Institutional review

Totally endoscopic coronary artery bypass grafting on the arrested heart is a prerequisite for successful totally endoscopic beating heart coronary revascularisation

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Abstract

Telemanipulators have been introduced into cardiac surgery recently expanding the scope of minimally invasive techniques and enabling endoscopic cardiac surgery. Our aim was to evaluate clinical results of totally endoscopic single vessel bypass grafting on the arrested as well as on the beating heart. Since 1999, 44 totally endoscopic single vessel arterial bypass grafting procedures were performed at our institution. Thirty-eight procedures were performed on the arrested heart (group A), and six such procedures on the beating heart (group B) using the daVinci telemanipulation system. In group A, totally endoscopic coronary artery bypass grafting (TECAB) with left internal thoracic artery (LITA) to left anterior descending artery (LAD) was performed in 33 patients and right internal thoracic artery (RITA) to right coronary artery (RCA) grafting in five cases. The overall conversion rate in group A was 18.4% and dropped down to 5% in the last 20 cases. In group B (n = 6), four patients received successful LITA to LAD grafting; two patients (33%) required conversion to minithoracotomy. The first 22 TECAB patients of group A (58%) had control angiography and demonstrated excellent graft patency upon discharge. All grafts in group B showed excellent function on angiographic control as well. The mean procedural time for single vessel TECAB was 4.2 ± 0.9 h, cardiopulmonary bypass (CPB) time was 136 ± 32 min and aortic cross-clamp time amounted to 61 ± 16 min. The present data show feasibility of totally endoscopic single arterial grafting on the arrested heart in a reproducible manner, though procedural times were still prolonged due to the difficult handling of the port access system and the complex time consuming endoscopic operation. A low conversion rate was achieved in arrested heart TECAB after a relatively short learning curve and is mandatory for successful totally endoscopic off-pump bypass grafting.

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1. Introduction

The use of robotically enhanced telemanipulation provides an alternative technique for endoscopic internal thoracic artery (ITA) dissection or construction of ITA to coronary anastomosis in the closed chest setting. Several groups have published data confirming the feasibility and safety of totally endoscopic coronary artery bypass grafting (TECAB) with the final goal to further minimise surgical trauma, reduce risk of wound infection, preserve a stable chest cavity, and thus to achieve a good cosmetic and functional result [1–3]. However, the experience in complete totally endoscopic procedures is limited to relatively small patient cohorts and limited information is available in the literature with regard to the success rate of TECAB or totally endoscopic off pump bypass surgery (TOPS). TECAB on the arrested heart using Port Access technology has been first published in 1999 and today appears to be a reproducible but time consuming procedure [1–3]. The first clinical reports on totally endoscopic off pump surgery reveal a high conversion rate [2]. The avoidance of cardiopulmonary bypass in closed chest surgery is crucial not only in order to reduce side effects of extracorporeal circulation [4] but also to refine procedural flow and shorten the operative time.

This series reflects 44 patients with the intention to treat...
as totally endoscopic revascularisation of the left anterior descending artery (LAD) or right coronary artery (RCA).

2. Patients and methods

After institutional ethical committee approval was obtained, and each single patient gave written informed consent, all consecutive patients without contraindication to port access surgery with single vessel disease of the LAD or the proximal RCA were approached as complete closed chest procedures [5].

The first TECAB procedure on the arrested heart (group A) was performed at our institution in 1999. In June 2001, the first patient received totally endoscopic left internal thoracic artery (LITA) to LAD bypass on the beating heart (TOPS, group B).

Average age of the 38 patients (25 males, 13 females) in group A was 58.4 ± 7.7 years vs. 50 ± 7.1 in group B (values are mean ± standard deviation). Left ventricular ejection fraction in group A was 61 ± 5% vs. 65 ± 4% in group B. Data analysis was performed with the Statview IV software package (Abacus Concepts, Berkeley, CA). Descriptive values are given as mean ± standard deviation.

2.1. Anesthesia for totally endoscopic procedures

After standard induction of anesthesia, patients underwent double lumen intubation for single lung ventilation. In group A, both radial arteries were cannulated for invasive monitoring of the endoaortic clamp. In addition, a pulmonary artery vent catheter was inserted percutaneously through the right jugular vein to decompress the heart. In group B, the monitoring was less extensive. However, all patients had continuous transesophageal echo (TEE) monitoring to assess cardiac function (group A).

2.2. Operative technique for TECAB on the arrested heart

The technique for TECAB on the arrested heart was described in detail by several groups [6,7]. Also, the components of the da Vinci surgical system with remote tissue manipulation were described elsewhere [8].

