Total endoscopic computer enhanced coronary artery bypass grafting

Volkmar Falka, Anno Diegelera, Thomas Walthera, Jürgen Banuscb, Jan Bruceriusa, Jörg Raumansa, Rüdiger Autschbacha, Friedrich W. Mohra

aDepartment of Cardiac Surgery, Heartcenter, University of Leipzig, Russenstrasse 19, 04289 Leipzig, Germany
bDepartment of Anesthesiology, Heartcenter, University of Leipzig, Russenstrasse 19, 04289 Leipzig, Germany

Received 7 September 1999; received in revised form 19 November 1999; accepted 29 November 1999

Abstract

Objective: In an effort to minimize access in coronary artery bypass (CAB) surgery, a total endoscopic approach using computer enhanced technology was developed. Methods: By July 1999 the da Vinci telemanipulation system (Intuitive Surgical, Mountain View, CA) was used in 66 patients with coronary artery disease. In 12 patients undergoing routine coronary artery bypass grafting (CABG) (group 1) the internal thoracic artery (ITA) to left anterior descending artery (LAD) anastomosis was performed remotely using the system. In 32 patients (group 2) endoscopic dissection of the ITA was performed followed by a conventional minimally invasive direct coronary artery bypass (MIDCAB) operation. In 22 patients (group 3) the complete operation was performed endoscopically through 4 ports (total endoscopic coronary artery bypass, TECAB). Port-Access cardiopulmonary bypass with cardioplegic arrest was used for TECAB. Results: In group 1 the time for performing the ITA to LAD anastomosis was 17 ± 10 min. Mean graft flow was 38 ± 25 ml/min. One anastomosis leaked and was repaired manually. In group 2 in 31/32 patients (96%) the ITA harvest was successfully performed with the system at mean of 61 ± 27 min. There was a substantial learning curve associated with ITA take-down. In one patient a dissection caused insufficient free ITA graft flow which necessitated additional vein grafting. Postoperative angiography demonstrated graft patency in all cases. In the TECAB group, the operation could be completed through four ports in 18 of the 22 patients (82 %) with operating times in the range 220–507 min. In four patients, elective conversion to a minithoracotomy was required due to failure to identify the LAD (1), bleeding from the anastomosis (1), grafting of a diagonal branch (1) and torsion of the pedicle (1). One patient required reoperation for bleeding from an ITA side-branch. Median intubation time was 13 h and stay on ICU and hospitalization were 20 h and 7 days, respectively. A 3-month follow-up angiography revealed patent grafts in all TECAB patients. Conclusion: Endoscopic ITA harvesting and performing of arterial anastomoses can be safely performed with the da Vinci system. TECAB is possible on the arrested heart with good functional results. However, a substantial learning curve has to be overcome which is reflected in long operation times and an initial significant conversion rate. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Coronary artery bypass grafting; Computer enhanced surgery; Robotics; Telemanipulation; Endoscopy

1. Introduction

Computer enhanced instrumentation systems have been introduced to overcome the limitations of conventional endoscopic instruments that have thus far prevented the application of endoscopic techniques in the field of cardiac surgery. Since the first use of a robotic arm for videoscopic guidance in minimally invasive mitral valve surgery [1], a number of successful cardiac surgical procedures using advanced telemanipulation systems have been reported [2–6]. This report summarizes the initial results of a single center using the da Vinci computer enhanced telemanipulation system in 66 patients undergoing coronary artery bypass grafting. Although a heterogenous group of operations is described below, a number of observations and technical considerations unique to the use of computer enhanced coronary artery bypass grafting are comunicated.

2. Methods

2.1. Telemanipulation system

The da Vinci™ system (Intuitive Surgical, Mountain View, CA) consists of a master console that connects to a surgical ‘manipulator’ with two instrument arms and a central arm to guide the videoscope. The user manipulates two ‘master’ handles at the surgeon’s console. The position
and orientation of the hands on the handles trigger highly sensitive motion sensors that translate the user’s hand movements to the end of the instrument at a remote location. The system has fixed remote center kinematics that minimizes side loads on the body wall and thus trauma at the point of entry. Joint motion of the system is provided by electronic actuators (DC servo motors).

