Single-stage hybrid coronary revascularization with long-term follow-up†

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Abstract

OBJECTIVES: Hybrid coronary revascularization, performing a left internal thoracic artery (LITA) to left anterior descending (LAD) bypass followed by percutaneous coronary intervention (PCI) in a non-LAD coronary artery lesion, represents an evolving revascularization strategy. It utilizes the survival benefit of the LITA-to-LAD bypass, while providing complete revascularization with PCI to a non-critical vessel to decrease procedural morbidity. However, quantitative patency results and clinical outcomes remain understudied. The objective of this study was to assess clinical follow-up and graft and stent patency at 6 months and 5 years in a single-stage hybrid revascularization population.

METHODS: From 2004 to 2012, a total of 96 patients (64 ± 12 years; 70 males and 26 females) consented to robotic-assisted LITA harvesting and a small left anterior thoracotomy for off-pump coronary artery bypass anastomosis onto the LAD. This was followed immediately by PCI in a non-LAD vessel in the same fluoroscopy-equipped hybrid operating room. Patients underwent a yearly clinical follow-up and a protocol-directed assessment of graft patency via a coronary angiogram at 6 months and cardiac computed tomography (CT) angiography with single-photon emission computed tomography myocardial perfusion scintigraphy (MPS) at 5 years.

RESULTS: Successful single-stage hybrid revascularization occurred in 94 of the 96 patients (2 patients required intraoperative conversion to conventional coronary bypass). Six-month protocol coronary angiogram follow-up has been performed in 85 patients. Fitzgibbon Grade A or B LITA-to-LAD patency at 6-month follow-up was 94% in those studied. A total of 105 stents were deployed (89 drug-eluting stents (DES) and 16 bare metal), and at 6-month follow-up in 85 patients, 79 stents were widely patent; 8 had in-stent restenosis, and 2 were completely occluded. To date, 19 patients have undergone 5-year coronary CT angiography and MPS. The LITA-to-LAD anastomosis was patent in 17 of the 19 patients. Of the 19 lesions in which PCI was performed, 17 were widely patent, while 2 circumflex DES were occluded. Five-year clinical outcome demonstrated 91% survival, 94% freedom from angina and 87% freedom from any form of coronary revascularization.

CONCLUSIONS: A single-stage hybrid revascularization strategy appears to have acceptable 6-month and angiographic patency results for both LITA-LAD grafts and PCI interventions. Survival, freedom from angina and freedom from revascularization also appear favourable at the 5-year clinical follow-up.

Keywords: Coronary disease • Minimally invasive surgery

INTRODUCTION

Minimally invasive coronary artery bypass represents an attractive and evolving field within cardiac surgery. Technological advancements in harvesting the internal thoracic artery, mostly with robotic-assisted techniques, and improved outcomes of percutaneous coronary intervention (PCI) created the initial interest among cardiovascular specialists in combining revascularization strategies to lower patient morbidity [1]. First described in 1996, hybrid coronary revascularization can be performed with a direct left internal thoracic artery (LITA) to left anterior descending (LAD) bypass on a beating heart followed by PCI in a non-LAD coronary artery lesion occurring in the same operating theatre [1]. In more recent years, this procedure has been occurring with greater frequency and demonstrating adequate short and mid-term outcomes of mortality and morbidity [2-5, 6-9]. Potential benefits of hybrid...
revascularization include achieving the proven long-term survival and symptomatic outcome associated with a LITA-LAD bypass graft, avoiding a full sternotomy and the negative effects of cardiopulmonary bypass, potentially faster recovery, overall decreased risk of blood transfusions [10] and decreased hospital length of stay [3, 11–13]. Several recent studies have demonstrated equivalent mortality, patency and major adverse cardiac event rates between a hybrid revascularization strategy and similar conventional on- and off-pump coronary bypass surgery [9, 14].

