Teaching the next generation of robotic coronary surgeons

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Robotic-assisted coronary bypass is an attractive option in the management of patients with isolated left anterior descending artery (LAD) disease or multi-vessel coronary disease providing the benefits of the left internal mammary artery (LIMA) to the LAD graft while avoiding the morbidity of a sternotomy. Although the learning curve is significant, both cardiothoracic surgery trainees as well as experienced coronary surgeons can learn this technique. As the prevalence of patients requiring these procedures increases, we must be prepared to respond by increasing our training of robotic coronary surgeons.

Keywords: Learning curve; robotic cardiac surgery; coronary bypass

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Introduction

Robotic-assisted coronary artery bypass grafting (CABG) is an attractive option in the management of patients with isolated left anterior descending artery (LAD) disease or multi-vessel coronary disease providing the benefits of the left internal mammary artery (LIMA) to the LAD graft while avoiding the morbidity of a sternotomy. For patients with multi-vessel coronary artery disease, this technique can be combined with percutaneous coronary intervention (PCI) as part of a hybrid revascularization strategy. Since performing our first case in 2009, we have now performed over 1,600 cases with excellent safety and efficacy results, including mortality less than 1%, graft patency of greater than 97%, and conversion to sternotomy in less than 3% of patients.

Technique

Our technique requires that single lung ventilation be achieved using a double lumen endotracheal tube or a bronchial blocker. A gel roll is placed underneath the left chest just inferior to the scapula so that the shoulder will gently fall away. Three 8-mm trocars are placed in the left chest, and carbon dioxide insufflation (typically 8–12 mmHg) is used. The insufflation is adjusted as needed based on the hemodynamics and the intrathoracic anatomy. Instead of placing the camera port in a specific interspace, we always aim to put the camera port at the midpoint between the costal margin and the clavicle. Prior to placing the camera port, the chest is entered with a blunt instrument (Kelly clamp) so that there is minimal force needed to insert the camera port. This is almost always the fourth or fifth interspace and lies usually at or just posterior to the anterior axillary line. The superior port is placed two interspaces superior and slightly medial to the camera port and is placed after localizing with a spinal needle so the surgeon can appreciate the angle and location of entry. Placing this port too posteriorly will lead to conflict with the left shoulder. The inferior port is placed two or three interspaces below the camera port and should be slightly inferior to the apex of the heart. Similarly, a spinal needle can be used to identify the best location for port placement (*Figure 1*). The da Vinci (Intuitive Surgical, Sunnyvale, CA, USA) robot is then used to harvest the LIMA in a semi-skeletonized fashion. We begin by removing the endothoracic fascia and transversus thoracic muscle to aid with exposure of the LIMA. The LIMA is harvested *en bloc* with the two mammary veins using the robotic clip applicator to ligate large branches. Cautery is set to two or three (on the XI system). It is our standard practice to harvest the LIMA in this manner, however, a skeletonized IMA may be harvested

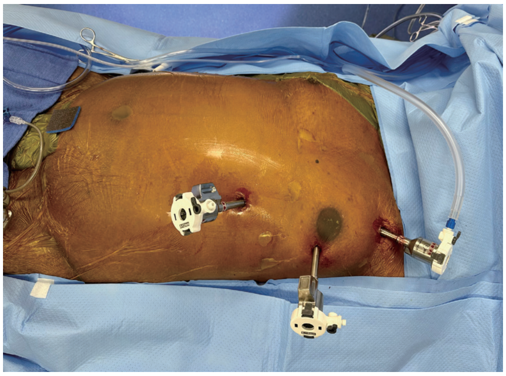

Figure 1 Robotic trocar placement.

Figure 2 Set up for LIMA-LAD anastomosis. LIMA, left internal mammary artery; LAD, left anterior descending artery.

using the same technique. A posterior pericardial window is made, and pericardial fat is removed from the anterior pericardium using electrocautery. Heparin is administered to achieve an activated clotting time (ACT) >300, and the LIMA is divided distally between clips. The pericardium is opened longitudinally and the distal LAD target is identified. Care is taken to avoid injury to the phrenic nerve superiorly and inferiorly if the pericardiotomy is extended horizontally. The robot is then undocked and a 3–4 cm non-rib-spreading anterolateral thoracotomy is created after localizing the incision using a spinal needle and the endoscope. A spinal needle is inserted into either the fourth or fifth interspace and the carbon dioxide insufflation is disconnected to allow the heart to return to its normal position.

