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Hybrid Coronary Revascularization for Multivessel Coronary Artery Disease: Strategies and Outcomes

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Abstract

Surgical and percutaneous treatments of coronary artery disease (CAD) have evolved in parallel over the last several decades. Both modalities now offer safe and effective relief from severe CAD, each with unique advantages and disadvantages. Hybrid coronary revascularization (HCR) provides a minimally invasive strategy that exploits the strengths of both traditional coronary artery bypass surgery (CABG) and percutaneous coronary intervention (PCI). HCR entails non-sternotomy left internal mammary artery (LIMA) harvest and grafting to the left anterior descending (LAD) artery, combined with percutaneous coronary intervention (PCI) to non-LAD vessels. The result is a complete revascularization, including the survival benefit of a LIMA-LAD graft, while avoiding the morbidity and convalescence associated with a sternotomy. This review will describe the methods of sternal sparing LIMA-LAD grafting in practice today andexplore the various strategies and current evidence for HCR.

Keywords: Hybrid coronary revascularization; Robotic-assisted CABG; Minimally invasive cardiac surgery

Introduction

Coronary artery bypass grafting (CABG) and percutaneous coronary interventions (PCI) have evolved over the last several decades to become two of the world's most commonly performed, and most scrutinized, procedures. When combined with medical therapy, both CABG and PCI have demonstrated effectiveness in improving symptoms related to obstructive coronary artery disease [1-3]. In addition, CABG has shown a long-term survival benefit, which has been attributed primarily to the practice of bypassing the left anterior descending artery (LAD) using the left internal mammary artery (LIMA) [4]. While LIMA patency is excellent in the long-term, patency rates of saphenous vein grafts to non-LAD territories at 10 and 20 years have been suboptimal, ranging from 50-70% and 30%, respectively [5,6]. PCI has evolved from early simple angioplasty to the stent era, which has made the procedure safer and more reproducible. The incidence of repeat intervention has decreased significantly, although it remains higher with PCI than with CABG [7]. Fueled by the mediocre outcomes with saphenous vein grafts and decreased restenosis rates with drug eluting stents (DES), hybrid coronary revascularization (HCR) had attracted significant interest in recent years from both surgeons and cardiologists because it combines the advantages of each revascularization modality [8,9]. Asternal sparing surgical revascularization of the LAD using the LIMA is paired with PCI of non-LAD vessels, providing a minimally invasive approach using a conduit that has proven effective in improving long-term survival and a PCI strategy that will improve symptoms related to coronary artery disease (CAD). If both LAD and non-LAD territories are suitable for each respective procedure, we believe patients can derive significant benefit from this combined approach.

This review describes the various approaches for non-sternotomy LIMA harvesting and anastomosis, as well as the different HCR strategies. The available literature addressing outcomes in HCR will be reviewed.

Non-sternotomy LIMA-LAD Bypass

MIDCAB

Minimally invasive direct coronary artery bypass was first reported in the 1990s and refers to the combination of LIMA takedown and LIMA-LAD anastomosis through a small anterior minithoracotomy [10,11]. This is accomplished via the 4th or 5th intercostal space and requires a specialized chest wall retractor and disarticulation or removal of costal cartilage. The advantage of MIDCAB, in comparison with other minimally invasive techniques, is that it does not require any specialized endoscopic or robotic training to accomplish LIMA harvest. On the other hand, extensive chest wall retraction is required and controlling postoperative pain can be difficult [12,13]. While MIDCAB has been demonstrated to be safe compared to conventional CABG, potentially incomplete LIMA harvest and the necessity for significant chest wall traction limit the potential benefits [14]. As a result, it is a far less attractive option than non-sternotomy CABG using thoracoscopic or robotic techniques, despite the necessity for additional equipment and expertise when using these techniques.

EndoACAB

Endoscopic atraumatic coronary artery bypass (EndoACAB) is defined as thoracoscopic LIMA harvest with a LIMA-LAD anastomosis accomplished through a minithoracotomy. Although this method requires single lung ventilation and CO2 insufflation of the chest, it has several advantages over traditional MIDCAB. Firstly, harvest can be accomplished without significant upward retraction on the chest wall, theoretically decreasing postoperative pain and avoiding costal disarticulation. Access is obtained via three endoscopic ports placed in approximately the 3rd, 5th, and 7th intercostal spaces. Secondly,

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visualization is much improved compared to traditional MIDCAB, and the LIMA can routinely be harvested along its entire length, mimicking what is typically accomplished via median sternotomy. Both pericardiotomy and target vessel localization can be performed endocoscopically, thus limiting the size of the thoracotomy and the degree of requisite retraction. Following LIMA harvest, pericardiotomy, and identification of the LAD, a small 4-5cm anterior minithoracotomy is performed over the LAD. A rib spreader, or preferably a non-rib-spreading soft tissue retractor, is used to provide adequate visualization for placement of the stabilizer and completion of the hand-sewn anastomosis. The primary disadvantage of this technique, and the likely reason it has not developed widespread use, is the technical expertise and steep learning curve associated with thoracoscopic harvest.

