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Robotic Totally Endoscopic Double-Vessel Bypass Grafting: A Further Step Toward Closed-Chest Surgical Treatment of Multivessel Coronary Artery Disease

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ABSTRACT

Background. After the introduction of robotic technology into the heart surgery armamentarium the performance of totally endoscopic coronary artery bypass grafting (TECAB) has become a reality. During the first years of development, the majority of TECAB cases were restricted to single-vessel disease, and the development of multivessel procedures is desirable. We report on a preliminary series of totally endoscopic double-vessel coronary artery bypass grafting.

Methods. From 2004 to 2006, 10 patients underwent endoscopic placement of the right internal mammary artery (RIMA) to the left anterior descending artery (LAD) in combination with left internal mammary artery (LIMA) grafting to an obtuse marginal (OM) branch. Indications for the operation were isolated left main disease or left main equivalents. All procedures were performed using the daVinci telemanipulation system, remote-access perfusion, and aortic balloon endo-occlusion.

Results. Seven of the 10 interventions were completed endoscopically, and 3 patients were converted to sternotomy. RIMA takedown time was 40 minutes (range, 29-49 minutes); LIMA takedown time was 38 minutes (range, 29-48 minutes). LAD and OM anastomotic times were 23 minutes (range, 14-53 minutes) and 38 minutes (range, 29-48 minutes), respectively. Total TECAB time was 477 minutes (range, 385-545 minutes). Median ventilation time was 15 hours (range, 6-40 hours), median intensive care unit stay was 41 hours (range, 15-141 hours), and patients were discharged after a median of 7 days (range, 5-22 days). No major adverse cardiac or cerebrovascular events occurred during short-term follow-up.

Conclusion. Totally endoscopic double-vessel coronary artery bypass grafting on the arrested heart is a reproducible procedure. This intervention offers maximal preservation of patient integrity, but the long operative times need to be investigated.

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BACKGROUND

Completely endoscopic coronary artery bypass grafting has become a reality after the introduction of robotic techniques into the surgical armamentarium. Using this technology, Loulmet and coworkers performed the first totally endoscopic coronary artery bypass grafting (TECAB) procedure in 1998 [Loulmet 1999]. Thereafter, several active groups have implemented this operation on the arrested or beating heart. TECAB was restricted to single-vessel disease and the performance of left internal mammary artery (LIMA) to left anterior descending artery (LAD) grafts in the beginning [Falk 2000; Dogan 2002; Bonatti 2004].

As the majority of cases that are treated surgically to date are multivessel coronary artery disease (CAD) patients, it is highly desirable for endoscopic double- and triple-vessel surgical revascularization procedures to be developed.

Occasional experimental and clinical reports on double-vessel TECAB are available in the literature [Falk 1999; Kappert 2000; Dogan 2002; Stein 2003]. We have recently reported one case of successful endoscopic placement of double IMA bypass grafts for treatment of left main coronary artery (LMCA) disease [Bonatti 2006]. We report on the clinical results after continued application of this technique in a series of 10 patients with isolated LMCA lesions or left main disease equivalents.

PATIENTS AND METHODS

From December 2004 to December 2006, 10 patients were scheduled to undergo double-vessel TECAB for LMCA disease. Demographic data are listed in Table 1.

Anesthesia. Following induction of anesthesia with midazolam (1-2 mg/kg), fentanyl (7-10 μg/kg), and rocuronium (0.6 mg/kg) and placement of a left-sided double-lumen endobronchial tube (Broncho-Cath; Mallinckrodt Laboratories, Athlone, Ireland), normoventilation was used (endtidal carbon dioxide concentration, 38-42 mmHg). Anesthesia was maintained with remifentanil (0.2-0.5 μg/kg per minute) and

Table 1. Demographic Data

Male	6 (60%)
Female	4 (40%)
Age, y (range)	59 (41-68)
Weight, kg (range)	77 (71-99)
Height, cm (range)	172 (158-180)
Hypertension	6 (60%)
Hypercholesterolemia	7 (70%)
Smoking	5 (50%)
DM	1 (10%)
Left ventricular ejection fraction, % (range)	62 (45-77)
Previous myocardial infarction	3 (30%)
Previous PCI	2 (20%)
PVD	0 (0%)
Previous transitory ischemic attack	0 (0%)
Previous stroke	0 (0%)
Chronic obstructive pulmonary disease	3 (30%)
Creatinine, mg/dL (range)	0.98 (0.78-1.3)
EuroSCORE (range)	2 (0-3)

propofol or sevoflurane. A central venous line, a Swan-Ganz catheter, and percutaneous defibrillator patches were placed. Bilateral radial arterial pressure lines and transesophageal echocardiography completed the monitoring.

