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Review

Hybrid coronary revascularization: the Emory experience

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Abstract

This article reviews the Emory University Experience with hybrid coronary revascularization and identifies key factors essential for the success of this relatively new and evolving strategy for the treatment of coronary artery disease. Key decisional and technical factors were identified. Careful patient selection, stepwise progression in learning the different aspects of the procedure, and close collaboration between cardiac surgery-interventional cardiology are key factors for success.

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INTRODUCTION

Hybrid Coronary Revascularization (HCR), has evolved over the past decade as a strategy for the treatment of multivessel coronary artery disease combining the most significant advantages of surgical coronary artery bypass (CABG) and coronary artery stenting in order to provide the best possible short and long term results with minimal invasion of the patient. The 88-90% 20-year patency rate of left internal mammary artery (LIMA) to left anterior descending (LAD) coronary artery is the pinnacle of what CABG can offer and is hard to beat[1-4]. This excellent patency rate translates into improved survival, improved relief of symptoms, decrease in major adverse cardiac events (MACE) and decrease need for reintervention[1-4]. Equally important, even though CABG has better long term outcomes than PCI for multivessel CAD[5], the newer generation drug eluting stents deployed to treat discrete lesions in non-LAD territories have excellent short term patency rates (6.6% target vessel failure at 8 months, 8.9% target vessel failure at 3 years)[6,7] comparable or superior to vein grafts to the same territories (25% vein graft failure at 12 to 18 months)[8] without the morbidity of CABG.

The hybrid strategy has a steep learning curve, particularly on the cardiac surgery side because the LIMA LAD anastomosis is done without a sternotomy, in an off-pump or beating heart fashion. The strategy also requires seamless teamwork between cardiac surgery and interventional cardiology.

The American College of Cardiology, American Heart Association, American College of Physicians, American Association for Thoracic Surgery, The Preventive Cardiovascular Nurses Association, The Society for Cardiovascular Angiography and Interventions and The Society of Thoracic Surgeons have issued joint guidelines for HCR, defined as the planned combination of LIMA-to-LAD artery grafting and PCI of one or more non-LAD coronary arteries[9].

Class IIa indications include limitations of traditional CABG (heavily calcified ascending aorta, poor non LAD target vessels but amenable to PCI, lack of suitable graft conduits) and unfavorable LAD anatomy for PCI (chronic total occlusion or excessive LAD tortuosity).

Class IIb indications include attempts to improve overall risk-benefit ratio of both PCI and CABG in patients who have multivessel coronary artery disease, would benefit from a LIMA to LAD bypass but have other comorbidities that put them at risk of complications after surgery (recent MI, fraility) or need rapid return to baseline activities.

This article aims to distill the lessons that we have learned at Emory University over the past decade of application of this strategy and provide guidance on the steps required to introduce it into the armamentarium of an institution.

CABG WITHOUT STERNOTOMY (MINIMALLY INVASIVE CORONARY SURGERY)

Efforts to avoid partially or completely the sternotomy to perform CABG started in 1995 with Dr Bennetti[10].

At Emory, we moved in the early 2000s to harvest the LIMA using video-assisted thoracic surgery techniques (VATS), a robotic arm, Aesop (Intuitive Surgical, Mountainview, CA) to hold the camera, and a 1.5-2 inch incision, if necessary with resection of a costal cartilage, to perform the LIMA to LAD anastomosis off-pump, using a port based cardiac positioner (Medtronic, Minneapolis, MN. Guidant, Santa Clara, CA, Estech, Danville, CA). The technique was called EndoACAB (endoscopic atraumatic coronary artery bypass). A significant experience of 607 patients was accumulated with excellent results: 30 day mortality of 1%, a mean ICU length of stay of 11.2 $\pm$ 9.9 hours, a hospital length of stay of mean 2.4 $\pm$ 1.3 days, a conversion to sternotomy or standard thoracotomy of 3.6% (0.7% emergent) and a five year survival of 92.9 $\pm$ 2.4%[11].

Unfortunately, the VATS technique to harvest the mammary was difficult to learn mainly because the LIMA was harvested with long-shafted instruments endoscopically.

Such instruments amplify hand tremors and have no articulation of the distal ends of the instruments to allow complex intrathoracic manipulations. The Aesop robotic arm, essential for holding the camera, was unfortunately discontinued from production. Furthermore, the advent of the robotic Da Vinci Surgical System (Intuitive Surgical Inc., Sunnyvale, CA) made this procedure somewhat obsolete.

The Da Vinci robot introduced a new level of precision, visualization and endoscopic freedom of movement inside the body with 3 dimensional articulating instrumentation and 10x high fidelity magnification. Thus, exposure and visualization was greatly facilitated and more complex movements could be made inside the chest. The 3-dimensional wristed instruments provided greater range of motion in a small space. The robotic instruments are able to filter the hand tremor, hence this becomes a non-issue. Dual consoles allow the technique to be taught much more easily, with seamless transfer of controls between mentor and trainee.

The majority of minimally invasive CABG procedures since 2009 at Emory have been performed with robotic-assistance, thus the term robotic-assisted CABG. The procedure has been extensively described in publications[12-16]. Briefly, patients are placed supine on the operating table and after induction 2 rolled sheets or a bump is placed under the left should with the superior tip of the bump placed just inferior to the scapula. The patient is positioned slightly towards the left of the table so that when the left arm is loosely tucked, the left shoulder gently hangs off of the bed. The lowering of the left shoulder is critical to avoid conflict with the robotic arms. The patient is then prepped and draped in the usual fashion for coronary bypass surgery, the middle of the chest is marked between the clavicle and costal margin [Figure 1]. There is no specific interspace but in general the camera port should be placed in the middle of the chest or just slightly lower at approximately the anterior axillary line.

