Coronary Artery By-Pass Grafting: An Historical and Clinical Review

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Abstract
Coronary artery by-pass represents today a central methodic for coronary revascularization. Since its introduction, technique and ability are grown-up considerable, lead today to a low rate of complications. Moreover, there are some aspects needed to be investigated, such as the use of the extracorporeal circulation, the use of single or dual thoracic arteries, or the endless dispute between surgical vs percutaneous revascularization. In this shortly review we provide a focus about history of surgical methodic, a discussion about the state-of-the-art for the most contested topics, and a viewpoint about the probable future developments in this field.

ABBREVIATIONS
BITA: Bilateral Internal Thoracic Artery; CABG: Coronary Artery By-Pass; FFR: Fractional Flow Reserve; iFR: Instantaneous Flow Reserve; LAD: Left Anterior Descending; LITA: Left Internal Thoracic Artery; ONCAB: On-Pump Coronary Artery By-Pass; OPCAB: Off-Pump Coronary Artery By-Pass; PCI: Percutaneous Coronary Interventions; RITA: Right Internal Thoracic Artery; RCT: Randomized Clinical Trial; SVG: Saphenous Veins Graft

INTRODUCTION
Coronary artery by-pass (CABG) had represented for several years the treatment of choice for myocardial revascularization, since his first description in 1967. CABG is still today the most common cardiac surgical procedure performed in the developed countries. For about 30 years CABG was the unique coronary revascularization methodic since developing of percutaneous coronary intervention (PCI) in 1977 offered an alternative option for patients. From the 90s, many randomized clinical trial (RCT) compared surgical versus percutaneous revascularization, both in acute than in stable setting [1-3]. Even if a definitive strategy is not yet approved, CABG showed to offer a better clinical outcome in some clinical setting, such as diffuse and multivessel coronary disease and diabetes patients [4]. The most recent trial actually available, the SYNTAX trial, showed as in patients with a more complex coronary anatomy, revealed by an high SYNTAX score (>33), is associated with a better prognosis in terms of cardiovascular event in patients treated with CABG at 5 years [5]. However, it is important to underline two aspects regarding these studies. First, comparison between PCI and CABG was conducted with first generation of stent, not more used in clinical practice. Second, old trials compared a “completed revascularization strategy” both in PCI than in CABG arm, while last tendencies of recent evidence suggest that an “ischemia driven strategy” with noninvasive or invasive assessment (FFR or iFR) could be more effective in reduce events both with PCI than with CABG revascularization [6,7].

HISTORY OF CABG

Since Alexis Carrel in 1910 [8] firstly appreciate the relationship between angina symptoms and coronary artery disease so much has been done. Over this time, CABG surgery has gone through three distinct eras of this revolutionary road. The first era was basically “experimental”, in whom visionaries’ surgeon imagined, pioneered and developed the basis of the modern revascularization techniques. The second era, or “vein graft” era was the one during the modern CABG surgery began and grow-up and the routinely use of the saphenous vein graft totally changed the approach to obstructive coronary artery disease and its treatment. The last and current era is “the combined venous and arterial grafting”, where almost the whole spectrum of coronary artery disease is treated with a combination of arterial and venous conduit, relying to the patient’s coronary anatomy, age, clinical condition and surgeon experience.

Carrel was the first surgeon who described a series of animal experiments by creating a “complementary circulation” for the diseased native coronary artery. Despite this early description of CABG, surgeons will be able to perform real and successful myocardial revascularization only three-four decades later due to a lack of technology and tools to operate on a beating heart.
The first described use of the internal thoracic artery (ITA) was proposed in 1945 by Arthur Vineberg [9] who implanted the left ITA (LITA) directly in the myocardium of the left ventricle and not directly on the coronary artery (left anterior descending -LAD- in that case). With the advent of the direct coronary anastomosis, the “Vineberg procedure” was gradually abandoned, but there are recent reports which describes a patency of the LAD as late as 30 [10] and 35-years [11] following this type of surgical procedure. In 1952 Demikhov described the LITA as direct graft to the LAD in dogs, with an acceptable graft patency up to two years, and similar success was reached by the Canadian group of Murray, Sabiston and Goetz [12-15]. Up to 1950s the main obstacle to the progress of CABG surgery was the inability to visualize the coronary artery anatomy and link the angina symptoms with specific atherosclerotic coronary disease. On October 30th, the group of the Cleveland Clinic accidentally performed the first world coronary angiogram. During an aortography performed in 24-year young man with an history of rheumatic aortic disease, Mason Sones injected contrast in the right coronary artery [16]. This event had opened the way to the birth of coronary angiography and had given a crucial boost to development of procedure for myocardial revascularization.

