Extracardiac Conduit Total Cavopulmonary Anastomosis

V. Mohan Reddy, Doff B. McElhinney, and Frank L. Hanley

Since the introduction of a physiologically corrective procedure for patients with tricuspid atresia,[1] the concept of total right-heart bypass has been applied to a wide range of complex congenital heart defects. Over the years, a number of modifications of the original Fontan operation have been proposed in an effort to improve outcomes.[2-6] Although an extracardiac variation of the Fontan concept was originally described by Humes et al and Nawa et al in 1988,[7,8] its routine application for all forms of single ventricle hearts was first adopted by Marcelletti et al.[9] For the past 5 years, we have used extracardiac conduit total cavopulmonary anastomosis as definitive palliation for almost all patients with functional single ventricle physiology.

Advantages of the Extracardiac Conduit Fontan Procedure

The extracardiac conduit Fontan operation has several theoretical and practical advantages that may lead to improved postoperative recovery and long-term outcomes: (1) it optimizes laminar flow patterns within the cavopulmonary connections and thereby minimizes energy dissipation; (2) it avoids extensive suture lines in the right atrium, thereby decreasing the substrate for postoperative atrial tachyarrhythmias; (3) it avoids cardioplegic arrest in many cases, thereby reducing the potential for postoperative ventricular dysfunction; (4) it prevents right atrial exposure to the elevated pressures of the systemic venous circuit, thereby decreasing the propensity for atrial dilatation and secondary supraventricular tachyarrhythmias, thrombus formation, and right pulmonary venous obstruction; (5) it avoids the sinus node area and decreases the risk of postoperative sinus node dysfunction; and (6) it preserves the option for creating a fenestration without returning to cardiopulmonary bypass in the event that an elevated transpulmonary gradient exists following repair.

