Editorial

Pragmatic Tips for Improving the Modern Outcomes of Coronary Artery Bypass Operations

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This article aims to serve as a pragmatic guide for cardiac surgeons on how to improve the outcome of coronary artery bypass graft (CABG) surgery and cover a multitude of topics in brief.

Ischemic heart disease (IHD) is currently the leading cause of mortality and morbidity worldwide. It is estimated that 126 million people are affected by the disease, accounting for 1.7% of the world population.[1] It is fully expected that the prevalence of IHD will continue to increase owing to the rising incidence of diabetes, metabolic syndrome, obesity, and most importantly aging of the population. Despite its great magnitude, the optimal management of IHD remains debated while medical treatment, percutaneous coronary intervention (PCI), and CABG comprise the 3 main treatment strategies.

The past 3 decades have seen several randomized clinical trials that have compared these strategies in terms of survival benefit or symptomatic relief.[2-5] However, many of these trials or observational studies suffer from methodological flaws, including selection bias and being underpowered. The most significant biases are selection bias (how to enroll patients), bias in study management (performance bias), how to record the outcome (detection bias), and publication or reporting bias. In the comparison of different treatment strategies for IHD, it is crucial to consider their temporal evolution. Similarly, continual changes in patient risks and anatomic profiles further complicate the selection of appropriate management strategies.

In recent years, the field of interventional cardiology has experienced a quantum leap that is in part related to technological advances, increasing expertise, and new adjunct therapies such as new oral and intravenous antiplatelet agents. All of these have led to improved acute and long-term outcomes for PCI. Multiple studies have compared the best available PCI practices and traditional surgical revascularization. Notably, significant advances have also been made in CABG technology and techniques. The introduction of off-pump surgery, total arterial revascularization, minimally invasive strategies (eg, minimally invasive direct coronary artery bypass [MIDCAB] and robotic CABG), and hybrid revascularization has expanded the armamentarium of cardiac surgeons. Moreover, perioperative measures, including more intensive monitoring and the routine use of transesophageal echocardiography, epiaortic scanners, and aortic connectors, have resulted in incremental improvements in clinical outcomes. Below, we will discuss several key factors that may further improve the outcomes of surgical revascularization and allow for the wider application of this method in the era of disruptive technologies.

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Conduit selection and preparation

The main drawback of CABG has historically been the failure of saphenous vein grafts, which is associated with adverse cardiac events such as myocardial infarction, death, recurrent angina, and repeat coronary revascularization.[6, 7] Despite its markedly worse long-term patency compared with the internal mammary artery, the saphenous vein remains the most widely used conduit in CABG. A vast body of literature has proven the accelerated degeneration of saphenous vein grafts, with only 40% to 50% being patent at 10 years.[8–10] Many researchers believe that poor harvesting techniques and intraoperative handling are the main reasons behind the poor patency of venous conduits. Several studies on the pedicled or no-touch harvesting technique have demonstrated the excellent patency of vein grafts in early and mid-term follow-up periods.[11, 12] It is hypothesized that the high-pressure distention or preservation of vein grafts in saline or even ex vivo blood can damage the endothelium. Specially formulated buffered solutions may confer a protective effect on the endothelium and be used to prepare vein grafts.[10, 13, 14] A study by Zou et al[15] suggested that shorter ischemic times for vein grafts were associated with reduced endothelial damage.

Perhaps, the most important factor in patient survival is graft selection.[16] Numerous studies have shown a significant benefit with the use of multiple arterial grafts.[17-19] In a cohort of 63 592 patients, Tatoulis et al reported 15-year patency rates exceeding 95% for the left and 90% for the right internal mammary arteries. The more muscular radial artery also showed patency rates greater than 90% at 10 years and above 85% at 20 years when anastomosed to a target vessel with a tight proximal lesion.[20-22] The superior patency of arterial grafts to saphenous vein grafts becomes more pronounced with increasing time from CABG. Nonetheless, 90% to 95% of all cardiac surgeons use the left internal mammary artery and the saphenous vein to revascularize diseased coronary vessels.[23] The hesitation to move toward total arterial revascularization is partly due to fear of potential risks associated with this type of procedure. For instance, sternal healing and the risk of deep sternal wound infection are of particular concern when bilateral mammary arteries are harvested, especially in older adults or patients with diabetes. This risk can be minimized by harvesting in a skeletonized manner with meticulous attention to sternal blood flow preservation.[24-26] Other barriers to the routine adoption of total arterial revascularization are longer operative times, the complexity of procedures like sequential grafting, unfamiliarity with the harvesting of arterial conduits, and a lack of randomized trial data.