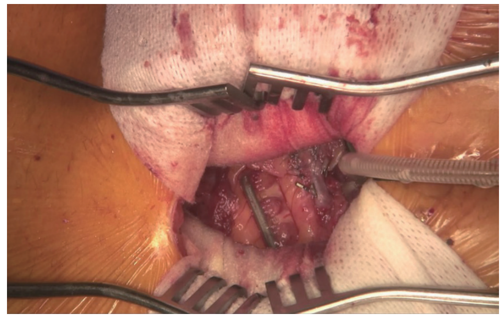

Figure 3 Completed LIMA-LAD anastomosis. LIMA, left internal mammary artery; LAD, left anterior descending artery.

With the endoscope, the surgeon is watching to see if the LAD at the planned site of anastomosis approaches the tip of the spinal needle. A soft tissue retractor (Edwards Lifesciences, Irvine, CA, USA) is used to provide gentle soft tissue retraction to expose the mid-distal third of the LAD. The Nuvo off-pump stabilizer (Medtronic Corp., Minneapolis, MN, USA) is inserted through the inferior robotic port site and used to stabilize the LAD at the planned site of the anastomosis (*Figure 2*). The LIMA is retrieved from the chest and prepared in the usual fashion. A soft silastic vessel loop is placed around the LAD proximal to the planned site of the anastomosis and a period of test occlusion is performed for three minutes to ensure hemodynamic and electrical stability. After the LAD arteriotomy is completed, an appropriately sized intracoronary shunt is placed and a manual LIMA-LAD anastomosis is then performed off-pump using an 8-0 polypropylene suture. The shunt is removed prior to the final few sutures, and the vessel is tacked in place using a 6-0 polypropylene suture (*Figure 3*). A 28-French Blake drain is left in the left pleural space via the inferior trocar site. The mini-thoracotomy incision is closed in multiple layers (*Figure 4*).

Hybrid revascularization

In patients where a hybrid revascularization strategy is planned, the PCI can be performed before or after the LIMA-LAD graft. Approximately 60–70% of patients have the LIMA-LAD graft done first, which allows for the LIMA graft to be assessed prior to PCI. In patients that present with acute coronary syndromes where the culprit vessel is the non-LAD vessel, PCI should be performed first. If possible, we typically wait 8–12 weeks after PCI

Figure 4 Closed incisions.

before surgery to allow for uninterrupted dual antiplatelet therapy. Our current protocol is to hold clopidogrel for one day prior to surgery. Patients on ticagrelor or prasugrel are transitioned to clopidogrel a week before surgery and then clopidogrel is held the day before surgery. In patients that have critical LAD anatomy or unstable symptoms, these have been approached safely by using intravenous platelet inhibitors for inpatients or uninterrupted clopidogrel. In these cases, it is important to discuss with interventional cardiology whether a traditional sternotomy approach or multivessel PCI would be the best option. Aspirin is continued including the day of surgery. If postoperative bleeding is minimal (<100 cc/h for four hours), clopidogrel is restarted six hours postoperatively. Approximately one week after surgery, we will transition back to ticagrelor if the patient is clopidogrel resistant. If PCI is to be performed after surgery, this can be completed during the same hospital stay, or in the outpatient setting depending on patient characteristics and scheduling factors. This flexibility is particularly useful for patients referred from other centers. Not only is this convenient for patients who may be coming from a distance, but it helps maintain positive relationships with referring interventionalists. In our experience, approximately half of the patients undergoing robotic-assisted CABG undergo a hybrid procedure.

