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OPINION ARTICLES

Minimally Invasive Coronary Revascularization. Technical Aspects and Current Results

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Abstract

Coronary artery bypass surgery has been for decades the gold standard for the treatment of coronary artery disease, especially in patients with 3-vessel disease. Despite the excellent results achieved through the application of this technique, problems related to median sternotomy and the use of cardiopulmonary bypass such as wound infections and cerebral stroke still play an important role in the postoperative course of these patients. Minimally invasive coronary revascularization techniques aim at reducing the rate of such complications while offering the same quality of revascularization.

Minimally invasive coronary surgery includes a set of coronary revascularization techniques that are completed without the use of cardiopulmonary bypass or through a left mini-thoracotomy at the level of the 4th or 5th intercostal space and aim at reducing the level of the aforementioned complications compared to the standard technique. Hybrid coronary revascularization is an alternative approach that combines surgical revascularization with percutaneous coronary interventions to extend the treatment spectrum even further. Through the application of these techniques, surgeons aim at minimizing the risk of infection of the surgical wound and significantly reduce the number of post-operative cerebral strokes. Also, numerous studies have shown that minimally invasive coronary surgery can offer better results in terms of duration of the mechanical ventilation, length of stay in intensive care, transfusions of blood products and consequently in reducing treatment costs.

Minimally invasive revascularization techniques are not only an important alternative to standard coronary surgery, but in the near future will constitute the standard treatment for this group of patients. This article aims to describe the techniques used to achieve minimally invasive coronary revascularization and to highlight the outcomes of the different approaches.

Keywords: CABG, OPCAB, minimally invasive, MICS-CABG, hybrid coronary revascularization, HCR.

Abrevviations

CABG - Coronary Artery Bypass Grafting; CPB - Cardiopulmonary Bypass; OPCAB - Off-Pump Coronary Artery Bypass; IMA - Internal Mammary Artery; MICS - Minimally Invasive Coronary Surgery; HCR- Hybrid Coronary Revascularization

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Introduction

Coronary artery bypass surgery (CABG) is routinely performed in almost every cardiac center around the world. According to the current guidelines CABG should be recommended for most patients with a multivessel disease.[1] During the last decades the continuous development of catheter revascularization techniques has put an incrementing pressure on cardiac surgeons to reduce invasiveness and complication rates related to CABG. Although considered a relatively "safe" procedure with mortality rates between 1-3%, complications such as postoperative stroke and wound infections are related to increased mortality and morbidity and have a considerable negative impact on the quality of life.[2–4] The most relevant complications

are due to the invasiveness of the procedure, the use of the cardiopulmonary bypass (CPB) and the ageing population. Efforts to reduce complications related to the use of CPB have led to the propagation of off-pump coronary artery bypass (OPCAB) and particularly the anaortic approach which has been shown to considerably reduce stroke rates.[5, 6] In the last two decades the usage of lateral thoracotomy for coronary revascularization has gained increasing acceptance in the surgical community. The avoidance of the median sternotomy and its related complications combined with the benefits of the surgical revascularization, may offer an attractive alternative to PCI for a selected group of patients. Also, the combination of minimally invasive revascularization techniques with PCI in the context of a hybrid revascularization strategy may become the treatment of choice for the majority of patients suffering from coronary artery disease (CAD).

This article aims to describe the techniques used to achieve minimally invasive coronary revascularization and to highlight the outcomes of the different approaches.

Off Pump Coronary Artery Bypass

OPCAB should also be considered a minimal invasive approach because it avoids the use of CPB and all its related complications. When performed without manipulating the aorta (an aortic; no-touch) it can reduce the postoperative stroke rates to 0-0.5%. [5–8] Different studies that compare the results achieved with OPCAB in comparison with on-pump coronary artery bypass (ONCAB) show conflicting results regarding short- and long-term outcomes.[8–10] The analysis of the 3 largest trials (ROOBY, CORONARY, GOPCABE) shows that the surgeons experience is crucial in achieving similar results between OPCAB and ONCAB. This was also confirmed in many registry data and meta-analytic studies. In a meta-analysis, Gaudino et al reported a reduction in adverse outcomes with increasing team experience.[11] In general, OPCAB reduces postoperative stroke when performed without manipulation of the aorta (an aortic), but its results can be comparable with ONCAB only in the setting of a high volume OPCAB center.[6, 8–11]

