Beating heart multi-vessel minimally invasive direct coronary artery bypass grafting: techniques and pitfalls

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Abstract: Coronary artery bypass grafting (CABG) has been changing since its initial reports. There has been a shift from standard CABG, which uses sternotomy and a single left internal mammary to the left anterior descending artery (LAD) grafting, plus vein grafts to other targets, and performed on bypass with aortic cross-clamping. We now have CABG using multiarterial grafts, avoiding manipulation of the aorta, and through a minimally invasive approach. Beating heart Multi-vessel Minimally Invasive Coronary Artery Bypass (Multi-vessel MICS CABG) has emerged as an attractive alternative in coronary revascularization. The minimally invasive approach mitigates some of the risks and long recovery associated with the more invasive standard full sternotomy approach. It decreases the rates of wound infection, transfusion, post-operative pain, time of recovery and sternal dehiscence, while maintaining the same outcomes as the standard approach with full sternotomy. There are multiple centers around the world that have reported safe and good outcomes with Multi-vessel MICS CABG, including the initial report from our center joint with Staten Island, NY. The aim of this paper is to describe the technique and pitfalls of Multi-vessel MICS CABG as used at our center and go over patient selection and outcomes. A video and several pictures are shown to facilitate the understanding and learning of this technique.

Keywords: Minimally invasive; coronary artery bypass surgery; surgical technique; off pump coronary artery bypass grafting (CABG)

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Introduction

Coronary artery disease is a prevalent disorder and is one of leading causes of deaths worldwide (1). Coronary artery bypass grafting (CABG) is the gold standard for managing severe coronary artery disease (2). Since its development in 1964 (3), the CABG procedure has been improved to delivery better outcomes and decrease complications for patients (4). One of the improvements is the beating heart Multi-vessel Minimally Invasive Direct Coronary Artery Bypass (Multi-vessel MICS CABG), which has been developed to be a less invasive procedure by obviating the use of a sternotomy. This technique aims to decrease the rates of wound infection, transfusion, post-operative pain, time of recovery and sternal dehiscence, while maintaining the same outcomes as the standard approach with full sternotomy (5,6). Multi-vessel MICS CABG has been a routine approach at our center since 2005 (7). Its experience and outcomes have been reported with excellent results by multiple centers after our initial series (7-11). The aim of this paper is to share the techniques and pitfalls learned during these years of experience.

Patient selection

All procedures performed in this study were in accordance with the ethical standards of the institutional research

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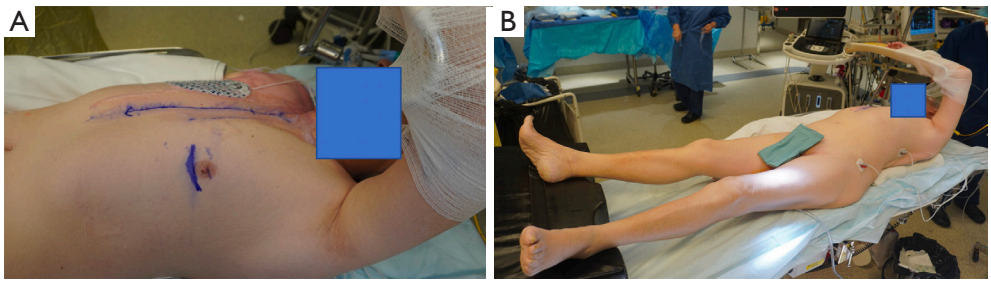

Figure 1 Patient position before the procedure. (A) Demonstrates the defibrillation external pads and the blue lines where the thoracotomy will be performed and possible sternotomy if conversion is needed; (B) shows the patient positioned in right lateral decubitus with a rolled flannel placed from the left shoulder to the left hip. Also note that the left arm is elevated.

committee and with the Helsinki Declaration (as revised in 2013). Pictured informed consent was obtained from the patient for publication of this article, the accompanying video and images.