2.3. Operative technique for totally endoscopic off pump surgery

The positioning of the patient on the OR table is similar to a TECAB procedure on the arrested heart. After endoscopic harvesting of the left ITA and pericardiotomy a fourth port (12 mm) is placed under the left costal arch to introduce an endoscopic stabilizer (Intuitive Surgical, Mountainview, CA). The latest version of this instrument has a flexible, endo-wristed tip, which resembles stabilizers known from open beating heart surgery. It is positioned at the target site by the patient side surgeon moving the shaft and the remote surgeon directing the tip of the stabilizer with two instruments. This stabilizer provides mechanical stabilization of the target region by applying pressure on the epicardium as well as attachment to the heart by vacuum (Fig. 1). After exact positioning, the stabilizer is rendered stiff and immobile by a pneumatically driven iron intern which is attached to the OR table. After observing hemodynamics, the silastic loops are placed around the LAD to achieve proximal and distal control. The anastomosis of the ITA to the LAD is performed in the same fashion as described previously for the arrested heart technique.

![Fig. 1. The endoscopic stabilizer for totally endoscopic coronary artery bypass on the beating heart (TOPS).](https://academic.oup.com/icvts/article-abstract/1/1/30/683340)
3. Results

Forty-four consecutive patients with single vessel coronary artery disease were revascularised without opening the chest. In group A, 38 patients underwent totally endoscopic LITA to LAD \( (n = 33) \) or RITA to RCA \( (n = 5) \) grafting on the arrested heart. Mean procedural time and intraoperative data as well as postoperative course are shown in Table 1.

In group A, the total conversion rate was 18.4%. Looking at the last 20 patients of this group, the conversion rate dropped down to 5%. Six patients required controlled conversion to minithoracotomy (anastomotic bleeding \( n = 2 \), prolonged cross-clamp time \( n = 1 \), difficulty to advance the Port Access endoclamp \( n = 2 \), injury to the ITA \( n = 1 \)). Two patients were reoperated due to bleeding from the anastomotic site, one of them under resuscitation. Unfortunately, this patient suffered a hypoxic brain damage. One TECAB patient with LITA to LAD grafting suffered a postoperative myocardial infarction due to vasospasm of the right coronary artery with subsequent PTCA and stent implantation. Except for one groin hematoma after femoral cannulation, there was no wound infection in group A.

The first 22 (58%) patients of group A received control angiograms prior to discharge from the hospital. Except for one ITA graft displaying a 50% stenosis in the middle segment all other grafts were patent with good function. We therefore stopped performing control angiography after the initial series to decrease costs and increase patient comfort. Fig. 2 shows a control angiogram of a LITA to LAD bypass performed on the arrested heart.

In group B, four patients received successful LITA to LAD grafting on the beating heart using an endostabilizer; two patients (33%) of group B required conversion to minithoracotomy: one conversion was due to ischemia intolerance on occlusion of a severely diseased LAD. The second conversion was necessary due to break of an endoscopic tool, which we had to take out of the chest via a left-sided minithoracotomy. All grafts in group B showed excellent function on angiographic control. The corresponding control angiogram is shown in Fig. 3.

4. Discussion

The necessity of surgical revascularisation of the LAD became a rare indication since the cardiologic repertoire

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Table 1  
Intra- and postoperative data of totally endoscopic coronary artery bypass on the arrested (group A) and on the beating heart (group B)