We routinely use the anaortic approach and prefer total arterial revascularization using bilateral internal mammary arteries (IMAs) or a combination of the left internal mammary artery (LIMA) with the radial artery in a T-graft fashion. This allows us to avoid any manipulation of the aorta (to reduce stroke rates) and also offer the excellent patency rates and long-term results achieved by arterial revascularization. In order to achieve the best position for the anastomoses and to stabilise the coronary to be bypassed we use commercial stabilisers. During the anastomoses we heparinize the patient to achieve an Activated clotting time of 300-350s. The postoperative treatment of these patients doesn´t differ substantially from the patients operated using CPB

Minimally invasive coronary surgery

Minimally invasive coronary surgery (MICS-CABG) is performed only in dedicated centers around the world, but it is slowly gaining acceptance as the results are confirming its efficacy. It includes a set of coronary revascularization techniques that are performed through a left mini-thoracotomy at the level of the 4th or 5th intercostal space and aims at reducing complications related to median sternotomy and to offer all the advantages of the minimal access. It can be performed with or without the use of CPB (OPCAB) and in the second case stroke rates can be significantly reduced. Complete myocardial revascularization is achievable with a comparable mortality as with conventional CABG.[12] Advantages include lower rates of wound infection, decreased need for blood products, decreased stroke rates, and earlier mobilisation.[12–14]

Technical aspects

The patient is positioned with a 30° reclination on the right in order to access the left 4th intercostal space (ICS). The incision can be placed more or less laterally depending on the heart dimensions and position that have to be evaluated preoperatively (Rö, CT). We tend to place the incision more medially when we need to revascularize only the anterior wall (single-vessel MICS-CABG) or more laterally in the case of more extensive revascularization (multi-vessel MICS-CABG). The femoral vessels and the subclavian artery should always be accessible in the case CPB is needed. A double lumen tubes must be used for the endotracheal intubation because at least in part, a single lung ventilation will be needed. After the incision over the 4th ICS an asymmetric rib spreader that allows for the spreading and elevation of the proximal rib is placed and the LIMA is visualized. The LIMA is taken down using appropriate micro-instruments. Although located on the other side of the sternum, the right internal mammary artery (RIMA) can also be dissected after the preparation of the mediastinum. (Figure 1) Depending on the revascularisation strategy radial artery from the nondominant arm or saphenous vein can also be used.

The revascularization can be achieved with or without the use of CPB:

MICS-OPCAB (MICS-CABG without CPB)

It is achieved using the same stabilisation devices as those used with OPCAB in conventional sternotomy, or a new generation of stabilisers that was developed for MICS-CABG (Octopus Nuvo ® Medtronic, Starfish NS ® Medtronic). The differences in positioning the heart and stabilising the coronaries to be anastomosed originate from the small incision and the limited mediastinal space. In order to achieve revascularization of the posterolateral and posterobasal coronary arteries the heart must be verticalized and this can cause compression of the right ventricle against the closed sternum. Also, the single lung ventilation in

this phase, can contribute to the reduction of the venous return and have deleterious effects on hemodynamic. An excellent cooperation with the anaesthetists is of paramount importance in maintaining hemodynamic stability during this phase.

