Multi-vessel off-pump total endoscopic coronary artery bypass—pearls and pitfalls

Miroslav P. Peev, Husam H. Balkhy

Section of Cardiac Surgery, Department of Surgery, University of Chicago, Chicago, IL, USA

Correspondence to: Miroslav P. Peev, MD. Section of Cardiac Surgery, Department of Surgery, The University of Chicago Medical Center, 5841 S. Maryland Ave, Chicago, IL 60637, USA. Email: miroslav.peev@ssmhealth.com.

Abstract: Coronary artery bypass grafting remains the most commonly performed cardiac surgical procedure worldwide. Despite few advances in conduit harvesting and anastomosis technique, standard midline sternotomy continues to be by far the most common route for surgical exposure and operation completion. Within the last two decades robotic coronary artery bypass grafting emerged as a safe and reproducible technique with excellent short- and long-term outcomes. This sternum sparing method allows the use of bilateral internal thoracic arteries (ITAs) as well as it provides the unique opportunity to access the various parts of the heart in a minimally invasive way while achieving substantially fewer complications, less pain, early discharge and return to work. In the following review, we describe our surgical technique and conduct of robotic off-pump totally endoscopic coronary artery bypass grafting. We share pearls and pitfalls that we encountered and learned performing over 950 robotic total endoscopic coronary revascularizations (TECABs) in 2 institutions over the last 15 years. The combination of careful multidisciplinary patient selection and an experienced high volume dedicated robotic cardiac surgery team is a prerequisite for the success of the operation.

Keywords: Multivessel TECAB; revascularization; stable coronary artery disease (stable CAD)

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Introduction

Surgical revascularization using a robotic platform was initially described more than two decades ago. Shortly after Alain Carpentier performed the first robotic repair of the mitral valve in 1998, Friedrich Mohr in Germany reported the first robotic assisted coronary anastomosis (1). Within the following years, the use of a surgical robot gained popularity demonstrating excellent safety profile and substantial efficacy. The ability to fully utilize the robotic platform for surgical revascularization allows the conduct of totally endoscopic multivessel revascularization. It is a unique advantage that facilitates not only the safe dissection of both internal thoracic vessels but also allows access to the various portions of the heart and coronary vessel targets while using the same ports. While minimally invasive coronary artery bypass (MIDCAB) represents the most widely adopted minimally invasive revascularization technique, it is often limited by the ability to use a single internal thoracic artery (ITA) as well as to only graft the left anterior descending artery (LAD).

Despite the proven advantages (excellent short and long-term outcomes, significant reduction in postoperative pain, shorter intensive care and hospital length of stay, early return to work) less than 1% of the coronary revascularizations are utilizing the robotic platform (2). The slow adoption of the technology has been justified by the necessity to acquire new set of surgical skills associated with a steep learning curve, the need of an experienced and dedicated robotic surgical team as well as the acquisition and maintenance costs of using the robotic equipment. In the following review we describe our technical experience in conducting off-pump total endoscopic coronary artery bypass (TECAB) based on a high-volume single surgeon practice.

Surgical technique

Preoperative planning

Patients with stable coronary artery disease (CAD) are candidates for robotic revascularization with the utilization of unilateral or bilateral ITAs using an off-pump approach. Currently, off-pump robotic TECAB is considered as the least invasive and at the same time most versatile surgical approach that could be offered to patients with single- and multivessel CAD. The indication as well as the patient selection is carefully determined by a multidisciplinary revascularization team that includes surgeons and cardiologists. We have previously described the various exclusion criteria based on our experience (3). Generally, all patients with stable CAD are candidates for TECAB with few absolute and relative exclusion criteria:

Absolute exclusion criteria

- Emergency surgery;
- Cardiogenic shock;
- Significant left pleural adhesions secondary to previous lung surgery.

Relative exclusion criteria

- Very poor pulmonary function (including patients who are not expected to tolerate single lung ventilation);
- Previous cardiothoracic surgery with no available ITA conduit.