A spinal needle is used to identify the rib and the interspace. We always use a blunt instrument similar to tube thoracostomy prior to inserting the camera port. The camera port can then be placed gently with a slight angle superiorly to avoid underlying cardiac injury. Immediately after this port is placed, carbon dioxide insufflation should be initiated from 8-12mm Hg with careful attention to blood pressure while creating a tension pneumothorax. Not infrequently, anesthesiology will need to make adjustments with loading conditions to allow the patient to tolerate this. The insufflation can be adjusted up or down (6-15 mmHg) as needed. The camera is then inserted, and the superior port is placed 2 interspaces above the camera port in either the 2nd or 3rd interspace, more medial than the camera port.

The inferior port is placed 2-3 interspaces in a similar medial-lateral position as the camera port. Note, the working arm ports should be placed with endoscopic guidance so you can see where the ports are entering the chest and in which interspace [Figure 2]. The da Vinci system is docked [Figure 3] and the LIMA can be harvested as a thin pedicle or skeletonized.

Our preference is to remove overlying muscle and fascia to completely expose the LIMA but to then take the vessel as a thin pedicle with electrocautery and clips to avoid any manipulation of the artery [Figures 4 and 5]. A small pericardial window posterior to the phrenic is then made, the pericardial fat is dissected off the anterior pericardium, and a full longitudinal pericardiotomy is then made to mirror the same pericardiotomy that would be made via sternotomy [Figure 6].

After dividing the LIMA distally with clips, the robot is undocked, the endoscope and a spinal needle are used to help with localization of the skin incision so that after a 3-4cm thoracotomy incision is made, the LAD target should lie directly underneath. No rib retractors are used but exposure is usually more than adequate with a soft tissue retractor without dividing or resecting any ribs or costal cartilage. The Nuvo stabilizer (Nuvo; Medtronic, Minneapolis, MN) is used to stabilize the LAD, a vessel loop is placed around the more proximal LAD and test occluded for 3min while the LIMA is prepared.

Then the anastomosis is done off-pump with a shunt in place in the same manner that would be done via sternotomy [Figure 7].

The shunt decreases the risk of electrical or hemodynamic instability which is a devastating complication in a case without ready access for cardiopulmonary bypass. Final angiographic results after completion of the HCR are presented in Figures 8 and 9.

HCR AND CARDIOPULMONARY BYPASS

Efforts to move towards a minimally invasive approach, have been spearheaded by surgeons who developed expertise in OPCAB, interested to combine the benefits of minimally invasive approaches and OPCAB. All of our robotic-assisted cases at Emory, are therefore performed off-pump for the LIMA LAD anastomosis, using specially designed, minimally invasive tissue stabilizers for robotic cases. In patients where we suspect we may need cardiopulmonary bypass, the initial favored approach is a standard median sternotomy.

TIMING OF HCR STEPS

It is important to understand that HCR has two components: minimally invasive or robotic assisted CABG and PCI. The sequence in which these two steps are performed matters and has clinical, scheduling, and even financial consequences. A comparative summary of the advantages and disadvantages of each sequence is presented in Table 1.

Our preference at Emory is to perform the LIMA-LAD first when possible. In patients with stable coronary disease, this has several advantages including the ability to perform the surgical procedure without concerns for dual antiplatelet therapy, and the ability to interrogate the anastomosis angiographically during the subsequent cardiac catheterization. However, for patients that present to the hospital with an acute coronary syndrome, the general rule is to treat the culprit lesion first.

The LIMA LAD anastomosis can be done during the same admission or staged 1-2 months later if the LAD anatomy permits[13,17]. The most convenient option for the patient is a concomitant procedure in a hybrid room where the PCI portion of the procedure can be performed immediately after the anastomosis.

The main advantage for the clinician is that graft patency can be confirmed immediately on the operating table and any technical complications can be addressed while still in the operating room.

However, the logistical challenges of scheduling for both surgeons and interventionalists can make this difficult.

SELECTION OF PATIENTS FOR HCR AND PERFORMING HCR IN SPECIAL CIRCUMSTANCES

The ideal candidate for HCR

Experience has taught us that the best suited patients for HCR are the ones with proximal, focal coronary lesions, in fairly large coronary arteries, that have a relatively low burden of calcium. The mid or mid to distal LAD is the prime target for a minimally invasive approach. An intramyocardial LAD is a relative contraindication for HCR, because it is very difficult to identify and trace such a vessel through the limited exposure of a small thoracotomy attention should be paid to examine the preoperative cardiac catheterization for straight segments of LAD, particularly ones that tend to move inward in systole more than the rest of the LAD, and particularly in the mid LAD.

Body habitus plays a significant role in the success of HCR. The ideal patient in the surgeon’s early experience should be tall, fairly thin, with large pleural cavities and relatively small heart. A large heart can make harvesting of the LIMA very difficult and increases the risk of either LIMA or cardiac injury. Early in our experience we required two criteria for inclusion: one was a good LAD target vessel for bypass and the second was a good body habitus for a minimally invasive left thoracotomy approach. We adhered strictly to this protocol for the first 200-300 cases but currently all we require is one of the above [Table 2].