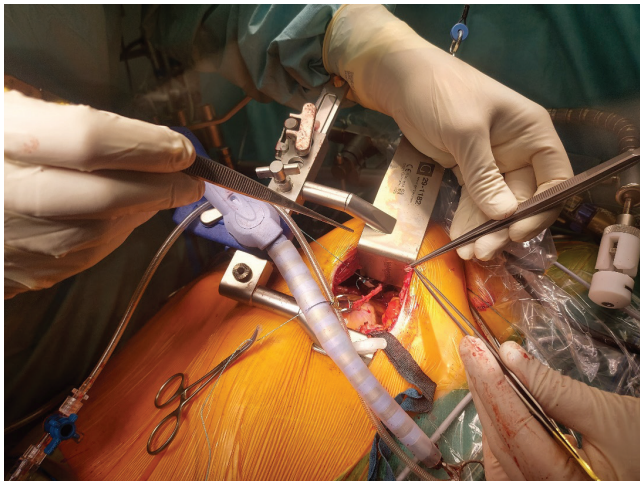

Figure 1 - T-graft completion using the left and right mammary arteries

The team should use all measures to prevent hemodynamic instability and should not hesitate to promptly connect the patient to the CPB because open CPR in the case of MICS-CABG will be ineffective (small incision, open pericardium). During this procedure, the same revascularization steps for OPCAB in conventional sternotomy should be followed. We start with the revascularization of the anterior wall and then proceed towards the lateral and posterior wall. As with all CABG patients we prefer to avoid manipulating the aorta and to use only arterial grafts, but when needed proximal venous anastomoses can be sewn using dedicated devices or side clamps. Postoperative pain management is of paramount importance for the early mobilisation of the patient. MICS-OPCAB is a complex procedure that requires an experienced and cooperative team in order to achieve good results. Teams performing MICS-OPCAB should first have an extensive experience in conventional OPCAB.

MICS-ONCAB (MICS-CABG with CPB)

The safer alternative is performing MICS-CABG with the help of CPB in the form of beating heart surgery or also in cardioplegic arrest. The former technique does not differ substantially from MICS-OPCAB, but hemodynamic compromise is not an issue as it is supported from the CPB. The femoral vessels or a combination of the subclavian artery with the femoral vein can be used for this purpose. There are some concerns about retrograde embolization when using retrograde perfusion (through the femoral artery) considering that this group of patients suffers from generalized atherosclerosis.[15,16] For this reason we prefer cannulating the subclavian artery for this purpose.

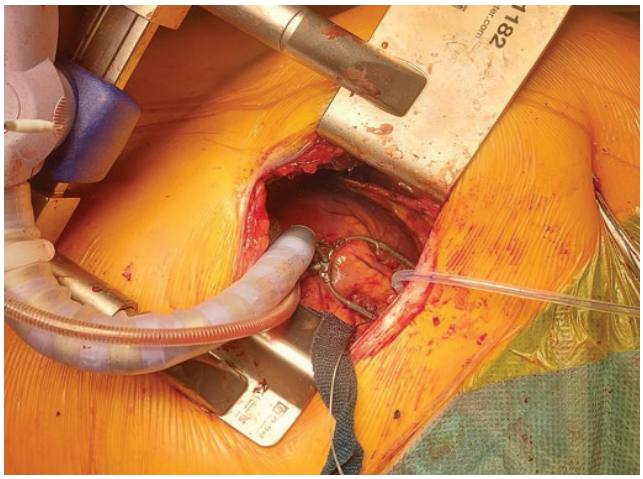

Figure 2 - Stabilisation of the marginal branch (Left Circumflex Artery)

A technique proposed from Babliak et al. (TCRAT) is gaining increasing acceptance in the surgical community because its reproducibility and safety. It involves using the CPB and arresting the heart as in conventional CABG. The aorta is clamped by inserting a clamp through a small (2 ICS right) incision. It allows to work on a empty heart that can

Author	Year	No.	CPB usage	Number of grafts	Perioperative Mortality (%)	Stroke (%)	Wound infection (%)	Hospital stay
McGinn	2009	450	34(7.6%)	2.1±0.7	1.3	0,4	0.9	5.9±3.4
Ruel	2014	91	21(24%)	2.3±0.9	0	0	0	4(3-9) *
Rodriguez	2017	306	73(23.8%)	1.8±0.7	0	0		
Nambiar	2019	940	78(8.2%)	3.2	0.9	0.2		3.1
Guida	2019	2528	6(0.2%)	2.8±0.9	1.0	0.3		
Snegirev	2020	245	6(2,4%)	2.6 ± 0.5	0.4	0.4		6.7 ± 1.3

**median (IQR)*

Table 1 Recent studies on minimally invasive coronary surgery

be easily manipulated to achieve revascularization using standard instruments. [17]

Numerous studies have shown that MICS-CABG can offer better results in terms of duration of the mechanical ventilation, length of stay in intensive care and hospitalization consequently reducing treatment costs. (Table 1) The same graft configurations as those used with conventional sternotomy are also available for MICS-CABG.