While harvesting more than 1 arterial conduit initially prolongs the operative time, the elimination of a proximal anastomosis with the *in situ* use of the right internal mammary artery or sequential anastomosis will compensate for this added time. The use of multiple arterial grafts is now recommended in the Society of Thoracic Surgeons practice guidelines for CABG.[27] Total arterial revascularization is a class IIB recommendation for patients younger than 60 years of age with few comorbidities in the American guidelines and a class IIA recommendation for patients with a reasonable life expectancy in the European Society recommendations.[28]

Adapting to total arterial revascularization should be a stepwise process. First, a sequential anastomosis to the diagonal branch can be performed using the left internal mammary artery for a parallel anastomosis, followed by the addition of a second arterial graft, preferably the radial artery, and finally transition to routine total arterial revascularization.

Endoscopic conduit harvest

First introduced in the mid-1990s as an alternative to the traditional open method, endoscopic vein harvest (EVH) has reduced the length of leg incisions that are associated with an increased risk of wound infection. Several randomized studies and meta-analyses have demonstrated that EVH significantly reduces the risk of wound complications.[29] However, there are general concerns about the quality of the harvested vein and its patency with the EVH method. Isolated studies have suggested higher rates of adverse outcomes with the use of EVH, including mortality, the recurrence of angina, or the need for intervention.[30, 31] Notably, most of these reports are dated and lack randomization. The "Regroup Randomized Clinical Trial" followed up patients for a median of 4.7 years after CABG and found no significant impact on the hazard risk of major adverse cardiovascular events with EVH when compared with the open harvest.[32] Thus, newer studies are more reassuring and support the continued use of EVH. Currently, more than 80% of vein harvesting in North America is done endoscopically.[33] Similarly, the radial artery can be harvested endoscopically to minimize surgical trauma. Shapira et al[34] confirmed that the structural integrity and vascular reactivity of endoscopically harvested radial arteries remained intact. Most importantly, EVH enhances patient satisfaction and acceptability without compromising the quality of the conduit.

Epiaortic ultrasonography

Stroke risk continues to be the Achilles' heel of cardiac surgery. Perioperative stroke, the devastating complication, is feared by surgeons and has a direct impact on mortality, morbidity, hospitalization costs, and long-term quality of life.[35] The prevalence of adverse neurologic events increases with age. It is worth mentioning that according to the Society of Thoracic Surgeons (STS) Adult Cardiac Surgery Database, the CABG periprocedural stroke rate has not changed over

the past decade.[36] Most periprocedural strokes are embolic and arise from atheromatous plaques of the ascending aorta or the aortic arch during cannulation or clamping. As a result, it is reasonable and prudent to assess the atheroma burden by epiaortic ultrasonography and modify the procedure based on the findings as indicated. A large study conducted by Rosenberger et al[37] retrospectively evaluated the impact of EAU on the surgical outcomes of 6051 cardiac surgical patients. The authors demonstrated that EAU led to a change in surgical management in 4.1% of the cases in the form of the no-touch technique, the cannulation site or the clamp location, aortic replacement, and no cross-clamp or circulatory arrest. Additionally, they found that the incidence of both stroke and transient ischemic attack was significantly lower in patients who underwent EAU. Their findings were subsequently confirmed by others.[38] In light of several other confirmatory studies, adherence to routine EAU in CABG is recommended.[39-41]

Off-pump CABG

Although there is long-standing controversy on the merits and flaws of off-pump (OPCAB) in comparison with conventional CABG, several analyses have suggested a beneficial effect of OPCAB in high-risk groups such as older adults (>75 y) and those with diabetes, left ventricular dysfunction, chronic kidney/lung disease, and the severe calcification of the ascending aorta. The potential advantages of OPCAB in these cohorts include diminished major cardiovascular events such as myocardial infarction, death, and stroke.[42, 43] Given the potential for improved outcomes in high-risk patients, OPCAB should be in the armamentarium of most cardiac surgeons.