Thanks to these important contributions, Vasilii I. Kolessov and Spencer published at the same time, in the 1964 and 1967 [17,18], their first clinical reported CABG in humans. Spencer’s group in the United States report the first case on LITA coronary artery bypass graft surgery should be performed with or without the presence of atherosclerotic coronary artery disease. Although the almost universal consensus about the superiority of an arterial graft on the SVG, and the first evidences supporting best results with bilateral ITA revascularization than isolated ITA, BITA grafting didn’t have the expected spread and it’s performed worldwide in the minority of CABG operation [approximately only the 4% in the United States [25]. There are a few perceived disadvantages on the BITA grafting, by the surgeon’s point of view, like the increased length of operative time or the necessity of an \textit{in situ} right ITA (RITA) to cross the midline for reaching the left coronary territory, when the artery is not long enough to reach it through the transvers sinus. Probably, the most frequent addicted reason for not using BITA is the supposed increased risk of deep sternal wound infection (DSWI). It’s been well validated that BITA use is associated with a raising risk of DSWI, but it’s particularly evident in defined group of patients with determined risk factors, like obesity, severe airways disease and diabetes [26]. However, the diffusion of a skeletonized harvesting technique, despite the pedicled usual way, has been shown to reduce the risk of sternal wound complications [27]. Many group have reported a non-significant augmented risk of sternal problems when skeletonized BITA grafting is used, including high-risk patients (i.e. diabetics) when compared to usual fashion single pedicledITA [28].

Concerning these questions, the Arterial Revascularization Trial (ART) [22], tried to give all the answers, as the largest randomized trial on this aspect of coronary surgery, enrolling about 3000 patients, and with future results on 10-years outcomes. The 1-year [29] and 5-year [30] recently reported really encourage the use of BITA grafting, despite an effective non-significant increase of sternal wound problem (1.3% more in BITA group). The published literature supports surgical revascularization with BITA and we hopeful wait for the 10-year Arterial Revascularization Trial (ART) results, for better define criteria and advantages/disadvantages of the double ITA use for coronary artery revascularization.

**DUAL VS SINGLE INTERNAL THORACIC ARTERY**

While the internal thoracic artery (ITA) was routinely used since 1970’s, only after the 1980 the first important results on its benefits were recognized and reported. The Cleveland Group was the first to describe the several benefits of the ITA graft despite of the saphenous vein [20], in terms of improved survival, reduced risk of new onset of symptoms and repeating revascularization on long-term follow-up (up to 10-years). These advantages were then associated with improved early outcomes too, especially on perioperative death, both in low then high-risk patients.

Following that, obviously, many groups started to speculate that bilateral ITA (BITA) graft could be better than one, for furthermore improve outcomes and to find a reliable alternative to the saphenous graft, characterized by all the limitations described before. Probably the first paper handling this concern was published in 1999 by the Cleveland group, confirming that BITA grafting was associated with greater survival and reduced risk of repeating revascularization when compared to single ITA [21].

Moreover, other concept to take in consideration is “how to use BITA grafting”. There are several papers [22-24] describing the best result when BITA are used in situ, and on left coronary territory, instead of using it as free graft, although its still not clear what could be the best configuration for bilateral ITA use.

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**On-pump vs off-pump strategy**

Even if actually there is a large body of evidence, if coronary artery bypass graft surgery should be performed with or
without extracorporeal circulation is still debated between cardiac surgeons. Historically, the change towards off-pump coronary artery bypass grafting (OPCAB) was introduced both to reduce the cost in evolving countries but also to avoid the harmful effects of the artificial extracorporeal circuit (i.e., mainly the systemic inflammatory response and coagulopathy) [31]. Moreover, avoidance of aortic cannulation and minimization of aortic handling would hypothetically reduce rate of cerebral stroke, hence reduce morbidity and perioperative mortality [32]. On the other hand, on-pump (ONCAB) supporter sustain that the comfort of the bypass circuit results in a better anastomotic technique that translates into a more complete revascularization and better graft patency.

Regarding the operative mortality, the majority of the large RCTs failed to show a significant difference in early mortality between OPCAB and ONCAB technique [30,31,33,34]. Deppe et al. in meta-analysis of RCTs on almost 16,900 patients found no difference in 30-day mortality. Kowalewski et al. in meta-analysis of over 19,000 patients demonstrated no significant difference in short term mortality [33].