Starting a robotic CABG program

The building of any new program must begin with establishing the necessary foundation. This begins with administrative support to guarantee resources such as a robotic system, specialized staff, operating room time, and necessary accommodations for the expected temporary decline in productivity as the new technique is mastered. Support of referring cardiologists is paramount to the success of a new robotic CABG program. To demonstrate efficacy of this new technique, we routinely performed on table angiography initially in our experience. For the index cases, patient selection is extremely important. In the beginning of our experience with this technique, we only offered this procedure to patients with a favorable body habitus (i.e., non-obese with no prior left-sided broken ribs), and with favorable coronary anatomy defined by a non-calcified non-intramyocardial LAD at the target grafting site.

Teaching the next generation of robotic coronary surgeons

The question of when and how to incorporate trainees is a complicated balance of maintaining academic training commitments and needing exceptional results in the beginning of a new program. Robotic-assisted coronary bypass is essentially two separate operations: the robotic LIMA harvest and the off-pump LIMA-LAD anastomosis. Current day surgical trainees are likely to have some experience and comfort with robotics since they are introduced to robotic general surgery procedures early in their training. This applies to both traditional 5+2/3 and 4+3 programs as well as integrated six-year programs. This is highly beneficial, although not mandatory, as most of the first-generation robotic coronary surgeons had no prior experience when learning this technique. Prior to using the robot in a patient setting, there are simulation software programs available so that learners can gain experience with the robotic system. Multiple hours of practice should be obtained on the simulator program for any surgeon starting robotics. Learning the hand and foot controls, understanding the lack of tactile feedback, and adjusting to the ergonomics and clutch system should all be mastered in a simulation setting. Intuitive Surgical also provides cadaveric training simulation programs for new surgeons at multiple United States of America (USA) sites.

Practically, teaching a trainee the surgical technique is similar to other procedures and is done in a graduated fashion. We break down the robotic LIMA harvest into the following steps: (I) port placement and docking; (II) removing overlying fat, endothoracic fascia and transversus thoracic muscle for LIMA exposure; (III) identifying the proper plane and the beginning of the LIMA harvest; (IV) clip application and then cautery of large branches; (V) posterior pericardial window, pericardial fat removal and pericardiotomy; (VI) completion of the LIMA harvest. Residents, fellows, and junior faculty can place the superior and inferior ports first with minimal risk. The camera port requires careful attention because of the risk of cardiac injury if too much force is applied during insertion. Usually after a Kelly clamp is inserted, the attending surgeon can feel if there is space between the heart and the clamp or if the heart is close or adjacent to the chest wall. In this case, the attending surgeon should place the port. Once carbon dioxide is insufflated, there is adequate space. The next step that residents can learn is the completion of the LIMA harvest. At this point, the LIMA is hanging off of the chest wall and the learner can become comfortable with using the cautery in the plane most medial to the medial vein. Injury to the LIMA is unlikely. The next step is more dissection and clip application to the distal third of the LIMA. Similarly, an injury here is less likely to preclude LIMA use because we rarely need the last 3–4 inches of LIMA for the anastomosis. As experience is gained, we allow more proximal dissection and clip application, reserving the most proximal portion of the LIMA close to the subclavian vein for those that have achieved proficiency and expertise. The other step that is usually very amenable for learners is the posterior pericardiotomy and the removal of the anterior pericardial fat pad, followed by the pericardiotomy. Removing the endothoracic fascia and transversus thoracis muscle is usually reserved for advanced learners that have already gained expertise in all the other parts of the LIMA harvest. Most of our robotic systems have dual consoles which allow ease in switching operators.

For any surgeon, learner or competent coronary surgeon, the first off-pump LIMA-LAD anastomosis should not be performed through a small anterolateral thoracotomy. Expertise in off-pump LIMA-LAD grafting should be mastered in sternotomy patients prior to attempting this through a small incision. For trainees that have demonstrated competency with coronary anastomosis as well as off-pump LIMA-LAD anastomoses, performing the LIMA-LAD in the robotic cases is part of their training. For beginners, we carefully select the patients to include those where the distance from the skin edge to the site of anastomosis is short. This eliminates large patients or deep chested patients where needle angles can be challenging. The LAD and LIMA should be good-sized vessels prior to the learner performing anything more challenging. For all surgeons that are learning this technique, we recommend an adequately sized anterolateral thoracotomy to make exposure as easy as possible. The set-up of the anastomosis, and ensuring adequate exposure is critical to facilitate construction of a perfect anastomosis through a small incision on the beating heart.