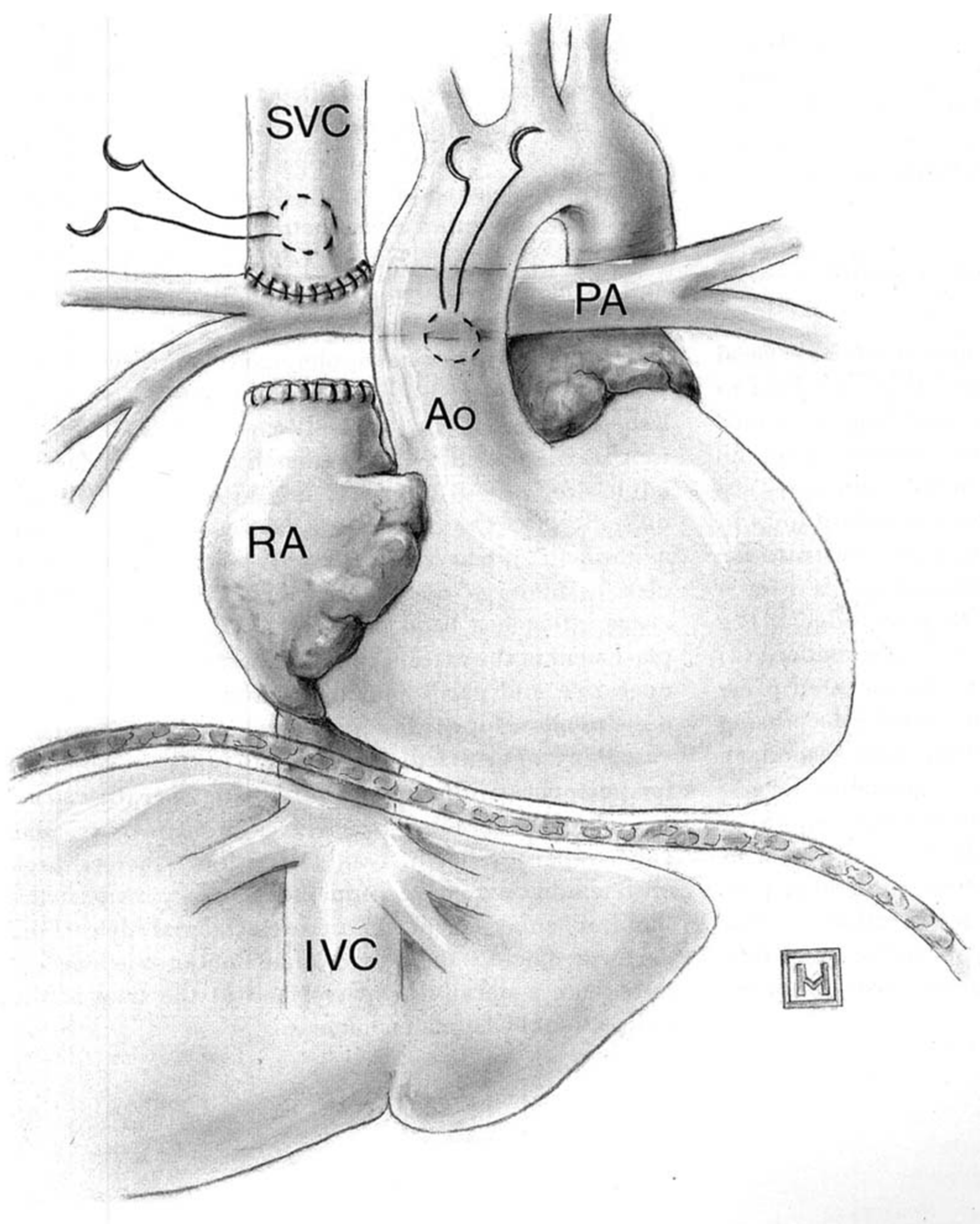
Surgical Strategy

An integral component of the extracardiac conduit Fontan circulation is a bidirectional superior cavopulmonary shunt. We prefer to perform this procedure before completion of the extracardiac conduit Fontan as either a primary palliative procedure between 2 and 4 months of age[10] or between 3 and 6 months of age following neonatal palliation with a systemic to pulmonary artery shunt or pulmonary artery banding.[11] In toddlers and older children who have been palliated earlier in life, we create a bidirectional cavopulmonary shunt before completion of the extracardiac Fontan in the majority of cases, although on occasion we will perform the cavopulmonary shunt during the same operation as Fontan construction. Of 60 extracardiac conduit Fontan procedures performed between 1991 and 1996, only 6 patients had not undergone a previous bidirectional cavopulmonary shunt.

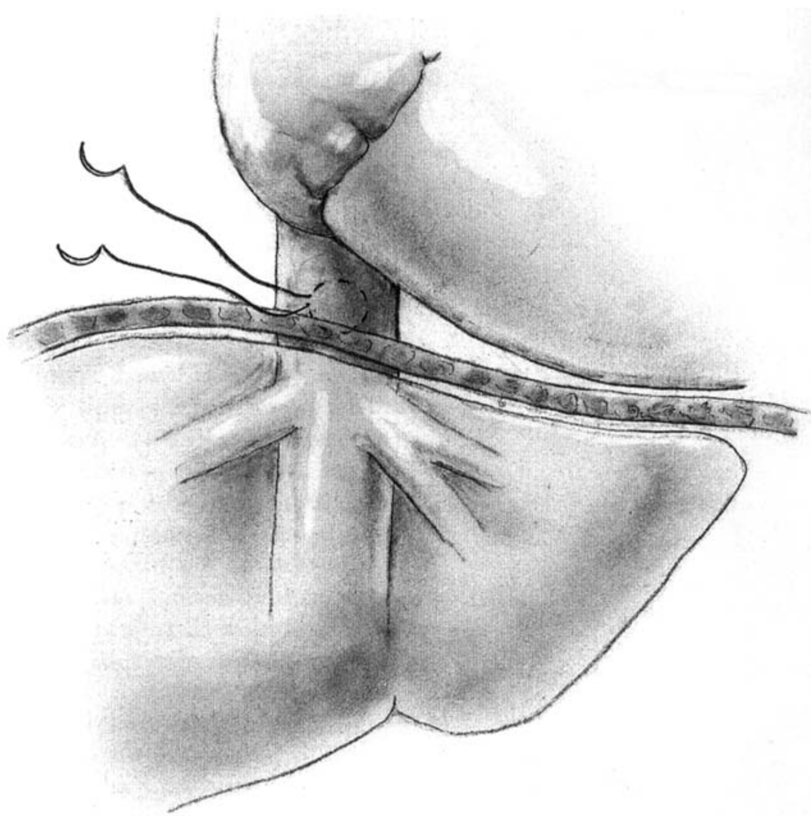
After the superior cavopulmonary shunt, the patient is followed closely until he or she reaches a minimum weight of 15 kg (usually about 3 years of age). At this weight, the patient is large enough to accommodate an adult size conduit (20 to 22 mm in diameter) without difficulty, thereby eliminating the need for reoperation as the patient grows. By the time the patient is scheduled to undergo the extracardiac Fontan operation, every effort has been made to limit the operation to placement of the extracardiac conduit alone to minimize operative and cardiopulmonary bypass time. This is done to allow for maximum preservation of pulmonary vascular and ventricular function to lower the potential for postoperative Fontan failure. This operative strategy requires that other procedures (ie, atrioventricular valve repair, relief of residual outflow tract or arch obstruction, extensive pulmonary artery reconstruction, or enlargement of an atrial septal defect) be performed before the extracardiac Fontan. Such procedures can generally be performed at the time of the bidirectional Glenn anastomosis.

