# MINIMALLY INVASIVE MULTIVESSEL CORONARY SURGERY AND HYBRID CORONARY REVASCULARIZATION: CAN WE ROUTINELY ACHIEVE LESS INVASIVE CORONARY SURGERY?

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**Abstract**

Coronary artery bypass grafting (CABG) is the gold standard in managing severe coronary artery disease. However, it is associated with prolonged recovery and potential complications, in part due to the invasiveness of the procedure. Less invasive CABG techniques attempt to improve the quality and quantity of life in the same way as surgical revascularization but with fewer complications.

Minimally invasive coronary surgery (MICS) through a small thoracotomy allows for complete revascularization with good results in graft patency. Perioperative mortality is low, and there is decreased need for blood transfusion, lower surgical site infection rates, and an earlier return to full physical function. Hybrid coronary revascularization (HCR) attempts to combine the advantages of coronary artery bypass grafting with those of percutaneous coronary intervention. Several studies have shown that HCR provides better short-term outcomes with regard to decreased ventilation and ICU time, reduced need for blood transfusion, and shortened hospital stay. However, the rates for major adverse cardiovascular events and mortality are comparable to conventional CABG, except for patients with a high SYNTAX score who displayed increased mortality rates. There is also strong evidence of a higher need for repeat revascularization with HCR compared to CABG.

Overall, MICS and HCR appear to be viable alternatives to conventional CABG, offering a less invasive approach to coronary revascularization, which may be especially beneficial to high-risk patients. This article discusses approaches that deliver the advantages of minimally invasive surgical revascularization that can be adapted by surgeons with minimal investment with regards to training and infrastructure.

## Introduction

Since the development of coronary revascularization in the 1970s, coronary artery bypass grafting (CABG) has evolved to become the gold standard in managing coronary artery disease (CAD). However, CABG is associated with clinically relevant complications, including stroke. These complications are due to the invasiveness of the procedure as well as the patient population, which has widened to include the sickest of patients. Concurrent with advancements in percutaneous techniques and medical therapy are the significant international efforts to decrease the invasiveness of surgical coronary revascularization to improve both quantity and quality of life after intervention.

The roster of less invasive surgical approaches that have been developed include minimally invasive direct coronary artery bypass (CAB), minimally invasive multivessel coronary surgery CAB through a small thoracotomy, endoscopic atraumatic CAB, totally endoscopic CAB, and hybrid coronary revascularization. With all of these techniques, there has been a move towards reducing the use of cardiopulmonary bypass through an off-pump (OPCAB) approach and increasing the use of novel technological or robotic assistance.

Advances with most of these techniques require massive monetary and time investments, so much so that their application becomes limited to few select centers. The objective of this article is to highlight two specific approaches that deliver the advantages of minimally-invasive coronary surgery, do not require excessive technology, infrastructure, and a high learning-curve, and can consequently lead to increased applicability among cardiovascular surgeons.

## Minimally Invasive Multivessel Coronary Surgery

Minimally invasive multivessel coronary surgery–coronary artery bypass grafting (MICS-CABG) through a small thoracotomy has several advantages over minimally invasive direct coronary artery bypass (MIDCAB). First, MIDCAB is limited to a single anastomosis of the left internal mammary artery to the left anterior descending artery (LIMA-LAD). The surgical exposure of MICS-CABG is made more laterally, resulting in less risk of costochondral or rib injury. Also, MICS-CABG enables revascularization with a similar configuration to that of a conventional sternotomy technique, using direct-vision LIMA harvesting and hand-sewn proximal and distal anastomoses.[1-3] Figure 1 shows the exposure for the distal anastomosis through the small thoracotomy. MICS may be performed with or without cardiopulmonary bypass (CPB) assistance, but the use of femorofemoral CPB in multivessel revascularization has shown to be safe, mitigate the learning curve, prevent conversions, and enable an operative time similar to that of a sternotomy.[1-5] Thus, surgeons skilled in performing sternotomy OPCAB can more easily negotiate the learning curve of MICS-CABG by selectively using CPB assistance.[3] Figure 2 shows the small thoracotomy and one-port incision in a patient who underwent MICS-CABG.

