

## Endoscopic Multivessel Coronary Artery Bypass Grafting Using Automated Device for Proximal Anastomosis

(#2003-31802 . . . May 28, 2003)

**Maurice-Andre Recanati, MD**, Jennifer K. White, MD, James Titus,  
Arvind K. Agnihotri, MD, David F. Torchiana, MD

Cardiac Surgical Unit, Department of Surgery, Massachusetts General Hospital, Boston,  
Massachusetts, USA



Dr. Recanati



### ABSTRACT

**Background:** The use of computer-enhanced telemanipulation robots in cardiothoracic surgery can reduce the need for open surgical access and enable closed-chest, endoscopic procedures, but these procedures have been limited to anterior target vessels. The feasibility of fully endoscopic multivessel, coronary artery bypass grafting (CABG) was examined.

**Methods:** Fully endoscopic, multivessel CABG solely through surgical ports was performed on 23 dogs weighing 75 to 85 pounds. A proximal anastomosis was made with the Symmetry bypass system aortic connector. The aorta was cross clamped, and cardioplegia solution was administered through the vein graft into the ascending aorta.

**Results:** Eighteen of 23 procedures yielded successful proximal anastomoses and 1 to 3 distal anastomoses.

**Conclusion:** Endoscopic anastomosis to the ascending aorta is feasible with the Symmetry bypass connector. Antegrade cardioplegia and aortic root venting can then be easily accomplished. This approach simplifies closed chest cardioplegic arrest for multivessel CABG.

### INTRODUCTION

Recent trends in cardiothoracic surgery have been aimed at minimizing incisions and surgical trauma [Talwalkar 1998, Reichenspurner 1999a, Duhaylongsod 2000]. Computer-enhanced telemanipulation robots, such as da Vinci (Intuitive Surgical, Mountainview, CA, USA) and Zeus (Computer Motion, Santa Barbara, CA, USA), have reduced the need for open surgical access and have made closed-chest, endoscopic procedures possible [Reichenspurner 1999b, Boyd 2000, Kappert 2000, Mohr 2001]. These procedures, performed on both beating and arrested hearts, have been limited to anterior target vessels [Dogana 2002].

Received February 7, 2003; received in revised form May 21, 2003; accepted May 28, 2003.

Address correspondence and reprint requests to: David F. Torchiana, MD, Massachusetts General Hospital, Bullfinch 209, 55 Fruit St, Boston MA 02114 (e-mail: Dtorchiana@partners.org).

Arguably, to perform a complete multivessel revascularization procedure through thoracoscopic ports, cardiopulmonary bypass and cardioplegic arrest are necessary adjuncts. Cardioplegia provides the benefits of a bloodless and motionless operating site. Decompressing and venting the heart during cardiopulmonary bypass creates more space in the thoracic cavity and allows access to all coronary vessels without hemodynamic compromise. Practically, cardiopulmonary bypass can be instituted with several approaches, such as the Port-Access system (Heartport, Redwood, CA, USA) [Glower 1999, Groh 1999] or peripheral cannulation and transthoracic cross clamping [Chitwood 1997]. A second prerequisite for multivessel endoscopic coronary artery bypass grafting (CABG) involves the ability to perform a proximal anastomosis to the aorta while operating solely through ports.

We describe a technique for performing fully endoscopic, multivessel CABG using only surgical ports in a canine model. A technique for performing the proximal anastomosis with an anastomotic device and a new method of delivering antegrade cardioplegia are described.

### MATERIAL AND METHODS

Endoscopic multivessel CABG was performed on canines (n = 23) of sizes ranging from 75 to 85 pounds. The study was performed in accordance with the *Guide for the Care and Use of Laboratory Animals* published by the National Institutes of Health (NIH publication 85-23, revised 1985).