TECAB. All operations were performed by a single surgeon (J.B.). The patient was positioned in a 30° right lateral decubitus position. After the setup of the da Vinci system (Intuitive Surgical, Mountain View, CA, USA), a camera port was introduced into the left 5th intercostal space on the anterior axillary line under the collapsed left lung. CO_2 was insufflated at target pressures of 8 to 12 mmHg. Instrument ports were then inserted through the 3rd and 7th intercostal spaces on the midclavicular line under thoracoscopic vision. The retrosternal tissue was divided, and the right pleura was entered. The right IMA (RIMA) was localized and the endothoracic fascia and transverse thoracic muscle were removed from the IMA pedicle to adequately visualize the vessel. Using electrocautery at 20 watts and endoscopic clips for division of the pedicle side branches, the RIMA was harvested from the 1st to the 5th intercostal space. The LIMA was harvested correspondingly. Heparin was given with a target activated clotting time of 450 seconds. After endoscopic placement of a temporarily occluding bulldog clamp, preparation of the distal graft portion on both IMAs as well as a free-flow check were carried out.

In parallel to these steps, the femoral artery and femoral vein were exposed in the left groin. After systemic heparinization, the right atrium was cannulated using a 25 F or 27 F Medtronic venous return cannula (96370; Medtronic, Minneapolis, MN, USA). A 21 F Remote Access Perfusion cardiopulmonary bypass system (ESTECH, Danville, CA, USA) was inserted. The pericardial fat pad was grasped with long-tip endoscopic forceps and removed from the pericardium using electrocautery. After creating an L-shaped incision in the pericardium, we identified the target vessels. A port for insertion of the Octopus TE stabilizer (Medtronic) was brought into the pleural cavity through a subxiphoid incision. The stabilizer was prepared for the exposure of the circumflex coronary artery system. Cardiopulmonary bypass was started, and the patient was cooled to a rectal temperature of 28°C. The ascending aortic occlusion balloon was inflated for induction of cardioplegia. Cold crystalloid cardioplegia was given in an antegrade fashion only and was repeated every 20 minutes.

The circumflex coronary artery target vessel was exposed using the Octopus TE and incised with a lancet endoscopic knife under running cardioplegia. The LIMA was then sutured robotically to the target vessel using a 7/0 Pronova (PN 8713; Johnson & Johnson, New Brunswick, NJ, USA) running suture. The RIMA to LAD anastomosis was carried out correspondingly but without additional stabilization. For the suturing maneuver, an assisting forcep was used through a 5-mm port in the 4th intercostal space in the left parasternal region. This instrument was controlled by the patient-side surgeon. The aortic occlusion balloon was deflated and the heart defibrillated if necessary. After rewarming and weaning from cardiopulmonary bypass, the patient was decannulated. Protamin was administered at a 1:1 base to re-establish preheparinization values of the activated clotting time. The left lung was re-inflated, and a chest tube was inserted into the left pleura. The other 2 thoracic ports were closed. Parts of the procedure are shown in the video.

Statistics

Results are reported on an intention-to-treat basis. Categorical variables are given as absolute values and percentages, and continuous variables are shown as median and range.

RESULTS

The procedure was successfully completed in 7 of the 10 patients. Three conversions to sternotomy were necessary. In one case, the LIMA graft to the OM branch was injured by an endoscopic instrument after successful completion of the

Table 2. Intraoperative Results*

RIMA takedown time, min (range)	40 (29-49)
LIMA takedown time, min (range)	38 (29-48)
Removal of pericardial fat pad, min (range)	10 (4-17)
Pericardiotomy, min (range)	7 (4-19)
LIMA to OM anastomosis, min (range)	31 (17-70)
RIMA to LAD anastomosis, min (range)	23 (14-53)
CPB time, min (range)	194 (63-342)
Aortic endo-occlusion time, min (range)	140 (37-223)
TECAB time, min (range)	477 (385-545)

*RIMA indicates right internal mammary artery; LIMA, left internal mammary artery; OM, obtuse marginal branch; LAD, left anterior descending artery; CPB, cardiopulmonary bypass; TECAB, totally endoscopic coronary artery bypass grafting.

Table 3. Postoperative Results*

Ventilation time, h (range)	15 (6-40)
ICU stay, h (range)	41 (15-141)
Hospital stay, d (range)	7 (5-22)
Revision for bleeding	0 (0%)
PRBC (range)	2 (0-9)
Inotropic support	0 (0%)
Low cardiac output	
IABP	0 (0%)
CK maximum, U/L (range)	1605 (547-4300)
CKMB maximum, U/L (range)	46 (30-82)
Atrial fibrillation	1 (10%)
TIA/stroke	0 (0%)
Renal failure	0 (0%)
Peripheral vascular problem	0 (0%)
Pneumonia	1 (10%)
Deep thoracic wound infection	0 (0%)
Sepsis	0 (0%)
MSOF	0 (0%)

*ICU indicates intensive care unit; PRBC, packed red blood cells; IABP, intra-aortic balloon pump; TIA, transitory ischemic attack; MSOF, multisystem organ failure.

bypass conduit. In the second case, the OM graft was revised because of anastomotic stenosis on the intraoperative angiographic control. In the third case, advancement of the RAP cannula was blocked on the iliac artery level, and the patient was converted to prevent major vascular injury. Operative times are listed in Table 2.

