Remote access perfusion for minimally invasive cardiac surgery: to clamp or to inflate?†

Christoph Krapf*, Peter Wohlra, Sarah Häußinger, Thomas Schachner, Herbert Hangler, Michael Grimm, Ludwig Müller, Johannes Bonatti and Nikolaos Bonaros

* Department of Cardiac Surgery, Medical University Innsbruck, Innsbruck, Austria
** Cleveland Clinic Abu Dhabi, Abu Dhabi, United Arab Emirates

* Corresponding author. Department of Cardiac Surgery, Medical University Innsbruck, Anichstraße 35, A-6020 Innsbruck, Austria. Tel: +43-512-50480773, fax: +43-512-50422528. e-mail: christoph.krapf@uki.at (C. Krapf).

Received 18 October 2012; received in revised form 28 December 2012; accepted 8 January 2013

Abstract

OBJECTIVES: Endoaortic balloon occlusion (EBO) and aortic transthoracic clamping (TTC) are the dominant methods of remote access perfusion (RAP) in minimally invasive cardiac surgery. The aim of the study was to compare the two methods in terms of feasibility, success and complications.

METHODS: From June 2001 to November 2011, 307 (median age; range) (57; 16–77 years) and 460 (62; 11–88 years) patients underwent minimally invasive CABG, ASD and mitral valve surgery using EBO and TTC, respectively. Perioperative procedure feasibility, success and postoperative complications were recorded.

RESULTS: Overall 30-day mortality was 0 and 2 (0.43%) for the EBO and TTC groups, respectively (P = 0.52). Overall and RAP-associated conversions were noted in 21 (6.8%) and 4 (1.3%) patients in the EBO and in 9 (2%) and 6 (1.3%) patients in the TTC groups (P < 0.001, P = 1.00, respectively). Incidence of major complications, including aortic dissection, major vessel perforation, injury of intrapericardial structures, limb ischaemia, myocardial infarction and neurologic events, was similar [EBO: 12 (4%); TTC: 11 (2.4%); P = 0.23]. Minor complications such as minor vessel injury, groin bleeding or lymphatic fistula were noted in 31 (10.1%) and 35 (7.6%), respectively (P = 0.23).

Successful RAP procedures defined as absence of RAP-associated conversions and major complications were equal [EBO: 295 (96%); TTC: 449 (97.6%); P = 0.23]. Complications detected during follow-up included pain: 30 of 249 (12%) and 13 of 279 (4.7%) (P = 0.002); sensational disturbances: 60 of 249 (24.1%) and 40 of 278 (14.4%) (P = 0.005) and wound-healing complications: 49 of 249 (19.7%) and 42 of 277 (15.2%) (P = 0.172) for EBO and TTC, respectively.

CONCLUSIONS: RAP can be successfully and safely implemented in minimally invasive cardiac surgery. EBO and transthoracic clamping of the ascending aorta are performing equally in terms of feasibility and procedural success.

Keywords: Remote access perfusion • Minimally invasive cardiac surgery • Procedural outcomes

INTRODUCTION

Minimally invasive cardiac surgery has been well established in the last decades and has evolved towards smaller incisions with the benefit of less surgical trauma, shorter hospitalization, decreased pain and better cosmesis [1–4]. A prerequisite for this trend was the development of remote access perfusion (RAP) systems over peripheral vessels for establishing cardiopulmonary bypass (CPB), systems for aortic occlusion, introduction of cardioplegia and venting. Two methods have been well established: Transthoracic clamping (TTC) and endoaortic balloon occlusion (EBO) systems [2, 5–7]. While TTC is a relatively cost-effective and easy-to-apply method providing the opportunity of establishing CPB via a different access and using conventional antegrade cardioplegia over the aortic root, EBO is the only established system that enables port-only endoscopic cardiac surgery, does not require a cardioplegia cannula in the ascending aorta and allows aortic clamping and cardioplegia administration in redo cases without the need to free dissect the ascending aorta.

New applications are often accompanied by disadvantages. Thus, the TTC and the cardioplegia cannula can cause aortic dissection, as well as severe bleeding of the ascending aorta, pulmonary artery or the left atrial appendage [8]. They can also interfere with surgical instruments and the videoscope. On the other hand, EBO can cause aortic dissection or dissection of other greater vessels [4]. The procedure is complex and expensive with the need for transesophageal echo and with a rather long learning curve [9]. Moreover, it is not available for patients with dilatation of the ascending aorta, peripheral vascular disease or moderate or severe aortic valve regurgitation [10].
The aim of our study was to investigate whether feasibility, procedural success and complications differ between the two methods in patients undergoing minimally invasive cardiac surgery using CPB and cardioplegic arrest.