SURGICAL TECHNIQUE

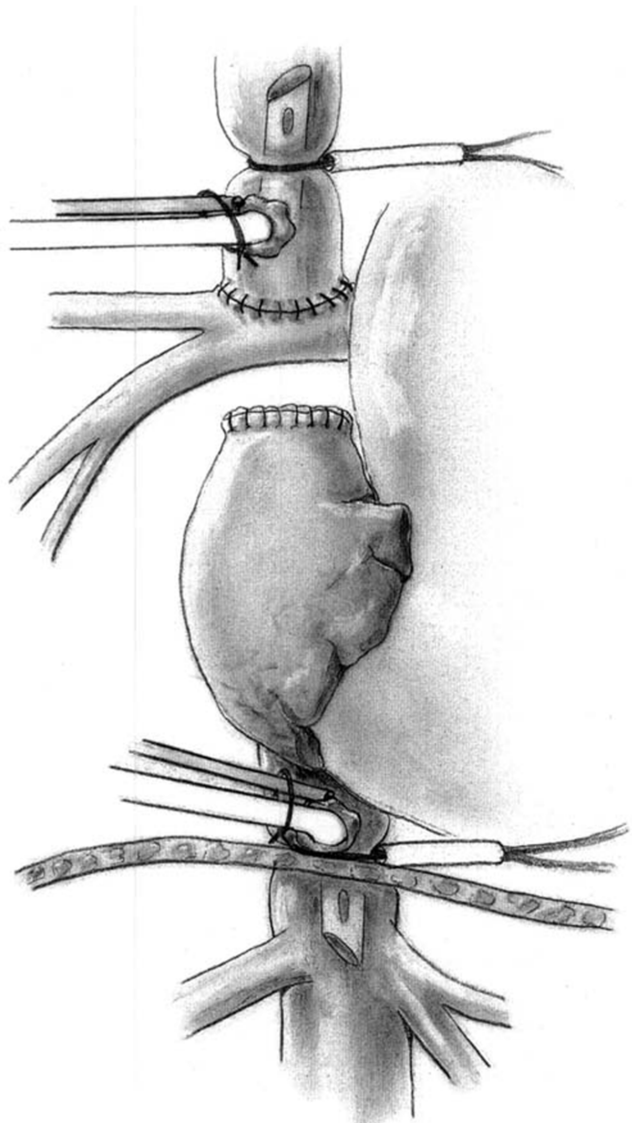
Because we typically complete the extracardiac Fontan after previous construction of a bidirectional superior cavopulmonary shunt, the technique described here will assume an existing cavopulmonary shunt. When the bidirectional superior cavopulmonary shunt is constructed at the time of Fontan, standard techniques of cavopulmonary anastomosis are used,[12] with the superior cavopulmonary shunt procedure performed before placing the inferior vena cava to pulmonary artery conduit, as described later. In addition, the technique described here is for an extracardiac conduit Fontan procedure without concomitant intracardiac procedures. When such intracardiac procedures are necessary, they are performed before completion of the Fontan procedure.