On a deeper level, the training of a robotic coronary surgeon primarily requires repetition. The question of learning curve length has been studied. Proposed in 1980, the Dreyfus model of skill acquisition describes the progression from novice to mastery through formal instruction and practice, based on the learner's recollection, recognition, decision making, and awareness (1). Although we tend to simplify this concept and blend the learner's progression, this remains the foundation behind the theory of learning curves. The difference between competence and mastery is an important distinction. Competence is defined as procedural consistency, safety and efficacy. Mastery, which requires substantial additional experience, is the inflection point when steady state is reached and outcomes or other metrics no longer improve.

Our institution recently evaluated our first 1,000 robotic bypass procedures to try to determine the thresholds for competence and mastery. Safety and efficacy were excellent with rates of 0.6% mortality and 3% conversion to sternotomy. Throughout the case series, operative time showed a consistent decline with a nadir at around 250 cases. After 500 cases, the conversion to sternotomy rate did not decrease further. Mortality, graft failure, length of stay, and extubation in the operating room all showed thresholds for mastery between 250 and 500 cases. Safety and efficacy were demonstrated even in the first one hundred cases, indicating a much smaller case number needed to achieve competency. We also noted a slight increase in procedure time and conversion to sternotomy towards the end of the patient series, which we attribute to the surgeon taking on more complicated cases and integrating residents into the procedure (*Figures 5,6*) (2). Although this large case number may be intimidating, it is important to note that the learning curve is surely dependent on the individual surgeon and is likely to be truncated for those who have had significant exposure to these procedures during training. Additionally, for a surgeon joining an already established robotic coronary program, not only will other members of the team be comfortable with the procedure, but the availability of an experienced robotic coronary surgeon is

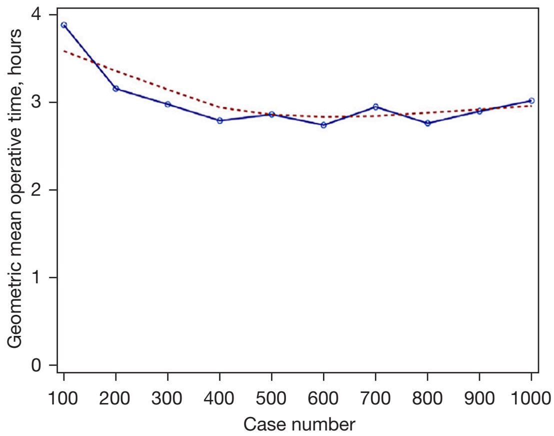

Figure 5 Operative time relative to surgeon experience.

likely to shorten the learning curve as well.

For the new robotic coronary surgeon, appropriate patient selection is imperative. In addition to the standard contraindications, including severe lung disease, prior cardiac or left chest surgery, and hemodynamic instability, you should not feel pressured to take on suboptimal patients initially. Obesity or large breasts present a challenge and should be avoided. Deep chests with a large anterior-posterior diameter can be more difficult as well and should be approached cautiously. Patients with large ventricles due to low ejection fraction should be avoided initially as this makes both the robotic portion as well as the distal anastomosis very challenging. In terms of coronary anatomy, ideal first patients are those with a long segment

