BRIEF COMMUNICATIONS

A NOVEL TECHNIQUE FOR ESTABLISHING TOTAL CAVOPULMONARY CONNECTION: FROM SURGICAL PRECONDITIONING TO INTERVENTIONAL COMPLETION

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Numerous intracardiac anomalies necessitate univentricular repair, the Fontan procedure, or total cavopulmonary connection (TCPC).¹ In high-risk patients (eg, mean preoperative pulmonary artery pressure > 19 mm Hg, pulmonary artery distortion, heterotaxy syndrome, and right-sided tricuspid valve as the only systemic atrioventricular valve), a staged univentricular repair has been developed with the use of the bidirectional Glenn anastomosis or a hemi-Fontan procedure. This staged procedure led to a significant improvement in early and late outcome after completion of the Fontan circulation.² However, notwithstanding the overall decline in the frequency of morbidity and mortality in the past decade caused by the evolution of surgical procedures, high-risk patients must nevertheless be subjected to the additional hazards of a subsequent operation after the Glenn anastomosis or hemi-Fontan procedure to complete the Fontan circulation.

TCPC completion by means of interventional catheter procedures after initial surgical preparation to create an intracardiac fenestrated baffle and a banding of the superior vena cava (SVC) has been reported.^{3,4} However, this surgical procedure subjects the high-risk patient to the additional potential side effects and risks of cardiopulmonary bypass. To obviate a staged surgical procedure and the use of cardiopulmonary bypass and the associated risks, we developed a novel technique by using a combined surgical and interventional completion of a Fontan circulation (Fig 1).

Technique

Surgical preconditioning. The following protocol was reviewed and approved by the Subcommittee on Research Animal Care, Hannover Medical School. All animals received humane care in compliance with the European Convention on Animal Care.

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Received for publication March 9, 2000; accepted for publication March 27, 2000.

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J Thorac Cardiovasc Surg 2000;120:1007-9

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0022-5223/2000 \$12.00 + 0 12/54/107824

doi:10.1067/mtc.2000.107824

Fig 1. Sketch of the combined operative and interventional procedure. A bidirectional Glenn anastomosis is established, and the Aneurx stent is deployed. A small PTFE (*Gore-Tex*) cuff around the IVC is used as resistance to safely anchor the stent.

Ten sheep with a mean weight of 35 ± 6 kg were endotracheally intubated after sedation with pancuronium bromide (0.1 mg/kg administered intravenously) and induction of anesthesia with pentobarbital (30 to 50 mg/kg administered intravenously). The animals' lungs were mechanically ventilated at an inspired oxygen fraction of 0.4, with a frequency of 15 ventilations per minute and a tidal volume of 20 mL/kg. The thorax was opened through a right anterolateral thoracotomy in the fourth intercostal space. The pericardium was opened longitudinally immediately proximal to the pulmonary veins and suspended. The SVC and inferior vena cava

Fig 2. Angiogram (lateral view) after surgical preconditioning (A) and after interventional completion (B) of the Fontan circulation.

(IVC) were then surrounded with a vessel loop. Heparin (100 IU/kg administered intravenously) was administered, and the right hilus was prepared to expose the right pulmonary artery (RPA). The clamping and transection of the RPA at the pulmonary bifurcation was well tolerated by all animals. The proximal end was closed with a running polypropylene suture. The distal end of the RPA was anastomosed end to end to a 10-mm polytetrafluoroethylene* (PTFE) prosthesis. After side clamping, the SVC was incised longitudinally on its lateral aspect and anastomosed to the shortened PTFE prosthesis, thus establishing a unidirectional Glenn circulation. The SVC was banded by means of a Vicryl 2-0 suture just above the cavoatrial junction, leaving a minimal lumen for subsequent balloon dilatation. The Vicryl suture was knotted over a central venous line (2 mm in diameter), which was inserted through the internal jugular vein. After the banding, the central venous line was removed percutaneously. A PTFE tube approximately 1 cm long and 2 cm in diameter was sutured around the IVC to provide resistance for subsequent interventional application of an expanded stent. After completion of the surgical preparation, heparin was neutralized with protamine chloride, and the chest was closed. On the same day, cardiac catheterization was performed in all animals.

Interventional catheter completion. For interventional conversion of the unidirectional Glenn anastomosis to a modified Fontan circulation, venous access was established percutaneously with the use of the right femoral vein and surgically with the use of the right internal jugular vein (IJV). Selective angiography (Berman wedge, 7F, arrow) identified the position of the graft connecting the SVC to the RPA. Hepatic

venous drainage was identified angiographically with the use of a 7F right Judkins catheter (Cordis) introduced from the femoral vein. To obtain a guide wire circuit, a 260-cm, 0.035-in guide wire (Cook) was then introduced from the femoral vein into the SVC and snared (Gooseneck, Microvena) from the IJV. For introduction of the stent graft (Aneurx, Medtronic; diameter, 16 mm; length, 85 mm), a 16F sheath (Cook) was introduced into the IJV and carefully advanced across the guide-wire circuit into the SVC. The Aneurx stent graft was then advanced through the right atrium so that its distal portion was located superior to the hepatic veins and its proximal portion inferior to the shunt connecting the SVC to the RPA. The self-expanding stent graft was then implanted. Angiography demonstrated patent cavopulmonary connection and hepatic venous drainage, as well as connection of the IVC to the SVC.

Results. All 10 animals survived the combined surgical and interventional procedure. The interventional stent could be deployed in each preparation, and the TCPC was sufficient in all animals. No stent displacements, perforations, or episodes of bleeding were observed.

Comment. Since the introduction of the Fontan principle in 1971,⁵ numerous surgical modifications and refinements led to improved outcome after surgery in the management of patients with functional univentricular circulation. In high-risk candidates for a Fontan operation, a staged approach is currently emphasized, requiring at least two operations or cardiopulmonary bypass for surgical preconditioning with consecutive interventional catheter completion of the Fontan circulation.^{3,4}

At Hannover Medical School, we developed a novel staged technique consisting of a combined surgical and interventional approach to complete the TCPC, potentially avoiding cardiopulmonary bypass. During the operation, a bidirection-

*Gore-Tex tube; registered trademark of W. L. Gore & Associates, Inc, Flagstaff, Ariz.

al Glenn circulation is established, and subtotal banding of the SVC at the cavoatrial junction is created, along with PTFE cuff placement around the IVC, all performed in the absence of cardiopulmonary bypass. Because the sheep's anatomic configuration, consisting of an oblique steeply descending pulmonary artery, did not allow direct anastomosis between the pulmonary artery and SVC, it was necessary to lengthen the pulmonary artery with a PTFE prosthesis. In human subjects, however, the Glenn anastomosis can be performed directly without such modification. The Fontan circulation can then be completed by subsequent interventional catheter deployment of an Aneurx stent graft, connecting the SVC and IVC (Fig 2). Before going into clinical trials, the question of scar tissue around the band site and hence potential problems at redilatation must be addressed in a long-term animal model. The PTFE cuff around the IVC is used as resistance to securely anchor the stent. Stents can be custom produced in conformance with an individual patient's anatomy. This intervention potentially avoids the follow-up operation to complete the TCPC. If the stent placement proves inadequate, the surgical option may still be considered to complete the Fontan circulation. Ideally, growth of the heart will not affect the stent fixation and function. However, this issue has not been of concern after either lateral or intracardiac tunnel operations.

In conclusion, we developed a novel staged technique for a combined surgical and interventional approach to complete the TCPC in univentricular cardiac repair. This new technique potentially overcomes two major risk factors for surgical Fontan completion: cardiopulmonary bypass and reoperation.

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