In 2008, our centre reported an initial experience of single-stage hybrid revascularization in 53 patients [4]. The 6-month protocol-guided coronary angiographic patency of the LITA to LAD was acceptable at 93% with a low rate of perioperative morbidity [4]. It is now 5 years since the original protocol was performed on this cohort of patients, and a primary goal of this study was to assess its clinical and angiographic patency results. A secondary goal of this study was to further assess the 6-month patency results from our entire increasing single-stage hybrid experience. Longer-term follow-up with quantitative assessment of graft patency and clinical outcomes is necessary before stronger recommendations can be made for broadening the application of a hybrid single-stage revascularization strategy [15].

MATERIALS AND METHODS

Patient population

Between 1 September 2004 and 1 July 2012, a total of 96 consecutive patients were scheduled for a single-stage hybrid coronary artery revascularization strategy. Ninety-four patients underwent successful intraoperative completion of LITA-LAD and PCI in the non-LAD lesion. Two patients, in the early series, experienced ventricular fibrillation during the beating heart LITA-LAD anastomosis, and required conversion to full sternotomy and subsequent conventional complete surgical revascularization. Preoperatively, all patients were reviewed by the heart team, which consisted of cardiac surgeons, interventional cardiologists and cardiac anaesthesiologists. All patients had a preoperative computed tomographic scan of the thorax and pulmonary function tests. Selection criteria included patients with double- or triple-vessel disease in whom the LAD lesion was not suitable for PCI, but was suitable for surgical revascularization and in whom the non-LAD lesions were amenable to PCI. Exclusion criteria consisted of patients with contraindications to robotic-assisted coronary surgery, off-pump coronary artery bypass surgery or contraindications to PCI. The single-stage approach used for all patients in this study consisted of robotic-assisted harvest of the LITA followed by LITA graft to the LAD performed on a beating heart through a left small non-rib-spreading anterior thoracotomy. This was immediately followed by PCI in a non-LAD coronary artery lesion in the same enhanced hybrid operating theatre during the same operative session.

Surgical procedure

The procedure for single-stage hybrid revascularization performed by our institution for this study has been formally described previously [4]. Briefly, the da Vinci system (Intuitive Surgical, Sunnyvale, CA, USA) was used for LITA harvest. A therapeutic activated clotting time of >300 s was achieved with heparin in 7 patients (all before year 2008), with the remaining 87 using a bivalirudin (The Medicines Company, Parsippany, NJ, USA) infusion to maintain anticoagulation throughout the procedure. After opening the pericardium and exposing the LAD, the LITA was divided. The LAD was stabilized using the Octopus TE stabilizer (Medtronic, Minneapolis, MN, USA) inserted via the appropriate intercostal space. A small non-rib-spreading incision was made and the LITA was manually anastomosed to the LAD using off-pump beating heart techniques. All graft flows were measured by Medistim (Medistim USA, Plymouth, MN, USA) transit-time Doppler assessment. Immediately following completion of the surgical component, and surgical wound closure, the PCI procedure took place in collaboration with the interventional cardiology team. Femoral access was obtained, ceiling-mounted viewing screens were positioned and a floor mounted C-arm was moved into position. Angiographic patency of the LITA-LAD graft was assessed, and the non-LAD lesion was addressed with either a bare-metal stent (BMS) or drug-eluting stent (DES). Prior to PCI completion, while still on bivalirudin infusion, 600 mg of clopidogrel was administered through a nasogastric tube, followed by 75 mg of clopidogrel once daily. Eighty-one mg of acetylsalicylic acid were administered through a nasogastric tube 6 h after the operation and then 81 mg was administered once daily. The femoral arterial sheaths were removed after the discontinuation of bivalirudin. Patients were assessed yearly for Canadian Cardiovascular Society (CCS) symptoms of angina and New York Heart Association (NYHA) symptoms of heart failure, along with a review of hospital admissions and physical examination by either a cardiac surgeon or cardiologist. Patients who reported symptoms of chest discomfort or shortness of breath were offered coronary angiograms for the assessment of graft patency. Clinical notes, health records and coronary angiograms were reviewed for all enrolled patients. Preoperative patient characteristics are summarized in Table 1.