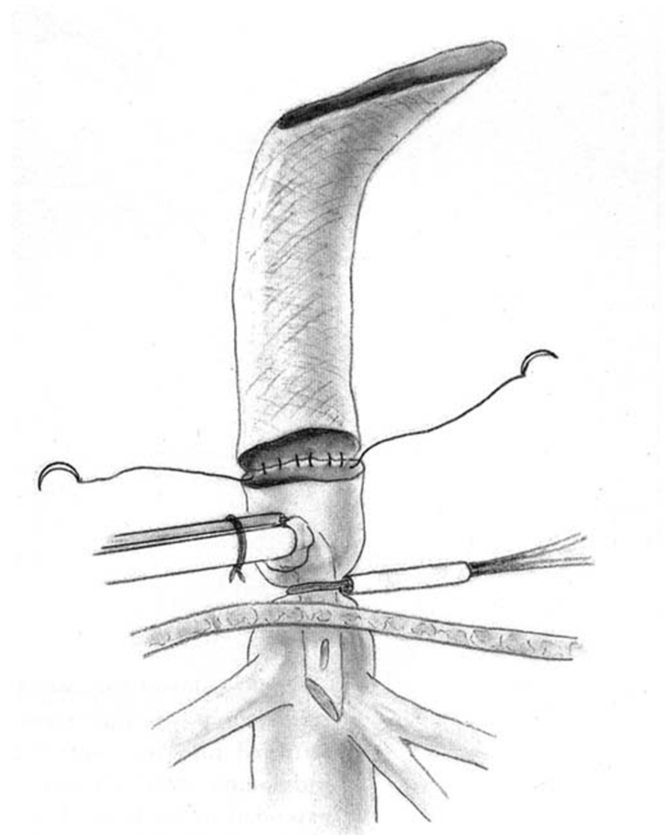
1 Because a Fontan procedure is frequently performed in a patient who has undergone at least one median sternotomy, the surgeon can expect to encounter the mediastinal adhesions typically found at resternotomy situation. Following median sternotomy and exposure of the heart, the aorta, superior vena cava (SVC) pulmonary arteries, and inferior vena cava (IVC) are carefully mobilized with electrocautery dissection. The pulmonary arteries are mobilized distally to the level of the hilum on the right side and beneath the aorta on the left. The SVC is mobilized to a level 5 to 6 cm above the cavopulmonary anastomosis, and a purse-string suture is placed 3 to 4 cm above the anastomosis at the level of the innominate vein. The ascending aorta is freed sufficiently to allow for control and cannulation, and a purse-string suture is placed anteriorly just below the origin of the innominate artery.



2 The IVC is mobilized to the level of the diaphragm, which normally requires taking down the inferior caval reflection of the pericardium. With this step, the entire suprahepatic IVC is exposed. A purse-string suture is placed in the IVC at the diaphragmatic reflection.

