Perspective

Coronary artery bypass grafting—fifty years of quality initiatives since Favaloro

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Coronary artery bypass grafting (CABG) remains one of the most commonly performed major surgical procedures worldwide and the most common procedure performed by cardiac surgeons. Rene Favaloro is widely credited with recognizing the true potential of CABG and subsequently popularizing the technique in a broad manner. Since the era of Favaloro in the late 1960s, the evolution of CABG can be understood through a series of quality initiatives that have defined which patients can benefit from the procedure and via which technique(s) they will derive the greatest benefit. Herein, we will review some of the key developments in CABG over the last 50 years with a focus on ongoing quality initiatives that will continue to refine the optimal applications and outcomes of CABG for the next 50 years.

Keywords: Coronary artery bypass grafting (CABG); hybrid coronary revascularization; total arterial revascularization; off-pump coronary artery bypass grafting

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Introduction

Coronary artery bypass grafting (CABG) remains one of the most commonly performed major surgical procedures worldwide and the most common procedure performed by cardiac surgeons (1). Several surgeons are credited with the "firsts" in the field of CABG, including Goetz (2) (1960: first right internal mammary artery to right CABG), Sabiston (3) (1962: first CABG employing human saphenous vein), and Kolesov (4) (1964: first sutured left internal mammary to left anterior descending artery CABG). Nevertheless, Rene Favaloro is widely credited with recognizing the true potential of CABG and subsequently popularizing the technique in a broad manner (5). Since the era of Favaloro in the late 1960s, the evolution of CABG can be understood through a series of quality initiatives that have defined which patients can benefit from the procedure and via which technique(s) they will derive the greatest benefit. Herein, we will provide a high-level review of the key developments in CABG over the last 50 years, with a focus on ongoing quality initiatives that will continue to refine the optimal applications of CABG for the next 50 years.

Myocardial preservation

While reviewing the decades of surgery that followed his popularization of CABG, Favaloro declared that myocardial preservation was the single most important development leading to improved outcomes in CABG (6). After the negative effects of induced ischemia and reperfusion that was occurring on the arrested heart during CABG were demonstrated in the 1970s (7), several advancements including refined cardiopulmonary bypass technology, improved anesthesia, and shorter operating times have allowed surgeons to complete the procedure with a reduced amount of myocardial injury (8). Most critically, however, cardioplegia solutions were developed to reduce myocardial energy demands during the period of ischemia while on cardiopulmonary bypass (9). Currently, two different formulations of cardioplegia are in widespread use, blood and crystalloid, and neither has demonstrated clear superiority over the other, despite dozens of RCTs pitting these formulations against one another (10).

Left internal mammary artery (LIMA) to left anterior descending (LAD)

Favaloro and his colleagues at the Cleveland Clinic initially relied on the saphenous vein graft as their conduit of choice, often combining a vein graft to the right coronary artery with the Vineburg procedure, during which one or both internal mammary arteries are directly implanted into the myocardium (11). Approximately 20 years later, however, their successors in Cleveland, led by Loop and Lytle, published landmark studies demonstrating superior short and long-term patency of arterial grafts in comparison to vein grafts (12). This finding translated into improved 10-year survival in patients who received an internal mammary artery grafts versus vein grafts to their left anterior descending coronary artery (83% *vs.* 71%) (13). These dramatic results resulted in a sea-change regarding the first-choice conduit for CABG: only 31% of patients undergoing CABG in 1988 received internal mammary artery (IMA) grafts (14), versus 88% in year 2000 and over 95% by 2010 (15). Today, IMA to LAD coronary artery is the unquestioned gold-standard in CABG, serving as a benchmark of quality and perhaps the only settled debate in the field of coronary revascularization.