All patients survived the procedure. Median ventilation time was 15 hours (range, 6-40 hours), median intensive care unit stay was 41 hours (range, 15-141 hours), and patients were discharged after a median of 7 days (range, 5-22 days). Further postoperative results are shown in Table 3. A 3-dimensional reconstruction of patent grafts at 3 months is shown in the Figure.

After a median of 4 months (range, 1-24 months), 2 patients reported episodes of chest discomfort that were not associated with myocardial ischemia on stress tests. All other patients are completely symptom free. No major adverse cardiac or cerebrovascular event occurred during follow-up.

DISCUSSION

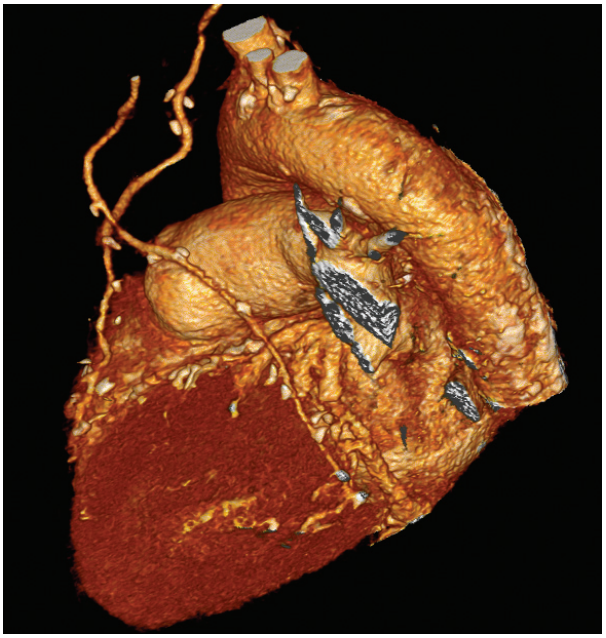
The current study demonstrates that completely endoscopic arterial coronary artery bypass grafting is reproducibly feasible using robotic technology, remote-access perfusion, endoaortic occlusion, and cardiac arrest.

Experimental work on multivessel TECAB was conducted in the late 1990s and early 2000s. Successful operations were reported in animal models and in the human cadaver [Falk 1999; Stein 2003]. Kappert and coworkers at the Dresden Heart Center described a double IMA TECAB procedure relatively early in the development of robotic TECAB [Kappert 2000]. As in our protocol, the RIMA was harvested before the LIMA. This method is chosen according to a general surgical principle to do remote and difficult actions before closer and easier ones. The Dresden group used peripheral-access perfusion and reported a procedure time of 7 hours and 40 minutes, a time frame that is very comparable to our experience. Kappert et al did not mention the exposure technique of the OM branch that was revascularized. They did, however, state that the operation was a major step toward totally endoscopic treatment of patients with multivessel disease.

The Frankfurt robotic cardiac surgery group mentioned 3 cases of double IMA grafting in their publication on robotic TECAB in 2002 [Dogan 2002]. They described the technique as very challenging and time consuming, but regarded the technique as helpful in patients with an increased risk of sternal wound infections. The majority of double-vessel revascularizations in their paper were sequential grafting of the LAD and diagonal branches using a single IMA.

Our group recently reported the first case of endoscopic double IMA grafting to the LMCA system using the Octopus TE as an exposing device [Bonatti 2006]. As demonstrated in the current series, this method is well reproducible.

It was interesting for us to see that harvesting of the RIMA and suturing of the LIMA to the OM differed from LIMA harvesting and RIMA to LAD suturing by only a few minutes. The experience that had been gained with single-vessel TECAB procedures probably helped to achieve this result.



Patent bilateral internal mammary artery grafts to the left anterior descending artery and the obtuse marginal branch at 3 months after double vessel totally endoscopic coronary artery bypass grafting. 3-Dimensional reconstruction on 64-row multislice computed tomography scan.

Tolerance of cardiopulmonary bypass times in the 3.5-hour range and aortic occlusion times in the 2.5-hour range for double CABG may be provocative but did not lead to significant myocardial enzyme release. Similar results were reported in the Dogan paper, which also stated nonsignificant postoperative rise in CKMB levels after double-vessel TECAB [Dogan 2002].