The surgical manipulators on the instrument arms have three degrees of freedom (pitch, yaw and insertion) and provide motion coupling to the end-effectors, exchangeable surgical instruments. These instruments provide another three degrees of freedom by means of a mechanical wrist for a total of six degrees of freedom (DOF). Additionally, tool actuation is provided at the tip of the instrument allowing for free motion in three-space. The system provides motion scaling, tremor filtering and the possibility to disconnect the slave from the master which enhance the precision, provide optimal hand-eye alignment and favorable ergonomics (Fig. 1). The vision system features a true 3D-imaging system with two separate optical channels. Two 3 chip CCD cameras with 800 lines of resolution are used. The images are presented directly in the viewer on two continuous tone CRT monitors. Resolution of the scope is 2.0 mrad/line pair. The surgeon controls the camera by pressing the footswitch that locks the slave tool manipulators in place and gives the surgeon control of the camera by means of the master manipulators. This method of controlling the endoscope provides for easy and fast positioning of target anatomy in the image while keeping the slave tool tips in the operator’s view. A detailed description of the system is provided elsewhere [7–9].

2.2. Surgery

In an effort to minimize the risk associated with the introduction of a new surgical technique, in a number of patients partial procedures were performed using the system. The procedure was broken down into two parts: internal thoracic artery (ITA) takedown and performing the anastomosis. Three different surgical procedures were subsequently performed with the system and are described below. In addition, the decision to include patients into group II rather than into group III was based on a number of reasons: (1) contraindications for the use of femoro-femoral cannulation or usage of the Endoaortic Clamp; (2) patient did not consent for total endoscopic coronary artery bypass (TECAB); (3) referring cardiologist requested off-pump surgery. Randomization was not performed.

2.3. Group I

A standard coronary artery bypass grafting (CABG) procedure via a median sternotomy and using cardiopulmonary bypass (CPB) was performed in 12 patients (Mean age 63 ± 11 years, seven male), with two- (three) or three-vessel disease (nine) requiring multi vessel grafting. After conventional graft harvesting the patient was placed on cardiopulmonary bypass, the distal anastomoses to the obtuse marginal branches and the right coronary artery were performed manually using vein grafts, radial artery or right ITA grafts. The left ITA to left anterior descending artery (LAD) anastomosis was performed remotely using the da Vinci system through the sternotomy incision as described elsewhere [7].

2.4. Group II

Group II consisted of 32 patients (mean age 61 ± 10 years, 20 male, mean ejection fraction 58 ± 14) with an indication for single vessel grafting of the LAD. Patients were placed in a supine position with the left chest slightly elevated by a roll. The left arm was lowered beyond the level of the posterior axillary line. Double lumen intubation was performed and standard monitoring and intravenous anesthesia was applied. The ITA was first harvested endoscopically with the system. After the left lung was deflated, a 12 mm Sealing-Port (Ethicon, Cincinnati, OH) was inserted at the 4th intercostal space (ICS) in the anterior axillary line. Continuous CO₂ insufflation was initiated and continued up to an intrathoracal pressure of 10 mm of mercury, depending on patient tolerance. A 30° scope was inserted through the port and the course of the LAD was identified. Two instrument ports were created at the 3rd and 6th ICS above the anterior axillary line (Fig. 2) and the da Vinci™ system was placed on the patient’s right side. The operation was contin-
ued from the master console. The ITA was dissected using low energy cautery (15 W). Only large side branches were clipped. Proximally, dissection was performed laterally to the phrenic nerve and medially up to the first rib. Distally, dissection was performed up to the 6th ICS. After ITA dissection was finished, the system was withdrawn and the patient was heparinized. A small anterolateral minithoracotomy was performed in the 4th ICS. A left anterolateral minithoracotomy was then made and the procedure was completed as a MIDCAB operation. For stabilization the Estech or Autosuture mechanical stabilization devices were used. Temporary proximal occlusion of the LAD was by snaring the vessel with a pledgeted 4.0 Prolene suture. Intraoperatively graft flow was measured using transit time Doppler flow probes.