We perform a standard preoperative work up that includes chest X-ray and comprehensive blood panel. Computer tomographic images of the chest are required in case the patient has a chest deformity, previous chest surgery or breast implants since that might affect the conduct of the procedure. Pulmonary function tests are obtained in selected patients with strong smoking history or preexistent diagnosis of chronic obstructive pulmonary disease (COPD).

All procedures performed in this study were in accordance with the ethical standards of the institutional research committee and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for publication of this article and the accompanying video.

Anesthesia, patient positioning and port placement

Anesthesia setup includes Foley catheter, radial arterial line placement for close hemodynamic monitoring as well as central venous catheter (usually via the right internal jugular vein). Single lung ventilation that is a prerequisite for the operation is achieved using a single lumen endotracheal tube with a left endobronchial blocker. If the patient remains intubated at the conclusion of the operation, the endobronchial blocker can easily be removed at the end of the procedure without the need for any endotracheal tube exchange. The use of transesophageal echocardiography is necessary for all patients unless there is a strong contraindication that would preclude any esophageal manipulation, e.g., esophageal stricture or severe varices.

All patients receive external defibrillator pads as follows: one located over the left scapula and the other one over the right anterolateral chest. In terms of surgical positioning—the body of the patient is brought to the left edge of the operating room table and a shoulder roll is applied underneath the left scapula in cranio-caudal orientation. It is important to allow the left shoulder to drop in order to create enough space and prevent interference with the right robotic arm. Surgical ports (8 mm) are introduced in the second (right robotic arm), fourth (camera port), and sixth (left robotic arm) intercostal spaces (ICS), in the anterior axillary line. In addition, a fourth 12-mm subcostal robotic port is placed between the xyphoid process and the midclavicular line (MCL) that will be utilized for the fourth robotic arm that is equipped with the EndoWrist (Intuitive, Sunnyvale, CA, USA) coronary stabilizer. Finally, a 12-mm sealed working port is placed in the second ICS at the MCL. After all ports have been introduced and shortly before docking, the operating room table is lowered and rotated 10° to 15° toward the right.

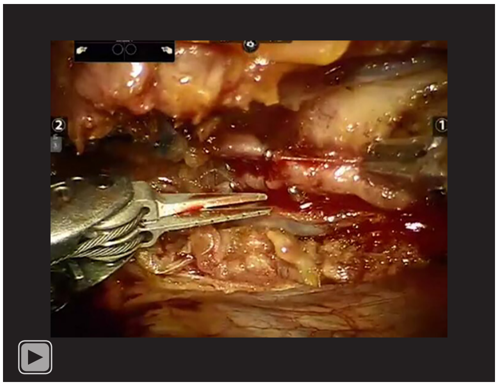
We strongly encourage the use of perioperative steroids (100 mg hydrocortisone) as a means to decrease potential postoperative pericarditis. Liberal use of beta blockers (metoprolol, esmolol drip) is strongly advised in order to maintain a heart rate in the 60–70 bpm range.

Conduct of the operation

A video summary of our surgical technique including specific pearls and pitfalls that we have identified within the last 15 years of our experience could be find in the educational video attached to the manuscript (*Video 1*).

Initial port placement and exposure

After introduction of the first three 8 mm ports (left hand,



Video 1 Summary of the key steps in multi-vessel off-pump total endoscopic coronary artery bypass including selected pearls and pitfalls that facilitate the safe conduct of the operation.

right hand and camera) the chest is insufflated with CO_2 to a pressure of 10 mmHg. The intrathoracic pressure is further adjusted based on blood pressure tolerance as well as ability to visualize the heart and the surrounding structures. We begin the operation by performing a posterior (~2 cm posterior to the left phrenic nerve) pericardiotomy. This maneuver allows the early visualization of the potential targets located on the lateral wall of the heart but also is a well proven method of decreasing postoperative atrial fibrillation (4). That is followed by an anterior pericardiotomy with visualization of the LAD target. The LAD is easily demonstrated as the most medially located vessel. This is an important concept that should prevent grafting of a large and medially located diagonal branch—an error that could easily occur when viewing the anterolateral surface of the heart from the left chest. Of note a variable amount of pericardial fat tissue will need to be mobilized in order to perform the anterior pericardiotomy and is later used to cover the anterior surface of the heart and the LAD graft.