Patency outcomes

After approval by the Health Sciences Research Ethics Board of the University of Western Ontario, all eligible patients were contacted,

<table>
<thead>
<tr>
<th>Profile</th>
<th>N = 96</th>
</tr>
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<tbody>
<tr>
<td>Sex, n (%)</td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>70 (72%)</td>
</tr>
<tr>
<td>Female</td>
<td>26 (28%)</td>
</tr>
<tr>
<td>Left ventricular grade</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>67 (71%)</td>
</tr>
<tr>
<td>II</td>
<td>22 (24%)</td>
</tr>
<tr>
<td>III</td>
<td>5 (5%)</td>
</tr>
<tr>
<td>IV</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>CCS functional class preoperative</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>II</td>
<td>10 (10%)</td>
</tr>
<tr>
<td>III</td>
<td>49 (52%)</td>
</tr>
<tr>
<td>IV</td>
<td>37 (38%)</td>
</tr>
<tr>
<td>Diabetes</td>
<td></td>
</tr>
<tr>
<td>Preoperative creatinine</td>
<td></td>
</tr>
<tr>
<td>S&lt;sub&gt;r&lt;/sub&gt; &lt;120</td>
<td>85 (90%)</td>
</tr>
<tr>
<td>S&lt;sub&gt;r&lt;/sub&gt; 121–180</td>
<td>6 (7%)</td>
</tr>
<tr>
<td>S&lt;sub&gt;r&lt;/sub&gt; &gt;180</td>
<td>3 (3%)</td>
</tr>
<tr>
<td>Body mass index &gt;30 kg/m&lt;sup&gt;2&lt;/sup&gt;</td>
<td>35 (37%)</td>
</tr>
</tbody>
</table>
and informed consent for participation was obtained. Consenting patients were booked for follow-up coronary angiogram at 6 months post procedure. A modified Fitzgibbon classification of graft patency, whereby A = completely patent, B = anastomosis of >70% narrowing and C = occluded vessel, was used to assess graft patency. Interventional cardiologists along with the cardiac surgeons at our centre assessed graft patency and assigned the modified Fitzgibbon classification. PCI interventions were assessed as either being patent, partial in-stent restenosis or occluded. Patients who were 5 years post procedure were contacted to follow-up with coronary computed tomography angiography (CTA) and myocardial perfusion scintigraphy (MPS) using technetium-99m (99mTc) 2-methoxyisobutyl-isonitrile (MIBI). Coronary CTA was performed on a GE Light Speed VCT 64-slice CT scanner (General Electric Healthcare, Milwaukee, WI, USA), while MPS-MIBI results were acquired using GE Infinia Hawkeye cameras (General Electric Healthcare). MPS-MIBI results were used to complement the anatomical findings from the CTA in order to determine the functional significance of equivocal or indeterminate CTA results. CTA/MPS-MIBI results were graded as patent, indeterminate on CTA without haemodynamic significance on MPS, indeterminate on CTA with haemodynamic significance on MPS and occluded (Table 2).

**RESULTS**

A total of 96 patients (64 ± 12 years; 70 males and 26 females) were scheduled for single-stage hybrid revascularization, of which 94 were successfully completed. Two patients required conversion to conventional coronary bypass because of haemodynamic instability. During the LAD anastomosis, it was discovered that the LAD vessels selected were of many different calibers, including totally occluded vessels with minimal flow through them, and some of these LAD vessels were found to be sclerotic. A total of 105 PCI stents were placed in the 94 patients (95 drug-eluting stents and 10 bare metal); of which 19 were placed in diagonal, 39 in right coronary artery territory, 21 in circumflex, 25 in obtuse marginal branch and 1 in a distal LAD. Detailed technical information of the PCI procedures is provided in Table 3.