Robotic-assisted CAB

Robotic-assisted CAB consists of a LIMA harvest performed through three endoscopic ports placed similarly to the thoracoscopic approach and a minithoractomy through which a handsewn LIMA-LAD anastomosis is performed. Pericardiotomy and target vessel localization are also performed prior to thoracotomy, providing the same advantages as the thoracoscopic approach, but visualization is markedly improved and the learning curve is significantly shorter. In addition, robotic assistance allows the surgeon to perform all of the above-mentioned steps with greater precision and speed compared to the thoracoscopic approach. As with thoracoscopic MIDCAB, the patient benefits from minimal chest wall trauma and a handsewn anastomosis.

Robotic TECAB

Some surgeons have successfully taken minimally invasive coronary revascularization a step further in performing robot assisted totally endoscopic coronary artery bypass (Robotic TECAB). In its early stages, this procedure was performed on the arrested heart, with intra-aortic balloon occlusion. LIMA-LAD anastomosis is performed using either prolene or anastomotic assistance devices. Although the minithoracotomy is avoided, this approach carries with it the deleterious inflammatory response of cardiopulmonary bypass (CPB), theoretically negating any advantage over the robotic MIDCAB approach. The beating-heart TECABtechnique that was later developed successfully avoids both the use of CPB and the necessity for a minithoracotomy. While short-term results have been good, the significant technical expertise required to safely perform this procedure combined with the minimal perceived advantage over robotic MIDCAB, has limited the widespread adoption of this technique. Achayra et al. draw a similar conclusion while concisely summarizing recent TECAB results [15].

Although our institution has previously published excellent minimally invasive CABG results with thoracoscopic MIDCAB, we have evolved to perform the robotic-assisted CAB technique exclusively. Considering the merits of each of the above techniques, we believe that robotic-assisted CAB is, at this time, the ideal minimally invasive revascularization technique, providing the best blend between practicality, "teachability", patient benefit, and operating room efficiency [16,17].

Hybrid Coronary Revascularization Strategies

In addition to the variety of operative techniques, there exist three strategies for timing of the hybrid revascularization, each with their own inherent advantages and shortcomings: 1) CABG followed by PCI, 2) PCI followed by CABG, or 3). Simultaneous CABG + PCI in a hybrid suite.

CABG followed by PCI

This approach entails initially performing minimally invasive CABG, followed days to weeks later by PCI of non-LAD territories. This can be done during the index hospitalization or at a later date, depending on the clinical scenario. The ideal timing of completion PCI has not been established and should be decided by taking into account the severity of the residual lesions and the overall clinical status of the patient following surgery.While this approach has several benefits, its primary advantage is that it permits CABG to be performed without the use of powerful antiplatelet agents (eg. Clopidogrel), which are necessary if PCI is performed preoperatively or as a combined procedure. Concurrent use of these medications mayincrease the risk of perioperative bleeding and the need for blood transfusions. Conversely, if PCI is performed before or concomitantly with the CABG procedure, delayed administration or temporary discontinuation of an antiplatelet agent would be expose the patient to an increased risk of acute stent thombosis. A second benefit of a "CABG first" approach is that patency of the LIMA-LAD graft can be verified angiographically at the time of stenting. Finally, this approach permits potentially high risk PCI to be performed for left main or diagonal branch bifurcation lesions with the protection of a LIMA-LAD graft. Patient selection is important and one must consider how the patient will tolerate LAD occlusion in the presence of significant untreated coronary disease. One must also be relatively certain that PCI of the non-LAD targets can be safely accomplished, to avoid the unfortunate situation of performing a sternotomy to rescue a failed PCI. The majority of our cases at Emory have been a "CABG first" approach, unless the culprit lesion involves a non-LAD artery. As mentioned above, this allows surgical intervention to be performed without increased bleeding risks due to antiplatelet therapy and avoids logistic issues of coordinating the surgical and cardiology teams to perform simultaneous revascularization.