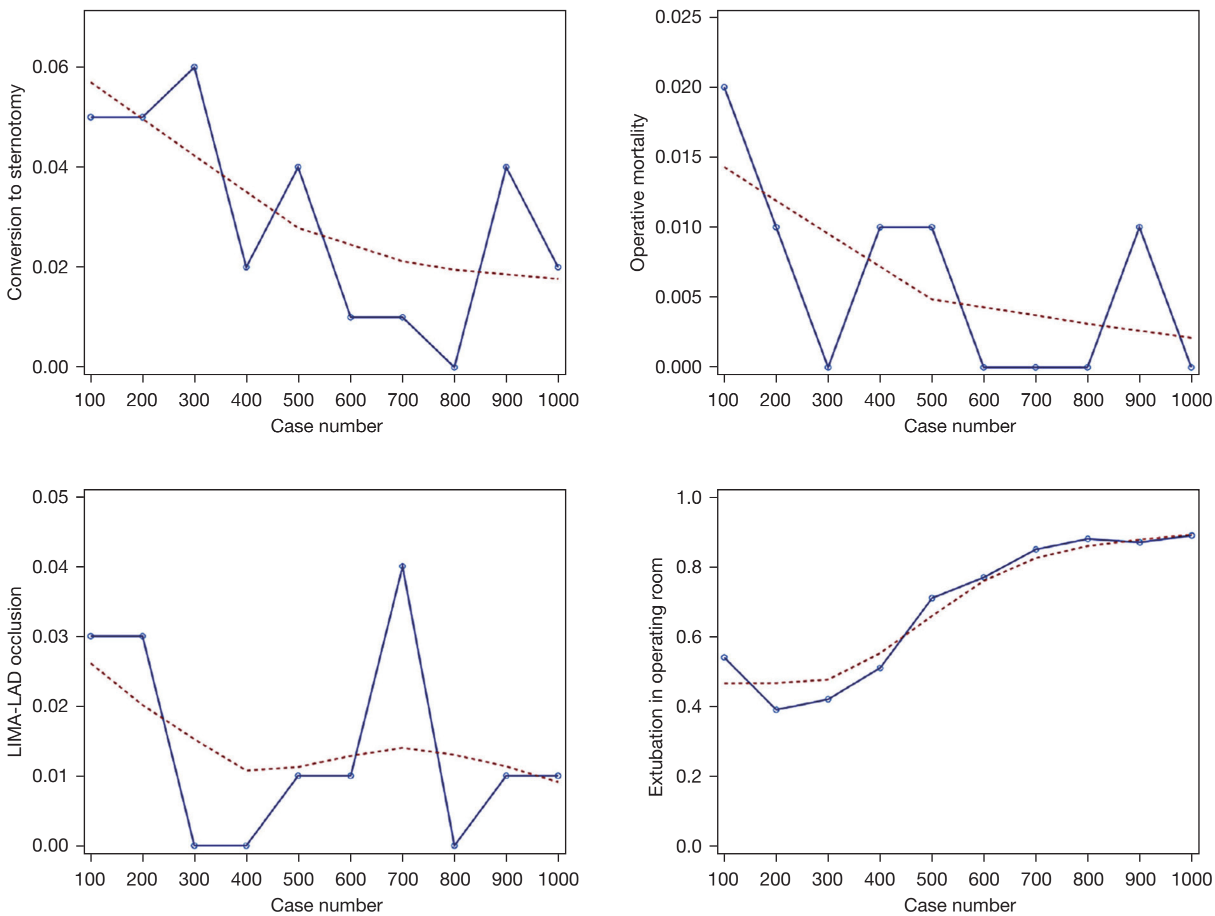

Figure 6 Conversion to sternotomy, operative mortality, LIMA-LAD occlusion, and extubation in the operating room all improved over the case series. LIMA, left internal mammary artery; LAD, left anterior descending artery.

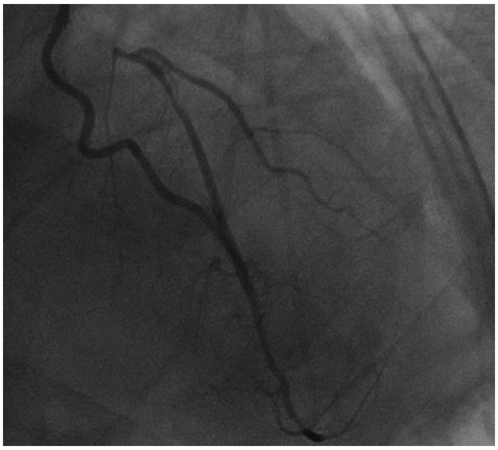

Figure 7 Completion angiogram showing antegrade and retrograde filling of the LAD. LAD, left anterior descending artery.

of non-intramyocardial, non-calcified LAD with at least an anticipated 1.5 mm diameter. Initially the surgeon will not be as fascicle at positioning the heart and working within the mini-thoracotomy and will have more limited options for distal anastomosis location. For patients with prior PCI to the LAD, care must be taken to ensure that there is a long enough stent free segment to select for anastomosis.