HCR in patients with chronic obstructive pulmonary diseases

Chronic obstructive pulmonary diseases (COPD) poses an interesting challenge for the performance of HCR. On one hand, increased lung volumes, increases left pleural cavity size and improves visualization and ability to harvest the mammary greatly. On the other hand, medium and small airway obstruction can trap air and make visualization difficult. Our preference is to use double lumen tubes versus bronchial blockers in such patients as this allows better deflation of the left lung. The use of CO_2 insuflation for robotic cases can result in respiratory acidosis and hypotension much faster than in patients without COPD; anticipation of these issues, administration of bronchodilators and frequent blood gas checks.

With CO_2 insufflation, the other option is to use low tidal volume bilateral lung ventilation during the LIMA harvest and deflate the left lung during the anastomosis. Intermittent bilateral lung ventilation can also be used throughout the procedure. In general we have found that almost all patients that are not on home supplemental oxygen are able to safely tolerate either single or low-tidal volume bilateral lung ventilation.

HCR in patients with chest wall deformities (prior trauma, chest wall radiation, kypho-scoliosis, pectus deformities)

Such patients can pose substantial challenges for minimally invasive CABG because of difficult visualization, and possible unpredictable course or complete occlusion of the LIMA in case of prior trauma with rib fractures or radiation. Again, decision should be made on a case by case basis, taking into account the severity of the deformity, its particular location, the likelihood of direct interference with the operation and most important the experience of the operator with minimally invasive CABG procedures.

HCR for left main disease

CABG is considered the standard of care for left main disease (LMD). Recently however, after results of the EXCEL trial, PCI has been upgraded as an acceptable alternative for LMD treatment. This has opened the possibility for HCR as a solution for LMD. Performing a “limited intervention” in cases of left main disease during the first step of the HCR, can have however adverse effects during the higher demands of postoperative recovery after a minimally invasive CABG procedure and until the patient can get completely revascularized with PCI. We compared 27 patients who had HCR with 81 contemporary patients treated with off-pump CABG for left main disease. In all but one HCR patient the left main was stented into the circumflex after LIMA LAD anastomosis. Immediate postoperative and medium term outcomes were similar, except that the need for perioperative blood transfusions was significantly lower in the HCR group than the sternotomy CABG group. There was a trend towards higher need for repeat revascularization at a median follow up of 3.2 years, but not statistically significant – 2 patients in HCR group versus 1 patient in CABG group, p=0.9[13]. Certainly this study was small, but shows that such an approach is feasible.

In general this option can be considered in patients with either distal left main bifurcation lesion or any lesion in the left main along with a proximal lad lesion. Isolated ostial or body lesions should not be considered for HCR b/c there will be significant competitive flow with the LIMA b/c there will no longer be a proximal lesion after PCI of the left main.

HCR for patients with low ventricular ejection fraction

Poor contractility makes any cardiac intervention more difficult and HCR is no exception. The challenge is augmented by the fact that the heart cannot be fully visualized during the CABG part of the operation. Such patients tend to tolerate poorly marginal oxygenation and ventilation that can occur with single lung ventilation. As a general rule, if cardiopulmonary bypass assistance may be needed, our preference is to perform median sternotomy.

HCR in patients with previous left lung surgery or who had previous left thoracotomies

In our experience, robotic HCR in those circumstances is generally contraindicated. The situation offers the challenge of creating an adequate working space to harvest the LIMA and perform the LIMA to LAD anastomosis, because of previous adhesions. Equally challenging can be the fact that the heart can be displaced much further to the left, particularly after left lower lobectomies. It is paramount, particularly in situations of previous left anterolateral thoracotomies, to verify the patency of the LIMA at the time of preoperative cardiac catheterization, as it could have been injured and ligated during the previous surgery. Also, after left lung cancer surgery, it is possible that the patient had radiation to the chest wall on the left and this can make harvesting the LIMA exceedingly difficult. For all these reasons the patient might be better served with a conventional CABG and alternative arterial conduits but these decisions should be made on a case by case basis with considerations for the risks and benefits of each approach.

SAFETY OF HCR

Quality of the LIMA conduit and LIMA LAD anastomosis

One of the most important questions about HCR concerns exactly that topic: given the different visualization during harvesting as well as limited exposure during the anastomosis, is this truly a comparable end product to the well-established gold standard results of median sternotomy LIMA to LAD operation? A comparison between our early HCR group versus median sternotomy off pump CABG group indicates that issues with either the LIMA or the LIMA to LAD anastomosis are potentially more prevalent in the HCR group[14]. However, these were rarely clinically driven ischemia events in the HCR group. Almost all of the patients in the hybrid group underwent LIMA angiography and almost none of the patients in the CABG group underwent postoperative angiography. Thus, the comparisons were not standardized, and minor defects early after anastomosis are more likely to be identified.

Our recommendation is to perform completion or postoperative angiography during the surgeon's early experience with robotic-assisted CABG for quality control purposes. This was our model for almost all of the first 3-400 cases. This provides opportunities for refinements in technique, ensures optimal quality outcomes, and ensures that excellent results are achieved with minimally-invasive approaches. Our current patency rate approaches 98% for patients who underwent completion or postoperative catheterization.

One important question is what to do if a mild narrowing or physiologically insignificant defect is detected at or near the distal anastomosis when PCI is performed during the second stage of HCR. There is no compelling literature data about this issue. Certainly an argument could be made about using invasive functional evaluation (fractional flow reserve calculations – iFR/RFR), however, technical issue that can occur in attempts to cross a fresh anastomosis with a wire could be a problem. Our experience, which we are in the process of analyzing for mid and longer term results, has been that the majority of these should not be intervened on early, particularly if there is TIMI 3 flow distal to the anastomosis. Repeat angiography in 6-8 weeks and possible iFR/RFR is recommended and if necessary, intervention can then be performed.