Bilateral ITA dissection in skeletonized fashion

In a multivessel TECAB, we utilize both ITAs. After performing the anterior and posterior pericardiotomy we turn our attention to the ITA dissection. We start with the right internal thoracic artery (RITA) by opening the mediastinal fat and entering the right pleura. Using a combination of monopolar and bipolar energy device the endothoracic fascia is opened and the RITA carefully dissected from the surrounding tissues. It is important to avoid any direct manipulation of the vessel in order to prevent potential trauma or dissection. During the skeletonization process we deliberately leave minimal amount of fat tissue attached to the artery that can be used as a “handle” for minimally invasive manipulation of the ITA, a maneuver that significantly improves the ease of the dissection. The RITA is dissected circumferentially all the way distal to the bifurcation while preserving few attachments to the chest in order to prevent inadvertent vessel torsion.

It is important to note that during instrument exchanges while harvesting the RITA the camera as well as the instruments should be returned to the left chest under direct visualization and staying high above the heart in order to prevent potential injury outside of the field of vision. The left internal thoracic artery (LITA) dissection is performed in a very similar fashion. In order to facilitate the proximal dissection of the RITA we use the help of the endo stabilizer in order to create sufficient traction of the mediastinal fat. The right internal thoracic vein usually runs medial to the RITA and is divided proximally between multiple clips which helps in providing a direct path for the RITA to reach the left heart targets. Exposure and multiple clipping of the first intercostal arterial branch mark the conclusion of the proximal dissection. The use of energy in the proximity of the first intercostal branch should be done carefully due to risk of potential injury to the nearby located phrenic nerve.

Introduction of endo-stabilizer and working port

As mentioned above, while the placing of the subcostal port allows the introduction of the endo-stabilizer, this maneuver creates the risk of violating the peritoneal cavity, injury of various intraperitoneal structures as well as creation of pneumoperitoneum with subsequent hypotension secondary to impaired venous return. In order to prevent such complications, we first release the subxiphoid attachments which on the one hand allows the heart to further displace towards the spine but also facilitates an easy and safe placement of the subxiphoid port under direct vision.

The final port is a 12 mm working port in the MCL in the left second ICS. After the port is placed carefully and lateral to the LITA, we initiate the AirSeal system (ConMed, Largo, USA). It provides a stable CO_2 insufflation, constant smoke evacuation, and valve-free access to the thoracic cavity. This system has been a major advance in totally endoscopic off pump surgery as it provides for a ‘CO_2 tight’ environment even when CO_2 leaks outside the chest or when applying suction in the intrathoracic cavity. This is an extremely important concept and maintains space in the chest which prevents injury to major structures.

Identification of exact coronary targets

Next, before completely transecting the ITA vessels it is crucial to finalize the location of the various targets [LAD, obtuse marginal branch (OM), etc.]. We use very low energy monopolar cautery to expose the exact location of the future distal anastomosis. A silastic snare is place around the vessel just proximal to the future anastomosis site. At this point we deliver Heparin with an activated clotting time (ACT) goal of 300 s. Shortly after, the mid/proximal ITA is occluded with a small 'bull-dog clamp' and an oblique partial arteriotomy, just proximal to the bifurcation, is performed. A 20 G epidural catheter (B Braun, Germany) is gently introduced into the ITA vessel and after initial aspiration to confirm intra-luminal position, papaverine is carefully injected. This catheter has a blunt tip and side holes so as not to injure the ITA during placement and injection. We believe that this maneuver allows not only to clear any intima related debris but also increases the diameter of the vessel especially after occasional vasospasm at time of manipulation. After delivery of the papaverine the catheter is rapidly removed, and the vessel is immediately clipped in order to allow some residual papaverine to remain within the lumen of the ITA. The conduit is now fully transected and assessed for length as to where it will be placed. We prefer placing the LITA on the LAD when the RITA is able to reach the marginal branch of the Circumflex artery by routing it deep to the anterior mediastinal fat. If the RITA will not reach the Cx target it is grafted to the LAD, and the LITA is used for Cx artery grafting.