2.5. Group III

Twenty-two patients (mean age 62 ± 8 years, 15 male, mean ejection fraction 63 ± 10, CCS class 2.0 ± 0.7) with proximal LAD stenosis (15) or occlusion (seven), underwent total endoscopic coronary artery bypass grafting (TECAB). Ten patients had previous catheter based interventions (PTCA or stenting). The entire operation was performed remotely with the da Vinci system. In addition to our standard monitoring, multiplane transesophageal echocardiography and transcranial Doppler flow measurements of the middle cerebral arteries were performed to monitor placement and positional stability of the endoaortic balloon [10].

ITA take down was performed as described above for group II. The distal end of the ITA was then skeletonized and prepared for the anastomosis in situ. The distal ITA was dissected free from its concomitant veins and fascia leaving those intact in order to provide counter-traction for further manipulation (cutting and trimming) and keeping the tension from the ITA. The internal thoracic veins were then clipped. At 2–3 cm proximal, the ITA was partially skeletonized for placement of a vascular clamp.

The pericardial fat was removed using cautery. The pericardial incision was begun at the mediastinal attachment and enlarged laterally so that by gravity the fat pedicle would widen the pericardial incision. The LAD and its collateral branches were identified. A marker clip was placed medially to the LAD. After the site of anastomosis was determined and sufficient ITA length for grafting was confirmed, the patient was fully heparinized. A fourth port was created in the 4th ICS in the midclavicular line and a trocar inserted. An angled vascular clamp (Scanlan, St. Paul, MN) was inserted through this port and placed on the proximal skeletonized portion of the LAD. The distal ITA was clipped, cut and trimmed but still left in situ still being attached by its concomitant veins. Flow was verified by briefly opening the vascular clamp. The right groin was dissected for cannulation for femoro–femoral bypass and placement of the Heartport endoaortic clamp as has been described elsewhere [11]. For best visualization of the anastomotic site the scope was switched to a 0° scope or 30° angled down, subject to the individual’s anatomy. After cardiac arrest was established, the ITA was detached and positioned at the anastomotic site with a 6-0 Prolene stay suture. The LAD was prepared using blunt and sharp dissection. The arteriotomy was made using a sharp blade and extended using Potts scissors while administering cardioplegia with high pressure. The anastomosis was performed using custom-made 8-0 Prolene suture (double armed, 7 cm of length) as described elsewhere [7]. The pedicle was fixed to the epicardium using a 6-0 suture. Before the vascular clamp was released the anastomosis was tested for leak-
age by running cardioplegia. The endoclamp was deflated and rewarming begun. During rewarming of the patient, angiography of the graft was performed using a 5 Fr ITA catheter (Baxter, Irvine, CA) via the left femoral artery. A single chest tube was inserted. The left lung was inflated and incisions were closed. The patient was then weaned from CPB and cannulae removed.

The institutional ethics committee approved the study protocol and all patients gave written informed consent.

3. Results

3.1. Group I

Patients received an average of 2.6 grafts. Time for cardiopulmonary bypass and clamp time were 65 ± 21 and 42 ± 17 min, respectively. Time for performing the ITA to LAD anastomosis with the da Vinci system was 17 ± 10 min. Flow measurement revealed normal flow patterns for all LAD anastomoses with an average flow of 38 ± 25 ml/min. There was one leakage from an LAD anastomosis that was repaired manually. Postoperative course was uneventful in all patients except one patient who underwent two vessel grafting (RA to CX, LITA to LAD). After skin closure sudden onset VT necessitated CPR. After defibrillation sinus rhythm was restored. Re-thoracotomy was performed and the patient was heparinized again. Flow measurement of the ITA graft revealed normal flow pattern with a mean graft flow of 47 ml/min. Despite good flow, the graft was modified. Inspection of the discarded ITA revealed an intimal dissection at the mid portion of the graft. One patient had a left hematothorax which required re-exploration. The root cause was bleeding from a side branch which was repaired by a clip. In two patients skin emphysema developed postoperatively that required prolonged chest tube drainage. Postoperative angiography (between POD day 3 and 6) demonstrated graft patency in all cases.

