Technique of closed chest coronary artery surgery on the beating heart

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Abstract

Objective: The application of an endoscopic stabilizer (Intuitive Surgical, Mountain View, CA, USA) enables closed chest off-pump coronary artery bypass via a four-point stab incision avoiding sternotomy and minithoracotomy. Methods: Between May 1999 and January 2001 we operated upon a total of 37 patients (five female, 32 male, median age 62 ± 9 years) suffering from coronary artery disease using totally endoscopic coronary artery bypass (TECAB), whereas an initial series of eight TECAB patients was operated upon using an endovascular bypass system (Heartport). The da Vinci surgical system was used in order to perform left internal mammary artery (LIMA) or right internal mammary artery (RIMA) harvesting and anastomoses on a beating heart in 29 patients (four female, 25 male, median age 64 ± 9.8 years). Altogether 26 patients suffering from single-vessel coronary artery disease (SVCAD) were revascularized applying LIMA to the left anterior descending artery (LAD) and three patients with two diseased coronary vessels received bilateral internal mammary artery grafting (BIMA), respectively. Results: In this series we had a 100% survival rate. Conversion rate to a median sternotomy was 3.4%. Patients were operated upon via four 1-cm chest incisions using the da Vinci robot for LIMA or BIMA harvesting and for performance of anastomoses on the beating heart. In the overall series of 56 patients intended to be treated by TECAB, 19 (33.9%) were converted to a minimally invasive direct coronary artery bypass procedure. Conclusion: This new robotic-enhanced surgical technique promotes an optimistic way of thinking about the further development of this procedure and its application in patients suffering from single-vessel CAD.

Keywords: Robotic enhanced surgery; Totally endoscopic coronary artery bypass; Off-pump coronary artery surgery; Endoscopic surgery; Minimally invasive cardiac surgery

1. Introduction

In the thrive towards a minimization of access in minimally invasive cardiac surgery (MICS) wrist-enhanced robotic instrumentation is currently leading to a turning point in the history of MICS as totally endoscopic coronary artery bypass (TECAB) grafting procedures become feasible [1–6].

With well-established minimally invasive cardiac surgical techniques getting enhanced by robotic procedures, a broader array of patients suffering from coronary artery disease (CAD) becomes eligible for minimally invasive operations avoiding sternotomy.

New technical innovations, such as the introduction of endoscopic stabilizers into MICS, enables TECAB procedures of CAD via four 1-cm chest incisions on the beating heart and the avoidance of extracorporeal circulation (ECC).

The present paper includes an initial series of totally endoscopic off pump coronary artery bypass grafting in 29 patients (four female, 25 male, median age 64 ± 9.8 years) suffering from CAD operated upon at the Dresden Cardiovascular Institute.

2. Methods

Between May 1999 and January 2001 a wrist-enhanced robotic system (da Vinci, Intuitive Surgical, Mountain View, CA, USA) was used in 201 patients (156 male, 45 female, median age 64 ± 10.5 years; left ventricular ejection fraction (LVEF) 68 ± 12.4%).

Out of this whole patient group 37 patients (five female, 32 male, median age 62 ± 9 years) underwent a TECAB procedure since the installation of the system in May 1999. An initial series of eight TECAB patients was operated upon using an endovascular bypass system (Heartport,
Redwood City, CA), whereas the latter patients received a beating-heart TECAB treatment.

The beating-heart TECAB procedure consists of two steps. The harvesting of the left or right internal mammary artery (LIMA/RIMA) and suturing of the coronary anastomoses. Both steps were performed using the three-dimensional-based computer-enhanced surgical system in the 29 patients (four females, 25 males, median age 64 ± 9.8 years) out of the beating-heart TECAB group. Altogether, 26 patients suffering from single-vessel coronary artery disease were revascularized applying LIMA to left anterior descending (LAD) grafting and three patients with two diseased coronary artery vessels received bilateral internal mammary artery grafting on a beating heart, respectively.