Major adverse cardiac and cerebrovascular events (MACCE - death, myocardial infarction and stroke)

In most published series there are no statistically significant differences in hospital MACCE between HCR group when compared to our conventional sternotomy patients [14,18-22]. However, our current experience suggests a low risk adjusted mortality rate <1%, and a stroke rate that is comparable to PCI at approximately 0.5%.

One important finding was that the incidence of perioperative myocardial infarction was not statistically different (0.7% versus 0.5%, in the HCR versus the conventional group, $p = 0.8$)[14]. This alleviates concerns that partial revascularization, either by single vessel CABG or PCI, during the initial part of the procedure, would increase the risk of perioperative myocardial infarction due to increased risk of perioperative demand ischemia during the interim period between both procedures[18-22].
In general, if patients present with an acute coronary syndrome secondary to a non-LAD culprit lesion, they should undergo PCI of the non-LAD culprit lesion first. If the LAD lesion is not critical, it can be staged 4-6 weeks later.

If the LAD lesion and the non-LAD lesion(s) are both critical, LIMA LAD grafting should be done first and PCI should be done postoperatively during the same hospital stay. For non-critical lesions, the procedures can be staged over weeks.

The goals of HCR should be the same as for CABG and multivessel PCI – complete revascularization for all patients.

Risk of bleeding

An important question about HCR is the risk of bleeding due to mandatory need for antiplatelet agents in the perioperative period. A pivotal role in the success of HCR is played by the use of drug eluting stents (DES). Such stents have a long term patency rate comparable to vein grafts, and second generation DES are less thrombogenic compared to bare metal stents however early thrombosis due to delayed endothelialization can still be an issue. Dual antiplatelet therapy is mandatory after DES and the risk of stent thrombosis, with associated myocardial infarction or sudden death doubles for the first generation stents, if that therapy is stopped[7,8,23]. Even with the second generation drug eluting stents, permanent discontinuation of dual antiplatelet therapy before thirty days from stent insertion results in high risk of stent thrombosis (hazard ratio 26.8 98.4-85.4), 95% confidence interval, $p < 0.0001$); permanent discontinuation after 90 days does not seem to be associated with higher risk of stent thrombosis[23].

For patients that have undergone a PCI first strategy for HCR, we recommend continuation of DAPT even for their surgery. Modifications of these recommendations will depend on guideline changes for the duration of DAPT for the latest generation of DES.

At Emory we use preferentially a staged strategy, performing the robotic LIMA LAD first, then the PCI, unless the culprit vessel is a non-LAD vessel, in which case PCI is performed first. With this strategy, our blood transfusion requirements have been statistically significant less in the HCR group than in the sternotomy CABG group (35.4% versus 56%, $p < 0.001$)[14]. Similar results have been confirmed by others[17]. A larger study is however necessary to elucidate this issue, as it is possible that performing routinely PCI first, before the portion of the procedure, can increase the risk of bleeding due to more widespread use of dual antiplatelet therapy. Our current transfusion rates for HCR procedures is approximately 15% of patients undergoing robotic-assisted CABG, which is significantly less than sternotomy patients - 25-30%.

A word of caution should be said also about the particular type of antiplatelet agents used: most of the studies have been done with the combination Aspirin and Plavix (Clopidogrel). Newer agents like Brilinta (Ticagrelor) or Effient (Prasugrel) have not been studied extensively in this setting and it is possible, particularly if PCI is done first and particularly if Effient (which is much more potent at platelet inhibition) is used, that the bleeding complications will be higher in the HCR group.

For patients on these newer generation antiplatelet agents, we usually transition them to clopidogrel if they are sensitive to this agent 7 days before surgery to avoid performing surgery on ticagrelor or prasugrel.

Mistaking a diagonal branch for the LAD

Mistaking a diagonal branch for the LAD can occur at times, particularly if the LAD is small, intramyocardial or the target LAD lesion is very distal, as mentioned above. If there is no stenosis between the ostium of the diagonal and the LAD, grafting a LIMA to diagonal instead of the LAD has two main drawbacks: the diagonals are smaller vessels and the diagonals lack septal perforators, which reduces substantially the vascular bed available for immediate perfusion. Both of these factors can result in decrease patency rates for the LIMA and inadequate long term flow in the anterior region of the heart.

For these reasons, if the mistake is recognized intraoperatively, we recommend transecting the LIMA as close as possible to the diagonal anastomosis after applying a small clip on the LIMA flush with the diagonal, and re-grafting the LAD with the LIMA. If this complication is recognized during the index procedure, it almost always can be addressed during the same setting by dividing the LIMA at the diagonal anastomosis and grafting it onto the LAD.

ADVANTAGES OF HCR: WHAT HCR CAN DO WELL AND WHAT IT DOES ONLY MARGINALLY BETTER THAN CONVENTIONAL CABG

The main advantages to a hybrid approach are the following:

1) the major benefit of CABG is still achieved with LIMA LAD grafting;
2) there is a lower transfusion rate[14,17] compared to conventional CABG;
3) risk of stroke is lower because there is no aortic manipulation and no cardiopulmonary bypass;
4) the risk of serious wound complications (mediastinitis) is avoided;
5) return to normal activity and recovery time are quicker and;
6) improved cosmesis.

The main goal with HCR is for patients with proximal LAD disease who may have otherwise been treated with PCI to the LAD are able to derive the long-lasting benefits associated with LIMA LAD grafting. Most of the patients that undergo robotic-assisted CABG would have otherwise been treated with multivessel PCI, not CABG.

