

Totally Endoscopic Coronary Artery Bypass Grafting on the Arrested Heart

Marc R. Katz, MD, FACS,¹ and Johannes O. Bonatti, MD, FETCS²

¹Bon Secours Heart & Vascular Institute, Richmond, Virginia, USA; ²Innsbruck Medical University, Innsbruck, Austria

ABSTRACT

In the late 1990s, totally endoscopic coronary artery bypass grafting was successfully introduced into the heart surgery armamentarium using robotic techniques. Surgeons have applied the daVinci telemanipulation system in order to develop completely endoscopic placement of internal mammary artery bypass grafts, mainly to the left anterior descending artery system. Multivessel procedures are currently under development. These operations can be carried out on the arrested heart using remote access perfusion and cardioplegic arrest via ascending aortic balloon occlusion. Another option is performing procedures on the beating heart using an endostabilizer and local coronary artery occlusion. In this review, the technique and specific aspects of the arrested heart version of totally endoscopic coronary artery bypass grafting are outlined.

INTRODUCTION

Coronary artery bypass surgery (CABG) is one of the most commonly performed and consequently most studied operations in modern medicine. Traditionally it has been performed via median sternotomy, allowing optimal access to all cardiac structures as well as the great vessels. Full cardiopulmonary bypass support has been a mainstay in providing a bloodless and motionless field. Continued innovation in the field of percutaneous intervention (PCI) has led to a marked reduction in the number of CABG procedures performed, despite documented superior results for surgery. Whether patients are fully informed about the long-term results of PCI versus CABG can be debated; however, it is clear that most prefer a less invasive, less debilitating option. One such option is totally endoscopic coronary artery bypass grafting (TECAB). This intervention can be carried out on the beating heart or on the arrested

heart. It is the aim of this review to report on the rationale, history, technique, and results of the TECAB operation performed using remote access cardiopulmonary bypass perfusion and cardioplegic arrest.

WHY ROBOTICS FOR ENDOSCOPIC CORONARY SURGERY?

Endoscopic surgery has had a huge impact on many surgical disciplines. The fields of orthopedics, gynecology, and general abdominal surgery have been revolutionized by endoscopic techniques. Standard endoscopic instruments, with only 4 degrees of freedom, reduce dexterity. The fulcrum effect of working through a fixed entry point requires reversed motions, long instruments exaggerate any tremor, and the visual motor misalignment of most endoscopic systems does not allow for the level of precision and control necessary for coronary artery revascularization. Heartport port access systems fell short of many surgeons' hopes for a simple minimally invasive interface; however, many aspects of the system remain in use to varying degrees. One of particular interest is the closed chest cardiopulmonary bypass instrumentation. Technologic advancement in surgical robotic systems coupled with other techniques have given rise to the first truly endoscopic cardiac surgical procedures [Loulmet 1999; Falk 2000; Mohr 2001].

History

Computer-assisted surgical robotic systems have been developed to overcome many of the limitations of standard endoscopic surgery. Initially 2 competing surgical robotic systems were in comparatively wide distribution, the Zeus System from Computer Motion and the daVinci System from Intuitive Surgical (Mountain View, CA, USA). The companies have since merged with the daVinci system surviving largely intact. Computers and robotics have been used in industry for many years to improve the precision and efficiency with which repetitive tasks are performed. This technology is just now beginning to show its promise in the surgical arena.

System Description

The daVinci surgical robotic system has been described as a computer-assisted telemanipulation device. The first version

Presented at the 3rd Integrated Coronary Revascularization (ICR) Workshop for Interventional Cardiologists and Cardiac Surgeons, Innsbruck, Austria, December 6-8, 2006.

Correspondence: Marc R. Katz, MD, FACS, Bon Secours Heart & Vascular Institute, 5875 Breemo Road, Richmond, Virginia 23226, USA; 1-804-287-7840; fax 1-804-287-7845 (e-mail: mkatz@NewHeartSurgery.com).