PCI followed by CABG

Performing PCI prior to minimally invasive CABG has several potential benefits as well. Firstly, if PCI fails or gives suboptimal results, traditional CABG remains available as an excellent fallback option. Secondly, addressing non-LAD lesions prior to surgery may facilitate minimally invasive CABG by minimizing the potential for ischemia during LAD occlusion. This is particularly true in the setting of critical non-LAD disease. Finally, in patients presenting with an acute myocardial infarction, non-LAD culprit lesions can be stented and minimally LIMA-LAD grafting can be performed once the patient has recovered. Options for anticoagulation management are dependent on the type of stent used (BMS vs. DES), the clinical scenario, and surgeon experience. For example, if a BMS is used in the context of an acute MI, it may be reasonable to wait 1 month and temporarily discontinue clopidogrel therapy in order to perform minimally invasive LAD grafting. On the other hand, in the setting of a recent DES and severe LAD disease, it may be appropriate to perform minimally invasive CABG on clopidogrel, despite the increased risk of perioperative bleeding. As our experience has evolved, we have become more comfortableoperating on patients without discontinuing clopidogrel therapy; however, the risks and benefits must be clearly explained to the patient.

Simultaneous CABG and PCI

A growing number of hospitals now have hybrid suites, which can be used to perform minimally invasive CABG followed immediately by PCI as a single procedure. This approach is attractive from both a patient convenience and economic vantage point. Questions remain unanswered as to whether this is the ideal approach for hybrid revascularization. The most evident advantage of this approach is the ability to verify patency of the LIMA-LAD graft intraoperatively, even before chest closure. Additionally, as with the CABG-first technique, it permits safe performance of otherwise high-risk PCI, such as left main or other complex stenting. Finally, this approach is often preferred by patients, decreasing anxiety related to multiple procedures by allowing a complete revascularization under a single anesthesia sitting. Disadvantages include prolonged operating room time and difficulty coordinating operative and cardiac catheterization teams. In addition to these administrative challenges, bleeding concerns related to incomplete heparin reversal and intraoperative full antiplatelet therapies have limited the widespread application of this approach.

At the present time, no data exists clearly favoring any one of these three approaches [18]. The advantages and disadvantages of each of these three HCR strategies must be considered when selecting a treatment plan for each individual patient based on anatomical and clinical criteria.

Patient selection

As with most minimally invasive procedures, patient selection is critical. In the case of HCR, the surgeon must consider whether the patient is a suitable candidate for both PCI of non-LAD territories and minimally invasive CABG. As a prerequisite, surgical candidates should be clinically stable with no uncontrolled chest pain and have favorable body habitus and coronary anatomy. Ideal candidates are non-obese patient with large thoracic cavities and non-intramyocardial LADs of large caliber.

We have seen two typical referral patterns for HCR patients. The first, and more suitable early in a surgeon's experience, is a healthy patient who recognizes the durability of CABG but wishes to avoid a sternotomy. The second group of patients would be at high risk for traditional sternotomy but present LAD disease that is not amenable to PCI or medical therapy. Contraindications to minimally invasive CABG include untreated left subclavian stenosis, morbid obesity, dense adhesions in the left chest (e.g. from previous surgery or infection), and severe lung disease. We strictly adhered to these principles early in our experience, however, more recently we have had success treating a carefully selected group of patients with poor pulmonary function or increased body mass index.

Results of Non-sternotomy CABG and HCR

Excellent results have been reported for all 4 minimally invasive techniques CABG. We have previously reported favorable results in a propensity-matched group of 597 patients undergoing non-sternotomy vs. sternotomy CABG [17]. 30-day mortality and adverse events, as well as midterm results, were similar. In a series of 100 consecutive MIDCABs, Mack et al reported an intraoperative graft patency of 99%, and no stenosis greater than 50% in 91% of patients [19]. Similar results were reported in a larger series of patients undergoing minimally invasive CABG, with 95.6% patency on routine predischarge angiograms in 709 patients [20]. Early and midterm clinical outcomes for MIDCAB have also been favorable; comparisons to median sternotomy showed equivalent outcomes, and comparisons with PCI have consistently shown a decreased rate of target vessel revascularization with no difference in other major cardiac events [14,21-25]. A meta-analysis of randomized trials comparing MIDCAB to PCI, which included a total of 711 patients, echoed these results [26].

Our institution has reported on early safety and feasibility,as well as midterm results, of EndoACAB [27]. In a series of 607 patients, Vassiliades et al reported a 1.0% 30-day mortality rate. Graft patency was 98.5% at a mean of 18.4 months postoperatively and 5-year event-free survival was 92%.It is worth reiterating however those, due to the technical challenges related to this procedure, other institutions have had difficulty reproducing these results.