PATIENTS AND METHODS

From June 2001 to November 2011, CPB via RAP was performed in a total of 767 patients, using two different surgical techniques (Table 1). The procedures performed included totally endoscopic coronary artery bypass grafting (242), totally endoscopic atrial septal defect closure (65), minimally invasive mitral valve surgery (446), minimally invasive resection of left atrial myxomas (12) and right atrial myxomas (2). Operations were achieved through minithoracotomy using long-shafted instruments or via port access using the Da Vinci Telemanipulator (Intuitive Surgical, Sunnyvale, CA, USA).

Extracorporeal circulation was established by femoro-femoral CPB or femoro-femoral and jugular CPB in all patients [9, 11].

In the EBO group, 307 patients underwent robotically assisted totally endoscopic coronary artery bypass grafting (TECAB) (198 patients with one bypass graft (81.8%), 30 patients with two grafts (12.4%) and 14 patients with three or more grafts) or ASD closure using port-access perfusion with balloon-carrying catheters for aortic endo-occlusion (Heartport® Heartport, Redwood City, CA, USA; Edwards Endoreturn® Edwards Lifesciences, Irvine, CA, USA or Estech® arterial RAP ESTECH, Danville, CA, USA) [10]. In the TTC group, 460 patients underwent minimally invasive mitral valve, atrial septal defect closure or myxoma surgery via anterolateral minithoracotomy, where aortic occlusion was performed with TTC (Scanlan, Saint Paul, MN, USA) [7]. All the patients were intraoperatively monitored by transoesophageal echocardiography (TEE). In case of failure in detecting the guide wire by TEE, a mobile C-arm was used for fluoroscopic imaging.

Surgical techniques

In the EBO group, the patients underwent RAP with aortic balloon endo-occlusion, cardioplegia administration and venting via the ESTECH® System (ESTECH, San Ramon, CA, USA) or the Edwards® Lifesciences/CardioVations ENDOCAB System (Redwood City, CA, USA). The ESTECH®, Edwards’ or Heartport® cannula was inserted into the common femoral artery. A guide wire was then advanced under TEE control into the ascending aorta. The tip of the cannula was placed ~1 cm distal to the aortic valve. Venous drainage was acquired via a single- or double-stage femoral venous cannula (Biomedicus® 22–28F, Edwards 24–28F or an ESTECH 23 of 25F). After CPB initiation, the aortic-occlusion balloon was inflated and cardiac arrest was induced by injecting 3 mg of adenosine via the cardioplegia line. The correct position of the cannula balloon was continuously monitored by TEE. Additionally, bilateral radial artery pressure curves were evaluated to avoid accidental occlusion of the innominate artery. In all cases repetitive St Thomas’ cardioplegia was administered for cardioplegic arrest.

All the EBO candidates were preoperatively screened by computer tomography [12], echocardiography and clinical examination to exclude inappropriate candidates for RAP. Patients with significant arteriosclerosis, diameter of the ascending aorta of >38 mm, history of aortic dissection, aortic malformations, aortic valve insufficiency of >1+, occlusive arterial diseases and femoral artery diameter of <6 mm as well as latex allergy were excluded from this procedure [10]. During the evaluated timeframe, 55 possible EBO candidates were not eligible for endoballoon occlusion and were excluded.

In the TTC group, all the patients underwent RAP and aortic occlusion via TTC. CPB was established by cannulation of the femoral vessels, using venous cannulas similar to those in the EBO group (one-stage Biomedicus® or a two-stage Edwards® or ESTECH®) and a Biomedicus® arterial cannula for the femoral artery. Occlusion of the ascending aorta was performed with a TTC through the second or third intercostal space, mid-axillary line. Cardioplegia was administered directly into the aortic root via standard cannula in an antegrade fashion. The TTC patients were preoperatively echocardiographically evaluated to exclude relevant aortic regurgitation. Additionally, clinical evaluation to exclude clinically relevant PVD was performed.

The common femoral artery was reconstructed with either a longitudinal direct suture or a Gore-Tex® (W. L. Gore & Associates, Newark, DE, USA) or an autologous pericardial patch.

In both groups, CPB was maintained at 2.4 l/min/m² in an antegrade fashion. Venous drainage was enhanced by applying negative pressure up to ~30 mmHg to venous reservoir. Cardiomyotomy suction was used. Moderate hyperthermia (32°C) and the alpha-stat strategy were used while on CPB.