Ischemic preconditioning

Before creation of the anastomosis, we perform ischemic preconditioning by snaring the coronary vessels for a period of 5 minutes. During this time period we carefully observe the electrocardiographic (EKG) monitor for potential changes, assess for any transesophageal echocardiography (TEE) related wall motion abnormalities and/or hemodynamic changes. Of major importance in this context is continuous, easy, and direct communication between the surgeon and the anesthesia team. In our experience this is best done using blue-tooth headsets and microphones (Quail Medical, UK) which facilitate exchange of vital information in a clear and concise fashion.

During the ischemic preconditioning the ITA is clipped to one arm of the stabilizer and its distal end spatulated. In order to optimize the length of the already skeletonized RITA but also prevent any tension, a "window" in the mediastinal fat is created. Minimal tension is acceptable since the length of the vessel will improve after CO_2 release.

Anastomosis technique

At this point, we proceed with the distal anastomoses using a so called "double shunt technique". Based on the size of the various vessels, we introduce a shunt in the coronary as well as in the ITA. The coronary shunt not only keeps the vessels stented and prevents bleeding from the native circulation, it also allows continuous distal coronary flow and perfusion and facilitates the conduct of the anastomosis substantially by decreasing the risk of back wall injury. The anastomosis is hand sewn using a short double-armed 7:0 monofilament Pronova suture (5,6). This particular suture type maintains "memory" that facilitates the creation of the anastomosis without the need of an assistant to follow the suture.

Flow measurement and conclusion of the operation

Once the anastomosis is completed and both shunts are removed the integrity is assessed for bleeding. In addition, we closely investigate the blood flow through the anastomosis using a flexible transit time flow measurement probe (Medistim, Norway). Such immediate feedback allows early recognition of potential technical issues that could be easily repaired at time of the index operation.

At this time protamine is administered and a loose closure of the anterior pericardium and pericardial fat is performed. That allows some degree of coverage and protection of the anastomosis. In addition, a loose and superficial closure of the anterior mediastinal fat "tunnel" for the RITA is performed as well. A 24 Fr Blake drain is placed in each pleural space. We position the left drain posterior to the lung hilum in order to avoid any disturbance or a potential injury of the ITA graft to the posterior wall. All instruments with exception of the camera are removed under direct vision. The CO_2 is slowly released allowing for final assessment of the "natural" ITA course in the absence of gas insufflation.

In the following paper we share pearls and pitfalls that we encountered and learned performing over 950 robotic TECABs in 2 institutions over the last 15 years. It is important to highlight that robotic cardiac surgery in general and in particular robotic revascularization requires the acquisition of a completely new set of surgical skills that widely differs from the ones used to conduct open heart operations. The associated steep learning curve is a function not only of the surgeon's experience and dedication but also of the experience of the entire surgical team (nursing staff, cardiac anesthesia, perfusion, etc.). We have previously highlighted that dedicated robotic cardiac team that is highly involved is paramount in building robotic cardiac program. As mentioned in our previous work, we strongly believe that it is essential for surgeons to be aware of the need for complete paradigm shift from a limited and infrequent-procedure approach to the full and extensive adoption of the current robotic technology (3).

Conclusions

Off-pump robotic total endoscopic coronary artery bypass continues to be the least invasive and most versatile surgical approach that could be offered to patients with stable CAD and is associated with excellent short- and long-term outcomes (7). The combination of careful multidisciplinary patient selection and an experienced high volume dedicated robotic cardiac surgery team is a prerequisite for the success of the operation.

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Footnote

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in the study were in accordance with the ethical standards of the institutional and/or national research committee(s) and with the Helsinki Declaration (as revised in 2013). Written informed consent was obtained from the patient for publication of this manuscript and the accompanying video.

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