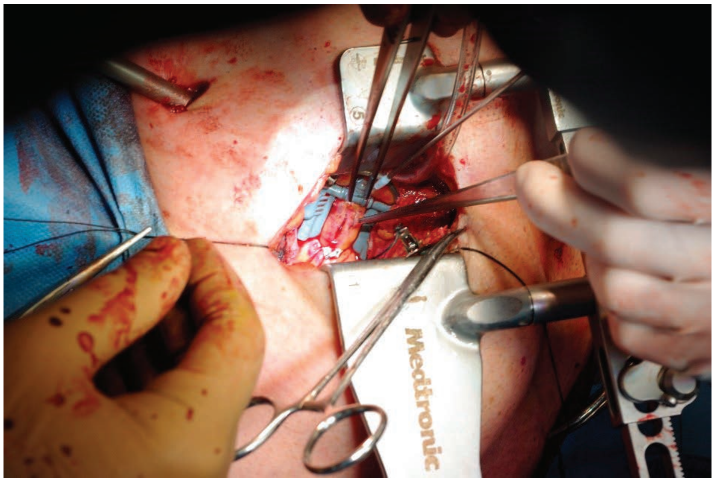


**Figure 1.** Distal anastomosis through the left small thoracotomy.

With MICS-CABG, complete myocardial revascularization is achievable in more than 95% of cases[1] since the technique allows access to the anterior, lateral, and inferior walls of the heart with or without use of CPB. Perioperative mortality is low at 1.3%.[1] Other advantages include a decreased need for blood transfusion, lower surgical site infection rates, and earlier return to full physical function.[1,3,4] Associated complications include sternotomy conversion and development of left-sided pleural effusion.[1,3,5] Postoperative pain can be an issue during the initial hours, but it is transient, controllable, and significantly reduced by the third postoperative day; it is also associated with an overall improved postoperative pain picture with improved pulmonary functions.[6,7] Notably, unlike sternotomy patients, MICS-CABG patients have no physical restriction postoperatively, which leads to improved independence. Even though MICS-CABG is more technically demanding, its anastomotic patency results were validated to be very good.[5,8] A recent study showed a 92% overall graft patency and 100% LIMA patency at 6 months.[5]

Patient selection is important: MICS-CABG should be performed on stable patients with preserved ventricular function (unless CPB assistance is used) and with no severe chest deformities or pulmonary comorbidities. It is not recommended for very obese patients. Coronary anatomy should be well-considered. The targets should be preoperatively determined to be good quality vessels that are easily identifiable, because room for heart manipulation is more limited compared to sternotomy exposure. Cardiopulmonary assistance provides decompression of a distended or hypertrophied heart and is of particular benefit for patients with diabetes, multivessel disease, and borderline ventricular function.

To open a MICS-CABG practice, it is essential that the surgeon be very experienced with OPCAB through a sternotomy, start with straightforward single- or double-vessel disease, liberally use CPB assistance, and have a dedicated anesthesiologist. After the initial minimal financial investment with regard to reusable surgical equipment and personnel training, the hospital costs can often be less compared to sternotomy OPCAB cases due to decreased transfusion and infection rates.

## Hybrid Coronary Revascularization

Hybrid coronary revascularization (HCR) is an approach that aims to combine the best of both cardiology and cardiac surgery by attempting to achieve successful revascularization through the least invasive way possible. HCR has been gaining ground due to advances in technology and techniques, an increasing acceptance of the "heart team" approach, and its popularity among patients and care teams.

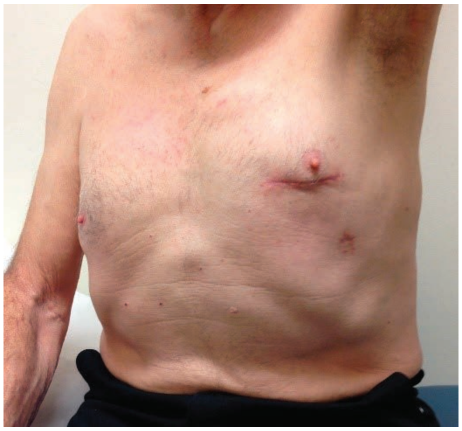

**Figure 2.** Postoperative picture of a patient who has undergone minimally invasive coronary surgery-coronary artery bypass grafting.