Multiple arterial grafting

Given the survival benefit conferred through the use of single arterial grafting, multiple arterial grafting using bilateral internal mammary arteries (i.e., left and right) has been proposed to achieve further incremental improvement in patient outcomes. Currently, the Arterial Revascularization Trial (ART) is comparing outcomes of bilateral versus single internal mammary artery CABG over 10-year. An interim analysis of 5-year outcomes showed no difference in survival (92.3% *vs.* 92.6%) or major adverse cardiac events (12.2% *vs.* 12.7%) between bilateral and single arterial grafting, but did demonstrate increased rates of sternal wound infections after bilateral grafting (3.5% *vs.* 1.9%) (16). Nevertheless, over very long-term follow-up, the available evidence suggests that total arterial revascularization may provide improved outcomes (17,18), and there does exist randomized data to support the use of total arterial revascularization over conventional CABG with a single arterial graft supplemented by vein graft(s) (19,20).

The radial artery has also been widely investigated as a potential conduit for CABG. Unfortunately, the results of these investigations have been mixed at best, and contradictory at worst (21). For example, the Radial Artery Patency Study (RAPS) demonstrated superior rates of patency at 1-year for the radial artery as compared to saphenous vein grafts (22), but a VA Cooperative RCT found no difference in 1-year patency between these same options (23). Other investigations have suggested that the use of the radial artery may improve patient survival over the long-term (24).

Despite the potential of total arterial revascularization to improve outcomes, this technique has unfortunately not become the standard of practice, especially in the United States. In fact, the most recent data from the Society of Thoracic Surgeons Adult Cardiac Surgery Database reveals that bilateral internal mammary artery use has consistently hovered around only 5% of all CABG procedures for the last decade and that utilization of the radial artery has declined by approximately 33% over the same period of time (25). Unlike cardiologists (who have essentially standardized the use of second-generation drug eluting stents for percutaneous coronary intervention), surgeons have apparently been unwilling to standardize the preferred second conduit for CABG (26). This data reflects a potential opportunity in the cardiac surgery community to improve quality outcomes, simply by standardizing a proven revascularization strategy.

Off-pump CABG (OPCAB)

Like total arterial revascularization, OPCAB reflects another topic of open debate in the field of coronary revascularization. Initially proposed as a revascularization approach with the potential to reduce the physiologic stress put on the body by mechanical circulation (27), OPCAB has not yet lived up to its initial promise. To date, over 60 RCTs have been published comparing OPCAB with conventional on-pump CABG, with OPCAB appearing to offer benefits for certain select patient populations (28). However, the largest randomized controlled trials to date have been a disappointment to proponents of broad OPCAB expansion. The CORONARY (29) and GOPCABE (30) trials recently demonstrated no difference between the techniques in low- and high-risk patient populations, respectively. Meanwhile, the VA ROOBY trial concluded that patients undergoing OPCAB had increased rates of major adverse cardiac events and graft occlusion at both 1- and 5-year of follow-up (31,32). A recent meta-analysis including the majority of these RCTs as well as rigorously adjusted observational studies (totaling >1 million patients) found that OPCAB does offer a short-term survival benefit that unfortunately evaporates by 5-year and is surpassed by on-pump CABG after 10-year (33).

Limited access, robotic CABG, and hybrid procedures

While OPCAB was proposed as a mechanism to reduce the physiologic stress of CABG surgery, several limited access techniques have been developed as a means to reduce the mechanical and physical stress of the open sternotomy incision traditionally used for CABG. For example, minimally-invasive direct coronary artery bypass (MIDCAB) is performed through a mini-thoracotomy incision that typically allows for left internal mammary harvesting and anastomosis to the LAD (34). More recently, robot-assisted minimally invasive CABG has gained traction as a viable option for surgeons as well. Robotic systems have been applied for a wide range of revascularization options, from robotic harvesting of the internal mammary with hand-sewn anastomosis, to LAD via mini-thoracotomy, to totally endoscopic coronary artery bypass (TECAB) during which internal mammary takedown and intrathoracic anastomoses are completed on the robot (35). This latter technique has been perfected and routinely performed by very few surgeons.