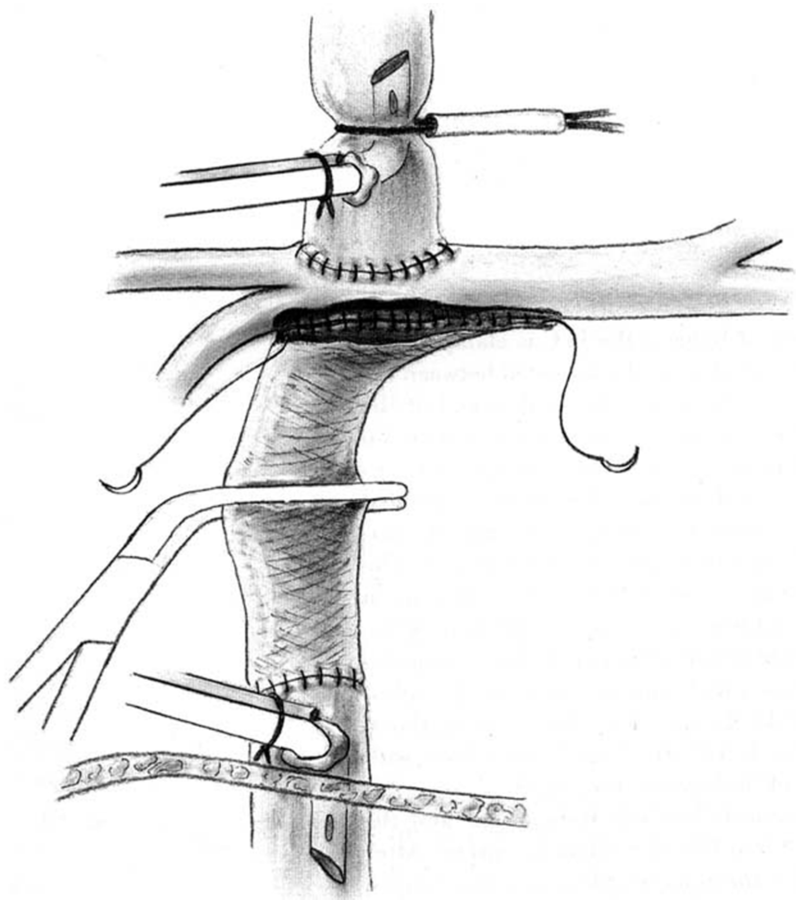


3 Following systemic heparinization, the ascending aorta, SVC and IVC are then cannulated through the previously placed purse-string sutures. Initially, the SVC is not snared or incorporated into the bypass circuit and superior caval return is allowed to perfuse the lungs through the cavopulmonary shunt. The cardiopulmonary bypass is commenced with inferior caval cannulation alone, using calcium supplemented blood prime in the bypass circuit, which allows the heart to remain beating and ejecting return coming through the superior cavopulmonary anastomosis. No active cooling is performed, and core temperatures are allowed to drift to around 33° to 35°C.