Informally, HCR has been practiced since the advent of percutaneous approaches and most commonly as an unplanned approach to salvage a CABG or percutaneous coronary intervention. The first series of planned HCRs were attempts to provide adequate revascularization for high-risk patients. Published in 1996, these attempts yielded acceptable results. Since then, more literature has validated its short- and midterm efficacy, and HCR is now included in the major revascularization guidelines.[9,10]

In the 2011 Guidelines for Coronary Artery Bypass Graft Surgery by the American College of Cardiology Foundation/American Heart Association, HCR was defined as a planned combination of LIMA-LAD with PCI to non-LAD coronary arteries. HCR was given a Class IIa recommendation in cases where there are limitations to traditional CABG (e.g., a heavily calcified aorta, poor target vessels), a lack of suitable conduits, or an unfavorable LAD for PCI in select two-vessel disease patients. A Class IIb recommendation was given to HCR as a possible reasonable alternative to multivessel PCI or CABG to improve the overall risk-benefit ratio.[9] More recently, the European Society of Cardiology/European Association for Cardiothoracic Surgery included HCR in its 2014 Guidelines for Myocardial Revascularization. It defined HCR as consecutive or concurrent surgical and percutaneous revascularization, and gave it a Class IIb recommendation, stating that HCR may be considered on specific patient subsets at experienced centers.[10]

There are three pathways available for HCR. The first is a concurrent or one-stage technique whereby CABG and PCI are performed in a hybrid room, one immediately after the other. Performing CABG first is the more favored approach, enabling early revascularization of the LAD, with the antiplatelet given during induction to provide protection during the PCI arm. Another advantage is the ability to angiographically confirm the patency of the LIMA-LAD graft and perform any percutaneous or surgical revision in the same setting. The major disadvantage is the higher risk of bleeding both during and soon after the surgical dissection due to overlap of anticoagulation and antiplatelet administration. There is also a risk of nephropathy due to the surgical and intravenous contrast stresses on the kidneys. Overall,