The indication of the revascularization should be decided by a heart team. Whenever feasible and according to the patient's wish the minimally invasive approach is the option of choice at our center. The selection of a patient for Multi-vessel MICS CABG must be well evaluated pre-operatively. Basically, this selection should take into consideration 3 elements: the surgical exposure, clinical stability during the procedure, and the coronary surgical anatomy. Once there is a good combination of these three elements, we deem that the patient is a candidate for the minimally invasive approach. Otherwise, the patient is selected for a convectional off-pump CABG through a sternotomy.

For the surgical exposure assessment, adequate thorax physical examination should be performed. Chest anomalies, such as severe pectus excavatum, and previous thoracic surgery are usually contraindications for the minimally invasive approach. It is important to inquire about history of pneumonia, chest radiation or trauma which may have led to adhesions and may compromise surgical exposure.

It is mandatory to seek features that may cause clinical instability during the procedure. The patient should be able to keep adequate pulmonary function with single right lung ventilation. Also, heart mobilization to expose the coronary arteries may cause hemodynamic instability in patients with ventricular dysfunction or atrial arrhythmias. Therefore, patients with lung disease associated with decreased pulmonary function tests, patients with significant ventricular dysfunction, and rapid atrial fibrillation are not good candidates for Multi-vessel MICS CABG.

Adequate caliber of the coronary artery target vessels should be present to achieve a good surgical outcome and facilitate the procedure. Ideally the targets should be 1.5 mm or wider. Adequate exposure to the left anterior descending artery (LAD), diagonal artery (Dg), Ramus artery (Rm), obtuse marginal arteries (OM), postero-lateral artery (PL) and Posterior descending artery (PDA) can all be achieved through a small left thoracotomy. The main right coronary artery (RCA), however, is difficult to expose through this approach.

A noncalcified aorta is important in cases where a side aortic clamp is planned to be inserted. The femoral vessels should always be assessed pre-operatively in case femoral cannulation is required for cardiopulmonary bypass (CPB) support.

Operative room preparation

Excellent team synergy is required for this procedure. Good communication and interaction between the main surgeon, surgical assistant, anesthesiologist, perfusionist, and nurses is a must. The procedure is carried on under general anesthesia and monitoring should be done with arterial and central venous line. Intubation strategies, such as double lumen endotracheal tube insertion or bronchial blocker, must be done to allow single right lung ventilation. Perioperative transesophageal echocardiogram is important to monitor cardiac function and to guide cannulation in case that CPB support is necessary.

The patient should be positioned in a right lateral decubitus (approximately 25° to 35°). A rolled flannel is placed from the left shoulder to the left hip. The left arm is elevated. The groins should always be easy to access, and also the CPB machine and perfusionist should always be in standby during the procedure in case CPB support is needed. The legs must be exposed for saphenous vein harvest and the right arm when the radial artery is used as a

Table 1 Check list material used in our institution for multivessel minimally invasive direct coronary artery bypass

Sternal saw ready for use and a routine coronary surgical instruments box
Rultract retractor
Knot pusher
Octopus handle holder
Thoratrak retractor
External defib pads
Long clip applier
Long insulated cautery tip
Octopus NUVO
Blow mister
Starfish
Gerald tissues
Long coronary scissors
Hair clips with holes
Long coronary probes
Lambert-Kay Aorta Clamp

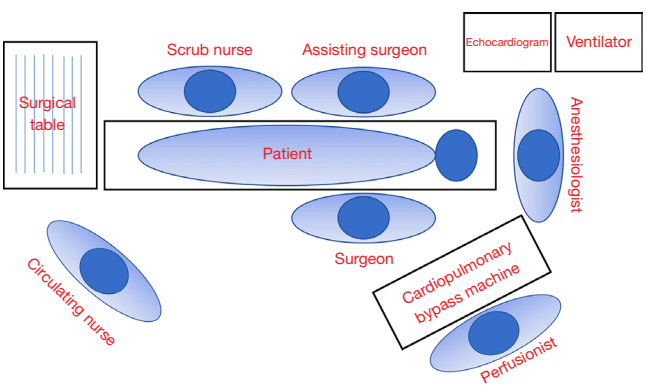

Figure 2 Layout of the operation room for beating heart multi-vessel minimally invasive direct coronary artery bypass grafting.

graft. In case the left arm is used, harvest of the radial artery needs to be completed before positioning. Defibrillation external pads should always be placed (*Figure 1*).