Preoperatively, 3.4% of the patients were in Canadian Cardiovascular Society (CCS) stage I, 41.4% in stage II, 54.7% in stage III and 3.4% in stage IV; 6.9% of the patients in New York Heart Association (NYHA) class I, 58.6% in class II, 34.5% in class III and 0% in NYHA class IV.

The patients had a complete follow-up including physical examination, 12-lead ECG and chest X-ray on the first and seventh postoperative day. All patients were scheduled for a stress ECG and clinical examination 4 weeks after surgery and for a clinical examination after 3 months. No routine postoperative angiography was performed. A 1-year follow-up including coronary angiography is still planned.

Exclusion criteria were decreased LVEF (<40%), decreased lung function (FEV1 < 1.0), obesity (body mass index (BMI) > 35) and intramyocardial LAD course or diffuse coronary artery sclerosis.

Perioperative data on age, sex, BMI, LVEF, left ventricular end diastolic pressure, duration of surgery, duration of endoscopic IMA dissection, duration of bypass, vessels affected by coronary sclerosis and actually performed anastomoses, ventilation time, intensive care unit stay and hospitalization were analyzed (Tables 1 and 2).

The patients are placed in supine position with the left arm resting slightly beneath the posterior axillary line. After introduction of general anesthesia a double lumen tube or an endotracheal blocker is used for single-lung ventilation during surgery.

The three 1-cm skin incisions are placed in the left chest in the third intercostal space (ICS) at the medioclavicular line for the right port, in the fifth ICS at the anterior axillary line for the central optical port and in the sixth ICS at the medioclavicular line for the left port, forming a triangle whose angle may vary depending on the habitus of the patient (Fig. 1).

Through the camera port warmed and humidified CO₂ insufflation is started at pressures between 5 and 10 mmHg. The camera system is then introduced via this central port. Following a brief exploration of the left chest cavity and identification of the LIMA, the slave unit of the da Vinci surgical system is placed to the right of the patient and the two other ports are introduced.

A slight upward movement of the camera port under CO₂ insufflation improved IMA dissection due to increase of the precordial space, which is essential for IMA takedown and left anterior descending artery (LAD) grafting. Using 30-W cautery, endoscopic LIMA takedown is begun, creating a pedicle.

Endoscopic internal mammary artery (IMA) takedown is always performed using the three-armed da Vinci robotic unit via three 1-cm chest incisions, choosing a single left-sided approach with the patient being placed on single right lung ventilation.

After IMA takedown via the three 1-cm chest incisions, the preparation of the IMAs for anastomosis is performed inside the chest of the patient in the case of TECAB or done under direct sight with the pedicle being pulled through the chest incision in the case of REDTCAB (robotic enhanced ‘Dresden Technique’ coronary artery bypass) [7,8] or MIDCAB (minimally invasive direct coronary artery bypass). The initial marking of the LIMA course in case of a planned bilateral IMA takedown is mandatory, as pedicle injury to the left IMA through the instrumentation can be avoided.

After IMA harvesting a vessel clamp is introduced via the skin incision at the level of the third ICS and is placed on the proximal IMA. Heparin is administered in order to achieve an ACT (anti-coagulation time) above 300 s.

The pericardial fat is then resected and the pericardium is opened in a rectangular fashion exposing the LAD. The LIMA pedicle is then dissected for anastomosis.

Via a further fourth 1-cm skin incision at the subxyphoidal area the endoscopic stabilizer is introduced. This endoscopic

<table>
<thead>
<tr>
<th>Technique</th>
<th>TECAB (on pump)</th>
<th>TECAB (off pump)</th>
</tr>
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<tbody>
<tr>
<td>Time of surgery (min)</td>
<td>280 ± 80.2</td>
<td>174 ± 65.6</td>
</tr>
<tr>
<td>LIMA harvesting time (min)</td>
<td>50 ± 16.9</td>
<td>34.5 ± 8.2</td>
</tr>
<tr>
<td>RIMA harvesting time (min)</td>
<td>54</td>
<td>42 ± 1.2</td>
</tr>
<tr>
<td>Time of anastomosis (min)</td>
<td>28 ± 5.1</td>
<td>30.5 ± 9.7</td>
</tr>
<tr>
<td>Cross-clamping time (min)</td>
<td>70 ± 6.1</td>
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</tbody>
</table>

* TECAB, totally endoscopic coronary artery bypass; LIMA, left internal mammary artery; RIMA, right internal mammary artery.