<table>
<thead>
<tr>
<th></th>
<th>Group A (arrested) ( (N = 38) )</th>
<th>Group B (beating) ( (N = 6) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR time (min)</td>
<td>246 ± 54</td>
<td>282 ± 48</td>
</tr>
<tr>
<td>CPB time (min)</td>
<td>138 ± 32</td>
<td></td>
</tr>
<tr>
<td>Cross-clamp time (min)</td>
<td>60 ± 16</td>
<td></td>
</tr>
<tr>
<td>Port placement time (min)</td>
<td>14.8 ± 5.7</td>
<td>17.3 ± 6.0</td>
</tr>
<tr>
<td>ITA harvesting (min)</td>
<td>62.3 ± 21</td>
<td>53.0 ± 10.6</td>
</tr>
<tr>
<td>Endoscopic anastomosis</td>
<td>18.2 ± 3.8</td>
<td>29.5 ± 5.3</td>
</tr>
<tr>
<td>Overall conversion rate</td>
<td>18.4%</td>
<td>33%</td>
</tr>
<tr>
<td>Postoperative data</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation time (h)</td>
<td>18 ± 15</td>
<td>15 ± 12</td>
</tr>
<tr>
<td>Chest tube drainage 24 h (min)</td>
<td>319 ± 146</td>
<td>278 ± 169</td>
</tr>
<tr>
<td>ICU stay (h)</td>
<td>24 ± 21</td>
<td>22 ± 3</td>
</tr>
<tr>
<td>Hospital stay (days)</td>
<td>8.6 ± 2.7</td>
<td>6.8 ± 1.6</td>
</tr>
<tr>
<td>Postoperative atrial fibrillation</td>
<td>3 (8%)</td>
<td>0%</td>
</tr>
</tbody>
</table>
with PTCA and stent implantation takes care of the majority of LAD lesions. In selected cases such as LAD occlusion or ostial lesions, however, the interventional treatment option appears to be too risky, so that minimally invasive operative revascularisation is desirable [8]. The standard minimally invasive approach to operative LAD revascularisation is either the MIDCAB or OPCAB technique. Both methods yield good results [9–11] but still require some opening of the chest. Robotic telemanipulators were introduced into cardiac surgery with the goal to further minimize the surgical access and finally enable totally endoscopic procedures.

We operated the first group of patients (A) on the arrested heart using port access technology providing optimal conditions to perform a telemanipulated anastomosis with the daVinci system. The cardiopulmonary bypass (CPB) via the port access cannulation system is a complex method in which every single step not only of the venous and arterial cannulation but also of the endoclamping is guided by TEE. This requires an experienced echocardiographer, who has to stay in the OR throughout CPB time. Secondly, the retrograde perfusion via the femoral artery with the addition of a prolonged CPB time is associated with an increased risk for neurologic complications [12]. The risk of retrograde aortic dissection has been reported by several groups and constitutes a serious threat for the patient [13]. Taking these complex modalities of endoscopically guided surgery and CPB via the port access system into account, and adding the extended anesthesiologic monitoring requirement including echocardiography, it is obvious that only a highly specialized team with devoted team members is necessary to refine procedural flow, shorten operating time and thus decreasing the conversion rate.

One reason for conversion, reported by other groups, is that the coronary target vessel cannot be identified due to intramural course. A second problem may appear in heavily calcified vessels, which cannot be anastomosed in endoscopic technique. We used preoperative multidetector CT scan (MDCT) to assess the location of the coronary target and to evaluate coronary wall quality [14]. This helps in preoperative planning to identify candidates, who are not suitable for an endoscopic approach, and to further reduce conversion rate. Thus we were able to revascularize five patients with intramural LAD successfully in totally endoscopic technique. One diagnostic tool, routinely used in such patients is preoperative Doppler flow measurement of femoral vessels to identify candidates not suitable for port access surgery. After such extensive preoperative preparation, we schedule patients for an endoscopic procedure and consider every intraoperative change of technique to minithoracotomy as a conversion case (intention to treat). The initial conversion rate of 18.4% in our series dropped to a minimum of 5.0% with growing experience of all team members and only after having overcome all the technical problems with the videoendoscopically guided technique.

In our series of single vessel revascularisation, we were confronted with different intraoperative problems leading to a controlled conversion to minithoracotomy. Bleeding from the anastomosis occurred partly because the running suture line was not tight enough or the operative field was not exposed adequately. Interrupted suture clips have been evaluated by other groups and may be appropriate in this scenario but have not been studied so far in this cohort. Adequate port placement was possible in all patients including extremely obese women with large breasts allowing sufficient endothoracic movement of the instruments. We believe that especially these patients benefit from an endoscopic procedure because the risk of wound infection is reduced to a minimum. Two patients were converted to minithoracotomy due to problems associated with port access surgery. Using port access technology in totally endoscopic surgery, two sophisticated techniques are combined, which prolong OR time and carry a potential higher risk for complications. The introduction of the TOPS technique eliminates these specific problems and may help to shorten the procedural time and enhance patient safety.

The threshold to convert a totally endoscopic operation to an open technique may be set at different levels depending on various factors. Especially, when a robotic program is initiated the threshold should be low, since a prolonged operating time with a long CPB time may increase the operative risk. Secondly, the team may be frustrated and the acceptance of such a procedure may decrease.