All equipment required for multi-vessel MICS CABG must be available in the Operative room. The check list material used in our institution is presented in the *Table 1*. *Figure 2* shows the layout of the operating room used by our team.

Video 1 The video shows a clinical case as an example of beating heart multi-vessel minimally invasive direct coronary artery bypass grafting.

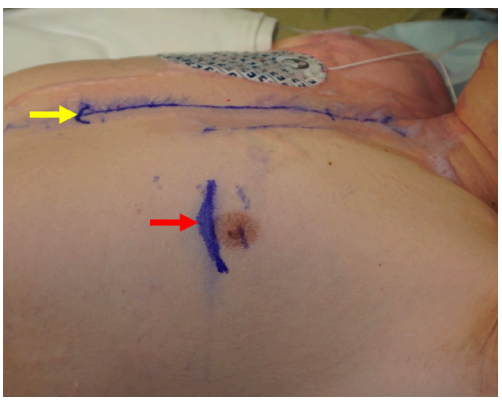

Figure 3 The illustration shows where the incision is placed (red arrow). Also note a mark is placed for the sternal incision in case conversion is necessary (yellow arrow).

Surgical procedure

An example of a case can be seen as *Video 1*. The incision is 4–6 cm long and at the 5th intercostal space on the left midclavicular line (*Figure 3*). Before starting the procedure, the sternum should be fully exposed in case conversion to sternotomy is required. After reaching the ribs, care must be taken to do not damage the internal mammary vessels while opening the intercostal space. Usually, the 5th intercostal space is the one opened, but if necessary to achieve good surgical exposure either the 4th or 6th intercostal spaces may be opened.

The Thoratrak retractor (Medtronic, Inc., Minneapolis, USA) is placed in the intercostal space. At this point, we may open the pericardium to access the coronary vessels

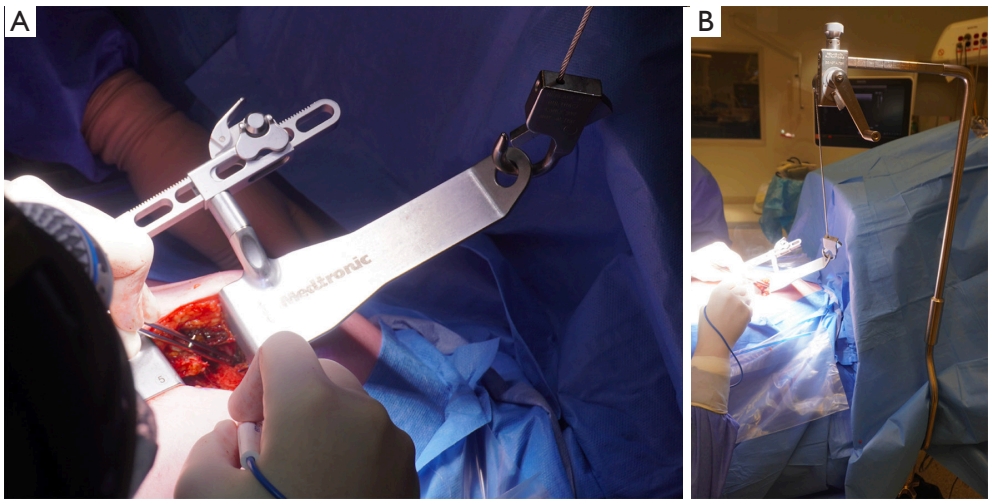

Figure 4 The set up for LIMA harvesting (A) shows the LIMA bed exposure with the Thoratrak retractor being pulled cephalic with the Rultract Retractor positioned in the left side of the patient as in (B). LIMA, left internal mammary artery.