### Table 2

<table>
<thead>
<tr>
<th>Technique</th>
<th>Grafted vessels and used conduits</th>
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<tbody>
<tr>
<td>TECAB (on pump) (n = 8)</td>
<td>LIMA-LAD (n = 7)</td>
</tr>
<tr>
<td>TECAB (off pump) (n = 29)</td>
<td>LIMA-LAD (n = 26)</td>
</tr>
<tr>
<td></td>
<td>LIMA-D (n = 2)</td>
</tr>
<tr>
<td></td>
<td>LIMA-OM (n = 1)</td>
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<td></td>
<td>RIMA-LAD (n = 3)</td>
</tr>
</tbody>
</table>

* TECAB, totally endoscopic coronary artery bypass; LIMA, left internal mammary artery; RIMA, right internal mammary artery; LAD, left anterior descending coronary artery; OM, obtuse marginal branch of the circumflex artery; D, diagonal branch.
device consists of two branches, like common beating-heart stabilizers. However, the branches can be guided from outside the chest. A joint at the heel of the stabilizing device allows a precise and stable positioning at the anastomotic site. For the attachment of silastic vessel loops, for later coronary occlusion, special cleats are placed on these branches ensuring a firm hold for the loops during coronary artery occlusion. An irrigation tube is attached above the heel-joint of the endostab, allowing saline-flushing for clear visualization of the desired anastomotic area (Fig. 2).

With the proximal and distal vessel loops placed along the site of anastomosis area, using the two robotic arms and after proper placement of the stabilizer on the LAD, blood flow through the coronary vessel is temporarily interrupted by tightening the loops. The anastomosis is then completed using wrist-enhanced instrumentation and a 7/0 polypropylene running suture.

After the anastomosis is completed, the vessel clamp is released and the anastomosis is explored for leakage. Protamine is administered and the actuators and camera are removed. The insertion of a soft thoracic catheter through the 1-cm incision in the six ICS in combination with subcutaneous and skin sutures completes the procedure.

Before transferral of the patient to the intensive care unit, a single-lumen endotracheal tube replaces the double-lumen endotracheal tube or the endotracheal blocker is simply removed.

3. Results

Survival was 100%. All patients left the operating room without inotropic support in sinus rhythm and without signs of acute myocardial ischemia.

Conversion to a median sternotomy was necessary in one patient (3.4%) due to damage to the left IMA. In the overall series of 56 patients intended to be treated TECAB, 19
(33.9%) were converted to a MIDCAB procedure. Hence, in five patients LAD identification was not possible endoscopically. Diffuse sclerosis of the LAD (five patients), difficulties with endoscopic stabilization (three patients), pleural adhesions (two patients), intramural course of the LAD (two patients) and two patients with an insufficient occlusion of the LAD were factors for a conversion to a MIDCAB procedure.

In three (10.3%) of the patients an explorative second-look control was performed because of increased postoperative drainage. Bleeding muscle tissue adjacent to the ports was coagulated thoroughly and hemostasis regained.

Perioperative data are listed in Table 1. The pattern of coronary vessels grafted and conduits used are listed in Table 2. Three (10.3%) patients with coronary artery disease affecting more than one vessel were treated with bilateral IMA (BIMA) grafting. In two cases with hypoplastic circumflex system and big LAD and diagonal branch BIMA grafting was applied. In one case with a double-vessel CAD, BIMA grafting proved feasible and was hence performed.

No routine postoperative angiography was performed, and a 1-year follow-up control angiography is planned. As a limitation to the study this should be noted. One patient developed chest pain on postoperative day 1. A consecutive coronary angiography revealed complete patency of the anastomosis (Fig. 3).