A second generation of surgical robots was introduced recently. The figure shows the daVinci S system by Intuitive Surgical (Mountain View, CA, USA).

was introduced in the late 1990s, a second generation daVinci S has been recently developed (Figure). It is a powerful computer interface between the surgeon and patient. The system consists of 3 major components: (1) the patient-side cart consisting of 3 arms (one scope holder and 2 instrument arms) in the daVinci or 4 arms (one scope holder and 3 instrument arms) and an interactive touch screen with telestration in the daVinci S; (2) surgeon's console with stereo viewer and master controls; and (3) vision cart housing the image processing system, insufflator, etc. The console houses the display system, master controllers (input devices), user interface, and electronic controller. The tool handles are serial link manipulators that act both as high resolution input devices, reading the position, orientation, and grip commands from the surgeon, and haptic displays. The image of the surgical site is transmitted to the surgeon via a high resolution (high definition in most recent models) stereo display. The system projects the image of the surgical site atop the surgeons hands, while the controller transforms the spatial motion of the tools into the camera frame of reference. Thereby the system restores hand-eye coordination and provides a natural correspondence in motions. The interface allows the surgeon to control camera positioning, while keeping the tool tips in view, to reposition the masters in their work space, and to focus the endoscope. Orientational alignment is always provided, and positional alignment can be changed to allow repositioning of the master handles independent of the instrument tips. Motion scaling and tremor filtration further enhance precision. The patient-side cart consists of sterilizable tools, the tool manipulators, the camera manipulator, the endoscope, and a touch-screen monitor. The end-effectors are fully sterilizable instruments that attach interchangeably to the manipulators and have automatic instrument recognition.

The instruments are wristed with 6 degrees of freedom plus tool function. The 4 arms of the cart manipulate 3 instruments plus the stereo endoscope. The manipulators are positioned by multi-link arms mounted to a fixed base [Mohr 1999; Guthart 2000].

Indications, Contraindications

Indications for the arrested-heart (AH) TECAB procedure were restricted to single-vessel disease in the early phase of development. Hybrid coronary reintervention and placement of bilateral mammary arteries allow current approaches to multivessel disease [Kappert 2000; Stein 2003; Bonatti 2006; Katz 2006]. Indications are listed in Table 1. Contraindications are listed in Table 2. Successful teams have thus far included only relatively young patients with few comorbidities. Long cardiopulmonary bypass times and operative times during the learning curve seem to be well tolerated.

Anesthesia

Standard cardiac anesthetic protocols are followed with the addition of double lumen endotracheal intubation, to allow single-lung ventilation. In some cases, a pulmonary artery vent is placed via the right internal jugular vein. In all endo-aortic balloon cases, bilateral radial artery lines are necessary to monitor for possible distal balloon migration. Routine transesophageal electrocardiography is needed both for endo-aortic balloon positioning as well as cardiac function monitoring. Percutaneous defibrillator pads are placed to allow for defibrillation after opening of the endo-aortic occlusion balloon if necessary.

Surgical Technique

The main steps of the operative technique and postoperative care are listed in Table 3.

Benefits of the Technique

No prospective randomized trials are available concerning advantages of TECAB, some advantages are, however, obvious.

TECAB Benefits. "The penultimate goal of minimally invasive coronary revascularization would be a procedure that combines the superior outcomes of traditional open chest

Table 1. Indications for Arrested-Heart Totally Endoscopic Coronary Artery Bypass Grafting

General indications for coronary surgery

Single-vessel coronary artery disease involving the left anterior descending artery (LAD) system
LAD and diagonal lesions (for placement of a sequential left internal mammary artery [LIMA] graft to diagonal branch and LAD)
Right coronary artery (RCA) ostial lesions (placement of a right internal mammary artery [RIMA] graft to RCA)
Multivessel disease involving the LAD in which the other coronary artery territories are amenable to percutaneous intervention (hybrid approach)
Isolated left main disease (for placement of a RIMA graft to LAD and a LIMA graft to the circumflex artery branches)

Table 2. Contraindications for Arrested-Heart Totally Endoscopic Coronary Artery Bypass Grafting

Absolute

- Ascending aortic diameter >35 mm
- Left ventricular ejection fraction <30%
- Severe chronic obstructive pulmonary disease
- Severe aortoiliac or femoral artery atherosclerosis
- Multi-morbid patients

Relative

- Previous thoracic or cardiac surgery
- History of pleuritis or pericarditis
- Intramyocardial left anterior descending artery

coronary artery bypass grafting with the invasiveness of PCI” [Damiano 2000]. TECAB is a major step toward this goal. The AH-TECAB operation was the first successful surgical approach to completely endoscopic coronary artery bypass grafting [Loulmet 1999].