Although these limited access and robot-assisted techniques allow for the gold-standard internal mammary to LAD bypass to be achieved, their primary limitation is the inability to perform multiple bypass grafts. Therefore, “hybrid” coronary revascularization, wherein minimally invasive internal mammary to LAD CABG is combined with percutaneous coronary intervention (PCI) of non-LAD coronaries, has been proposed to ensure total revascularization of all diseased coronary systems while reducing procedural morbidity. Early multi-center observational data collected in a National Institutes of Health-funded study comparing hybrid revascularization with multi-vessel PCI has demonstrated an equipoise in 1-year major adverse cardiovascular outcomes between these approaches, though the study was not powered to detect significant differences (36). In the fall of 2017, enrollment in a multicenter, prospective, randomized controlled trial evaluating hybrid revascularization versus PCI in over 2,000 patients began (37). While results will likely not be available for several years, this effort reflects one potential future direction of coronary revascularization in which optimal revascularization with minimal morbidity is achieved by a heart team comprised of both surgeons and cardiologists.

Public reporting

In determining which CABG techniques deliver the best outcomes in any given patient population, surgeons necessarily rely on outcome data. While prospective RCT data is considered optimal, clinical trials are burdensome, expensive, inevitably criticized for inherent design flaws, and take years, or even decades, to complete. Thus, large databases, including the Society of Thoracic Surgeons Adult Cardiac Surgery Database, serve an important role in collecting essential data on cardiac surgery outcomes. Although large data is necessarily analyzed in a retrospective fashion, the very large sample sizes afforded for analysis by these databases allows for rigorous adjustments to provide robust comparisons between study group (1). Another potential use for these national databases, however, is public reporting of outcomes data, which was met with some early consternation by the surgical community, given concerns about how publicly released data might be adjusted and contextualized for any given surgeon’s or hospital’s patient and case mix.

Interestingly, the Adult Cardiac Surgery Database was initially developed in response to inadequately adjusted mortality data for CABG published by the United States government in the late 1980s (38). After several decades of collecting data on CABG, and other cardiac surgery, outcomes, the Society of Thoracic Surgeons began to allow voluntary reporting of hospital and/or practice group CABG results in 2010. Today it is generally accepted, with approximately 65% of US programs participating in voluntary public reporting. A recent analysis on hospitals that have elected to participate in public reporting demonstrated that these programs have significantly higher CABG volumes, and improved performance as compared to programs not voluntarily reporting outcomes (39). Perhaps most importantly, there was no evidence found to suggest the hospitals participating in public reporting were practicing risk-averse surgeries and declining high-risk patients to improve outcomes, as the expected mortality in reporting and non-reporting groups were equivalent (38).

Public reporting of data therefore appears to be practiced by hospitals and groups performing CABG in higher volumes and with higher quality outcomes. This information is important to patients seeking optimal care, but, perhaps even more importantly, this should motivate continuous quality improvements across all practice groups. As low-quality programs are selected out based on their publically reported data, patients will be driven to high quality, high volume CABG centers who can provide coronary revascularization using optimal CABG techniques for any given patient.

Conclusions: is it time to subspecialize?

In reviewing the 50 years of CABG since Favaloro, what can we learn? First, while the vast expanse of accumulating evidence is not always clear about which CABG technique is superior, what is obvious is that the field of cardiac surgery has continued to innovate and push towards improved quality since the era of Favaloro. Second, given the complexities and intricacies of modern coronary revascularization, it may be time to recognize a CABG-specific sub-specialization for cardiac surgeons capable of performing state-of-the-art bypass surgery (26). These surgeons would implement off-pump, limited access, and/or hybrid CABG when appropriate, prioritize total arterial revascularization, adapt quickly to new techniques with proven advantages, and manage patients with coronary artery disease as part of a Coronary Revascularization Heart Team at high quality, high volume CABG hospitals. Fifty years ago, Favaloro brought CABG to the forefront of the field of cardiac surgery and the practice of medicine in general; for the next 50 years and beyond, cardiac surgeons must push for more robust data, relentless innovation, and improved quality outcomes in order to maintain the prevalence of CABG and ensure optimal care of patients with coronary artery disease.

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Footnote

Conflicts of Interest: The authors have no conflicts of interest to declare.

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