#### Preparation for Procedure

The animal was anesthetized with chloralose (100 mg/kg) and urethane (1 g/kg) administered intravenously into a forelimb vein and intubated. After shaving of the chest, inguinal, axillary, and jugular areas, a 7F cannula was inserted through the right brachial artery and fitted to a transducer to record blood pressure and pulse rate. A second 7F cannula was introduced through the right cephalic vein and used to measure central venous pressure. The animal was anticoagulated with a bolus of 6000 units of heparin prior to insertion of the cannulas and maintained on 1000 units hourly.

Cutdown of the femoral veins and the right jugular vein was made, and the vessels were catheterized for cardiopulmonary bypass. Arterial return was via the left femoral artery.

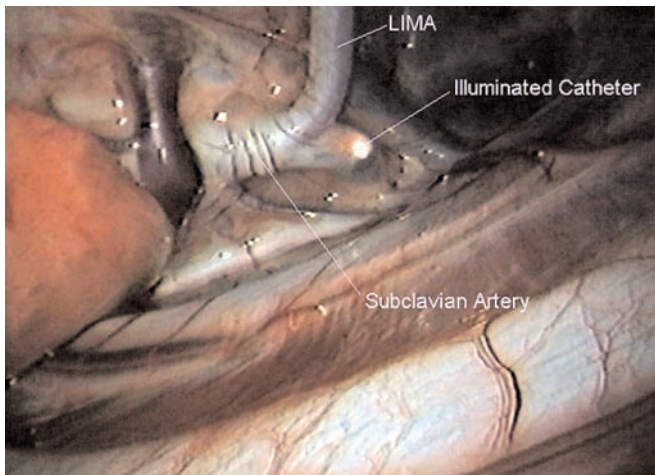


Figure 1. Insertion of angioplasty catheter into the left internal mammary artery (LIMA).

With the animal placed supine, a 12-mm camera port was inserted in the sixth intercostal space 7 cm from the left sternal edge. A 30-degree stereoscopic thoracoscope (Vista Cardiothoracic Systems, Westborough, MA, USA) was inserted, and a 5-mm port was placed in the fifth intercostal space 1 cm posterior to the camera port to accommodate the right robotic manipulator. A similar port for insertion of the left manipulator was placed 1 intercostal space caudad to the camera port.

For proximal control of blood flow through the left internal mammary artery (LIMA), an angioplasty catheter with a 3.25-mm balloon (Cordis, Miami, FL, USA) was inserted through the left brachial artery. This catheter, which was fitted to a fiberoptic light source, was guided into the LIMA by visualization of the transilluminated tip through the thoracoscope (Figure 1).

#### **IMA Takedown**

The canine was tilted 30 degrees toward the right side, and with the IMA balloon deflated, the IMA was mobilized with a harmonic scalpel (UltraCision, Ethicon, Somerville, NJ, USA) controlled through the robotics interface (Zeus; Computer Motion). The distal 2 cm of this dissected pedicle was skeletonized through the robotic interface in preparation for anastomosis. After clipping of the distal IMA through a subxiphoid port, the balloon-tipped angioplasty catheter was inflated, and the artery was divided proximal to the clip.

#### **Preparation for Anastomosis**

After removal of all robotic instruments, the animal was returned to the supine position. The pericardium was opened, and the aortic fat pad was dissected with standard handheld thoracoscopic instruments. With the root of the great vessels exposed, a Silastic tape was passed through the transverse pericardial sinus and looped around the aorta and pulmonary artery. The Silastic tape, which was used to maneuver the heart and aid in placement of the aortic cross clamp, exited the body through the subxiphoid port.

#### **Proximal Anastomosis**

A 10-cm segment of human saphenous vein was prepared by lysis of the valves with a valvulotome and loaded onto an appropriately sized St. Jude connector device. The animal was placed on full bypass. Pump flow was diminished to a low level as the aortic cutter (Symmetry; St. Jude Medical, St. Paul, MN, USA), which was inserted via a 12-mm parasternal port, was used to create an anterior aortotomy. The anastomotic device was placed into the aortotomy, pump flow was resumed, and the device was deployed (Figure 2). A bulldog clamp was placed on the distal end of the vein, which remained externalized through the port. FocalSeal (Focal, Lexington, MA, USA), a synthetic polyethylene glycol-based sealant, was applied to reinforce the anastomosis. It should be noted that to allow the St. Jude cutter to fit through the port and reach the aorta, the handle sometimes had to be modified by replacement with a longer but thinner handle. A small catheter was inserted through the vein graft and guided into the ascending aorta by transillumination with a fiberoptic light guide.