Patient Benefits. Minimal surgical trauma and rapid recovery are the main advantages of this procedure. As compared to mini-thoracotomy approaches, scarring is further reduced, results are cosmetically more attractive, and no rib spreading with minimal intercostal nerve trauma results in less pain. Short hospital stays have been described, and all groups who performed this operation report very early return of the patients to full activities [Falk 2000; Dogan 2002]. Due to minimal exposure of the operative field to the operating room environment, the bacterial burden is low. In published series deep thoracic wound infections are extremely rare. According to current experience robotic techniques offer advantages in obese patients. Basically the operative exposure in obese patients is not much different from nonobese, and avoiding a sternotomy or deep thoracotomy incision offers even greater advantage to this group of patients.

Surgeon Benefits. There are major benefits for the surgeon with this system. The console surgeon works without a sterile gown at the console. This gives him or her more flexibility and he or she can walk around the operating room and coordinate the team, a task that is critical in all robotic, endoscopic procedures. The console position is both comfortable and ergonomic for most surgeons. As compared to thoracotomy approaches in minimally invasive CABG, there is a larger direct visual field into the pleural and pericardial cavities. Three dimensional vision and up to 10-fold magnification are additional helpful adjuncts. In comparison to conventional endoscopy, the daVinci system offers improved dexterity, motion scaling, and tremor elimination.

In the AH version of the TECAB procedure, the heart-lung machine provides a safety net. On cardiopulmonary bypass the heart is unloaded and both lungs can be deflated. This results in a tremendous gain in space, a fact that is critical in TECAB. Approaches to the circumflex coronary artery system are much easier under cardioplegia, and anastomotic suturing is easier than on the beating heart. One has to take into consideration that movements of the heart and the target vessel are

accentuated in a magnified view and work on the beating heart is a challenge. Therefore mastery of AH-TECAB is essential before moving to a beating-heart platform. In the literature, conversion rates in AH-TECAB [Falk 2000; Dogan 2002;

Table 3. Procedure Workflow

-
- (1) Evaluation:
 - Catheterization
 - Multidetector computed tomography
 - Patient selection
 - (2) Operative steps:
 - Patient positioning
 - Port placement
 - (Camera port in the 5th intercostal space on the anterior axillary line, working ports in the 3rd and 7th intercostal spaces on the mid clavicular line)
 - CO2 Insufflation 8-12 mmHg
 - Internal mammary artery takedown and preparation
 - Prevention of torsion
 - Leave part of pedicle attached for counter traction
 - Pericardial fat pad reflection laterally
 - Pericardiotomy
 - (Performed in an L-shaped fashion, begin as medial as possible)
 - Coronary artery identification before arresting the heart
 - (Placement of marking clip)
 - Peripheral cannulation
 - (Can be performed by the patient side surgeon in parallel to distal left internal mammary artery preparation and pericardial opening)
 - Positioning of the endo-aortic occlusion balloon under transesophageal electrocardiography guidance
 - Initiate cardiopulmonary bypass
 - Endo-aortic balloon inflation and induction of cardioplegia
 - Final target vessel exposure and incision
 - Anastomosis using a 7-cm 7/0 Prolene or CV8 Gortex double-armed suture or nitinol clips
 - Deflation of the endo-aortic balloon
 - Defibrillation or application of a single shot of adenosine if ventricular fibrillation occurs
 - Weaning from cardiopulmonary bypass
 - Decannulation
 - Femoral vessel closure
 - Intrathoracic hemostasis check
 - Port removal
 - Placement of chest tube through left instrument port
 - Port and inguinal incision closure
 - (3) Postoperative care:
 - Intensive care unit or recovery room:
 - Ventilation during first few postoperative hours or extubation in operating room
 - Hemodynamic surveillance and management
 - Rhythm management per routine
 - Pain management (usually resolves with in 48 hours of procedure)
 - Regular ward:
 - Early mobilization
 - Pain management
 - Chest tube removal
 - Removal of intravenous catheters and urinary catheter
-

Argenziano 2006; Bonatti 2006] are lower than in beating heart TECAB [Kappert 2001; Jacobs 2003].