| Author | Year | N | Risk score | 1-stage | Approach | Off-pump use (%) | DES use (%) | Re-exploration for bleed (%) | Perioperative mortality (%) | Perioperative stroke (%) | Length of hospital stay (days) | Follow-up duration | Repeat revascularization (%) | Freedom from MACCE (%) | Survival (%) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gasior | 2014 | 200 | E 3.1 ± 2.1 | no | MIDCAB/ EACAB | 100* | 100 | - | 0 | 0 | 8.8 ± 4.3 | 1 yr | 2.0 | KM 89.8 | 98 |
| Adams | 2014 | 96 | - | yes | Robot-assist | 100 | 90 | 4.2 | 0 | 1.0 | 4 (3-7) | 5 yrs | 13 | - | 91 |
| Halkos | 2014 | 300 | S 1.6 ± 2.1 | both | Robot-assist/ EACAB | 100 | 78 | 2.0 | 1.3 | 1.0 | 5 (2-76) | 30 d | 4.3 | 96.4 | 98.7 |
| Harskamp | 2014 | 103 | diabetic | both | Robot-assist/ EACAB | 100 | 89.3 | 8.7 ** | 2.5 | 1.7 | < 5 days for 48.3% | 2.9 yrs | - | 95 at 30 d | KM 87.7 |
| Harskamp | 2014 | 143 | ≥ 65 years | both | Robot-assist/ EACAB | 100 | 80.8 | 7.0 ** | 2.8 | 1.4 | < 5 days in 45.5% | 3.3 yrs | - | 94 at 30 d | KM 86.8 |
| Zhou | 2013 | 141 | E 2.3 ± 2.2 | yes | Partial sternotomy | mixed | ? | 2.8 | 0.7 | 0.7 | 8.2 ± 2.5 | Hospital stay | - | - | - |
| Repossini | 2013 | 166 | S 4.7 ± 3.8 | no | MIDCAB | 100 | 34.3 | 0 | 1.2 | 0 | 6.5 ± 1.8 | 4.5 ± 2.3 yrs | 4.8 at 1 yr | 83 | 93 |
| Srivastava | 2013 | 238 | E 2 | both | TECAB | 0 | ? | 2.6-4.6 | 0-1.7 | 0.8 | 5-6 | 2 yrs | - | 80-83 at 1 yr | 93 - 100 |
| Shen | 2013 | 141 | E 3.1 ± 2.3 | yes | Partial sternotomy | 100 | 100 | - | 0.007 | 0.01 | 8 ± 3 | 2.9 yrs | 4 | 93.6 | 99.2 |
| Leacche | 2013 | 80 | | yes | - | 24 | 90 | | | | | | | | |
| | SYNTAX ≥ 33, Euroscore > 5 | | | | | | | 0 | 22 | 11 | 6 (1-25) | 30 d | - | 67 | - |
| | SYNTAX ≥ 33, Euroscore < 5 | | | | | | | 0 | 25 | 0 | 6.5 (5-32) | | | 95 | |
| | SYNTAX < 33, Euroscore > 5 | | | | | | | 0 | 0 | 4 | 6 (3-19) | | | 96 | |
| | SYNTAX < 33, Euroscore < 5 | | | | | | | 7 | 2 | 0 | 5 (3-97) | | | 75 | |
| Bachinsky | 2012 | 25 | S 0.5 ± 0.2 | yes | Robot-assist, anterior chest | 100 | 71 | 0 | 0 | 0 | 5.1 ± 2.8 | 30 d | 0 | 100 | 100 |
| Halkos | 2011 | 147 | 0.02 ± 0.02 | Both | Robot-assist/ EACAB | 100 | majority | - | 0.7 | 0.7 | 6.6 ± 6.7 | Hospital stay | 12.2 | 98 | KM 86.8 for 5 yrs |
| Hu | 2011 | 104 | - | yes | Partial sternotomy | 100 | 98 | 3.8 | 0 | 0 | 8.2 ± 2.6 | 1.5 yrs | 1.9 | 99 | 100 |
| Delhaye | 2010 | 18 | - | no | Full sternotomy | 27.8 | 100? | 0 | 0 | 0 | 10 (10-11) | 1 yr | 5.6 | 89.8 | 100 |

E: Euroscore; S: STS risk score; MIDCAB: minimally invasive direct coronary artery bypass; EACAB: endoscopic atraumatic coronary artery bypass; KM: Kaplan-Meier estimate; *: mentioned as beating heart, assumed OPCAB; **: Bleeding Academic Research Consortium type 4 CABG-related bleeding.

**Table 1.** Recent studies on hybrid coronary revascularization.

| Author | Year | Number of studies | N | | Mortality rate | | | MI | | | Stroke | | | Blood transfusion | | | ICU stay | | | Hospital stay | | | Repeat revascularization | | | 1-year MACCE | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | HCR | CABG | OR | RR | p | OR | RR | p | OR | RR | p | OR | RR | p | OR | RR | p | OR | RR | p | OR | RR | p | OR | RR | p |
| Phan | 2015 | 8 | 505 | 1159 | | 0.88 (0.34-2.33) | 0.8 | | 0.67 (0.49-0.93) | 0.01 | | 1.03 (0.33-3.24) | 0.96 | | 0.54 (0.4-0.74) | < 0.0001 | | | 0.004 | | | 0.01 | | 3.58 (2.03-6.31) | < 0.0001 | | 0.78 (0.34-1.78) | 0.55 |
| Harskamp | 2014 | 6 | 366 | 824 | 0.85 (0.24-2.99) | | 0.8 | 0.58 (0.17-1.99) | | 0.39 | 0.93 (0.24-3.59) | | 0.92 | | | | | | | | | | 3.25 (1.8-5.87) | | < 0.001 | 0.49 (0.20-1.24) | | 0.13 |

OR: odds ratio at 95% confidence interval (CI; RR: relative risk at 95% CI; MACCE: major adverse cardiovascular and cerebrovascular events.