Hybrid coronary revascularization (HCR)

HCR has the advantage that combines surgery with percutaneous interventions to achieve revascularization with reduced invasivity. This concept is gaining acceptance because it combines the best of both worlds, and it is recommended in the current guidelines. [1] Mostly consists the revascularization of the anterior wall with the LIMA as MICS-CABG and the completion by PCI of the remaining lesions. With increasing experience in multivessel MICS-CABG, the concept of HCR can be adapted to the individual lesion and morphologic characteristics. It is conceivable that in a near future every patient will be a candidate for HCR and the individualized revascularization strategy will be discussed in the coronary team.

There are 3 ways to achieve HCR:

The concurrent (or one-stage) HCR is performed in a hybrid operating room were CABG and PCI are completed in direct succession. The advantage with this approach is the revascularization is complete within the first procedure and there is no vulnerable time window resulting from incomplete revascularization. The major disadvantage is the increased risk of bleeding due to the administration of antiplatelet therapy needed for the PCI.

The staged HCR with CABG first consist in revascularizing the LAD (MICS-CABG) and then complete the revascularization with an elective PCI day or weeks later. The risk for bleeding is lower compared to the one-stage procedure and there is no need for a hybrid operating room. The major disadvantage is the vulnerable window for ischemia between the 2 revascularization procedures.

The staged HCR with PCI first is less used because of the risk for bleeding when operating under antiplatelet treatment. The advantage is that it can be done in patients with myocardial infarction after treating the culprit lesion with PCI. However, there is a window of vulnerability for the non-protected LAD.

There are many small studies and a limited number of meta-analyses that evaluate the results of HCR. (Table 2) They have consistently shown shorter ventilation times, shorter ICU times, less blood product and shortened hospitalization for patients treated with HCR but have until now failed to demonstrate improvements in mortality. [18–20] In general, HCR may be considered for a group of high-risk patients and with a suitable anatomy.

Conclusion

Minimal invasive coronary surgery offers a valid alternative to conventional CABG. It offers the advantages of minimal invasive surgery and doesn´t compromise the quality of revascularisation. If combined with PCI in the context of HCR, MICS-CABG has the potential to become the treatment of choice for this group of patients. The evidence comparing these revascularization strategies is limited and consists in small studies and meta-analyses. Randomized trials are needed to elucidate the results of the different strategies and to identify patient subgroups that profit from specific approaches.

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Author	Year	No.	Surgery	Staged	Bleeding(%)	Periop. Mortality(%)	Stroke(%)	Hospital stay
Delhaye	2010	18	Sternotomy	no	0	0	0	10(10-11)
Repossini	2013	166	MIDCAB	no	0	1.2	0	6.5±1.8
Halkos	2014	300	EACAB/TECAB	both	2	1.3	1.0	5(2-76)
Gasior	2014	200	MIDCAB/EACAB	no	NA	0	0	8.8±4.3
Harskamp	2014	143	EACAB/TECAB	both	7	2.8	1.4	NA
Puskas	2016	200	Mixed	both	NA	0.5	2.5	NA
Hage	2019	147	TECAB		3.5	0	2.1	4.5(2.1)

TECAB: Totally Endoscopic Coronary Artery Bypass; EACAB: Endoscopic Atraumatic Coronary Artery Bypass; MIDCAB: Minimally Invasive Direct Coronary Artery Bypass; NA: not available

Table 2 Studies comparing different approaches to HCR

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