In both groups, distal leg perfusion was established standardized after arterial-femoral cannulation and the efficacy of distal femoral perfusion was evaluated by near-infrared spectrometry since 2007 [13].

A left-sided double-lumen endotracheal tube was placed to allow single-lung ventilation in cases needed. In selected cases, an additional 15–17F one-stage venous cannula was

<table>
<thead>
<tr>
<th>Table 1: Patient demographics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Patients, n</td>
</tr>
<tr>
<td>Age (years) 57 (16–77)</td>
</tr>
<tr>
<td>Gender (M/F) 205/102</td>
</tr>
<tr>
<td>BMI 25.93 (18–40)</td>
</tr>
<tr>
<td>Smoking, n (%) 98 (32)</td>
</tr>
<tr>
<td>Hypertension, n (%) 198 (65)</td>
</tr>
<tr>
<td>Diabetes, n (%) 37 (12)</td>
</tr>
<tr>
<td>Hyperlipidaemia, n (%) 201 (66)</td>
</tr>
<tr>
<td>Creatinine (mg/dl) 0.94 (0.5–1.6)</td>
</tr>
<tr>
<td>CVD, n (%) 20 (7)</td>
</tr>
<tr>
<td>PVD, n (%) 6 (2)</td>
</tr>
<tr>
<td>COPD, n (%) 35 (11)</td>
</tr>
<tr>
<td>Logistic EuroSCORE 1.5 (0.88–20.63)</td>
</tr>
<tr>
<td>LVF (%) 64 (20–88)</td>
</tr>
<tr>
<td>NYHA</td>
</tr>
</tbody>
</table>

BMI: body mass index; CVD: Cerebrovascular disease; PVD: peripheral vascular disease; COPD: chronic obstructive pulmonary disease; LVF: left ventricular ejection function; NYHA: New York Heart Association Classification.
in the superior vena cava through the right internal jugular vein to allow total CPB.

Postoperative management

The patients were monitored at the intensive care unit overnight and discharged to an intermediate care unit when spontaneous respiration set in and hemodynamics had stabilized. As soon as drainage volume dropped below 100 ml /24 h, chest drains were removed. All the patients underwent clinical evaluation of peripheral vessel status immediately postoperatively and at discharge.

Intraoperative data

Intraoperative data were inserted in a prospective database. In case of complications, the results were retrospectively completed. Aortic dissection, major vessel perforation, injury of intrapericardial structures, limb ischaemia, myocardial infarction and neurologic events were defined as major complications. Minor vessel injury, groin bleeding or lymphatic fistula were defined as minor complications. Feasibility of RAP was defined as all operations without conversions due to RAP failure. Success was defined as all operations without RAP-associated conversions or complications. All postoperative interviews were performed as part of a nationwide standardized quality assurance programme, which was approved from the local ethical committee.

Postoperative long-term-follow-up

Follow-up was systematically collected by means of telephone interviews, using a postoperative control survey, where 11 topics were mentioned (Table 2). The median duration of follow-up was 3 (range: 0.4–11) years and the follow-up completeness was 69%.

Statistics

All numerical values are provided as medians (min–max). All categorical values are presented in absolute numbers and percentages. A probability value <0.05 was considered statistically significant using the chi² test and Fisher’s exact test for categorical variables and Mann–Whitney U-test for numeric variables. The statistical computer package SPSS® 20.0.0 for Windows® (Chicago, IL, USA) was used for statistical analysis.

RESULTS

Overall 30-day mortality was 0 and 2 (0.43%) for the EBO and the TTC groups, respectively (P = 0.52). CPB time [EBO 111.5 min (32–428) vs TTC 192 min (17–477) P < 0.0001], and cross-clamp time [EBO 64 min (20–230) vs TTC 110 min (14–397) P < 0.0001] were significantly longer in the TTC group, whereas operating time [EBO 300 min (175–1050) vs TTC 292 min (25–960) P = 0.0009] was significantly longer in the EBO group.

There was significant difference in the average ICU stay [EBO 20 h (11–456) vs 20 h TTC (6–918), P = 0.025] and hospital stay [EBO 9 days (5–42) vs TTC 8 days (5–48); P = 0.008] between both groups. Overall and RAP-associated conversions were noted in 21 (6.8%) and 4 (1.3%) EBO patients, whereas the TTC group performed with 9 (2%) and 6 (1.3%) (P < 0.001, P = 1.00), respectively.

Incidence of major complications including aortic dissection, major vessel perforation, injury of intrapericardial structures, limb ischaemia, myocardial infarction, neurologic events was similar [EBO: 14 (4.4%); TTC: 16 (3.7%); P = 0.45].