Regarding the mid and long-term event-free rate, in the ROOBY trial there were 2,203 patients randomly assigned to either OPCAB or ONCAB. It was the first trial where off patients were recruited in based on the surgeon’s experience (minimum number of 20 cases) though some argue that the learning curve extends beyond this set point [34]. The primary long-term (1 year) composite of death, repeat revascularization, non-fatal myocardial infarction was higher (9.9% vs. 7.4%, P=0.04) for the OPCAB group with no significant differences between the individual composite components. The sensitivity analysis revealed a trend toward more death from cardiac causes in the on-pump group (2.7% vs. 1.3%, P=0.03). A Cochrane systematic review of RCTs off-pump versus on-pump found an increased risk of death with off-pump in the long term (>30 days) follow-up studies [relative risk (RR), 1.34; 95% CI: 1.08–1.67; P=0.009] [35]. Luo et al., in a recent meta-analysis of RCTs found no difference in patients with over 6 months’ follow-up [odds ratio (OR), 1.02; 95% CI: 0.86–1.22; P=0.81] [36]. The Coronary Artery Bypass Grafting Off- or On-Pump Revascularization Study (CORONARY) remains the largest RCT to date that recruited 4,752 patients [37,38]. At 1 year the study reported no difference in primary composite of death, myocardial infarction, stroke, or new renal failure requiring dialysis. The primary outcome event had occurred in 288 participants (12.1%) in the off-pump group and 316 participants (13.3%) in the on-pump group (HR with the off-pump procedure, 0.91; 95% CI: 0.77–1.07; P=0.24). There was no significant difference between the rates of the individual primary outcome components. The 5-year long term outcomes from the CORONARY trial are still awaited.

Regarding the stroke and neurocognitive outcomes, considering that minimization of aortic manipulation and avoidance of the extracorporeal circuit had showed to reduce the risk stroke and cerebral embolization respectively, a reduce stroke rate should be expected in the on-pump setting. Unfortunately, all the most prominent off-pump versus on-pump trials to date failed to show a reduction of stroke rates with use of OPCAB. Only in a recent meta-analysis by Kowalewski et al., on 40 RCTs was found a significant 28% reduction in odds of cerebral stroke (OR, 0.72; 95% CI: 0.56–0.92; P=0.009; I 2 =0%) in the OPCAB group [33].

Regarding the postoperative renal dysfunction, while in the ROOBY trial no significant difference was found between OPCAB and ONCAB, in terms of renal failure requiring dialysis [34], in the CORONARY trial the use of OPCAB was associated with a significantly reduction in acute kidney injury (28.0% vs. 32.1%; RR 0.87; 95% CI: 0.80–0.96; P=0.01) [37].

Regarding the graft patency and the need for repeat revascularization, several trials reported poor graft patency for patients undergoing OPCAB [39-41]. The ROOBY trial found a significantly lower graft patency in the off-pump group than in the on-pump group (82.6% vs. 87.8%, P<0.01) at 1 year [34]. Similar results were found by Zhang et al. in a recent meta-analysis of 12 RCTs, on a total of 3,894 patients (4,137 grafts). Interestingly, the authors found an increased risk of occlusion of vein grafts but no difference in arterial graft patency [left internal mammary artery (IMA) and radial artery conduits] [42]. In the longest follow-up study to date (up to 6 to 8 years) of patients recruited in two randomized trials comparing OPCAB to ONCAB, Angelini et al., demonstrated that the probability of graft occlusion was no different between off-pump (10.6%) and on-pump (11.0%) groups (OR, 1.0; 95% CI: 0.55–1.81; P=0.99). Furthermore, the authors found the graft occlusion to occur more likely at the distal anastomosis (OR, 1.11; 95% CI: 1.02-1.20) in both groups [43].

FUTURE PERSPECTIVES AND CONCLUSION

Even if CABG is a relative recent methodic, many technological and skill progress are been made since its introduction. There are still some question debating, regarding the optimal strategy of revascularization and the appropriate technique to use in each patient. An emerging question is if the surgical revascularization must be driven by angiographic assessment of by ischemia assessment. Historical, surgery was used to perform a complete revascularization based on angiographic presence of coronary stenosis (>75%). Otherwise, in the last decade many trials in PCI setting focused attention to perform revascularization only with a document ischemia [6,44]. The ongoing trial SYNTAX II [45], based on an ischemia driven revascularization even in surgical groups, perhaps will provide a new evidence regarding the possibility also in surgical patients to no perform a complete anatomotic revascularization but only an ischemia revascularization, as compared with patients treated with PCI.

REFERENCES


Angelillis et al. (2018)  
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