**Table 2:** Grading system developed for the assessment of graft patency and haemodynamic significance of any occluded or stenosed bypass graft

<table>
<thead>
<tr>
<th>Grade</th>
<th>Graft quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Patent</td>
</tr>
<tr>
<td>2A</td>
<td>Artefact or stenosis on coronary CTA, not haemodynamically significant on MPS-MIBI</td>
</tr>
<tr>
<td>2B</td>
<td>Artefact or stenosis on coronary CTA, haemodynamically significant on MPS-MIBI</td>
</tr>
<tr>
<td>3</td>
<td>Occlusion</td>
</tr>
</tbody>
</table>

CTA: computed tomography angiography; MPS-MIBI: stress myocardial perfusion scintigraphy with technetium-99m 2-methoxyisobutyl-isonitrile.

**Perioperative results**

There was no 30-day or in-hospital mortality. In the series of 94 patients who underwent successful single-stage hybrid revascularization, there was one postoperative myocardial infarction, one postoperative stroke and four patients returned to the operating room for bleeding. The median postoperative length of stay was 4 (range 3–9) days. Seven of the 94 patients received a blood product during their hospitalization. The median length of hospital stay was 4 (range 3–7) days.

**Patency outcomes at 6-month protocol follow-up**

At 6-month post single-stage hybrid revascularization, a protocol-directed coronary angiogram was completed in 85 of the total 96 patients (89% follow-up). The 2 patients who underwent intraoperative conversion to conventional coronary bypass declined follow-up. An additional 5 patients were lost to follow-up, and 4 refused follow-up. Of the 85 LITA-LAD grafts assessed, 56 were Fitzgibbon Class A and 24 were Fitzgibbon Class B at a mean follow-up of 6.8 (range 4.3–40.8) months. Fitzgibbon Class C occurred in a total of five grafts. Assessment of the 89 stents performed in the 85 patients at 6-month follow-up demonstrated complete patency in 79, in-stent restenosis of >50% in 8 and complete occlusions in 2.

**Clinical and angiographic follow-up from 6 months to 5 years**

Within the 5-year follow-up period, 6 patients (5 males and 1 female, age 71 ± 9.5) presented with symptoms of angina and underwent repeat coronary angiography (mean follow-up of 21 ± 12 months, range 9–40 months). Repeat coronary angiography revealed patent LITA to LAD grafts in all patients. These findings were the same as the earlier 6-month angiographic follow-up (Fitzgibbon Class B in 2, and Fitzgibbon Class A in 4). One patient.
demonstrated an occluded DES that had been patent at 6-month follow-up. Optimal medical management was continued for all patients.

A total of 53 patients met the criteria for 5-year clinical and angiographic follow-up. One-year survival was 100% (94 of 94) and 5-year survival 91% (48 of 53). The cause of death on chart review was cardiac aetiology in 2 patients and unknown in the other 3. On clinical follow-up at 5-year assessment, 94% of patients were free from angina (CCS Class 0) and 87% had freedom from revascularization. All patients at the 5-year follow-up were offered protocol-directed and myocardial ischaemia assessment follow-up. To date, 19 patients have undergone follow-up at a mean duration of 65.5 (±8.4) months. The mean age of this cohort of patients is (59.9 ± 11.4) years, with 15 males and 4 females. Assessment of LITA-to-LAD grafts demonstrated patency in 17 grafts (89.5%) with two occlusions. A total of 22 stents (19 DES and 3 BMS placed in the 19 lesions) were assessed; three in the obtuse marginal artery, seven in the right coronary artery, six in the diagonal artery, two in the circumflex artery and one in distal LAD. One patient required two stents across a single lesion, and 1 required three stents across a single lesion. Patency results demonstrated complete patency in 17 stented lesions, with two occlusions involving single stents in the circumflex artery of two different patients. Follow-up continues in this patient cohort as recruitment is ongoing.

DISCUSSION

Hybrid coronary artery revascularization represents an alternative strategy for revascularization in patients with multivessel coronary artery disease. We report favourable long-term angiographic patency results for both LITA-to-LAD anastomosis and PCI-to-non-LAD lesions. We also demonstrate important long-term clinical outcomes in terms of freedom from angina, freedom from reintervention and excellent overall 5-year survival.