**Table 2.** Meta-analyses of studies comparing hybrid coronary revascularization with conventional coronary artery bypass grafting.

| | MICS | HCR, one-stage | HCR: CABG-PCI | HCR: PCI-CABG |
|---|---|---|---|---|
| Sensitivity to coronary anatomy complexity | Low | Yes: should be low SYNTAX score for non-LAD vessels | Yes: should be low SYNTAX score for non-LAD vessels | Yes: should be low SYNTAX score for non-LAD vessels |
| Sensitivity to coronary geometry | All targets should not be intramyocardial | LAD should not be intramyocardial | LAD should not be intramyocardial | LAD should not be intramyocardial |
| Applicability to high risk patients | Intermediate | Yes | Yes | Yes |
| Suitable for urgent/emergent cases | Urgent | No | No | Urgent/ emergent |
| Risk of ischemia | Minimal | Minimal | Possible nonanterior wall ischemia during surgery, but well-protected LAD during PCI | Possible anterior wall ischemia while awaiting surgery |
| Risk of bleeding | Low | High: anticoagulation administered once, patient might be loaded with antiplatelet during the perioperative course | Intermediate: anticoagulation administered twice | High: anticoagulation administered twice, patient loaded with antiplatelet during the perioperative course |
| Antiplatelet management | Resume post-op for 3-12 months | Load antiplatelet prior to PCI (usually after CABG), maintain for 6-12 months | Load antiplatelet after CABG and prior to PCI, maintain 6-12 months | Load platelet prior to PCI, maintain for 6-12 months (high risk for thrombosis upon discontinuation in preparation for CABG) |
| DES risk | None/low | Risk for thrombosis if PCI first then CABG, if there is no antiplatelet coverage, and query protamine effect | None | Risk for thrombosis if no antiplatelet coverage, and query protamine effect |
| LITA-LAD patency confirmation | Transit flow meter; angiography not routine | Angiographic | Angiographic | Transit flow meter; angiographic not routine |
| Rescue procedure | Redo CABG or PCI as needed | Rescue PCI or CABG if there is evident LITA-LAD problem as evidenced by angiography during PCI | Rescue redo CABG if with PCI complication (higher risk) | Rescue PCI or CABG if clinically evident (routine post-op diagnostic angiographic not done) |
| Mortality risk | Similar to conventional CABG | Similar to conventional CABG | Similar to conventional CABG | Similar to conventional CABG |
| Stroke risk | Low, especially if anaortic approach | Low | Low | Low |
| Risk of kidney injury | Low | High due to double insult from surgery and dye | Intermediate | Intermediate |
| Degree of heart team coordination | Minimal | High | Intermediate | Intermediate |
| Length of hospital stay | Likely shortest | Short | Long | Long |
| Level of personnel training | High | Intermediate–high depending on complexity of surgical arm | Intermediate–high depending on complexity of surgical arm | Intermediate–high depending on complexity of surgical arm |
| Costs | Low: training, disposables | High: hybrid room, training, stents, disposables | Intermediate: training, stents, disposables | Intermediate: training, stents, disposables |
| Patient satisfaction | High | High | Likely intermediate due to wait time | Likely intermediate due to wait time |
| MICS: minimally invasive coronary surgery; HCR: hybrid coronary revascularization, CABG: coronary artery bypass graft; PCI: percutaneous coronary intervention; DES: drug-eluting stent; LAD: left anterior descending artery; LITA: left internal thoracic artery. | | | | |

**Table 3.** Advantages and limitations of minimally invasive coronary surgery-coronary artery bypass grafting and hybrid coronary revascularization.

this approach entails a high level of coordination between the cardiology and cardiac surgery personnel, but it potentially provides a high level of satisfaction for the patient, particularly because it is a less invasive procedure with a shorter total procedure wait time.

The second HCR pathway is to perform the HCR with the CABG done first, followed by an elective PCI a few days or weeks later. This affords protection of the LAD during the intervention on high-risk non-LAD vessels, especially a left main disease with an ostial left circumflex stenosis. Another advantage is the ability to check the patency of the LIMA-LAD during the PCI arm and perform a revision if needed. The bleeding risk is lower than in concurrent HCR, but the patient must undergo separate procedures. The major disadvantage is the possibility of ischemia on the non-LAD territories during the early, pre-PCI perioperative period. There is also a potential for redo-CABG if there are complications during the PCI arm, with a higher risk associated with the second chest re-entry on an urgent or emergent basis. On the other hand, a hybrid room is not needed, and the two components of the heart team may regulate their schedules separately.