#### **Delivery of Cardioplegia**

After cross clamping of the aorta distal to the vein with a Chitwood clamp (Scanlon, St. Paul, MN, USA), a 500-mL bolus of cardioplegic solution was delivered through the vein graft into the ascending aorta (Figure 3). Cardioplegia was delivered at 4°C and reinfused as a 250-mL bolus every 20 minutes. This method allowed the left ventricle to be easily vented by application of intermittent suction through the catheter, which was previously threaded through the vein into the ascending aorta. Venting via the vein alone was not successful because the vein collapsed under negative pressure.

#### **Distal Anastomosis**

The LIMA to left anterior descending coronary artery (LAD) anastomosis was performed with the heart arrested and vented. The end of the LIMA was spatulated and sewn to the LAD with surgical clips (U-Clip; Coalescent Surgical,

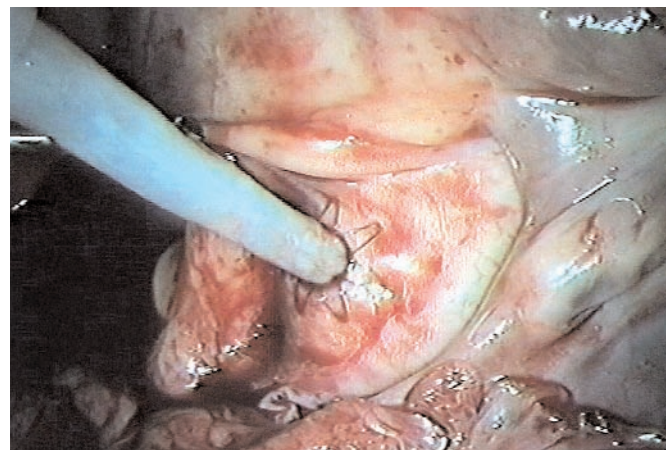


Figure 2. Anastomosis of a saphenous vein graft onto the ascending aorta with the Symmetry bypass system aortic connector (St. Jude Medical).

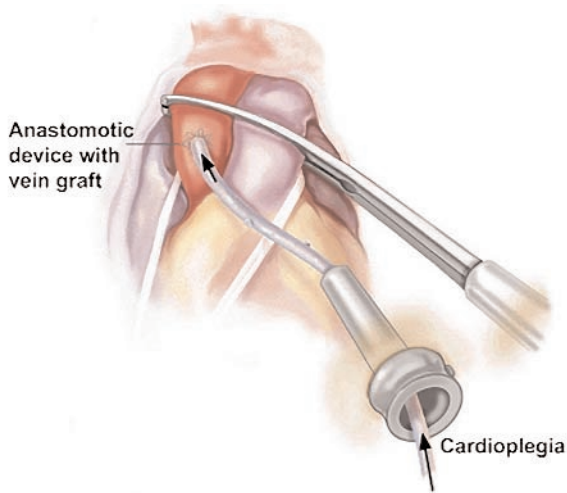


Figure 3. Position of the vent catheter through the vein graft. Silastic tape is used to maneuver the heart and aid in placement of the aortic cross clamp.

Sunnyvale, CA, USA) or running CV8 Gore-Tex suture (W. L. Gore, Flagstaff, AZ, USA) by means of the robotic interface (Figure 4). If the right internal mammary artery was used, this anastomosis was conducted next.

Subsequently the venous graft was anastomosed to the appropriate coronary artery with a similar technique. Before the final distal anastomosis was made, an additional bolus of 250 mL of cardioplegia solution was administered to the heart, and the vent catheter was withdrawn from the vein.