Minimally invasive and hybrid coronary revascularization

Broadening the indications for and increasing the use of PCI have intensified the focus on the optimization of short- and long-term outcomes after CABG. Minimally invasive coronary surgery (MICS) may represent an attractive alternative to a full sternotomy. It can be done under direct vision or via video assistance. The safety and feasibility of MICS have been confirmed in several studies.[44, 45] This technique is often used in patients with proximal left anterior descending (LAD) lesions and, on occasion, diagonal branches that are not amenable to PCI. Moreover, limited series have demonstrated the superiority of MICS over PCI in single-vessel disease with respect to the long-term need for coronary reintervention.[46, 47] A left internal mammary artery graft to the LAD is, without doubt, the single most significant conduit that offers a prognostic benefit based on its proven long-term patency and survival advantages. More recently, the hybrid approach to coronary revascularization with MIDCAB on the LAD and the stenting of the circumflex and right coronary artery territories have garnered interest.[48] Despite theoretical benefits, randomized trials comparing this method with conventional CABG are presently lacking.

Fractional flow reserve (FFR)-guided CABG

Since the introduction of CABG, emphasis has been on complete revascularization, with data continuing to emerge on the potential benefits of complete revascularization concerning surgical outcomes. The remarkable success of CABG in symptom relief or survival benefit is attributed mostly to complete rather than partial revascularization. The decision to bypass the coronary vessels has been based on the visual estimation of anatomic stenosis in coronary angiography to bypass all vessels with more than 50% luminal narrowing, but the visual assessment has at least a 20% variance rate. The concept of complete revascularization sometimes leads to “over grafting”. Several studies have demonstrated that bypassing functionally insignificant lesions does not provide any measurable perfusion to the territory. In addition, this can accelerate atherosclerosis in the native coronary vessel and result in early graft failure. FFR measurement involves determining the ratio between the maximum achievable blood flow in a stenosed coronary artery and the theoretical maximum flow in a normal coronary artery to determine the likelihood that the stenosis impedes the blood flow to the myocardium. Interventional cardiologists started to enter FFR in their daily practice a few years ago due to the unreliability of angiography to identify the true ischemic lesion, especially in intermediately severe lesions. Several studies are indicative of the applicability of FFR in CABG candidates.[49] Nonetheless, radical changes to the established field of surgical coronary revascularization require robust data based on large prospective randomized trials and long-term follow-ups to demonstrate the pragmatic impact of this new technology.

Intraoperative graft assessment

There are different tools to assess graft patency and flow in the operating room. Transit-time flow measurement (TTFM), epicardial ultrasound (ECUS), and completion angiography in a hybrid suite all can verify graft function. Since its inception in 2010, intraoperative graft evaluation has been mentioned in the European Guidelines for Myocardial Revascularization (class I recommendation, level of evidence C).[50]

TTFM is a technology based on the measurement of ultrasonic signal transmission speed across the vessel. Numerous studies have revealed the predictive value of TTFM in the verification of graft patency and its predictive impact on postoperative graft failure.[51, 52] Parallel to the increasing popularity of OPCAB and total arterial

revascularization, the necessity to qualify grafts on-table is appreciated more than before. In a study by Seetharama Bhat et al, [51] grafts out of 1203 grafts had to be revised based on the flow measurement (Girish Gowda SL. Ps Seetharama Bhat, Chandana NV, Manjunath N, Manjunath CN. Intraoperative Graft Flow Measurement in Off-Pump Coronary Artery Bypass Grafting Indicating Graft Revision: Our Experience of 1203 Grafts. J Cardiovasc Disease Res 2019;10:27-30). The rectification of a dysfunctional graft before chest closure leads to a reduction in postoperative adverse cardiac events. TTFM is not the optimal tool to verify graft patency due to the influence of several other factors that may affect the flow, as well as the absence of an established threshold to dictate revision. As a result, other tools can be used to add to the accuracy of the quality assessment of grafts. ECUS has been introduced as an alternative or ancillary procedure. It has the advantage of providing both morphologic and functional quality assessments of anastomoses.[53-55] While the physical bulk of ultrasound transducers hampered the use of ultrasound within the open chest in the 1980s, subsequent mini-transducers can reach all parts of the heart and even pass through a trocar in endoscopic procedures. With the aid of ECUS, it takes only a few minutes to assess an anastomosis. In addition, ultrasound can be used before anastomosis to visualize the target vessel and localize the site of the anastomosis based on the diameter, stenotic lesion, calcification, and side branches of the target coronary artery. In a study, the use of ECUS led to a change in the anastomotic site from the initial conventional selected site in a quarter of cases, which is remarkable.[56, 57]