DEVELOPING A SUCCESSFUL HCR PROGRAM.

The prerequisite for a surgeon to start a successful HCR program is to master the techniques of at least one minimally invasive CABG approach and off-pump coronary bypass. These two goals are difficult to be tackled simultaneously. Off-pump LIMA LAD grafting is best mastered in open sternotomy cases, under the careful supervision of a seasoned mentor. The pathway for training however could be different for a young surgeon just out of training versus an experienced surgeon routinely performing the on pump, arrested, technique. For the young surgeon, training in a program experienced with off-pump and beating heart surgeries in its different varieties or joining a group with extensive expertise in such techniques, would be the best path forward. The surgeon will be coached in avoiding serious mistakes and will gain the expertise and confidence to become a skilled surgeon. These skills can then be translated into a minimally invasive platform.

For the seasoned surgeon with expertise in on pump arrested CABG, a short period of observation in a busy off-pump program, followed by transition to perform LIMA to LAD anastomosis on a beating heart, but in a pump assisted fashion, followed by performance of LIMA to LAD completely off-pump in conjunction with conventional on pump, arrested technique for the other anastomoses, would lead to expertise during one’s own practice.

The harvesting of the mammary artery can be learned as a second step or simultaneously. A minithoracotomy approach harvest is probably the easiest to learn in a self-taught manner, after observing cases and watching videos. Robotic cases, due to the complexities of positioning the robot, training a whole team and actually learning the technique, are a much more ambitious goal, and would require either a mini-fellowship or be reserved as a later goal.

First of all, the exposure, be it mini-thoracotomy or a 2-inch, non-rib spreading incision used for robotic cases, offers a very different view of the heart than a surgeon is traditionally used to. This translates into difficulties in identifying the LAD target.

From the minimally invasive view, the LAD is the furthest vessel to the right; problems can appear however, when the LAD is buried in epicardial fat or is intramyocardial. It is paramount to make sure that the vessel furthest to the right on the anterior aspect of the heart has a general direction tracking to the apex of the heart. This can be verified by direct inspection through a minithoracotomy approach or by camera inspection with the robot, and marking the vessel with a marking pen or clip after opening the pericardium robotically prior to performing the small access incision for the LIMA to LAD anastomosis.

CONCLUSION

In conclusion, HCR is a novel technique that in the hands of expert surgeons can offer the next level of care for appropriately selected patients, combining the benefit of long term results offered by sternotomy CABG with short term rapid recovery and minimal morbidity. Such an approach is feasible if time and energy is invested in training and logistical development of a collaborative approach.

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Authors' contributions

Conception, design and editing of the article: Pusca SV, Halkos ME

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All authors declared that there are no conflicts of interest.

Ethical approval and consent to participate

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Table 1. Comparison of the three strategies available to perform the steps of HCR

Minimally invasive CABG first	**Stent first**	**Same setting**

Advantages		
Less risk of bleeding during the CABG	Bail out to conventional surgery if PCI unsuccessful without need for second surgery; helpful option for CTO PCI of non-LAD vessels	Convenient for patient
LIMA LAD provides protection during subsequent PCI	Allows immediate, expeditious coronary revascularization in patients presenting with acute coronary syndromes in non LAD territories with lesions amenable to PCI	Lower total periprocedural length of stay
Able to study the LIMA LAD anastomosis at time of subsequent PCI		Most financially efficient
Disadvantages		
Incomplete revascularization during the higher cardiac demands of postoperative recovery	No LIMA LAD protection for multivessel PCI	Difficult coordination of multiple teams: scheduling is inefficient as one team has to wait for the other to finish and ties up operating room and cath lab personnel
Unsuccessful PCI requires a second surgery	Highest risk of bleeding during CABG due to need for dual antiplatelet therapy after stent (extended administration)	Slightly higher risk of bleeding due to loading dose of dual antiplatelet agents for PCI
Requires two separate procedures	Requires two separate procedures	Longest procedural duration

Table 2. Relative indications and contraindications of HCR

Relative Indications	Relative Contraindications
Low-intermediate SYNTAX score	High SYNTAX score
Proximal focal coronary lesions	Left thoracotomy, left lung surgery
Low burden of calcium in the coronary arteries	Home oxygen requirements
Good target vessels (large LAD)	Hemodynamic instability
Large pleural cavity	Preoperative need for intraaortic balloon pump
Small heart	Obese (particularly morbidly obese) patients
Thin, tall body habitus	Suspicion of intramyocardial LAD