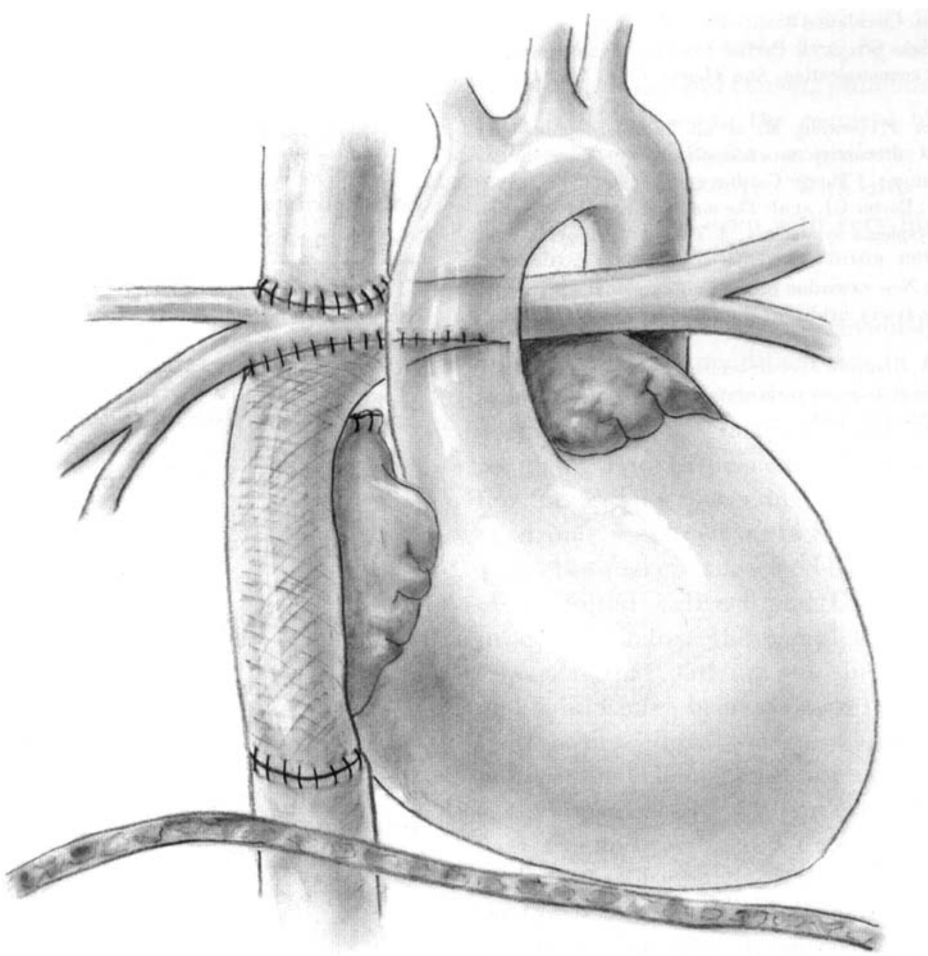
4 After the institution of bypass, the IVC is clamped just inferior to the cavoatrial junction and transected between the clamp and the snared IVC cannula. The cardiac end of the transected IVC is doubly oversewn with running 4-0 or 5-0 nonabsorbable monofilament suture. The extracardiac conduit of either cryopreserved aortic allograft or expanded polytetrafluoroethylene (Gore-tex; W.L. Gore and Associates, Milpitas, CA) vascular tube graft is then tailored. The size of the conduit usually ranges from 20 to 25 mm in diameter. In younger children, we delay completion of the extracardiac conduit Fontan until the patient has reached a weight of at least 15 kg, at which time an adult-sized conduit (20 to 22 mm) can usually be inserted. The cross-sectional diameter of the conduit is usually slightly oversized with respect to the diameter of the inferior vena cava.

An end-to-end anastomosis between the conduit and the IVC is performed with 4-0 or 5-0 monofilament suture. After completion of the inferior anastomosis, the conduit is clamped at midlevel and the IVC cannula snare is released, allowing the inferior half of the conduit to fill with blood. Any anastomotic suture line bleeding can be repaired at this time. Cardiopulmonary bypass is continued with the cannula unsnared to allow for more accurate approximation of conduit position in the mediastinum. The length of the conduit is then tailored to the undersurface of the right pulmonary artery. The superior orifice of the conduit is bevelled at an angle less than or equal to 45° relative to the long axis of the conduit. This allows for an oblique conduit to pulmonary artery anastomosis with a substantially greater anastomotic surface area rather than with direct end to side connection. In addition, this allows for greater offsetting of the superior and inferior cavopulmonary connections, which has been shown by computational fluid dynamics to minimize energy losses at the cavopulmonary junction.[13,14] Furthermore, this oblique anastomosis effectively serves as a central pulmonary arterioplasty, and the angle of the bevel can be adjusted to maximize this effect. At this point, the SVC is cannulated and snared and full cardiopulmonary bypass is instituted.



5 The inferior surface of the right pulmonary artery is incised from a point opposite the origin of the right upper lobe pulmonary artery leftward into the central left pulmonary artery. If more distal left pulmonary artery stenosis or hypoplasia is present, the incision can be extended to the level of the left lung hilum. The anastomosis between the bevelled conduit and the pulmonary arteriotomy is then performed using running 5-0 nonabsorbable monofilament suture. If more distal branch pulmonary artery stenosis is present, we prefer to repair it with allograft patch augmentation at this point in the procedure, although augmentation arterioplasty may also be performed before completion of the conduit to pulmonary artery anastomosis. After anastomosis is completed, the clamp on the conduit and the snare on the SVC cannula are released and any points of anastomotic bleeding are addressed.