The verification of graft patency may have legal implications as well. Surgeons can start to use ECUS in selected cases, and gradually it can be a standard protocol in the operating room.

CABG aside, every major cardiac operation (eg, valvular and endovascular) is checked on completion using an imaging modality to ensure procedural success. In CABG, such a method has not been the standard of care due to the time-consuming nature of the operation and difficult logistics. Nowadays, it is clear that many early graft failures are due to technical errors, which are present in 5% to 20% of patients at the time of discharge.[58] Completion on-table angiography is a quality assessment tool that ensures graft patency and, in the case of technical problems, guides the next intervention as revision or PCI.[59] It requires a hybrid suite, which is anticipated to be the standard of care in all large hospitals in the near future. Further, it provides the atmosphere for decision-making by the heart team and better collaboration of different specialties such as cardiac or vascular surgeons, interventional cardiologists, and cardiac anesthesiologists. Another hypothetical advantage of completion angiography is that it can change the surgeon's behavior by providing immediate feedback regarding technical imprecisions (eg, minor graft kinking) or discrepancy between the target coronary artery and the conduit. Whether completion on-table angiography should be the standard of care in every CABG procedure requires a large randomized study with a sufficient follow-up period. Be that as it may, at present, it is advisable in selected cases with technical difficulties, uncertainty about the conduit or the anastomosis, and evidence of myocardial ischemia after the termination of the cardiopulmonary bypass.

Longitudinal medical management

Despite many advances in coronary revascularization, either PCI or CABG, medical treatment remains the cornerstone of medical management. According to the 2011 American Heart Association (AHA)/American College of Cardiology (ACC) guidelines for secondary prevention and risk reduction therapy for patients with coronary disease and the 2011 ACC/ACC guidelines for those undergoing CABG/PCI, recommended drugs include optimal doses of antiplatelet drugs, beta-blockers, angiotensin-converting enzyme inhibitors/angiotensin II receptor blockers, and lipid-lowering drugs.[60] Although the use of medications in patients following PCI is largely evidence-based, the use of these drugs following CABG often deviates from guidelines and represents an important area of concern. Due to poor patient education, there is a common belief that after bypassing the stenotic vessels, there is no need for further medication. Kurlansky et al[61] conducted a study on 973 CABG and 2255 PCI patients, with an 8-year follow-up. They concluded that regardless of the coronary revascularization strategy, medication adherence had a dramatic effect on long-term outcomes. A considerable point in the trials that compare CABG with PCI is the rate of medication adherence, which is lower in the CABG group in almost all trials.[61] Some benefits of PCI might be explained by better compliance with guideline-directed medical therapy. Failure to implement guideline-directed medical treatment at hospital discharge and follow-up is a correctable insufficiency of postoperative care, which should be emphasized by cardiac surgeons.

Summary and future directions

CABG continues to account for the majority of adult cardiac surgical practices. Notwithstanding technical aspects and new technologies, it is incumbent upon us as cardiac surgeons to respect CABG more than before. In many adult cardiovascular surgery departments, there are some surgeons known as "aortic" or "mitral" surgeons who have specialized training or expertise in the said areas. Nevertheless, there is a general belief that every cardiac surgeon is a "bypass" surgeon. CABG, in our mind, is one of the most precarious and demanding operations in cardiac surgery due to its complexity and the number of steps required to accomplish a successful operation. Multiple arterial grafts, OPCAB,

totally endoscopic CABG (TECAB), and robotic surgery all have enhanced the complexity of bypass surgery and, consequently, the need for special training is appreciated more than ever. The surgeon of the future must evolve and adapt to new techniques while vigilantly protecting patients and their outcomes

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