Figure 1. Robotic CABG: planning of the incisions

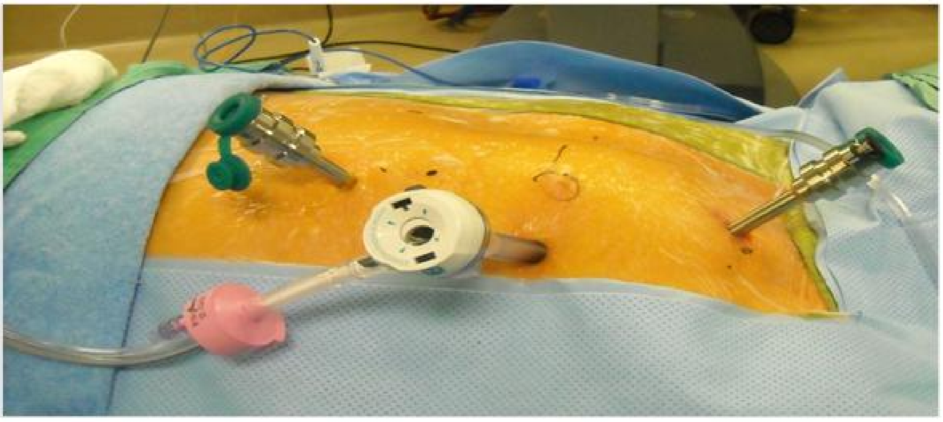

Figure 2. Robotic CABG: port insertion

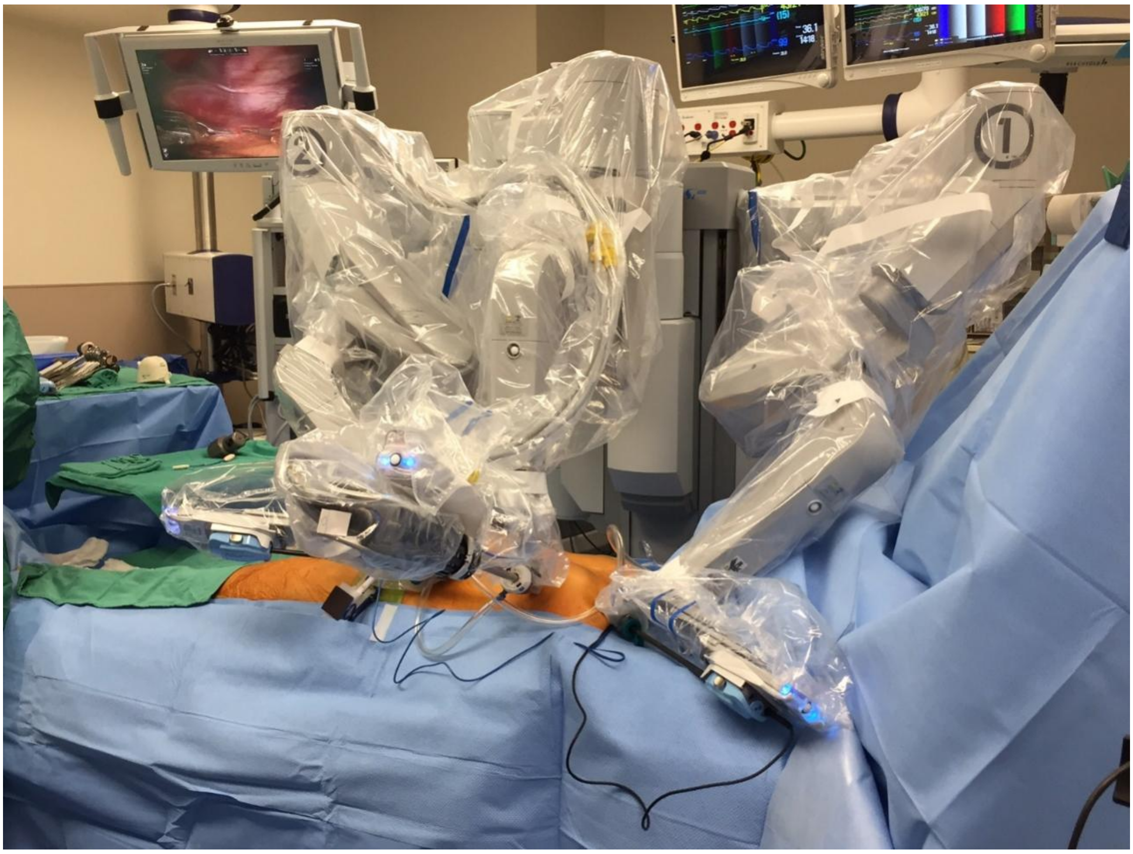

Figure 3. Robotic CABG: docking of the Da Vinci robot

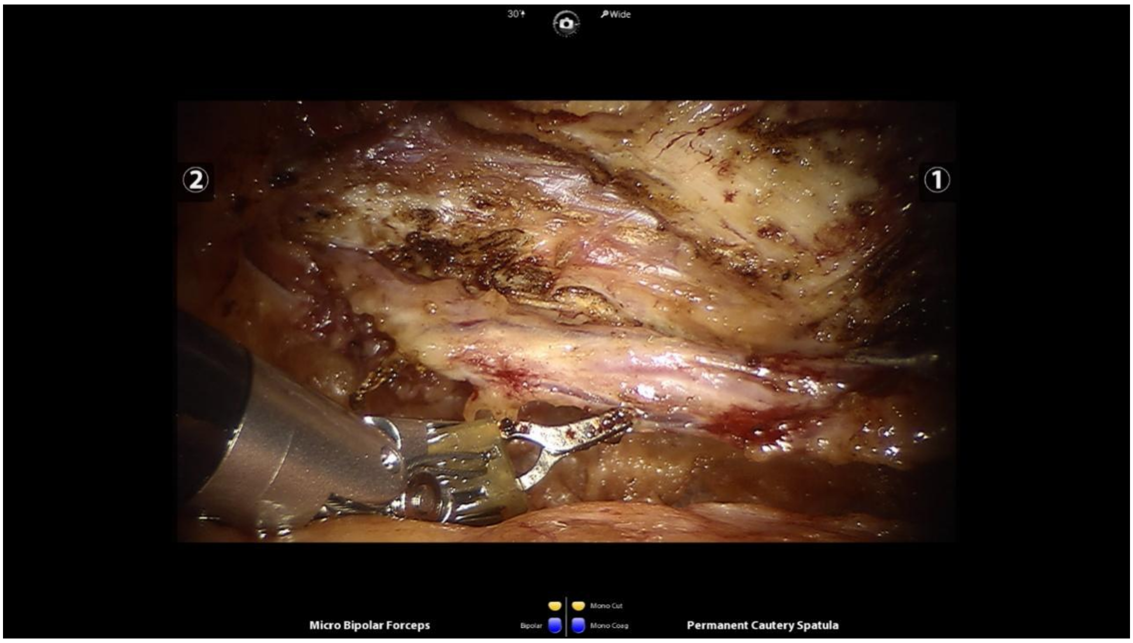