Specific Aspects of Remote Access Perfusion and Endo-Aortic Occlusion

Technology. Port access technology was developed in the 1990s and was an important step toward totally endoscopic cardiac procedures. Aspects applicable to TECAB involve mainly cardiopulmonary bypass via a femoral approach. The key component is the endo-aortic balloon catheter. This is placed via a specially designed femoral arterial canula and with transesophageal electrocardiography guidance situated in the aortic root. A 35 cc balloon can then be inflated to occlude the ascending aorta from within. Ports at the catheter tip allow for infusion of antegrade cardioplegia, aortic root venting, and pressure measurement. Cardioplegic arrest can thus be established without any canulae within the operative field. Other components of the port access system are a pulmonary artery vent catheter for additional decompression and a coronary sinus catheter for retrograde cardioplegia delivery (these are optional for AH-TECAB procedures). Both are placed via a right internal jugular approach [Stevens 1996; Wimmer-Greinecker 2004] These technologies have their own set of risks and potential complications and thus experience with them is a key prerequisite for successful AH-TECAB.

Training Protocols and Stepwise Procedure Development

TECAB is not merely the sum of an internal mammary artery (IMA) takedown and an anastomosis [Falk 2000]. Both European and US experiences have clearly demonstrated that a stepwise approach to this procedure is the safest route to success [Falk 2000; Dogan 2002; Bonatti 2004]. The following protocol evolved from the international multi-center trial that lead to FDA clearance of the daVinci system for coronary revascularization [Argenziano 2006].

Dedicated Robotics Team. The first key to developing a program to perform AH-TECAB surgery is to organize a dedicated team that includes anesthesia, nursing, perfusionists, surgeons, and assistants. The value of a consistent group cannot be over-emphasized as these cases deviate significantly from standard practice norms in most institutions. This group should jointly proceed through the extensive stepwise training. Development and repetition of the procedure choreography and standard protocols will increase efficiency and help minimize ischemia time and overall case times. These procedures require explicit communication as well as a great amount of patience and discipline.

System Training. All team members should participate in the standard robotic system training. The surgeon(s) and assistants will have additional training specific to cardiac applications of the daVinci system. This has typically involved both didactic and laboratory animal or cadaver operative experience. The anastomotic suturing technique is typically trained on a porcine heart in the wetlab.

Robotically Assisted IMA Mobilization. This is obviously a key component of the procedure, although the basics of the

technique are quite similar to the open procedure, working in a totally endoscopic environment with different exposure, perspective, and landmarks does involve a significant learning curve. The FDA study required 15 left IMA (LIMA) takedowns as part of open cases over a 3-month time period. As the surgical experience progresses, additional elements are added including endoscopic bulldog placement, skeletonization of the distal end, spatulation of distal end, and IMA transection. The procedure should be accomplished in less than 90 minutes and result in a graft suitable for anastomosis. Another intermediary step prior to TECAB was the requirement of at least 3 of these IMA mobilization procedures to be associated with minimally invasive direct coronary artery bypass grafting (SVST) cases. The advantage of this is accentuation of the importance of adequate length and hemostasis (versus those performed prior to a sternotomy case). Endoscopic IMA takedown is not merely a training exercise for the surgeon but affords the patient benefit of minimal sternal lift in the sternotomy cases and markedly improved visualization of the hemithorax and coronary identification for the minimally invasive direct coronary artery bypass grafting procedures.

Minimally Invasive CPB Training. Endo-aortic balloon technology, as previously described, has its own learning curve, and mastery of these techniques are essential for AH-TECAB procedures. The FDA study group required at least 10 remote access perfusion cases with no conversions prior to embarking on an AH-TECAB. Proper patient selection including preoperative computed tomography angiography is of utmost importance to guarantee adequate patient safety.

TECAB Specific Training. The next steps in the program, to enable safe performance of AH-TECAB procedures, was to add reflection of the pericardial fat pad, pericardiectomy, and left anterior descending artery (LAD) identification to the IMA takedown cases. Subsequently the move to endoscopic anastomoses was begun by requiring 30 arteriotomies and 30 anastomoses in a laboratory-like setting (usually involving isolated pig hearts). Critical assessment of the technique, time involved, and quality of the anastomosis is helpful. Case observation by the dedicated robotics team is of prime importance to learn the logistics and choreography of the procedure.

TECAB Training Cases. The last training phase was the performance of at least 2 robotically performed LIMA to LAD anastomoses on an arrested heart as part of a single- or multi-vessel sternotomy case. Other grafts were performed manually first and then the robotic system was brought up and the LIMA anastomosis was performed through the open sternum. This allows for direct assessment of the anastomosis and this training step allows the surgeon to learn target vessel exposure in the epicardial fat. That part of the procedure is probably the only one where the lack of tactile feed back on the robotic system is an issue. This challenge can be compensated with ongoing optical training but requires repetitive exercise before it can be safely performed in the complete endoscopic setting. Visual clues, like changes in tissue tension lines, allow one to learn to “feel with your eyes.” Follow-up catheterization was performed in these cases as well.