In recent years, there has been an increasing trend towards hybrid revascularization procedures as cardiac surgeons and interventional cardiologists strive to treat multivessel disease and maintain equivalent outcomes with overall less morbidity [8, 16]. However, it remains important for newer techniques to undergo rigorous quantitative assessment and comparison with conventional ‘gold standard’ techniques. The 6-month patency results achieved in this study are similar to our previous outcomes and to that of other centres [4]. Specifically, Vassiliades et al. [17] compared the hybrid revascularization strategy with off-pump coronary bypass surgery patients and demonstrated non-inferiority in terms of death/stroke/non-fatal myocardial infarction at 3 years. Hu et al. also demonstrated equivalent early and mid-term clinical outcomes for simultaneous hybrid coronary revascularization and a propensity-matched subset of patients undergoing conventional off-pump coronary artery bypass surgery patients and demonstrated non-inferiority in terms of death/stroke/non-fatal myocardial infarction at 3 years. The continued assessment of long-term clinical outcomes and patency from a hybrid approach is required before more definitive recommendations regarding the indications for hybrid revascularization can be made [18]. Hybrid revascularization is currently a Class IIa recommendation with a level of evidence of B for patients with limitations to traditional coronary artery bypass grafting (CABG), lack of graft conduits or an unfavourable LAD for PCI. Hybrid revascularization is currently a Class IIb recommendation with a level of evidence C to improve the overall risk/benefit ratio. The 5-year quantitative assessment of graft patency and clinical outcomes of this study may contribute to strengthening and eventually broadening the clinical indications for single-stage hybrid revascularization in multivessel coronary disease.

Another finding of this study is the identification of a learning curve among those performing hybrid revascularization and the potential improvement in clinical outcomes with greater experience. Since 2008, we have not experienced any conversions to full sternotomy, return to the operating room for bleeding, renal failure or stroke. Centres of excellence performing these procedures should continue to expect continued improvement in outcomes with greater volumes.

In this study, we elected to include repeat coronary angiography from all patients presenting with symptoms, suggestive of angina outside of the protocol follow-up period. In the 6 patients requiring reassessment, all demonstrated a patent LITA-LAD and only 1 developed in-stent stenosis of a DES. While this sample size is very small, it highlights the long-term patency benefit of a LITA-LAD bypass and the relatively low restenosis rate of DES PCI techniques in hybrid coronary revascularization.

Potential weaknesses of this study included the lack of a comparison group who underwent complete revascularization using either PCI (inclusion of the LAD) or conventional on-pump CABG. We compared our rates of graft/stent patency, survival and freedom from symptoms from literature sources rather than a direct comparison group. Another limitation is changing the mode of assessment from the gold standard coronary angiography to that of CTA at 5 years. However, coronary CTA has demonstrated satisfactory sensitivity and specificity when compared with conventional angiography while avoiding some of the risks inherent with conventional coronary angiography. To address the shortcomings of CTA when faced with surgical clips, motion artefact, coronary calcium and smaller intracoronary stents, the anatomical results were paired with functional results from MPS-MIBI studies performed the same day. A major benefit of using MPS to supplement the CTA results is the ability to more accurately assess the functional significance of indeterminate or equivocal CTA results. MPS also allows for the quantification of ischaemia, if present. Formal quality-of-life scales were collected for this patient population and are pending analysis and future publication. It is also important to evaluate the degree and complexity of double-vessel coronary artery disease suffered by patients undergoing the hybrid approach. Leacche et al. [9] demonstrated hybrid coronary revascularization to be a safe alternative to coronary artery bypass grafting in many patients with multivessel coronary artery disease; however, in high-risk patients with complex coronary artery disease (EuroSCORE ≥5), coronary artery bypass grafting appears to have superior outcomes. A formal comparison in terms of lesion complexity and patient co-morbidity with a group undergoing conventional or off-pump CABG has not been performed and would be a useful adjunct to this study.

Potential future advancements in postoperative management of hybrid revascularization patients include the development of ‘fast track’ perioperative management. As a management strategy, it allows patients to be extubated immediately in the operating room post procedure and decreases the need for intensive care perioperative management. Such management programmes may further lower hospital length of stay, result in improved patient satisfaction and reduce overall costs and resource requirements while maintaining excellent outcomes.