Figure 4. Robotic CABG: starting the LIMA dissection

Figure 5. Robotic CABG: continuing the LIMA dissection

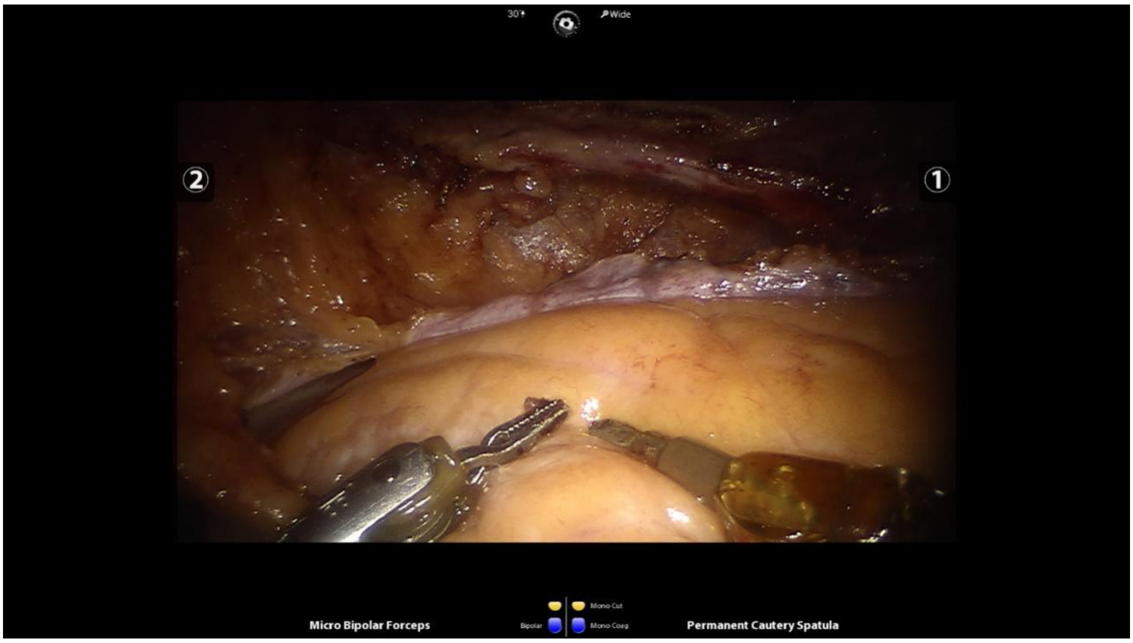

Figure 6. Robotic CABG: identifying the LAD

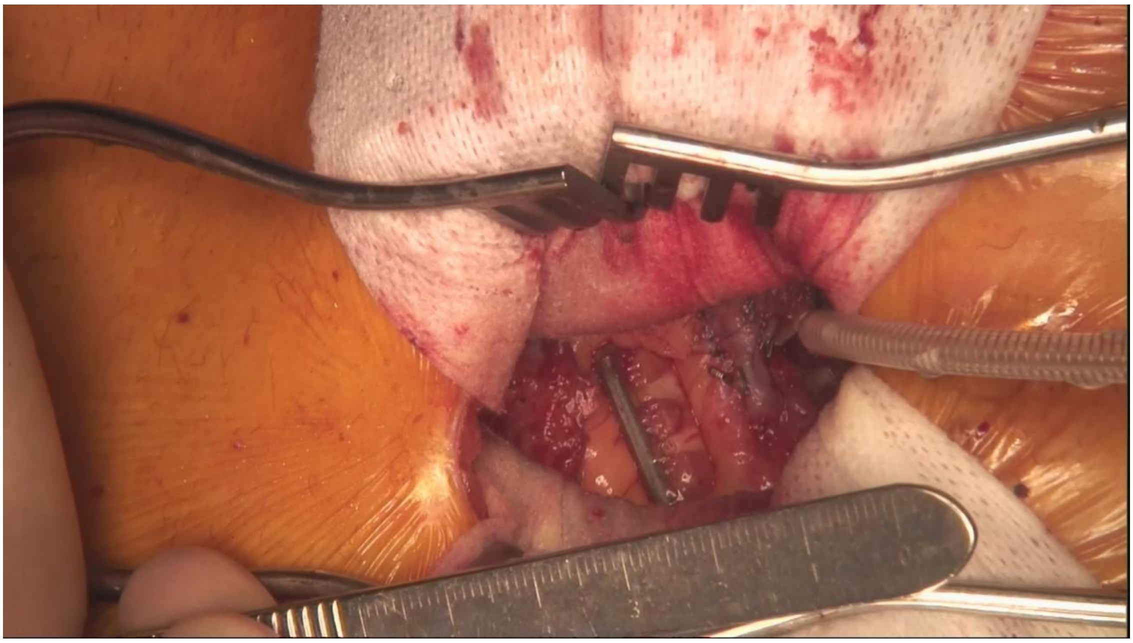

Figure 7. Robotic CABG: stabilization and distal anastomosis