**RESULTS**

Twenty-three procedures with the St. Jude device for proximal anastomosis were undertaken. Eighteen yielded successful proximal anastomoses and 1 to 3 distal anastomoses. Of the 5 failures (21%), 3 occurred during the first 4 cases, and the other 2 were distributed randomly.

Although the canine aorta is not an ideal model because it is short, covered in fat, and thicker than in humans, the reasons for failure were diverse. The need for the cutter to be applied perpendicular to the aorta, so that a circular cross section is made for the anastomosis, prevented successful anastomoses in 2 cases. In 2 other cases, the device did not deploy properly in the aortic lumen. To avoid avulsion of the grafted vessel, which occurred in some cases, it was important to hold the vein near the anastomosis while the device was withdrawn. Pump flow must be resumed prior to deployment, so as to stretch out (and thus thin out) the walls of the aorta. The quality of the vein and proper loading onto the anastomotic device were important variables in ensuring successful anastomosis (n = 1).

Endoscopic bypass surgery on the canine model with the St. Jude device for the proximal anastomosis was conducted from July 2001 through October 2002 by a single cardiac surgeon at Massachusetts General Hospital. At least 1 experiment was performed each month, and LIMA takedown times

varied between 45 and 120 minutes and averaged approximately 75 minutes.

**DISCUSSION**

**IMA Takedown**

IMA dissection was performed using the robotic interface. Although it is possible to take down the IMA with manual thoracoscopic techniques, a robotic interface facilitates dissection, and the surgeon benefits from superior ergonomics, being able to perform the procedure from the robotic console. The major drawbacks to using this method for IMA takedown remain the significant learning curve required to operate through this interface and the increased time required for the robotic procedure compared with standard methods.

In humans, endoscopic dissection of the IMA can be difficult as the artery is followed distally because the vessel tends to course deep in the transversus thoracis muscle and out of

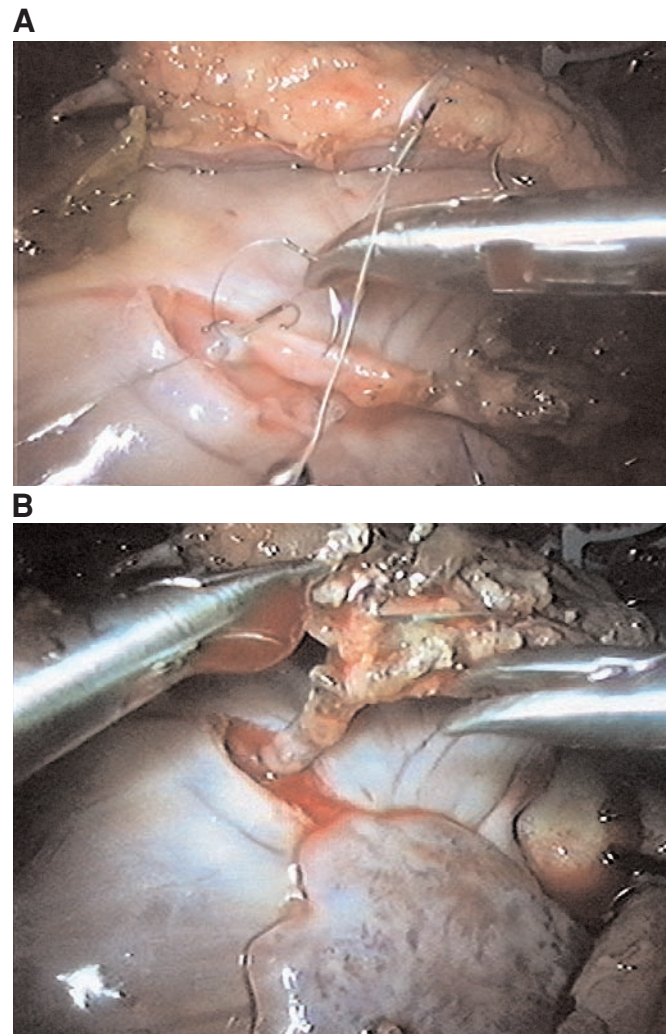


Figure 4. Distal anastomosis. A, Use of U-clips (Coalescent Surgical) in left internal mammary artery to left anterior descending coronary artery anastomosis with the Zeus robotic interface. B, Completed anastomosis.