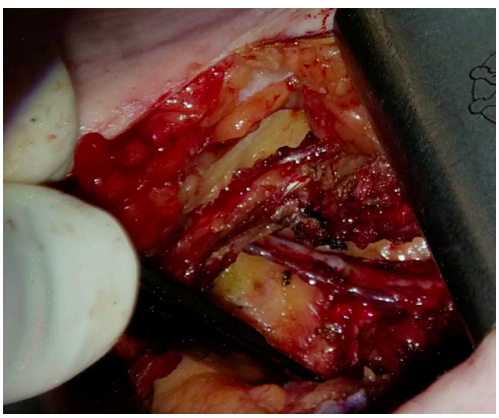

Figure 5 Left internal mammary artery harvested through a small thoracotomy.

and predict the surgical exposure. After that the assistant usually begins to harvest the venous or radial graft in the usual fashion. The left internal mammary artery (LIMA) is harvested from a lateral approach under direct vision. A special retractor (Rultract Skyhook retractor, Rultract Incorporated, Cleveland, USA) is used to pull the Thoratrak retractor for LIMA harvest (*Figure 4*). As seen in *Figure 4* the Rultract Skyhook retractor is placed in the left side of the patient and the incision is pulled towards the left shoulder. If the LIMA is not easily visualized, dissection of the mediastinal reflection from behind the sternum may help. Skeletonized or pediculated techniques for LIMA harvest may be used according to the surgeon preference (*Figure 5*). Heparin is administered to achieve an ACT of 280 or more, and next, distal ligation and cut of the LIMA is done.

Once the conduits are harvested, exposure of the ascending aorta for proximal anastomoses is initiated. First, the Rultract Skyhook retractor is positioned to the right side of the table to pull the Thoratrak retractor proximally towards the ascending aorta (*Figure 6A*). Then the pericardium is opened until its superior reflection at the upper part of the ascending aorta. Pericardium traction stitches are placed to bring the aorta closer to the incision and the skin closer to the aorta. A gauze is placed between the aorta and the superior vena cava, which brings the aorta a bit closer to the incision. A 6 mm incision is made inferiorly the main incision in the left 6th or 7th intercostal space. This 6 mm incision allows the introduction of the Octopus NUVO (Medtronic, Inc.), which is positioned over the right ventricular outflow tract (RVOT) to flatten and displace it toward the left posteroinferior direction (*Figure 6*). Gentle left downward compression on the RVOT generally avoids hemodynamic instability. Once the position is adequate the Octopus is fixed with a holder. Following those steps, the aorta should be accessible to the surgeon and a standard partial occlusion clamp can be placed for proximal anastomoses. Palpation or epicardial scanning prior to clamping should be done to assess the aorta and in cases that aortic disease is suspected clamping should not be performed to avoid the risk of embolic events. In such cases, we perform a composite graft from the LIMA. In cases in which the aorta is not diseased, the side clamping should be

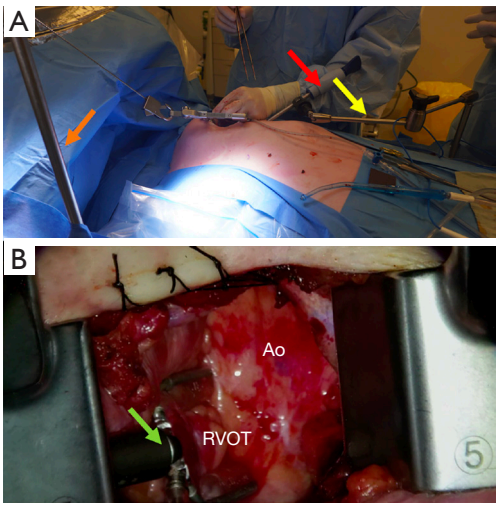

Figure 6 The set up for the ascending aorta exposure. In (A), the orange arrow aims the Rultractor Retractor which is placed in the right side of the table for adequate aorta exposure. This makes the Thoratrack Retractor to be pulled towards the ascending aorta. The red arrow aims the Octopus handle, and the yellow arrow aims the Holder which stabilizes the Octopus; (B) shows the RVOT being pulled posteroinferior to allow exposure of the Ao. The green arrow aims the tip of the Octopus. RVOT, right ventricular outflow tract; Ao, aorta.