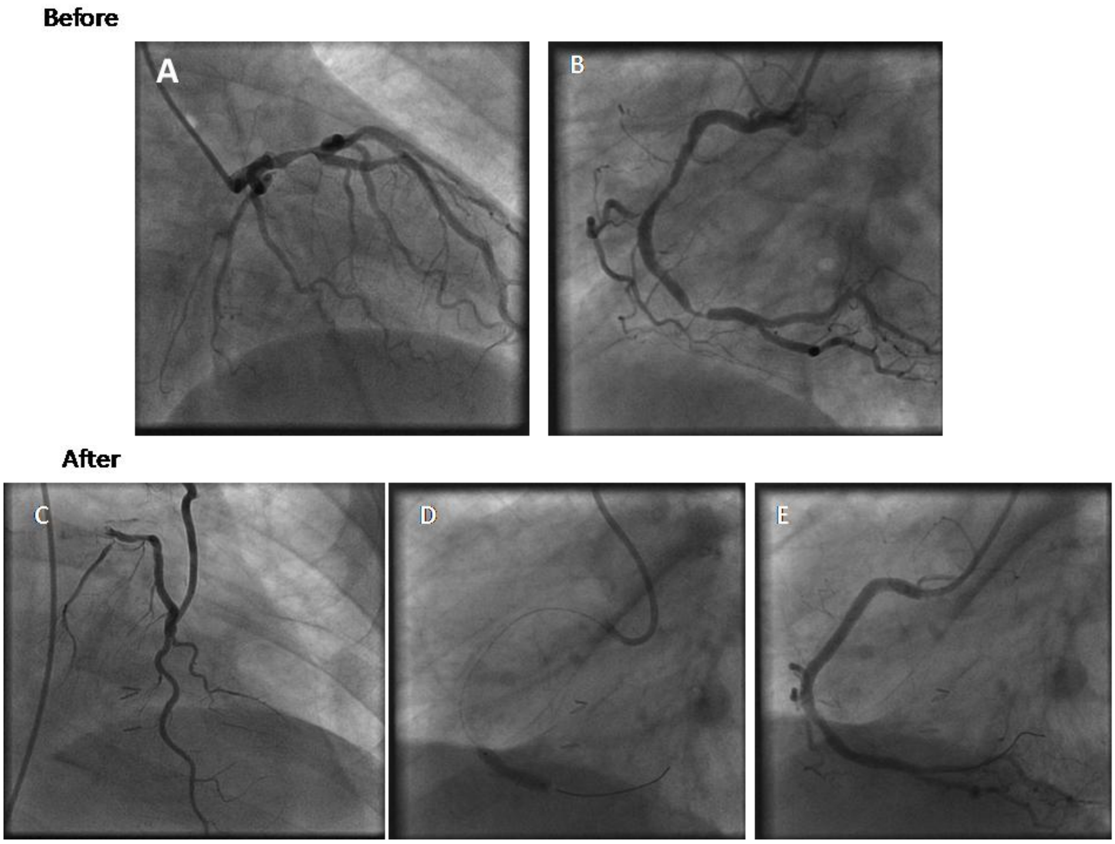

Figure 8. HCR coronary angiogram: robotic LIMA to LAD and stenting of the proximal circumflex artery

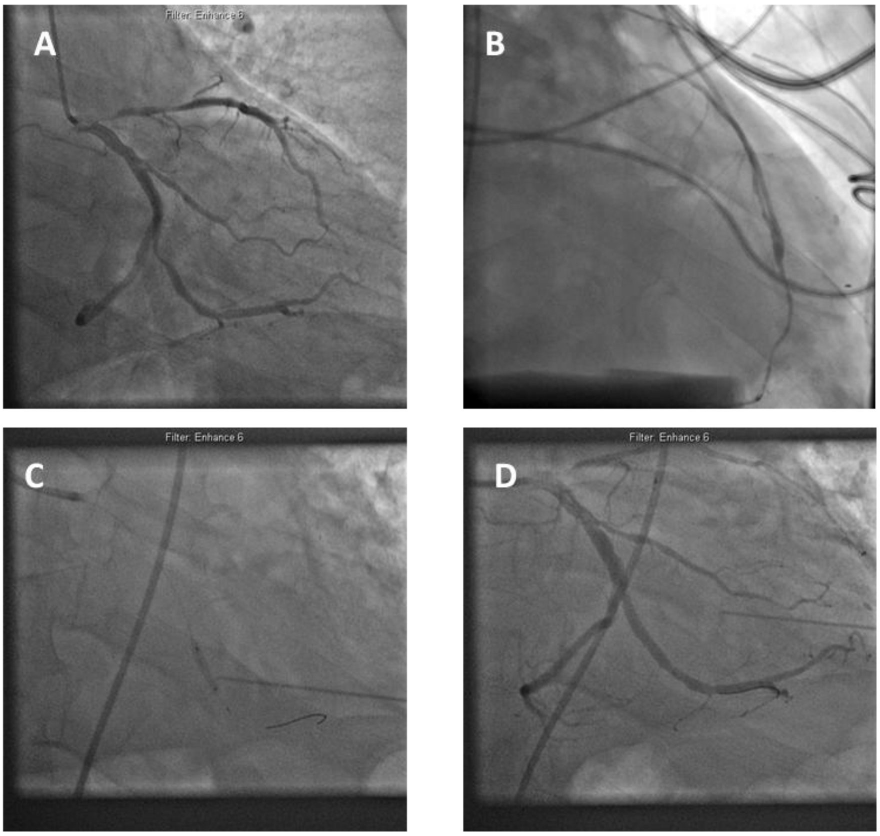

Figure 9. HCR coronary angiogram: robotic LIMA to LAD and stenting of the distal circumflex artery