Feasible RAP-supported interventions defined as absence of RAP conversions were equal [EBO: 303 (98.7%); TTC: 454 (98.7%); P = 1.00]. Successfully RAP-supported interventions defined as absence of RAP conversions and major were equal in both groups [EBO: 295 (96%); TTC: 449 (97.6%); P = 0.23]. Reasons for non-RAP-related conversions in the TTC were perioperative myocardial infarction in 1 patient and pleural adhesions in 2 patients. In the EBO group, non-RAP-related conversions were primarily driven by surgical difficulties related to endoscopic surgery during bypass graft preparation and performing of the anastomosis (Table 3).

Minor complications such as minor vessel injury, groin bleeding or lymphatic fistula were noted in 31 (10.1%) and 35 (7.6%), respectively (P = 0.23). One patient in the EBO group developed intraoperative aortic dissection after deflation of the intraaortic balloon was immediately converted to sternotomy for aortic repair using the frozen elephant trunk technique and additional

<table>
<thead>
<tr>
<th>Table 3: Perioperative complications</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBO (n = 307)</td>
</tr>
<tr>
<td>Local femoral dissection (%)</td>
</tr>
<tr>
<td>Aortic dissection (%)</td>
</tr>
<tr>
<td>Perioperative myocardial infarction (%)</td>
</tr>
<tr>
<td>Overall conversion (%)</td>
</tr>
<tr>
<td>Conversion not associated with RAP (%)</td>
</tr>
<tr>
<td>Conversions associated with RAP (%)</td>
</tr>
</tbody>
</table>

EBO: endoballoon occlusion; TTC: transthoracic clamping; RAP: remote access perfusion.
replacement of the ascending aorta. One patient had to be converted because of technical problems with the whole RAP system, another one because of balloon rupture and one because of failure of the balloon occlusion. Local intima injury of the femoral vessels occurred two times in EBO and was managed either by percutaneous stenting (1 case) or surgical local fixation of the intimal flap (1 case). Reconstruction of the femoral vessels using either linear direct suture or Gore-Tex® or autologous pericardial patch was needed in all the EBO patients and in 14 of 460 (3%) of the TTC patients.

In the TTC group, 2 patients had to undergo patch repair of the ascending aorta due to mechanical trauma by the TTC and the cardioplegia cannula. Another patient had to be converted after injury of the right pulmonary artery by the TTC. Traumatic injury of the left atrial appendage occurred in 1 patient, which was managed in a second pump-run via minithoracotomy. In 1 patient, traumatic rupture of the right ventricle and in another patient traumatic rupture of the superior vena cava occurred. Arterial embolectomy was performed in 1 patient of the TTC group due to thrombotic intraoperative occlusion of the right femoral artery.

Postoperative leg ischaemia was detected in 4 patients (1.3%) in the EBO group and 1 patient (0.2%) \( (P = 0.067) \) in the TTC group. There was 1 patient in the TTC group who developed compartment syndrome \( (P = 0.41) \). Lymphatic fistulas developed in 26 (8.5%) patients of the EBO group and 12 (2.6%) \( (P < 0.001) \) patients of the TTC group (Table 4).

Because of balloon-migration or ineffectiveness of aortic clamping in the EBO group, repositioning of the balloon had to be done in 29 (9.4%) of the patients. There was the need for replacement of the arterial cannula in 6 patients (1.9%), in 4 of them (1.3%) because of balloon rupture. Fluoroscopy for positioning of the system was necessary in 7 (2.3%) of the EBO patients.

Postoperative assessment using the telephone questionnaire revealed pain, sensational disturbances and wound-healing complications as the most prominent issues (Tables 5 and 6).

**DISCUSSION**

In this largest series of RAP for minimally invasive cardiac surgery reported so far, we aimed to analyse possible differences in operative feasibility, success and complications between TTC and endoballoon occlusion regarding their use to establish CPB and cardiac arrest. In addition, long-term assessment was performed using a self-designed questionnaire. Taken together, our results showed no difference in terms of perioperative mortality and morbidity, as well as technical feasibility, procedural success and occurrence of RAP-associated conversions and major complications. There was an obvious difference between the patient groups regarding primary diagnosis. Nevertheless, this study provided, for the first time, comparable results between the two techniques on RAP and peripheral cannulation.