view [Netter 1989]. Thus it is very important to optimize placement of the endoscope to maximize vision as well as to optimize the location of the instrument port, because port placement directly influences access to the surgical field and the dexterity of the surgical instruments and reduces instrument collisions [Loulmet 1999, Kappert 2001]. In our studies IMA takedown often was hindered by instrument collisions. For this reason, possible optimal port placement has been predicted in humans with a mathematical model based on anatomical information obtained from preoperative computed tomographic scans [Cannon 2003].

Use of a balloon-tipped angioplasty catheter to obtain proximal control of the IMA offers advantages over insertion of a bulldog clamp through a thoracoscopic port. The field is less cluttered, and flow through the artery can be controlled quickly from outside the body. In addition, after the anastomosis is completed, the distal catheter port may be used for delivery of cardioplegia to the LAD or for injection of contrast material for completion angiography. Further investigations are necessary to study the effects on the endothelium of inflation of a balloon tip. High-pressure balloon inflation can be as damaging to endothelium as an overly tight bulldog clamp. Our experience has shown that cannulating the IMA under direct visualization is easier than performing the procedure under fluoroscopy. A bulldog clamp may be used in cases in which the IMA cannot be cannulated for technical reasons.

### **Proximal Anastomosis**

The anastomotic device was used while the animal was on cardiopulmonary bypass to allow for control of the arteriotomy and to prevent uncontrolled bleeding. This step is especially important in this setting because the chest remains closed, visualization of the operative field depends on a clean camera lens, and the aorta would be difficult to control in a timely fashion.

For performance of the proximal anastomosis, the ascending aorta must be clearly visualized. A device capable of rapidly washing the scope lens, without the need to remove the thoracoscope from the chest, was constructed to prevent intraoperative periods of “blindness.”

With use of the Symmetry device, it is crucial to free the aorta from connective tissue to avoid deployment of the connector only in the aortic adventitia and to avoid entanglement in fat tissue.

The St. Jude device is not configured for endoscopic use, largely because the shaft of the cutter is unnecessarily large in diameter and may not be long enough to reach the aorta. With minor modification this device could be adapted for endoscopic use.

### **Cardioplegia**

In the narrow confines of the closed chest, institution of cardiopulmonary bypass and cardioplegia offer advantages over the off-pump approach. In addition to facilitating arteriotomy and offering a safety advantage should bleeding occur during proximal anastomosis, use of bypass allows the heart and lungs to take up less room and yields a

more generous surgical field. Furthermore, during bypass, the heart can be maneuvered for exposure of distal vessels without hemodynamic compromise. It would also be possible to perform CABG during cardiopulmonary bypass with a beating heart and to benefit from cardiac decompression. The issues of vessel control and stabilization are still to be addressed.

The advantage of using the Chitwood clamp, instead of devices such as Heartport or Endodirect, rests in eliminating the risks of aortic dissection and migration of the balloon.

With the aorta cross clamped, cold cardioplegia solution is delivered through the saphenous vein and flows antegrade through the coronary circulation. After cardioplegia is given, the left ventricle can be vented via the aortic root. When cold cardioplegia solution is used, the risk of a weakened anastomosis must be considered. The nitinol clips used with the St. Jude device soften and become more malleable at lower temperatures, and sealant is recommended for strengthening the anastomotic site.

Insertion of a vent catheter through the vein graft could cause endothelial injury and lead to adverse long-term consequences. The issue is relative because the vein needs to be cannulated to be loaded onto the anastomotic device. Results of long-term patency studies looking at veins manipulated by angioplasty or valvulotomes for in situ, nonreversed peripheral bypass have suggested this maneuver can be done without adverse sequelae [Shah 1996].