At last a completely endoscopic placement of a LIMA graft to the LAD can be tackled. It is advisable to have an experienced proctor stand by during the first AH-TECAB cases. The few surgeons who are currently performing TECAB have formed a network and procedure development toward multi-vessel endoscopic CABG is a matter of ongoing discussions at specific focus group meetings. There is an absolute willingness to support new groups who wish to embark on TECAB.

RESULTS

Despite the presence of learning curves and the fact that a new highly complex procedure was implemented, published AH-TECAB results concerning mortality and quality of revascularization are good. Table 4 shows results from the main papers. Conversion was in the 20% range in the early phase of development but were better than in beating heart versions of the procedure, which reached conversion rates in the 30% range [Kappert 2001; Jacobs 2003]. The conversion rate for LIMA to LAD placement on the arrested heart at Innsbruck Medical University has dropped from 9 of the first 45 cases (20%) to 2 of the second 45 cases (4%). It is important to note that conversion in AH-TECAB leads to moderately increased ventilation time and intensive care unit stay but does not seem to translate into increased mortality or a compromised revascularization result [Bonatti 2006].

Significant learning curves for procedure parts and the full version of AH-TECAB have been reported in the literature throughout the first years of application [Falk 2000; Kappert 2001; Dogan 2002; Bonatti 2004; Argenziano 2006; Oehlinger 2007]. In the FDA trial, the angiographic procedure success rate for endoscopically placed LIMA to LAD grafts was 91%. The Innsbruck group has recently reported angiographic graft patency after robotic suturing on the arrested heart in the high 90% range [Schachner 2007].

General advantages of the procedure are found in the early rehabilitation phase. In Richmond, the average length of stay has been 2.5 days and return to full activities including manual labor jobs has occurred in as little as 6 days postoperatively.

It is common knowledge that robotic TECAB programs have been opened and closed at some centers. Many of these centers failed during their early attempts because a stepwise approach was not taken and experience from successful centers did not flow into the implementation phase. The importance of the prerequisites and a strong foundation with the ancillary technology cannot be over emphasized.

Table 4. Data from Previous Reports

	Journal	Conversion Rate	Mortality
[Loulmet 1999]	JTCVS	50%	0%
[Falk 2001]	EJCTS	18%	0%
[Dogan 2001]	JTCVS	22%	0%
[Mohr 2001]	JTCVS	18%	0%
[Bonatti 2006]	JTCVS	23%	0%
[Argenziano 2006]	Ann Thor	6%	0%

SUMMARY AND CONCLUSIONS

Robotic technology and remote access perfusion systems allow single- and double-vessel coronary artery bypass grafting procedures through thoracic ports and a mini-incision in the groin. This operation can be performed with good results in patients with little comorbidity. Proper patient selection and preoperative evaluation is critical. Compared to beating heart TECAB, the arrested heart version offers additional space in the pleural cavity and a technically easier suturing process. In multi-vessel TECAB, exposure of the lateral and back wall of the heart is significantly enhanced. A stepwise approach to AH-TECAB and specific training in remote access perfusion technologies is absolutely necessary before performance of the full version of AH-TECAB. Significant reductions of procedure times and conversion rates have been reported recently.