Overall 30-day mortality is low and comparable in both patient groups and lower than EuroSCORE had predicted. Especially in the beginning of our totally endoscopic CABG programme, only low-risk patients were accepted in a stepwise and modular learning in terms of both RAP and the extent of coronary surgery (starting with RAP, endoscopic LIMA harvesting and performance of robotic anastomosis in sternotomy patients) [9]. With increasing experience, we addressed totally endoscopic single-vessel procedures with peripheral cannulation and endoballoon aortic occlusion and thereafter performance of multiple coronary anastomoses to treat multivessel disease. During the same timeframe, the minimally invasive mitral valve programme using similar peripheral cannulation techniques and transthoracic

---

**Table 4:** Postoperative complications

<table>
<thead>
<tr>
<th></th>
<th>EBO ((n = 307))</th>
<th>TTC ((n = 460))</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local femoral dissection</td>
<td>1 (0.3)</td>
<td>0 (0)</td>
<td>0.40</td>
</tr>
<tr>
<td>Lymphatic fistula (%)</td>
<td>26 (8.5)</td>
<td>12 (2.6)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Leg ischaemia (%)</td>
<td>3 (1)</td>
<td>1 (0.2)</td>
<td>0.31</td>
</tr>
<tr>
<td>Stroke (%)</td>
<td>4 (1.3)</td>
<td>3 (0.7)</td>
<td>0.45</td>
</tr>
<tr>
<td>Femoral reconstruction</td>
<td>0 (0)</td>
<td>1 (0.2)</td>
<td>1.00</td>
</tr>
<tr>
<td>Pulmonary embolism (%)</td>
<td>0 (0)</td>
<td>1 (0.2)</td>
<td>1.00</td>
</tr>
<tr>
<td>Myocardial infarction (%)</td>
<td>0 (0)</td>
<td>2 (0.4)</td>
<td>0.52</td>
</tr>
</tbody>
</table>

**Table 5:** Follow-up complications

<table>
<thead>
<tr>
<th></th>
<th>EBO</th>
<th>TTC</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pain in the groin area (%)</td>
<td>30/249 (12)</td>
<td>13/279 (4.7)</td>
<td>0.002</td>
</tr>
<tr>
<td>Wound-healing complications in the groin area (%)</td>
<td>49/249 (19.7)</td>
<td>42/277 (15.2)</td>
<td>0.17</td>
</tr>
<tr>
<td>Sensational disturbances in the groin area (%)</td>
<td>60/249 (24.1)</td>
<td>40/278 (14.4)</td>
<td>0.005</td>
</tr>
<tr>
<td>Lymphatic fistula (%)</td>
<td>7/249 (2.8)</td>
<td>9/277 (3.2)</td>
<td>0.61</td>
</tr>
<tr>
<td>Pain in the cannulated leg (%)</td>
<td>19/249 (7.6)</td>
<td>5/277 (1.8)</td>
<td>0.001</td>
</tr>
<tr>
<td>Differences in skin appearance of the cannulated leg (%)</td>
<td>6/249 (2.4)</td>
<td>12/277 (4.3)</td>
<td>0.23</td>
</tr>
<tr>
<td>Restriction in leg movement (%)</td>
<td>3/249 (1.2)</td>
<td>1/277 (0.36)</td>
<td>0.35</td>
</tr>
<tr>
<td>Sensational disturbances of the cannulated leg (%)</td>
<td>49/249 (19.7)</td>
<td>59/278 (21.2)</td>
<td>0.66</td>
</tr>
<tr>
<td>Cold-warm sensational disturbances of the cannulated leg (%)</td>
<td>13/249 (5.2)</td>
<td>6/277 (2.2)</td>
<td>0.061</td>
</tr>
<tr>
<td>Thrombosis of the cannulated leg (%)</td>
<td>4/249 (1.6)</td>
<td>0/277 (0)</td>
<td>0.050</td>
</tr>
</tbody>
</table>

**Table 6:** Occurrence of PVD during follow-up

<table>
<thead>
<tr>
<th>PVD Fontaine</th>
<th>EBO ((n = 307))</th>
<th>TTC ((n = 460))</th>
<th>(P)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6</td>
<td>2</td>
<td>0.057</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0.47</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0.47</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0</td>
<td>0.47</td>
</tr>
</tbody>
</table>

EBO: endoballoon occlusion; TTC: transthoracic clamping.
aortic clamping was developed. Low-risk patients with suitable peripheral vessels in CT scan were included at the beginning. This stepwise approach allowed a steep learning curve [11] and a safe performance of totally endoscopic CABG, ASD closures and minimally invasive mitral valve repairs using RAP [7, 8, 14, 15]. The second factor that contributed to high procedural safety was the introduction of a team approach for these procedures. Installation of RAP includes a close cooperation between cardiac surgeons, anaesthesiologists and perfusionists. Changes in team members or methods used were avoided in order to ensure continuity. In line with our results, perioperative mortality for minimally invasive cardiac surgery is also in the existing literature similar to the one observed in conventional approaches in highly selected patients [16–18].