The third approach is performing the HCR with the PCI done first. The major advantage is that it can be done on an emergent basis on patients presenting with a culprit vessel on a non-LAD territory. Another advantage is that an unsuccessful PCI or a PCI complication can be addressed during the CABG arm. There is, however, a risk of ischemia during PCI around an unprotected LAD. Also, drug-eluting stent thrombosis may occur during the perioperative window when the antiplatelet agents are discontinued and the heparin anticoagulation is reversed. Another potential disadvantage is that the LIMA-LAD patency is not routinely checked angiographically, which means that important graft or anastomotic problems may be overlooked. A hybrid room is not needed, and there is less scheduling stress on the heart team. This is typically done on patients who have an acute coronary syndrome with a non-LAD culprit lesion.

Several studies have shown that in well-selected patients, HCR provides better short-term outcomes with regards to decreased ventilation and ICU time, reduced requirement for blood transfusion, and shortened hospital stay. However, there has been no strong evidence regarding improved mortality, and late comparative outcomes are still insufficient.[11-26] Table 1 shows the results of the most recent studies comparing HCR with CABG (on or off pump). Due to the difficulty in implementing a randomized controlled study on surgical patients, all except one (Gasior 2014) are observational studies.[11] These newer studies were performed either as a single- or double-staged HCR, and the approach varied from median sternotomy to robot-assisted endoscopic atraumatic CABG with or without CPB assistance. Drug-eluting stents were used in most of the patients. The perioperative mortality was low, from 0% to 1.3% in the overall population,[11-26] which is comparable to modern-day mortality rates for conventional CABG. Harskamp reports a mortality of only 2.5% on diabetic patients and 2.8% on patients older than 64 years.[14,15] Leacche stratified patients based on the SYNTAX and Euroscore and found that those with a high SYNTAX score, regardless of the Euroscore, had high perioperative mortality rates of 22% to 25%.[20] The reported stroke rates were 0% to 1.7%.[11-26] It is notable that despite the anaortic approach used for the HCR CABG arm (mostly in situ LIMA conduit), the stroke rates are not much lower.

There are two meta-analyses that evaluate the studies done on HCR and conventional CABG patients (Table 2).[27,28] Phan and Harskamp both showed that there is no benefit for perioperative mortality, stroke, or 1-year freedom from major adverse events when using HCR over CABG. Phan showed that there are significantly lower myocardial infarction and blood transfusion rates and lower ICU and hospital stays for HCR. Both studies showed strong evidence of a higher need for repeat revascularization with HCR when compared to CABG.

Taken together, these data show that HCR has acceptable short-term benefits and may be considered for a subset of well-selected, high-risk patients with low SYNTAX scores. However, the evidence is weak, and there is a further need for randomized controlled studies to better illustrate the characteristics of patients who will benefit and to determine the best approach as to sequence, timing, and antiplatelet coverage.

## MICS-CABG versus HCR

Table 3 summarizes the advantages and limitations of the four techniques illustrated in this paper. From an applicability point of view, it suggests that among the techniques, MICS-CABG and HCR with CABG done first are both associated with easier patient selection, less risk for bleeding, and easier adaptability for the surgeon and heart team.

## Conclusion

In summary, MICS-CABG and HCR are viable alternatives to conventional CABG, offering a less invasive approach to coronary revascularization. This may be especially beneficial to high-risk patients and may be more easily adopted by surgeons due to a minimal investment with regard to training and facility acquisition.

**Conflict of Interest Disclosure:** The authors have completed and submitted the *Methodist DeBakey Cardiovascular Journal* Conflict of Interest Statement and none were reported.

**Keywords:** minimally invasive coronary surgery, MICS, hybrid coronary revascularization, thoracotomy, coronary artery bypass grafting

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