For performance of the final distal anastomosis, the vent catheter must be withdrawn. The coronary sinus could additionally be catheterized to deliver retrograde cardioplegia. Having the ability to deliver cardioplegia in a retrograde fashion, in addition to antegrade as previously described, might offer an advantage in ensuring myocardial perfusion. This part of the procedure can be achieved through a device compatible with endoscopic surgery, such as an EndoPlege catheter (Ethicon). In addition, the lumen of the IMA balloon catheter can be used for cardioplegic delivery.

## **CONCLUSION**

We used a canine model to show that endoscopic anastomosis to the ascending aorta can be performed with the St. Jude anastomotic device. We also demonstrated that with direct access to the aorta, antegrade cardioplegia as well as aortic root venting can easily be accomplished and a closed chest approach to cardioplegic arrest made simpler and less costly.

## **REFERENCES**

- Boyd WD, Rayman R, Desai ND, et al. 2000. Closed-chest coronary artery bypass grafting on the beating heart with the use of a computer-enhanced surgical robotic system. *J Thorac Cardiovasc Surg* 120:807-9.
- Cannon JW, Stoll JA, Selha SD, Dupont PE, Howe RD, Torchiana DF. 2003. Port placement planning in robot-assisted coronary artery bypass. *IEEE Trans Rob Autom*. In press.

Chitwood WR, Wixon CL, Elbeery JR, Moran JF, Chapman WH, Lust RM. 1997. Video-assisted minimally invasive mitral valve surgery. *J Thorac Cardiovasc Surg* 114:773-80.

Dogan S, Aybek T, AndreBen E, et al. 2002. Totally endoscopic coronary artery bypass grafting on cardiopulmonary bypass with robotically enhanced telemanipulation: report of forty-five cases. *J Thorac Cardiovasc Surg* 123:1125-31.

Duhaylonsod FG. 2002. Minimally invasive cardiac surgery defined. *Arch Surg Review* 135:296-301.

Glower DD, Komtebedde J, Clements FM, Debruijn NP, Stafford-Smith M, Newman MF. 1999. Direct aortic cannulation for port-access mitral or coronary artery bypass grafting. *Ann Thorac Surg* 68:1878-80.

Groh M, Grossi EA. 1999. Multivessel coronary bypass grafting with minimal access using cardiopulmonary bypass. *Curr Cardiol Rep* 1:331-4.

Kappert U, Cichon R, Schneider J, et al. 2000. Closed-chest coronary artery surgery on the beating heart with the use of a robotic system. *J Thorac Cardiovasc Surg* 120:809-11.

Kappert U, Schneider J, Cichon R, et al. 2001. Development of robotic enhanced endoscopic surgery for the treatment of coronary artery disease. *Circulation* 104:102-7.

Loulmet D, Carpentier A, d'Attellis N, et al. 1999. Endoscopic coronary artery bypass grafting with the aid of robotic assisted instruments. *J Thorac Cardiovasc Surg* 118:4-10.

Mohr FW, Falk V, Diegeler A, et al. 2001. Computer-enhanced "robotic" cardiac surgery: experience in 148 patients. *J Thorac Cardiovasc Surg* 121:842-53.

Netter FH. 1989. *Atlas of human anatomy*. West Caldwell, NJ; Ciba-Geigy.

Reichenspurner H, Boehm D, Gulbins H, et al. 1999a. Robotically assisted endoscopic coronary artery bypass procedures without cardiopulmonary bypass. *J Thorac Cardiovasc Surg* 118:960-1.

Reichenspurner H, Damiano R, Mack M, et al. 1999b. Use of the voice-controlled and computer-assisted surgical system Zeus for endoscopic coronary artery bypass grafting. *J Thorac Cardiovasc Surg* 118:11-6.

Shah DM, Leather RP, Darling RC 3rd, Chang BB, Paty PS, Lloyd WE. 1996. Long term results of using the in situ saphenous vein bypass. *Adv Surg* 30:123-40.

Talwalkar NG, Cooley DA. 1998. Minimally invasive coronary artery bypass grafting: a review. *Cardiol Rev* 6:345-9.