3.2. Group II

In 31/32 patients (96%) ITA harvest was successfully performed with the system at a mean time of 61 ± 27 min. There was a substantial learning curve associated with ITA take-down (Fig. 3). Currently, take down time is 40–50 min. In two additional candidates for endoscopic ITA take down, the ITA could not be harvested due to pleural adhesions and or insufficient space between the mediastinum and the sternum despite CO₂ insufflation. Time for anastomosis was 16 ± 6 min. Flow measurement revealed graft patency in all but one case (mean graft flow 42 ± 17 ml/min). One patient had insufficient ITA graft flow after dissection. This patient underwent an additional sternotomy and had a vein graft placed on the LAD on the beating heart. Inspection of the discarded ITA revealed an intimal dissection at the mid portion of the graft. One patient had a left hematothorax which required re-exploration. The root cause was bleeding from a side branch which was repaired by a clip. In two patients skin emphysema developed postoperatively that required prolonged chest tube drainage. Postoperative angiography (between POD day 3 and 6) demonstrated graft patency in all cases.

3.3. Group III

In 18 of the 22 patients (82 %) the operation could be primarily completed through four ports only (Figs. 4 and 5). Four patients were converted for various reasons. In one
patient the LAD could not be identified due to excessive fat tissue. Subsequently, a left minithoracotomy and MIDCAB procedure was performed. One patient had leakage from the anastomosis which required a small anterior minithoracotomy and manual repair. In one patient intraoperative angiography revealed an occluded graft. A left minithoracotomy was performed and a twisted ITA-pedicle was found. The pedicle was reoriented using two stay sutures and fibrin glue. Flow measurement revealed a graft flow of 37 ml/min hereafter. Angiography demonstrated a patent graft and anastomosis. In one patient intraoperative angiography revealed that instead of the LAD a large diagonal branch was grafted. Since the critical LAD stenosis was downstream of that diagonal branch, a T-graft to the LAD was performed using a piece of radial artery. Procedural times and postoperative data are provided in Table 1. One closed chest patient required a secondary minithoracotomy for hemorrhage. A bleeding side branch was found as a cause. Two patients complained about paresthesia in the left pectoral region, which resolved at follow-up. One patient required long-term IC therapy for postoperative confusion.

At 3 months follow-up all patients were free from angina. Angiographically, all grafts were patent. One patient with an unremarkable discharge CXR developed progressive dyspnoe 2 weeks postoperatively. A repeat CXR revealed pleural effusion and atelectasis of the left lower lobe that required multiple bronchoscopic interventions.

4. Discussion

The introduction of computer enhanced instrumentation systems has prepared the ground for endoscopic cardiac surgery [8,12,13]. A number of groups have started to expand their minimally invasive programs towards an endoscopic approach using the two telemanipulation systems that are currently available [2,4,5,14]. Experimental studies have shown that the anastomotic quality is comparable to what can be achieved with a conventional technique [7] and in first clinical cases it has been demonstrated that closed chest bypass grafting is possible on the arrested heart [2,6]. In an experimental animal study successful endoscopic bypass grafting has also been performed on the beating heart using a custom made endoscopic stabilizer [15]. This report summarizes the early single center experience using the da Vinci telemanipulation system for computer enhanced coronary artery bypass grafting. After an initial trial in May 1998 using a prototype [2] we started in December 1998 to routinely use the system in different subsets of patients to endoscopically dissect the internal thoracic artery or to sew the anastomosis of the ITA to the LAD. In the TECAB group, the whole operation was performed endoscopically with the system. During this series the telemanipulation system worked reliable and no system failures occurred. The 3D imaging system provides excellent depth perception and high resolution (60 μm at a working distance of 3 cm) unequalled by any other currently available 3D-vision system. Six degrees of freedom at the tip of the instruments, motion scaling and tremor filtering provide the dexterity that is required for precise endoscopic tissue manipulation. However, procedure flow is compromised by the lack of active assisting personnel. When reviewing the early results using computer enhanced instruments it is important to point out that the learning curve associated with the use of such systems is paralleled by the new experience of working in an endoscopic environment. This will be true for most cardiac surgeons with no or little endoscopic background. The TECAB technique warrants further discus-