Complex endoscopic surgery in general requires long operative times, and time frames comparable to ours have been described for robotic endoscopic procedures in visceral and thoracic surgery [Giulianotti 2003; D'Annibale 2004]. Conversion rates in these procedures are also significant. Two of our patients had to be converted because of a problem at the LIMA graft to the circumflex coronary artery system. This may reflect a new surgical challenge that was present.

In the Frankfurt group's report, as in our series, postoperative ventilation time, intensive care unit stay, and hospital stay seem prolonged even when compared to conventional coronary artery surgery [Dogan 2002]. It will have to be demonstrated whether these times can be reduced with further experience.

Freedom from angina pectoris in this preliminary experience was satisfactory and may demonstrate an adequate revascularization result. No major adverse cardiac or cerebral event occurred during the intermediate postoperative phase. Larger patient numbers are certainly required to confirm the efficacy of double-vessel TECAB.

In our opinion, the described totally endoscopic double-bypass grafting procedure offers several advantages versus double LIMA grafting through sternotomy. We see improvements versus so called multivessel small thoracotomy procedures that are performed after endoscopic harvesting of both IMAs [Srivastava 2006]. Our technique offers the highest preservation of a patient's integrity because a port-only approach is taken. Sternotomy may be a routine act but remains an irreversible and even destructive action that is taken during conventional coronary artery bypass grafting or off pump coronary artery bypass grafting through median access. Minithoracotomies are a major advance but are often painful [de Canniere 2001], prone to infection, and cosmetically less attractive than portholes. For patients who belong to risk groups for deep sternal wound infections, our approach may be an appealing option, as the sternum is completely preserved, and damage to the skin, soft tissue, and thoracic cage is minimal.

Left main disease, despite successful attempts of percutaneous interventional treatment [Chieffo 2005], remains a clear indication for surgery. To offer an endoscopic version of surgery represents a new and attractive option in the therapeutic armamentarium.

For the surgeon, the completely endoscopic approach includes the advantage that his or her 3-dimensionally enhanced vision is placed directly into the thoracic cavity. Cumbersome views into mini-incisions and difficult vision on 2-dimensional screens are avoided. In addition, the microsurgical work on the coronaries is viewed in up to 10-fold magnification, and tremor-free work with multiple degrees of freedom is possible. At last the surgeon does not need to scrub and wear sterile protection, but can easily leave his or her workplace and walk around the operating room to coordinate the surgical team.

We conclude that completely endoscopic placement of 2 IMA grafts to the left coronary artery system is feasible using robotic technology and remote-access perfusion. With the investment of a prolonged operative time, patient integrity can be preserved at the highest levels.

REFERENCES

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, 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.

Chieffo A, Stankovic G, Bonizzoni E, et al. 2005. Early and midterm results of drug-eluting stent implantation in unprotected left main. Circulation 111:791-5.

D'Annibale A, Morpurgo E, Fiscon V, et al. 2004. Robotic and laparoscopic surgery for treatment of colorectal diseases. Dis Colon Rectum 47:2162-8.

De Canniere D, Jansens JL, Goldschmidt-Clermont P, Barvais L, Decroly P, Stoupel E. 2001. Combination of minimally invasive coronary bypass and percutaneous transluminal coronary angioplasty in the treatment of double-vessel coronary disease: two-year follow-up of a new hybrid procedure compared with "on-pump" double bypass grafting. Am Heart J 142:563-70.

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, Moll F, Rosa D, et al. 1999. Transabdominal endoscopic computer-enhanced coronary artery bypass grafting. Ann Thorac Surg 68:1555-71.

Falk V, Diegeler A, Walther T, et al. 2000. Total endoscopic computer enhanced coronary artery bypass grafting. Eur J Cardiothorac Surg 17:38-45.

Giulianotti P, Coratti A, Angelini M, et al. 2003. Robotics in general surgery: personal experience in a large community hospital. Arch Surg 138:777-84.

Kappert U, Cichon R, Schneider J, Schramm I, Schüler S. 2000. Closed chest bilateral mammary mammary artery grafting in double-vessel coronary artery disease. Ann Thorac Surg 70:1699-701.

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.

Srivastava S, Gadasalli S, Agusala M, et al. 2006. Use of bilateral internal thoracic arteries in CABG through lateral thoracotomy with robotic assistance in 150 patients. Ann Thorac Surg 81:800-6.

Stein H, Cichon R, Wimmer-Greinecker G, Ikeda M, Hutchinson D, Falk V. 2003. Totally endoscopic multivessel coronary artery bypass surgery using the da Vinci Surgical System: a feasibility study on cadaveric models. Heart Surg Forum 6:E183-190.