REFERENCES

- Argenziano M, Katz M, Bonatti J, et al, TECAB trial investigators. 2006. Results of the prospective multicenter trial of robotically assisted totally endoscopic coronary artery bypass grafting. *Ann Thorac Surg* 81:1666-74.
- Aybek T, Dogan S, Andreben E, et al. 2000. Robotically enhanced totally endoscopic right internal thoracic coronary artery bypass to the right coronary artery. *Heart Surg Forum* 2000;3:322-4.
- Bonatti J, Schachner T, Bernecker O, et al. 2004. Robotic totally endoscopic coronary artery bypass: program development and learning curve issues. *J Thorac Cardiovasc Surg* 127:504-10.
- Bonatti J, Schachner T, Bonaros N, et al. 2005. Ongoing procedure development in robotically assisted totally endoscopic coronary artery bypass grafting (TECAB). *Heart Surg Forum* 8:E287-91.
- Bonatti J, Schachner T, Bonaros N, Laufer G. 2006. A new exposure technique for the circumflex coronary artery system in robotic totally endoscopic coronary artery bypass grafting. *Interact Cardiovasc Thorac Surg* 5:279-81.
- Bonatti J, Schachner T, Bonaros N, et al. 2006. Technical challenges in totally endoscopic coronary artery bypass grafting. *JTCVS* 131:146-53.
- Damiano R, Ehrman W, Ducko C, Tabaie H, et al. 2000. Initial United States clinical trial of robotically assisted endoscopic coronary artery bypass grafting. *J Thorac Cardiovasc Surg* 119:77-82.
- Damiano R. 2000. Editorial: endoscopic coronary artery bypass grafting—the first steps on a long journey. *J Thorac Cardiovasc Surg* 120:806-7.
- Dogan S, Aybek T, Andressen 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.
- Falk V, Diegeler A, Walther T, et al. 2000. Total endoscopic computer enhanced coronary artery bypass grafting. *Eur J Cardiothorac Surg* 17:38-45.
- Falk V, Gummert J, Walther T, Hayase M, Berry G, Mohr F. 1999. Quality of computer enhanced totally endoscopic coronary bypass graft anastomosis—comparison to conventional technique. *Eur J Cardiothorac Surg* 15:260-65.
- Falk V, Jacobs S, Mohr F. 2003. Closed chest robotically assisted CABG. *MMCTS* 2003.000934.

- Guthart G, Salisbury J. 2000. The Intuitive Telesurgery system: overview and application. Proc IEEE ICRA, San Francisco, CA.
- Jacobs S, Falk V, Onnasch J, Mohr F. 2003. Thorakoskopische Koronar-chirurgie. Stand und Entwicklungsmöglichkeiten *Chiurg* 74:310-14.
- Jacobs S, Falk V. 2001. Pearls and pitfalls: lessons learned in endoscopic robotic surgery—the daVinci experience. *Heart Surg Forum* 4:307-10.
- Kappert U, Cichon R, Schneider J, Schramm I, Schüler S. 2000. Closed chest bilateral mammary artery grafting in double-vessel coronary artery disease. *Ann Thorac Surg* 70:1699-701.
- Kappert U, Schneider J, Cichon R, et al. 2001. Development of robotic enhanced endoscopic surgery for the treatment of coronary artery disease. *Circulation* 2001;104(suppl I):I102-7.
- Katz MR, Van Praet F, deCanniere D, et al. 2006. Integrated coronary revascularization: percutaneous coronary intervention plus robotic totally endoscopic coronary artery bypass. *Circulation* 114:I473-6.
- 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 F, Falk V, Diegeler A, Autschbach R. 1999. Computer enhanced coronary artery surgery. *J Thorac Cardiovasc Surg* 117:1212-5.
- Mohr F, Falk V, Diegeler A, et al. 2001. Computer enhanced robotic cardiac surgery: Experience in 148 patients. *J Thorac Cardiovasc Surg* 121:842-53.
- Oehlinger A, Bonaros N, Schachner T, Ruetzler E, Friedrich G, Laufer G, Bonatti J. 2007. Robotic endoscopic left internal mammary artery harvesting—what have we learned after 100 cases? *Ann Thorac Surg* [in press].
- Schachner T, Bonaros N, Feuchtner G, Muller L, Laufer G, Bonatti J. 2005. How to handle remote access perfusion for endoscopic cardiac surgery. *Heart Surg Forum* 2005;8:E232-5.
- Schachner T, Feuchtner GM, Bonatti J, et al. 2007. Evaluation of robotic coronary surgery with intraoperative graft angiography and postoperative multislice computed tomography? *Ann Thorac Surg* [in press].
- Stein H, Cichon R, Wimmer-Greinecker G, Ikeda M, Hutchinson D, Falk V. 2003. Totally endoscopic multivessel coronary artery bypass surgery using the daVinci Surgical System: a feasibility study on cadaveric models. *Heart Surg Forum* 6:E183-90.
- Stevens J, Burdon T, Peters W, et al. 1996. Port Access coronary artery bypass grafting: a proposed surgical method. *J Thorac Cardiovasc Surg* 111:567-73.
- Wimmer-Greinecker G, Deschka H, Aybek T, Mierdl S, Moritz A, Dogan S. 2004. Current status of robotically assisted coronary revascularization. *Amer J Surg* 188(suppl):76s-82s.
- Wimmer-Greinecker G, Dzemali O, Aybek T, et al. 2005. Perfusion strategies for totally endoscopic cardiac surgery. *MMCTS* 2005.001206