Table 1

| intraoperative and postoperative data of patients undergoing TECAB |
|---------------------------|--------------|
| **Intraoperative data**    |              |
| Set-up time (min)          | 16 (11–23)   |
| ITA take down (min)        | 57 (48–137)  |
| Trimming of ITA (min)      | 15 (8–22)    |
| Pericardiotomy (min)       | 19 (14–31)   |
| Identification of LAD      | 5 (2–25)     |
| Cannulation (min)          | 19 (12–40)   |
| Dissection and arteriotomy of LAD (min) | 6 (2–26) |
| Anastomosis (min)          | 22 (15–34)   |
| Duration of CPB (min)      | 126 (61–165) |
| Clamp time (min)           | 68 (42–116)  |
| Angiography (min)          | 33 (21–49)   |
| OR-time                    | 330 (220–507)|
| **Postoperative data**     |              |
| Intubation (h)             | 13 (5–28)    |
| ICU (days)                 | 1 (0–3)      |
| Hospitalization (days)     | 7 (5–20)     |
sion especially, as it is not simply the sum of ITA takedown and performing an anastomosis. The relatively high conversion rate in the TECAB group reflects a variety of issues that became evident during this preliminary trial and initiated changes in the procedure.

4.1. Patient selection

Patients with left ventricular dilatation or anterior wall aneurysms after infarction are not ideal candidates for endoscopic bypass grafting because of the limited space between the heart and the sternum. In our series two patients with enlarged left ventricles after anterior MI’s had to be converted to a MIDCAB procedure because despite CO₂ insufflation up to an ITP of 12 mm of mercury not enough working space for ITA harvest could be created. In the beginning we tried to identify the ideal anatomy for TECAB. In general, a larger chest is desirable since it allows a larger triangle for port placement, which helps to minimize the risk for collisions. A relation between the ease of performance and the shape of the chest (barrel shaped, flat) could however not be established. Also the body-mass-index is not predictive for performance since it does not take into consideration fat distribution. In women large breasts may alter port placement. In general this should not exclude these patients from the procedure, especially in the light of the reported incidence of wound complications in obese women undergoing MIDCAB [16].

4.2. Patient positioning

To avoid external collisions between the arms we think that a supine position with a slightly elevated left shoulder and little table rotation towards the right works best. The left arm should be lowered, as less collisions occur compared to an overhead position. In addition, the risk of plexus injury that has been reported with the left arm placed over the head is minimized [6]. At our institution a radiolucent table is used to allow for intraoperative coronary angiography that we found to be very valuable for immediate quality control especially in TECAB procedures.

4.3. Port placement

The importance of optimal port placement has been emphasized by Loulmet and others before [6]. Port placement differs as compared to what has been described for manual endoscopic ITA takedown procedures [17–19]. This is mainly due to the fact that a large triangle minimizes the risk for collisions between the arms. Also, given the current system configuration with all three arms mounted on one cart, the camera is always in the center. Despite the relatively high position of the ports, motion of the right instrument arm is sometimes restricted by the patient’s left shoulder while dissecting the distal end of the ITA. It is important to have in mind that using a telemanipulator one is able to work in an ambidextrous manner. It is advisable to switch hands (i.e. work with cautery in the left hand at the distal portion of the ITA) when collisions (i.e. with the patient’s shoulder) limit the range of an instrument. This may also be helpful during the anastomosis, as some stitches are easier to perform with the left hand. Modified instruments are currently being introduced to allow a wider range of motion inside the chest. In addition an additional stand alone left sided cart for the camera arm has been successfully applied to clear the room between the instrument arms. A longer distance between the entry point and thus the remote center and the working field will theoretically minimize the risk of collisions between the manipulators. We have explored the possibility of a right side approach which has been beneficial in the cadaver lab. In one TECAB patient, port placement was mirroring the left sided approach. The right lung was deflated and the mediastinum was taken down. Coming from the right, view of the left ITA resembles that of an open case which might increase the comfort of take-down for those who do not have a major experience with manual endoscopic ITA harvest. Other possible advantages are that identification of the LAD may be facilitated since the border between the right and left ventricle is better visualized. In addition the right coronary artery can be easily identified which makes the right side approach very promising for endoscopic double ITA grafting to the RCA and LAD. Although both pleuras were opened, one lung is deflated and CO₂-insufflation was used, ventilatory problems were not encountered. For multi-vessel revascularization, a transabdominal, transdiaphragmatic approach may also be an alternative [20].