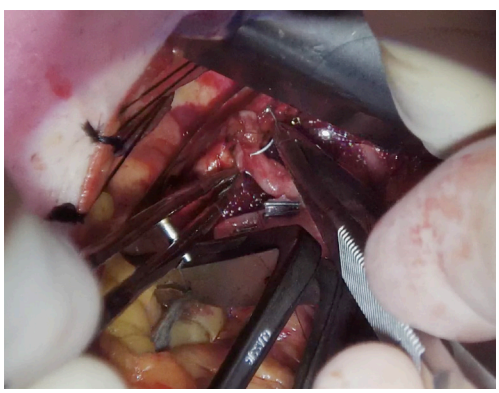

Figure 7 Direct vision of the proximal anastomosis with a side clamp applied in the ascending aorta.

placed under a systolic blood pressure of 80–85 mmHg and the proximal anastomosis are performed under direct vision like in the standard fashion using a 6-0 Prolene suture (*Figure 7*). Often, a knot pusher is used to tie the suture of the proximal anastomosis. Once checked hemostasis of the proximal anastomosis, we take out all the apparatus used for the ascending aorta exposure. At this point, the Rultract Skyhook retractor is no long routinely needed.

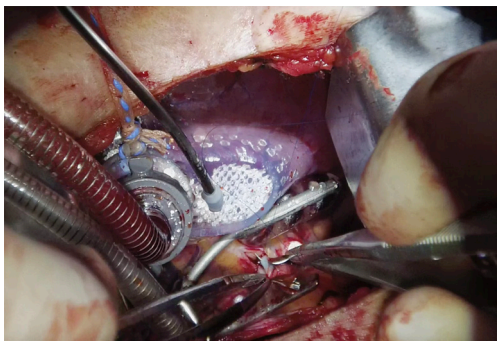

Figure 8 Distal anastomosis being performed. In this figure it is noted the presence of the starfish and the octopus being used during confection of the distal anastomose on the left obtuse marginal coronary artery.

The next step is the distal anastomoses. The blood pressure should be brought up. We aim a systolic blood pressure of 140–150 mmHg. The sequence of distal anastomoses is dictated by the surgeon's preference and the potential degree of ischemia in each territory.

It is important to mention that for an adequate exposure of the coronary target, the Thoratrak retractor and the Octopus NUVO are used. Complementarily, an armless Starfish Heart Positioner (Medtronic, Inc.) is used whenever the target coronary is the OM, Rm, PL or PDA—please see the *Video 1*. The Starfish is not needed for the LAD and Dg exposure, as those coronaries are right under the incision and no major heart mobilization is required for that purpose.

For the confection of the distal anastomosis, the Starfish is applied whenever the target vessel is the OM, Rm, PL and PDA through the main incision, and/or the Octopus is applied in the sequence in all target coronaries, using the 6mm incision at the $6^{th}/7^{th}$ intercostal space (*Figure 8*). It is crucial to have the holder for stabilization of the Octopus as it permits stability where the distal anastomosis will be performed. In cases in which adequate exposure of the target vessels is not achieved, the use of CPB or conversion to sternotomy should be done. If the patient presents hemodynamic stability with adequate coronary exposure, we procced to the distal anastomosis. For coronary bleeding control, a temporary suture is placed around the coronary artery to be grafted, proximally to the planned arteriotomy. This occludes the coronary for a short period and allows better visualization. A blower is also used to improve visibility of the coronary. After arteriotomy, an

intracoronary shunt can be placed and the suture around the coronary may be taken out. It is important not to leave the graft too long by stretching it a bit to the anastomotic site and by cutting with an extra 2 cm or so. Then, the distal anastomosis is performed with a 7-0 or 8-0 Prolene suture with standard instruments. We check all bypass grafts with a doppler flow probe. Protamine is administered after confirmation of adequate graft flow and hemostasis.