When starting your robotic coronary practice, it is important to remember that the most important focus is to perform a safe and effective operation. Expectations should be set with yourself and the operative team so that there is no pressure to perform a speedy operation. For the mini-thoracotomy, making a larger incision makes not only the exposure and anastomosis easier, but it allows your assistant to be able to facilitate the anastomosis. Most importantly, there will be cases where conversion to sternotomy will be needed. If the decision to convert is made because of concerns about the quality of the anastomosis or because of safety, than this is always the appropriate decision. When conversion is performed under controlled circumstances, the outcome should be unchanged. All efforts should be made to avoid emergently converting under duress.

Common reasons for needing to convert to sternotomy include unexpected left chest adhesions, hemodynamic instability, LIMA injury, intolerance of LAD test occlusion, difficult exposure for the anastomosis, or inability to identify a suitable LAD target. In terms of building confidence with this procedure, the post-operative or completion angiogram is paramount. Not only is this an excellent tool for building confidence among your referring cardiologists, but it is an excellent tool to evaluate your anastomotic technique. Ideally, all LIMA angiograms will show flow into the distal LAD as well as retrograde into the proximal LAD (*Figure 7*). However, small findings, for example, a subtle narrowing in the LAD just proximal to the anastomosis, can indicate that a suture was taken too deep on the heel of the LIMA. Typically, this is seen with TIMI 3 flow and is inconsequential to the graft function, however, it is a useful learning tool that many coronary surgeons do not have access to.

Teaching the next generation of robotic coronary teams

The success of a robotic coronary program does not just lie in the hands of the surgeon, but also requires a well-trained and enthusiastic team. From an anesthesia standpoint, there are several key factors required for a successful robotic coronary program. Single lung ventilation must be obtained with either a double lumen endotracheal tube or a bronchial blocker. Experience and comfort with off pump coronary bypass is critical as well. We routinely employ regional nerve blocks performed by our anesthesia team, which decreases post-operative narcotic use. Although this is not mandatory, this is a great benefit to a robotic coronary program. Initially, in our experience, only a select group of anesthesia providers performed these cases. As this has become a very commonly performed procedure, most of our providers are now involved and comfortable with the necessary skills needed. Anesthesia residents are regularly involved and learn the vital skills as well.

The operating room staff face a learning curve as well. Staff will need to become proficient with all aspects of the DaVinci robotic system, including the circulating nurse setting up the video cart and driving/docking the robot. The scrub tech must have a level of experience with safe instrument exchanges, as this procedure is performed in a small anatomic space and an unsafe instrument insertion could lead to a catastrophic injury. Unlike our robotic mitral valve surgeries where we have dedicated teams, we have adapted the way we perform these robotic coronary procedures to safely do so with any of the operating room staff. The most dangerous portion of the procedure is when the surgeon is sitting at the robotic console. We routinely perform all instrument exchanges under direct vision to minimize any potential for injury during the frequent exchanges from the electrocautery to the clip applier. We are also able to monitor the hemodynamics by using the tile pro feature so as to ensure that carbon dioxide insufflation is safely tolerated. From a systems standpoint, the intensive care unit (ICU) and advanced practice provider (APP) teams must adapt. Although these patients are sometimes similar to a traditional CABG patient from a recovery standpoint, there are some important differences. In the cases of patients undergoing a hybrid revascularization strategy, they remain incompletely revascularized until their PCI. Several years into our experience with this technique we implemented a fast-track protocol which allowed appropriately selected patients to bypass the ICU after robotic CABG. For those patients who successfully bypassed the ICU, there was a 15% reduction in total inpatient costs without compromising mortality, stroke, and other adverse events (3).

Conclusions

Robotic coronary artery bypass is an increasingly popular option amongst patients and referring providers. As the prevalence of patients requiring these procedures increases, we must be prepared to respond by increasing our training of robotic coronary surgeons.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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