In the last several years, robotic-assisted CAB has been gaining popularity due to the advantages detailed above and several small series have reported good early outcomes. Our group recently published our series of 271 consecutive robotic-assisted CAB procedures consisting of robotic LIMA harvest with LIMA-LAD anastomosis through a 3-4cm anterior minithoracotomy [28]. Nesher et al. reported on a series of 146 consecutiverobotic-assisted CAB patients with no in-hospital deaths and 96.3% patency rate in 64 routine angiographies [29]. Robotic-assisted CAB has also shown a benefit in hospital length of stay, return to full activity, and pain scores when compared to conventional CABG. More recently, Currie et al reported long-term follow-up of 82 patients who underwent robotic-assisted CAB with a 93.4% patency rate at a mean follow-up of 96 months [30]. This study also demonstrated a positive effect on the patients' quality of life, however, there was no comparison to standard CABG.

Data from the few centers that have adopted TECAB has been favorable as well. In 2006 a multicenter trial of 98 patients reported a low rate of conversion to sternotomy (6%), a low MACCE rate, and freedom from reintervention or angiographic failure of 91% [31]. Since that time, high volume TECAB centers have consistently shown good clinical results, however angiographic follow-up has been limited [32]. Few authors have called into question the safety of single vessel TECAB, however, some have argued that multivessel TECAB may be deleterious when compared to conventional surgery [33].

High-level evidence for to HCR is still lacking, with no randomized trials available in the literature and all results to date coming from single-institution reports. Furthermore, data extending to 10-years for PCI with DES is unavailable, and given that SVGs likely offer some protection from "future lesions", it is unclear how outcomes with DES will compare to SVGs. However, the data that is currentlyavailable has shown HCR to be safe and effective. Since the earliest reports were published in 1996, studies have consistently described low mortality, a low incidence of conversion to sternotomy, and excellent graft patency with an acceptable incidence of repeat revascularization in non-LAD territories [34-43]. Shen et al. recently published a series of 141 patients who underwent concomitant HCR via a partial lower sternotomy [44]. These patients were propensity matched with groups of patients having undergone CABG alone or PCI alone. MACCE rate was 6.4% in the HCR group, which was numerically lower than with CABG (13.4%) and significantly lower than PCI (22.7%, p=0.003 compared to HCR).Other studies have shown advantages with HCR over CABG in reference to ICU and hospital length of stay, intubation time, perioperative blood loss, transfusion requirements, and patient satisfaction [45,46]. While short-term data would suggest outcomes with HCR that are comparable to CABG, long-term results are limited. In 2011 we published a report comparing results in 147 patients treated with HCR matched to 588 patients treated with multivessel OPCAB [47]. Transfusion rates were higher with the OPCAB group, while the incidence of MACCE was similar between the 2 groups. Not surprisingly, at median follow-up of 3.2 years, repeat revascularization was higher with HCR (12.2% vs. 3.7%, p<0.001), however, the vast majority were in the vessels treated percutaneously and there was no difference in estimated 5-year survival

84.3% vs. 86.8%). A recent report suggested that patients with higher SYNTAX scores that are greater risk perioperative of mortality may have better 30-day outcomes with traditional CABG [48]. When we evaluated a subset of patients with left main coronary artery stenosis, we found a higher incidence of repeat revascularization with HCR that was not statistically significant [16]. Another large series, reported by Hu et al., compared the results of simultaneous hybrid revascularization with OPCAB and showed superb results in both groups with no need for revascularization at 18 months [49].

Several authors have demonstrated that despite higher initial costs with HCR, particularly if robotic technology is used, savings in postoperative expenses result in favorable cost effectiveness analysis compared to OPCAB [38,46,50]. Initial costs of purchasing the robotic telemanipulation systems are often not included in these reports and would obviously impact overall costs; however these expenses are spread over several surgical services. These studies have also showed an earlier return to work with HCR, which results in less absenteeism and societal cost savings.

Conclusion

When compared to traditional CABG, HCR may be advantageous with regard to ICU and hospital LOS as well as lower transfusion requirements. These benefits likely come at the cost of an increased incidence of repeat revascularization and higher initial costs, however, the short- and mid-term data available to date are very encouraging, with excellent in-hospital outcomes and no evidence of compromised survival compared to traditional CABG. HCR has proven to be a viable alternative to both multivessel PCI and traditional CABG that affords complete revascularization for patients with multivessel CAD. We believe that robotic assisted surgery will play an important role in the future of HCR by providing the surgeon with the heightened visualization and dexterity to operate in small spaces. This technology will no doubt continue to evolve and overcome some of its current limitations, becoming even safer and more exploitable by appropriately trained or proctored cardiac surgeons. In an era where patients and cardiologists seek the least invasive treatment option with variable consideration for long-term results, HCR offers the durability and survival benefit of LIMA-LAD bypass and the symptom relief PCI in a minimally invasive bundle. While initial reports comparing HCR to CABG have been favorable, larger well-designed trials with long-term follow-up are necessary to solidify the role of this approach in the treatment of patients with multivessel coronary artery disease.

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