The initially long duration of surgery could be significantly shortened after the introduction of the beating-heart TECAB procedure (Fig. 4), since no ECC was used.

Troponin-T and creatine kinase/creatine kinase-myoglobin (CK/CK-MB) fractions were always within normal levels, thus excluding myocardial infarction. Postoperative ventilation time was $4 \pm 8.1$ h and intensive care unit stay amounted $21 \pm 20$ h. The patients were discharged from hospital on postoperative day $6 \pm 1$.

A 4-week postoperative stress ECG and 12-week postoperative clinical examination of all patients is still going on. So far this short-term follow-up was performed in $55.2\%$ and revealed no signs of myocardial ischemia. However, one patient (3.4%) claimed to suffer from angina 4 weeks postoperatively. Coronary angiography revealed a progradient lesion of the circumflex artery and the patient had an uneventful percutaneous transluminal coronary angioplasty.

Twelve weeks postoperatively, so far 81.2% of the patients were in Canadian Cardiovascular Society (CCS) stage I, 12.5% in stage II and 6.3% in stage III; 68.7% of the patients in New York Heart Association (NYHA) class I and 31.3% in class II.

4. Discussion and conclusion

With the installation of a computer-based robotic surgical system at our institution in May 1999 we were able to treat CAD using a computer-enhanced fully endoscopic minimally invasive surgical technique without sternotomy and thoracotomy.

The technical development of an endoscopic stabilizer (Intuitive Surgical, Mountain View, CA, USA) led to a beating-heart closed-chest procedure via four 1-cm chest incisions. With the demonstrated surgical technique at hand, an optional new concept for the minimally invasive surgical treatment of CAD can be developed [9,10].

The conversion rate to a MIDCAB procedure (33.9%) may decline in the future by growing experience with this new endoscopic technique. Further technical improvements concerning LAD occlusion, endoscopic stabilization, and better LAD identification may lead to overcome the present obstacles. One out of three patients with the current technical standard so far applied becomes eligible for a true beating-heart TECAB.

The feasibility of endoscopic BIMA grafting on the beat-
The heart cannot be judged overenthusiastically. It may only be beneficial to a very peculiar patient group and still poses controversial discussion.

Proper port placement setup plays an essential role in this endoscopic bypass procedure. The robotic arm placement setup is paramount to reduce the degree of difficulty, ensuring the success of the procedure (Fig. 1). The previously postulated rule of creating a triangle-like port arrangement in the left chest of the patient is not always reliable to ensure a safe case. Modifications have to take place in accordance with the patient’s habitus.

By experience and intuition the surgeon will, however – keeping this golden rule in mind – create an arrangement, which is suitable for ensuring proper instrumentation movement inside and outside the chest by a careful evaluation of the patient intercostal spaces, rib cage, body mass index, breast size and tissue rigidity. The ports have to be moved according to these factors (Fig. 1) to avoid actuator collisions.

Our early experiences using an essential alternative to conventional heart surgery are positive and represent only the first steps towards future developments. Closed-chest OPCAB grafting of SVCAD was performed using the da Vinci system. This new minimally invasive technique is a promising alternative for patients suffering from SVCAD, avoiding median sternotomy and minithoracotomy.

Six days of hospitalization may seem prolonged for a minimally invasive procedure; it is, however, related to the German medical care system. A further reduction of the postoperative hospital stay, down to 3–4 days, seems to be possible.

The TECAB technique on the beating heart is a unique and new method for the surgical treatment of coronary artery disease. The surgical procedure performed without any thoracotomy via a four-point stab incision allowed to fully maintain the integrity of the chest wall. Postoperative convalescence with only little visible scars is excellent (Fig. 5).

In our opinion, the report on our initial experience described herein reflects a major step forward towards a future totally endoscopic surgical treatment of patients with more complex coronary artery pathology, especially for patients showing serious risk factors for extracorporeal circulation and sternotomy-related complications.

References


Fig. 5. The image shows a patient after a TECAB procedure on the beating heart on postoperative day 7.