In select patients, we have performed the inferior cavopulmonary anastomosis on partial cardiopulmonary bypass, without superior caval cannulation. With this technique, a large side-biting vascular clamp is placed on the undersurface of the right pulmonary artery, allowing flow from the superior cavopulmonary anastomosis to continue unimpeded into the left pulmonary artery. This approach requires adequately large pulmonary arteries that the clamp can be placed without occluding the SVC. In addition, superior caval cannulation is required if central or left pulmonary artery augmentation is required.



6 Cardiac function is assessed by means of transesophageal echocardiography and directly-placed pulmonary arterial and left atrial pressure catheters. The patient is weaned from bypass with or without inotropic support, with decannulation of the IVC first, followed by the SVC, and finally of the aorta. The completed extracardiac conduit Fontan is as shown. If Fontan pressures are ≥18 mm Hg or the transpulmonary gradient is ≥10 mm Hg, we generally place a fenestration by performing a 4 to 5 mm side-to-side anastomosis between the conduit and the right atrial free wall. Another option for fenestration is to place a synthetic tube graft (6 to 8 mm) from the conduit to the free wall. Following completion of the procedure, hemostasis is achieved and temporary atrial and ventricular pacing leads are placed in patients without a previous permanent pacemaker. Mediastinal and pleural (if the pleura are opened) chest drains are placed.

REFERENCES

1. Fontan F, Baudet E: Surgical repair of tricuspid atresia. Thorax 26:240-246, 1971
2. Kreutzer G, Galindez E, Bono H, et al: An operation for the correction of tricuspid atresia. J Thorac Cardiovasc Surg 66:613, 1973
3. Fontan F, Kirklin JW, Fernandez G, et al: Outcome after a "perfect" Fontan operation. Circulation 81:1520-1536, 1990
4. Driscoll DJ, Offord KP, Feldt RH, et al: Five- to fifteen-year follow-up after Fontan operation. Circulation 85:469-496, 1992
5. Laks H, Pearl JM, Haas GS, et al: Partial Fontan: Advantages of an adjustable interatrial communication. Ann Thorac Surg 52:1084-1095, 1991
6. de Leval MR, Kilner P, Gewillig M, et al: Total cavopulmonary connection: A logical alternative to atriopulmonary connection for complex Fontan operations. J Thorac Cardiovasc Surg 96:682-695, 1988
7. Humes RA, Feldt RH, Porter CJ, et al: The modified Fontan operation for asplenia and polysplenia syndromes. J Thorac Cardiovasc Surg 96:212-218, 1988
8. Nawa S, Teramoto S: New extension of the Fontan principle: Inferior vena cava-pulmonary artery bridge operation. Thorax 43:1022-1023, 1988
9. Marcelletti C, Corno A, Giannico S, et al: Inferior vena cava-pulmonary artery extracardiac conduit: A new form of right heart bypass. J Thorac Cardiovasc Surg 100:228-232, 1990
10. Reddy VM, Liddicoat JR, Hanley FL: Primary bidirectional superior cavopulmonary shunt in infants between 1 and 4 months of age. Ann Thorac Surg 59:1120-1126, 1995
11. Reddy VM, McElhinney DB, Moore P, et al: Outcomes after bidirectional cavopulmonary shunt in infants less than 6 months old. J Am Coll Cardiol 29:1365-1370, 1997
12. Lamberti JJ, Spicer RL, Waldman JD, et al: The bidirectional cavopulmonary artery shunt. J Thorac Cardiovasc Surg 100:22-30, 1990
13. de Leval MR, Dubini G, Migliavacca et al: Use of computational fluid dynamics in the design of surgical procedures: Application to the study of competitive flows in cavopulmonary connections. J Thorac Cardiovasc Surg 111:502-513, 1996
14. Van Haesdonck JM, Mertens L, Sizaire R, et al: Comparison by computerized numeric modeling of energy losses in different Fontan connections. Circulation 92:322-326, 1995 (suppl II)

From the Division of Cardiothoracic Surgery, University of California, San Francisco, San Francisco, CA.

Address reprint requests to V. Mohan Reddy, MD, 505 Parnassus Avenue, M589, San Francisco, CA 94143-0118.

1085-5637/97/0203-0005$5.00/0