Regarding the RAP, several factors played a role in method selection: the fact that endoballoon occlusion is the only reproducible method, which allows totally endoscopic coronary procedures, the short learning curve of TTC and the reproducibility of both methods. As of that, the vast majority of the Endoballoon group consisted of TECAB patients, while the vast majority of the TTC group included mitral valve patients. It was an institutional decision to use both methods of RAP, as EBO remains the only matured technique that enables port-only cardiac surgery. But concerning the higher costs of EBO, strict patient selection criteria and longer learning curves, we consider TTC as the most important technique for RAP in minimally invasive cardiac surgery.

The overall incidence of conversion was found to be higher in the EBO group, which is associated mainly with technical difficulties, which occurred during robotically assisted totally endoscopic procedures using a first-generation robotic system [19]. However, intraoperative conversions declined with increased experience. Schachner et al. concluded in 2011 that learning curve cases are the most important independent predictors for conversions in robotic TECAB, which are associated with increased morbidity, but do not significantly affect hospital mortality [18, 20]. RAP-associated conversions were, on the other hand, similar between the groups, whereas conversions in the TTC group were associated mainly with RAP-related complications (bleeding from the cardioplegia cannula in the ascending aorta or injury of intracardiac structures with the clamp). Concerning the feasibility of the two methods defined as operation without conversion due to RAP failure or RAP-associated complications, both groups performed equally well. In a mixed series of TECAB procedures where all learning curve cases were included, Schachner et al. described an overall conversion rate of 14% [18]. Chan et al. reported fewer conversions when dealing with TTC. The authors changed their operative strategy from EBO to TTC to minimize the risk of aortic dissection. Whether aortic dissections in reality occurred is not described in the article [4].

In terms of success, defined as absence of RAP-associated conversions or major complications both groups performed equally in general but differently in terms of which complication occurred. The TTC and the accompanied cardioplegia cannula are more frequent causes of severe bleeding of the aortic and surrounding structures. Owing to space limitations, manageable situations in open-heart surgery can become a real challenge in minimally invasive procedures. In our hands, two-thirds of the conversions of the TTC group were RAP associated. Although other authors report no occurrence of conversions in similar procedures [21], it is of utmost importance to clearly set the exact indication and time point of conversion in order to apply minimally invasive techniques safely. There is a paucity of publications regarding the reasons and outcomes of patients converted to larger thoracic incisions, which seems to be mainly associated with the circumstances under which conversion was performed (crash vs elective conversion) [21, 22]. In our hands, conversion in totally endoscopic coronary surgery did not affect perioperative mortality or long-term survival [20].

Aortic dissection has been described as a dreadful complication of RAP and occurred once in the EBO group. This underlines the need for previous CT scans of the great vessels and strict adherence to the inclusion criteria [12]. Although we observed a single aortic dissection, the low number of cases does not allow comparisons with intraoperative aortic dissections in conventional sternotomy cases (incidence of 0.06% in the STS database). Perioperative myocardial infarction rate was slightly higher in the EBO group, which is associated mainly with the more frequent use of the technique in coronary patients. This assumption is supported by the findings of Loforte et al., which reported equal rates of perioperative myocardial infarction in patients undergoing mitral valve surgery with the two techniques. In contrast, intraoperative detected microemboli by transcranial Doppler were twice as high in the TTC group. Whether this finding was clinically relevant or not is not described in this study [23].

Concerning minor complications, EBO and TTC performed equally in most items. The two systems differed in cannulation techniques; and therefore, there was a need for longer incisions and of reconstruction of the arterial vessels in the EBO patients. This may be associated with the invasiveness of cannula insertion in the EBO group. Introduction of cannulas via the femoral vessels for establishing CPB involves transient perfusion deficits of the cannulated femoral artery and contains the risk of leg ischaemia [19]. For minimizing the risk of compartment syndrome, we established distal leg perfusion with standard monitoring by near-infrared spectroscopy [13]. Leg perfusion monitoring is essential especially in patients with coronary heart disease as due to the nature of atherosclerosis they are on increased risk of peripheral vascular disease.