By the end of the procedure, a Blake drain is inserted in the left pleural space via the 6th or 7th intercostal space through the incision where the Octopus was placed. The left lung is reinflated, and proper lie of the grafts and the chest tube should be checked during lung reexpansion. The intercostal space is reapproximated and the subcutaneous tissue and skin are closed. Intercostal nerve blockage is an option to optimize immediate post-operative pain control.

It is important to mention that the priority is (I) safety and (II) efficacy in any surgical procedure. The security of a patient, and the efficiency of a procedure should never be jeopardized due to seeking the "comfort" of a minimally invasive approach. The surgeons performing Multi-vessel MICS CABG should have a low threshold for conversion to sternotomy and/or CPB initiation, especially during their early experience—this is not a failure unless a delayed conversion has already led to a complication. The sternotomy and CPB support should be used in scenarios such as uncontrolled ischemia, bleeding or impossibility of achieve good surgical visualization or exposure.

Clinical outcomes

The outcomes of Multi-vessel MICS CABG have been extensively published by our group (7-9). In our last publication (8), 510 consecutive patients who underwent MICS CABG from September 2005 to December 2020 were analyzed. In this population, the median age of the patients at the time of operation was 64.0 years old and 83% were men. The clinical presentation was acute coronary syndrome in 12% of these patients. In about 82% of these population, the ejection fraction was higher than 45%. Around 16% of the patients required CBP support intraoperatively and in 4% of this cohort conversion to full sternotomy was needed. Median ICU length of stay was 24 h and median duration of hospital stay was 5.0 days. Mortality and major adverse cardiac or cerebrovascular events (MACCE) in the first 30 days after the procedure occurred respectively in 0.2% and in 1.4% of these patients.

Comments

The technique presented in this paper, the beating heart multi-vessel minimally invasive direct coronary artery bypass grafting, is viable, feasible, and a secure option for surgical revascularization in well selected patients with CAD. We strongly believe that Multi-vessel MICS CABG is a reproducible technique that may be applied in multiple expert centers (12).

This paper describes the surgical technique and its steps in details. However, there are pitfalls for all those who perform this procedure. Incorrect rib space for entry is a very common pitfall, that makes surgical exposure inadequate. If needed, the surgeon should not hesitate to open the intercostal space above or below according to his judgment. Another common pitfall is inadequate left lung isolation, which may be solved with bronchoscopy. If not, a wet sponge may be placed on the left lung. When faced by any major complication and adverse scenario, such as uncontrolled bleeding, graft injury, hemodynamic instability, or inability to achieve good surgical exposure remember that conversion to full sternotomy and CPB support are always an option. The minimally invasive approach should never jeopardize the security and safety of the patient.

Further investigation comparing results between the standard approach with sternotomy *vs.* the minimally invasive approach is needed. No randomized controlled trial has been published yet comparing results between the standard approach with sternotomy *vs.* the minimally invasive approach. We are leading an international randomized controlled trial called MIST (Minimally Invasive Coronary Surgery Compared to Sternotomy Coronary Artery Bypass Grafting; NCT03447938), which will ascertain whether Multi-vessel MICS CABG provides a faster recovery and equivalent or better long-term outcomes compared with sternotomy CABG (13).

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Footnote

Provenance and Peer Review: This article was commissioned by the Guest Editors (Johan van der Merwe and Filip P. Casselman) for the series "International Perspectives on Minimally Invasive Coronary Artery Revascularization"

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Conflicts of Interest: Both authors have completed the ICMJE uniform disclosure forms (available at https://jovs.amegroups.com/article/view/10.21037/jovs-22-5/coif). The series "International Perspectives on Minimally Invasive Coronary Artery Revascularization" was commissioned by the editorial office without any funding or sponsorship. MR is a MICS CABG proctor and PI for the MIST trial (both with support from Medtronic, Inc). The authors have no other conflicts of interest to declare.

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 this 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 any accompanying images and videos.

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