In conclusion, we have demonstrated that single-stage robotic-assisted hybrid coronary revascularization is a safe and effective means for treating multivessel coronary artery disease. We
obtained excellent results in terms of 6-month patency, long-term freedom from angina and freedom from coronary reintervention. Five-year follow-up results, though low in overall numbers, are nevertheless encouraging. As we continue to expand our series and follow our cohort of patients in the long-term, we hope to continue to obtain these excellent results and, in turn, offer this revascularization strategy to a wider patient population.

Conflict of interest: none declared.

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APPENDIX. CONFERENCE DISCUSSION

Dr N. Al-Attar (Paris, France): This work is indeed the state of the art in hybrid coronary revascularization, although your five-year data is still largely incom-
plete at the current date, but the six-month follow-up is quite good, and that
brings me to my question.

You showed that at six months, having excluded eight symptomatic patients, 6% of the left internal thoracic arteries were totally occluded, 29% were
diseased with Fitzgibbon classes C and B respectively. So that’s about a third of your patients. And at five years there was 6% recurrence of angina and 13% required revascularization. So in light of your data, what is your target popula-
tion? What is the clinical profile of a patient for him or her to be proposed for a hybrid revascularization versus pure PCI or just standard CABG? You have alluded to scoring these patients with a SYNTAX score or the EuroSCORE, both in the paper and in your talk, but you don’t give those data.

Dr Adams: No, I agree. The ultimate patient I think for a hybrid procedure is a patient who has either a high EuroSCORE or other comorbidities, such that he cannot tolerate conventional coronary bypass, or a patient who refuses or will not have conventional coronary bypass. At our institution, patients with double- vessel coronary disease who have an occluded LAD, or have disease in their LAD, whom the cardiologists feel is not amenable to PCI, they will consult with our cardiac surgeons and our cardiologists in a heart team, and they are still trying to figure out which patient is the best. I have a lot of patients who will say, ‘I will not undergo surgery but I will undergo PCI’. This procedure may be of benefit to them, because they will get the benefits of the LITA to the LAD.

I agree with you that it is difficult to compete, maybe impossible to compete, with bilateral ITA grafts in a younger patient, to avoid the sternotomy, but in a patient who won’t accept it or in a patient who cannot tolerate it for other reasons, then maybe this option can help them with their ischaemic heart disease. But it is tough to identify right now who the ultimate patient is.

Dr Al-Attar: And my second question was related to bleeding, patients who have CABG and PCI in the same setting in a single-stage. Well, this is an attractive option, having the whole procedure and a complete revascularization performed in one setting. In the manuscript you had noted you had zero rates for return due to bleeding, but do I see that four patients came back. Can you elaborate?

Dr Adams: Of those four patients who came back, two of them were tech-
nical and two when closing were intercostal arteries that were hit and the patient bled about 200 to 300 in the first hour and immediately went back to the operating room, the thoracotomy was opened, and in fact there was an intercostal bleeding on two. Another one was a branch off of the left internal thoracic artery that was bleeding as well, and in another patient they could not find a source; this was a patient who had liver dysfunction and was just generally coagu-
lopathic. In no patient did we require to go through a sternotomy and reopen. So I feel strongly that it was probably three technical errors early in this series.

And when it comes to the harvest of the left internal thoracic artery, with the da Vinci system that we use, there are no clips, so it was just cautery. So at some point maybe early in the series we weren’t quite cauterying enough there.

Dr M. Sayeed (Bangalore, India): Could you throw some light on your antipla-
telet strategy, considering you are doing this in a single session.

Dr Adams: Patients will take aspirin the morning of surgery, immediately after the LITA to LAD anastomosis; it is 600 mg of clopidogrel down an NG tube. We’ve elected to use bivalirudin as the anticoagulation and heparin, and we published on this, and so we are still using both right now. So anticoagulation with bivalirudin or heparin; the antiplatelet agent is aspirin the morning of surgery, 600 mg immediately, and then when the patient goes home, it is ASA and clopidogrel for dual-antiplatelet therapy.