4.4. ITA take down

Harvesting of the ITA is best performed slowly using low energy cautery to allow for sufficient coagulation of side branches before cutting. This technique avoids clipping and numerous instrument changes. Smoke development is also minimized. After some adverse events in the beginning (side branch bleeding, one occlusion), ITA take down is now well standardized. In the plateau phase of the learning curve no more complications occurred. However, collisions can still occur the proximal and distal end of ITA harvest as the arms operate almost parallel to each other. It is important to alleviate any force felt by the operator at the console to minimize the risk of a sudden ‘spring’ effect while dissecting the ITA. It is also very important to maintain a high enough intrathoracic pressure as to provide as much working space between the anterior chest wall and the mediastinum as possible. In our experience an ITP up to 10 mmHg never caused significant hemodynamic impairment. This observation matches with the findings of Ohnaka et al. who demonstrated that despite a significant increase of right heart filling pressures there was no change in heart rate, arterial pressure, or LVEF during prolonged elevated ITP with endoscopic ITA take-down [21]. Accord-
ing to their findings, high gasflow rates should be avoided unless needed for gas leakage.

4.5. Prevention of pedicle torsion

In one case torsion of the pedicle caused graft occlusion and required a minithoracotomy to allow reorientation and fixation. In his report on two successful TECAB procedures Loulmet [6] pointed out that twisting can occur when control of the pedicle is lost. Reorientation can be complicated given the limited field of view which hinders viewing the entire length of the ITA. To avoid this problem, the graft is now left in situ as long as possible. A stay suture at the anastomotic site is knotted to the epicardium close to the anastomotic site, so that when the graft is finally brought down, one hand can always hold onto the pedicle, while the other hand can guide the needle through. This way constant control of orientation is provided. It is also advisable to create a small pedicle with no excess fat or muscle tissue to minimize the risk of twisting by lung excursions. Exteriorization of the distal ITA through one of the ports as has been suggested in the past [6] is not recommended as it is a potential source for graft injury as well as a possible cause of graft torsion. Using the described in situ technique for distal ITA preparation exteriorization of the graft seems obsolete.

4.6. Identification of target vessel

In the beginning the pericardiotomy was made too lateral so that obtuse marginal or diagonal branches dominated the field of view. Due to the high magnification even a small diagonal branch can, and in fact was once in our series misleadingly be taken for the LAD. We now routinely open the pericardium as medial as possible which is usually at its mediastinal attachment. Then, a window is created that extends proximally until both the pulmonary artery and the left atrial appendage are in view. Following this line, the LAD is usually easily identified. In addition it is also helpful to watch for the different contraction patterns of the right and left ventricle to determine the course of the LAD. Once identified it is helpful to mark the target vessel by a clip to the surrounding tissue. After cardioplegia has been administered and the heart is decompressed the mediastinum shifts to the right changing the view. In addition, a different scope (30° angled down or 0°) might be used later during the procedure yielding a different perspective of the heart. By initially marking the target vessel, confusion caused by changing views can be avoided later.

4.7. Cardioplegia

Any type of cardioplegia may be used but we prefer the use of crystalloid cardioplegia because it enables constant flushing of the anastomotic site which helps to keep the surgical field bloodless, even in the event of back-bleeding. However, it is important to first identify the target vessel as one disadvantage of crystalloid cardioplegia is its low contrast.