Differences in cross-clamp time and in total operation time can be explained by the dissimilar surgical procedures and were found to be slightly longer than in previous publications [8, 24]. However, having taken into account the complexity of the procedures performed (multivessel TECAB with composite grafts or sequential anastomoses in the EBO group, as well as double-valve repair with left atrial ablation for atrial fibrillation in the TTC group), these differences can be easily justified. In both procedures there is high potential for reduction of operating time as well as CPB and aortic cross-clamp time not only after surpassing the obstacles of the learning curve but also after adopting technological developments. The introduction of third-generation (four surgical arms) robotic systems with enhanced imaging quality as well as the use of 3D scopes in conventional thoracoscopy are major contributors to this direction. Regarding the surgical technique, the introduction of anastomotic devices or devices for automatic ring fixation in the annulus of the mitral valve is still under development. As of that, there is still space for improvement. Nevertheless, already higher procedural costs of EBO in terms of preoperative patient evaluation, expensive technology and postoperative follow-up have to be kept in mind.

Documentation of sensational disturbances, pain and wound complications in the groin are important issues in the long term. Though wound-healing problems seem to be equal between
both cannulation-methods, more patients suffer of pain and sen-
sational disturbances in the EBO group. Interestingly, the develop-
ment of peripheral vascular disease (PVD) appeared not so of-
ten. A PVD of Fontaine 2 and more occurred in only 3 patients
but all out of the EBO group. Whether this finding is associated
with the cannulation technique used with a generalized ather-
sclerosis involving coronary and femoral vessels should be
the subject of further investigations. According to the STS data,
wound and sternum complications occurred in 0.4% of the
patients. Wound complications in minimally invasive cardiac
surgery are not completely eradicated but occurred in 0.08% of
the patients in the STS database. In a propensity-matched com-
parison of 28,000 patients, a total of five sternal wound infec-
tions were avoided as a result of a non-sternotomy incision [25].

Although our study was designed to avoid possible statistical
bias by patient selection and documentation, there are some
limitations, which are worth mentioning: Patients’ assignment to
the EBO or the TTC group was dependent mainly on the diagno-
sis and the type of surgical technique used. Patients with coro-
ary artery disease assigned for TECAB underwent RAP by means
of EBO, as this is the only reproducible technique allowing a
port-only coronary procedure. Patients with mitral valve disease
were assigned for mitral valve surgery via minithoracotomy as
the available standard robotic system would not support totally
deroscopic mitral valve surgery. In patients with atrial septal
defects, both procedures were performed according to the sur-
geon’s preference. However, all the patients underwent a surgical
exposure of the femoral vessels in the groin and retrograde ar-
terial perfusion as well as similar venous drainage. Therefore,
procedural success and complications, as well as periprocedural
outcomes and wound complications were comparable between
the groups.

CONCLUSIONS
Taking together our results, RAP systems can be successfully
implemented in minimally invasive cardiac surgery. It seems that
TTC and EBO perform equally in terms of perioperative feasibility
and success as well as in terms of safety. Long-term complications
are rare. Further investigations including a prospective rando-
mized study in patients who undergo similar cardiac surgical pro-
cedures are still needed to identify the optimal RAP technique for
minimally invasive cardiac surgery. Before these results are avail-
able, endoballoon occlusion was the only reproducible technique
to perform totally endoscopic port-only performed procedures,
while TTC is a less complex and easily reproducible technique for
minimally invasive cardiac surgery via minithoracotomy.

Conflict of interest: none declared.