One patient suffered a serious complication. He had to be reexplored on the intensive care unit due to bleeding from a myocardial injury. Unfortunately, this had to be done under resuscitation with the sequelae of a hypoxic brain damage. Since opening of a patient, who underwent a totally endoscopic cardiac procedure, is more time consuming and requires the appropriate tools we strongly recommend to have a battery driven sternal saw available on the ward. One patient developed postoperative myocardial infarction due to extreme vasospasm of the right coronary artery. This patient had previous totally endoscopic left ITA to LAD grafting so that the complication was not at all associated with the procedure.

Despite attempts to perform totally endoscopic surgery with the help endo-wristed and other telemanipulated systems (Zeus, Computer Motion Inc, Goleta, Calif.) on the beating heart the success rate of such procedures remains controversial. After modification of the initial version of the stabilizer sufficient epicardial immobilization of the target site seems to be achieved. Our impression is that pressure to the epicardium is contributing more to stabilization than does vacuum attachment. The second issue of TOPS is that usually the amount of space between the heart and the chest wall is limited. CO₂ insufflation up to 16 mmHg is our current technique to create space, always taking into account the risk of impaired diastolic function at higher levels of insufflation. A shift of the heart occurs when CO₂ leaks out of the chest while the stabilizer is still in place and may cause significant injury. Therefore strategies of
expanding the space, which is required for sufficient endostabilization and instruments, are currently being evaluated at other centers. Anastomotic suturing on the beating heart may be impossible due to backbleeding from septal perforating branches. However, clearing of the anastomotic site via an additional irrigation line of the stabilizer was sufficient in our early experience.

Overall, further development is necessary with regard to endostabilisation and may be necessary for endoluxation of the heart to expose the target site. If these requirements are achieved other target vessels may be addressed. For our group the experience on the arrested heart was very helpful to handle the emerging problems of totally endoscopic beating heart surgery. Only after reaching a reasonably low conversion rate in arrested heart TECAB we would suggest to approach TOPS.

### References


### Appendix A. Conference discussion

**Dr B. Messmer (Aachen, Germany):** I have three things. One is the preoperative imaging. We know that the technique is not really safe until now to see the vessel all the way down to the periphery, and so you may run into troubles. This is one question.

The second question is with regard to the right coronary artery. You said that you can anastomose the mid part but not the distal part. Can you go to the crux, because the bifurcation is the site of the most stenosis we see on the right coronary artery? It may even be sometimes very difficult to reach with the right internal mammary all the way down to the crux cordis. This is my second question.

And the third one has to do something with the first one. Can you really always properly identify not only the vessel but also the optimal site of the anastomosis, because sometimes you have more than one stenosis in the LAD and you need to split one or to have the optimal site for the anastomosis?

**Dr Dogan (Frankfurt, Germany):** I will answer the first and third question first. With the additional information we get from the CT scan, it is possible to identify superficial LADs from intramural vessels, and since the operation is completely different, you don’t have the same feedback as in conventional surgery, it really sometimes is very difficult to identify the optimal target site because you don’t feel your finger in there. So that additional MDCT imaging has helped us a lot to find the appropriate target site. Then, with the endoscopic approach, it is possible to dissect the whole length of the IMA, starting from the subclavian artery all the way down to the end bifurcation, and actually I can’t remember a case where we couldn’t reach far enough to the apex to put down the anastomosis. Actually we did injure two IMAs and had to convert for that reason, but length was never a problem.

And with regard to the right coronary, you are right, it is not possible to go to the crux of the vessel, IMA length is one reason, and the second reason is that you need additional stay sutures on the surface of the heart to pull up the acute margin and to expose properly the anastomotic site. So what we did is we selected patients with ostial lesions where we could go to the mid portion.

**Dr A. Mazzacone (Verona, Italy):** I would like to congratulate you and your group for this technically really appealing work, but looking at this issue from another aspect, in light of the contents of the paper which has not been presented, which was referring to the need for a complete revascularization, and having in mind what is going to be presented by the next paper which is about the general quality of the coronary arterial tree which every day we are going to face with, how often are you in a position of getting the right patients and how often are you going to conflict with the interventional cardiologist to treat by endoscopic surgery these patients?

**Dr Dogan:** I agree with you, the main problem is that only very few patients with single vessel disease show up in our practice, but every one of us knows that sometimes cardiologists put in several stents into the LAD or do multiple PTCAs, and since the restenosis problem is still not solved with the interventional approach, there are patients out there requiring a mono bypass to the LAD. We see one such patient with single vessel disease in one to two weeks. It is not a big population of patients, of course, but we have cardiologists who refer precisely for minimally invasive bypass grafting of the LAD. Whether we should go to multivessel revascularization, I don’t know. It is a very difficult question because it is very challenging and only a few patients had multivessel grafting. So this is still the future.