Dr Sayeed: One last question. Your LIMA occlusions, are they due to a tech-

cial problem with the LIMA itself, or is it the anastomosis site?

Dr Adams: I think mostly it is at the anastomotic site from looking at the angiograms myself. It is possible that it is the LITA harvest. When you utilize the robotic technique fully with catherization, it is possible it is that. The series that we are at has an isolated LITA to LAD series independent of Harvard of about 400 patients, and they are seeing stenosis rates about the same in that series. So Downloaded from https://academic.oup.com/ejcts/article-abstract/45/3/438/438612 by guest on 04 March 2019
Hybrid coronary revascularization: a task for the true heart team!

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Keywords: Hybrid coronary revascularization • Heart team • PCI • Multi-vessel coronary disease

Ever since the concept of integrated hybrid coronary revascularization was first introduced in the mid-1990s [1], it has sparked much debate among the cardiovascular community. Hybrid coronary revascularization for multivessel coronary disease is defined as, ideally, combining the proven long-term survival benefit of surgical left internal mammary artery (LIMA) to left anterior descending (LAD) grafting with percutaneous coronary intervention (PCI) to non-LAD territories. While there is overwhelming consensus that LIMA to LAD grafting should be performed in a minimally invasive, sternum-sparing and off-pump minimally invasive direct coronary artery bypass (MIDCAB) procedure, the timing of the respective revascularization modalities remains controversial.

Performing PCI first has the advantage of ‘paving the way’ for subsequent minimally invasive surgical revascularization. However, in this case, PCI would have to be performed in the presence of unprotected anteroseptal myocardium and a LAD stenosis, which would probably be considered the culprit lesion in many cases. Furthermore, following successful PCI of lesions in the right coronary artery (RCA) or circumflex artery (CFX), surgery would have to be performed under combined platelet inhibition therapy. Also, reversing heparin by systemic protamin application towards the end of the surgical procedure carries the inherent risk of stent thrombosis.

If LIMA to LAD MIDCAB were performed first, PCI could subsequently be performed under the protection of a revascularized anteroseptal myocardial wall. However, the surgeon needs to be aware of possible critical ischaemia in non-LAD regions during surgery. Also, failed secondary PCI might lead to a more complex, technically challenging repeat surgical procedure. In a successful staged procedure of primary LIMA to LAD grafting followed by PCI, angiographic quality control of the surgical graft may be counted as an advantage.

Clearly, both scenarios of staged hybrid coronary revascularization remain suboptimal, with inherent advantages and disadvantages. Nonetheless, the vast majority of studies pertaining to this topic are designed in a staged fashion [2]. Performing revascularization of multivessel disease in a single-stage hybrid procedure as described by Adams et al. [3] in the current issue of this journal may overcome most of the above-mentioned limitations even though this strategy imposes physicians with its own logistical challenges. Ideally, such procedures should be carried out in a modern fully equipped hybrid operating theatre providing treating the full armamentarium of therapeutic options on physicians. Performing LIMA to LAD MIDCAB first and PCI second immediately following surgery allows for angiographic patency control of the surgical graft. Also, PCI to the remaining lesions can then safely be performed under the protection of revascularized LAD territory. Whether or not the da Vinci system is necessary for LIMA harvest can be debated. However, as it allows for atraumatic take-down of the artery along its full length and as the alternative would be the use of a rib-spread ing retractor without the possibility of mobilizing the proximal portion of the graft, it appears to be the best option at present. This is in spite of high maintenance and operational cost.

Planning, indication and performance of the procedure as well as post-procedural care should best be carried out by a dedicated interdisciplinary heart team consisting of institutionalized interventional cardiologists and cardiac surgeons in close collaboration. Due to the complexity of this type of procedure, it is probably best performed at specialized heart centres with extensive experience of all involved specialties in treating patients with advanced coronary artery disease. Combining the expertise and skill sets of both cardiac surgery and interventional cardiology will provide an adequate