardiography and catheterization showed a very competent pathway, and so there was not a problem with the tunnel. However, we were able to perforate the atrial wall in the catheterization laboratory, creating a fenestration and actually improving the protein-losing enteropathy, so that is an advantage to this technique of extracardiac Fontan.

Finally, what are your current preferred age and weight criteria for performing this operation? Since you have confirmed in at least 10 patients that the in situ pedicle extracardiac conduit grows with the patient, do you think that it is necessary to wait for the patient to reach a certain size before proceeding to the Fontan operation as some surgeons do when placing a conduit that does not have growth potential?

Dr Hasaniya. That is an excellent question. As you mentioned, the growth potential has been documented also by other reports in the literature. Because of that, in the past 7 or 8 years, we have performed the Fontan operation around 2 years of age in most of our patients, unless there is some other contraindication. If we do an age analysis, the majority of the patients at present undergo the Fontan operation around 2 years of age.

Dr Austin. Is there something special about 2 years, or is that just because everybody else does it that way?

Dr Hasaniya. That is what we do. We do have a small subgroup of children under age 2 (18–22 months) who had completion Fontan with good outcomes. This technique allows for completion Fontan at a younger age. In fact, a smaller sized child may be advantageous and easier to treat with shorter cardiopulmonary bypass time, less time to cool, and shorter time to rewarm. Yes, this is a definite advantage of the technique.

Dr Austin. Again, my congratulations to you and your coauthors for developing and sticking with this innovative approach to the Fontan operation.

Dr James S. Tweddell (*Milwaukee, Wis*). You said in your conclusion that this technique adapts to flow dynamics. Can you expand on that a little bit? What did you mean precisely by that?

Dr Hasaniya. If you look at the diameter of the tunnel at the IVC junction and the mid tunnel, when we measured that over 3 years, in some of these patients the diameter increased, some of them stayed the same, and some of them became smaller. As you know, when you create the tunnel it is done by eyeballing, so the tunnel does either increase, decrease, or not change, depending on the flow demands. This is why when we index that to the body surface area, we get a flat line.

Dr Tweddell. I see. And your hospital length of stay was laudably short, 4.2 days. That is really fantastic, but about 20% of the patients were readmitted. Did you look at that group of patients to determine why they were readmitted?

Dr Hasaniya. We are in the process of studying these patients. I know that in a few reported series, the hospital stay is usually around 10 days or more. What we have been adopting in recent

years is to send these patients home with a Blake drain on the right side, and we teach the parents to record the output daily. We observe them as outpatients until the drainage is low, and then we take drain out as outpatients.

Dr Tweddell. What percentage of patients were sent home with a drain in?

Dr Hasaniya. Nowadays, close to 100% are sent home with a Blake drain in place.

Dr Ayman Abdul-Ghani (*Anniston, Ala*). Congratulations on your study. Why did you study only 10 patients for the growth pattern?

Dr Hasaniya. The reasons were lack of time and lack of money. We did not have money to pay the technician to really analyze more than 10 patients. These patients had several echocardiograms done. We selected whatever could be done by the technician and we did the analysis on these 10 patients.