REFERENCES
[2] Schwartz DS, Ribakove GH, Grossi EA, Schwartz JD, Buttenheim PM,
Baumann FG et al. Single and multivessel port-access coronary artery
by pass grafting with cardiopulmonic arrest: technique and reproducibility. J
golden age of minimally invasive cardiothoracic surgery: current and
et al. Evolution of cannulation techniques for minimally invasive cardiac
et al. Port-access coronary artery by pass grafting: a proposed surgical
Minimally invasive port-access mitral valve surgery. J Thorac Cardiovasc
[7] Chitwood WR, Elbeery JR, Moran JF. Minimally invasive mitral valve
1477–9.
Minimal invasive mitral valve repair for mitral regurgitation: results of
Robotic totally endoscopic coronary artery by pass: program develop-
ment and learning curve issues. J Thorac Cardiovasc Surg 2004;127:
504–10.
perfusion cannula in minimally invasive cardiac surgery. Heart Surg
et al. Experience on the way to totally endoscopic atrial septal defect
et al. Multislice computed tomography for preoperative and post-
operative assessment in totally endoscopic coronary artery by pass graft-
[13] Schachner T, Bonario N, Bonatti J, Kolbitsch C. Near infrared spectro-
copy for controlling the quality of distal leg perfusion in remote access
et al. Effectiveness and safety of total endoscopic left internal mammary
artery by pass graft to the left anterior descending artery. Ann J Cardiol
Delianides J et al. Minimally invasive mitral valve surgery: a 6-year ex-
63–4.
[16] Van Nooqen GJ. Multicenter experience with the remote access perfu-
surgery: a systematic review and meta-analysis. Eur J Cardiothorac Surg
2008;34:943–52.
G et al. Robotically assisted minimal invasive and endoscopic coronary
et al. Technical challenges in totally endoscopic robotic coronary artery
G et al. Predictors, causes, and consequences of conversions in robotic-
ally enhanced totally endoscopic coronary artery by pass grafting. Ann Thorac
Minimally invasive versus conventional open mitral valve surgery: a
meta-analysis and systematic review. Innovations (Phi1a) 2011;6:84–103.
Minimally invasive versus sternotomy approach for mitral valve surgery:
Video-assisted minimally invasive mitral valve surgery: external
aortic clamp versus endoclamp techniques. Innovations (Phi1a) 2010;5:
413–8.
Pompili MF et al. Port-access coronary artery by pass grafting with the
use of cardiopulmonary by pass and cardiologic arrest. Ann Thorac Surg
J. Maxwell Chamberlain Memorial Paper for adult cardiac surgery.
Less-invasive mitral valve operations: trends and outcomes from the
APPENDIX. CONFERENCE DISCUSSION

Dr J. Maessen (Maastricht, Netherlands): It is a retrospective study, so I guess you had a hard job in dealing with all the data, but you also gave us a hard job, because your title is suggesting an answer to the question ‘which is better, inflating or clamping?’ But did you really expect that your study would be able to give us an answer, because, as your study has shown, the indication for inflating or for clamping is different, and it also changed during the study.

So to start with, what actually was your hypothesis and what decided whether, for instance, the patient was operated upon with a robot or in a different way?

Dr Krapf: Both programmes were started at the same time and the aim was to see whether there would be any difference in the complications. Initially we also tried to use the endoballoon occlusion system for mitral valve patients, but it was an institutional decision that we concentrate the endoballoon occlusion system for coronary patients and we transferred to clamping in the mitral, in the wall perforations and as well as in the ASD and myxoma operations. But we do know from the literature that other institutions use a mix of the techniques, as they also use the endoballoon for mitral valve operations.

I think a point to mention is that it takes time to learn the endoballoon occlusion system and to implement it in daily practice; endoballoon occlusion has a longer learning curve. And so it is an institutional decision what you do in which case. And, you are right, we have different patient demographics because of different disease, but in this study, we aimed to compare feasibility and perioperative complications in the groin, where we have a similar method for cannulation. And, yes, some aspects of both techniques are quite similar and comparable.

Dr Maessen: Do the results change your strategy?

Dr Krapf: Not at the moment, no.

Dr Maessen: I also have some concerns when I see the operating time, and I wonder whether you have a policy that you changed to conversion because of operating time? You have an operating time of 300 mean and with extremes to 18 hours. Do you consider this still as being minimally invasive or can you explain that?

Dr Krapf: On this point, you are right. Our strategy was in the beginning of the development of the endoballoon occlusion programme that we have a limited operation time with this system and then we have to change. So this is one reason for the range of operative times and the rather long operative times in some patients. But minimally invasive means that we have less trauma to the patient, less operative trauma. We do think that, considering the complexity of the techniques, that the operative time is acceptable.

Dr N. Bonaros (Innsbruck, Austria): Just to answer the question about the excessive operative time in one case, of course, you mentioned the result. There was one patient with an intraoperative aortic dissection due to the endoballoon occlusion. The repair of the dissection resulted in a prolonged operative time.

Dr R. Lorusso (Brescia, Italy): I have a question regarding the cannulation. Do you have a standardized protocol? Do you change or adapt the cannula size according to the patient’s body surface area? As Professor Maessen said, did you change your strategy from a certain point on about leg perfusions, so now you always put a distal perfusion? Can you comment on that? It is about the cannulation protocol and strategy.

Dr Krapf: The strategy is that we have singular arterial cannulation.

Dr Lorusso: You adapt to the size of the patient?

Dr Krapf: Yes, we adapted to the size of the patient, of course. And as I have shown, we have in some cases the need for additional cannulation. The distal leg perfusion was implemented since the beginning of the programme because of the knowledge of the risks of distal leg perfusion.

Dr Lorusso: So you had some compartmental syndrome?

Dr Krapf: Yes, we had, but it was rare.