4.8. Leakage from anastomosis

There are a number of techniques to perform an ideal anastomosis and it is beyond the scope of this article to suggest that the technique used here works best. The described technique to perform an endoscopic coronary anastomosis followed the intention to perform an: (1) open anastomosis with all stitches being visible; (2) stitching inside-out of the target vessel; and (3) avoiding any knots at the heel or toe of the anastomosis. Thus, the technique resembles the parachute technique used in open cases except for the fact that it is performed without assistance. In an experimental blinded study it was shown that the quality of these computer enhanced anastomosis was equal to those that were performed manually [7]. However, it became evident in this series that the technique has its drawbacks. In order to provide enough counter-traction during suturing at least one stay suture that approximates the pedicle to the site of the anastomosis is necessary. Nevertheless, the initial three stitches in the ITA are difficult because the pliable graft creates no friction for the needle. Sharper needles may help to solve this problem. It is of utmost importance to tighten the suture after every stitch in order to avoid leakage which we saw in two cases (one in group I and III, respectively). Once the anastomosis is finished, the heel is difficult to control endoscopically. In one TECAB case we had to perform a minithoracotomy due to the leakage from the heel of the anastomosis. We found it to be helpful to anchor the unused needle of the double armed suture remote from the anastomosis in the epicardium such that it creates some tension on the thread while suturing. Since not enough force feedback is provided to judge suture tension, visual clues (straightening of the suture, lifting of tissue) must be used to grade the amount of tension that is required without breaking the thread. This requires some experience and is best trained at the bench. Finally, before knot tying, the anastomosis should be inspected for loose loops. We have not observed leakage in the most recent cases.

5. Conclusion

In summary, the system has proven its potential to perform endoscopic bypass grafting of the left ITA to the LAD on the arrested heart. The da Vinci system enables safe endoscopic ITA take down and allows for high precision during endoscopic anastomotic suturing. The concept of endoscopic bypass grafting seems promising although no long-term follow-up can as yet be provided. The procedure was constantly redefined and a number of potential problems were eliminated by the techniques described above. However, both system and procedural development are considered evolutionary and clearly there is as yet no
clear clinical benefit. It is our belief that beating heart procedures will be possible in the near future and that a technique for endoscopic multivessel revascularization will soon be developed.

References


Appendix A. Conference discussion

Dr H. Shennib (Montreal, Canada): You have gone through a learning curve and I think that you will see that your IMA takedown has plateaued around 40–50 min, your anastomosis time is also much improved, and at one point probably I suspect that there will be a plateau for this too. In other words, you have perfected it to a certain point. I would like to ask you, Volkmar, what do you see in the future? Is it going to be sort of a hand/controlled robotic sort of slave anastomosis or are we going to be moving to automated anastomotic devices?

Dr Falk: There is of course a lot of technologies that will change the way of surgery as we see it now, and I think clearly that there will be anastomotic devices that, especially in conjunction with robotic technology, may change the technique of doing anastomoses. Also I think that we might change the technique completely by adding some assistance to it. In the beginning we thought it was absolutely necessary to do this all by yourself, and of course it is very difficult to assist, but there will be ways that we can have additional assistance inside the chest, and that will improve also the times we have just shown.

Dr A. Moritz (Frankfurt, Germany): I have just one technical question. Besides all the problems you indicated, we also found that during dissection of the mammary you usually get very strict spasm of the vessel. Do you have any ideas how to overcome it, because if you have to sew on this small area, or the breast, you are actually working on a virtually small structure and spastic vessel, you are actually working on a virtually small structure. Do you have any ideas how to overcome it, because if you have to sew on this small and spastic vessel, you are actually working on a virtually small structure that increases, and maybe some of the bleeding problems encountered in many institutions may be due to this spasm.

Dr Falk: I have to say that we have not seen so many spasms, and I think that clearly if you have a long enough pedicle it shouldn’t be too much of a problem. However, it is of course true that you have only limited possibilities to manage everything, and if there is any doubt about the quality of graft, we would rather consider a conversion, which we have done in the past.

Dr A. Schuele (Dresden, Germany): The results pretty much match our experience, especially the IMA takedown time. I have seen on one of the pictures that you still use four incisions. Do you think it is necessary to use fourth one, because in the recent cases we have used three incisions?

Dr Falk: It is not absolutely necessary to have four incisions, and Diedier Loumet has shown that previously, too, that you can do the procedure through three incisions only. We still feel very confident of having one additional port to hand in suture matter, and I don’t know if there is a really big difference between three or four ports. I would even add another port if I could get some assistance to the procedure. But you are, of course, right, you can do it through three ports only.