Off-pump coronary artery bypass grafting

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Abstract: Coronary artery bypass grafting (CABG) prior to the discovery of cardiopulmonary bypass (CPB) was performed on a beating heart or "off-pump". Development of CPB created the optimal conditions of a bloodless and motionless operative field resulting in majority of CABG procedures being performed with the aid of CPB or "on-pump". However, invasiveness of CPB is a well-established phenomenon and accounts for the morbidity and mortality associated with conventional CABG. Off-pump CABG was rediscovered, more than two decades ago, as a less invasive strategy to abolish or at least reduce the morbidity and mortality associated with CPB. Theoretically off-pump CABG, by avoiding CPB, may improve outcomes by reducing organ dysfunction. In reality several top-quality clinical trials, conducted since the resurgence of off-pump CABG in 1990s, comparing off-pump and on-pump CABG have not been able to substantiate perceived supremacy of beating heart bypass surgery over conventional CABG with respect to key outcomes. At the same time concerns regarding partial revascularization, graft failure and long-term survival have prevented off-pump CABG from widespread adoption. This narrative review gives an insight into the evolution, indications, contraindications, technique, and outcomes of off-pump CABG as well as concerns and controversies associated with it.

Keywords: Coronary artery bypass grafting (CABG); cardiopulmonary bypass (CPB); coronary artery graft patency; off-pump coronary artery bypass grafting (off-pump CABG); surgical myocardial revascularization

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Introduction

In the current era of substantial increase in coronary angioplasty volumes and concomitant reduction in surgical myocardial revascularization rates, coronary artery bypass grafting (CABG) is still regarded as the benchmark treatment for three-vessel coronary artery disease or left main stem stenosis (1). Surgical myocardial revascularization performed with the assistance of cardiopulmonary bypass (CPB) and cardioplegic arrest, commonly known as conventional or on-pump CABG, is considered the gold standard (2). However, numerous physiologic disturbances affecting the hemostatic mechanisms, immune mediators and inflammatory responses are sequelae of CABG on CPB that culminate in deterioration of function of various organs. Furthermore, handling of an atherosclerotic ascending aorta during cannulation and cross-clamping can enhance embolization and stroke risk (2). Appreciation of these deleterious effects of on-pump CABG prompted revival of off-pump CABG nearly quarter of a century ago (3).

Off-pump CABG since its renaissance has been intensely scrutinized and attracted negative criticism. Whereas a large number of retrospective nonrandomized observational studies, prospective randomized controlled trials (RCTs), and meta-analyses have verified the status of off-pump CABG as a safe and effective technique (4), the larger

Table 1 Evolution of off-pump CABG

Year	Development
1876	Adam Hammer establishes the pathophysiology of coronary artery disease
1910	Alexis Carrel first describes CABG in animals
1950	Vineberg first to implant internal mammary artery into the myocardium
1953	Gordon Murray reported experimental placement of arterial grafts into the coronary circulation
1955	Sidney Smith first to harvest long saphenous vein and use it as an aorto-coronary conduit
1957	Bailey reports first successful coronary endarterectomy in man on beating heart
1958	Longmire reports another open coronary endarterectomy without CPB
1960	Goetz *et al*. reported non-suture method using tantalum rings for coronary anastomosis
1964	Kolesov performs successful internal mammary artery to coronary artery anastomosis in humans on the beating heart
1967	Favaloro performs successful CABG in humans using saphenous veins
1990s	Benetti, Calafiore, Subramanian achieve direct anastomoses between LIMA and LAD artery on beating hearts, operating through 10 cm incision between ribs
1995	Launch of products to enable beating heart multivessel CABG through median sternotomy
1997	Octopus®, the first tissue suction stabilizer for beating heart CABG launched
1998	Duhaylongsod, Mayfield and Wolf report successful thoracoscopic harvesting of LIMA at various centers
2000	Falk, Diegeler, Walther, Auschbach and Mohr report a succession of developments in minimally invasive robotic surgery

CABG, coronary artery bypass grafting; CPB, cardiopulmonary bypass; LIMA, left internal mammary artery; LAD, left anterior descending. Reprinted with permission from Springer Nature Customer Service Centre GmbH: Raja SG. editor. Cardiac Surgery: A Complete Guide. Springer Nature, Copyright 2020. doi: https://doi.org/10.1007/978-3-030-24174-2.

and more modern randomized trials have been unable to demonstrate absolute supremacy of off-pump CABG over on-pump CABG (5-8). In fact, concerns about completeness of revascularization, suboptimal graft patency and long-term survival have prevented it from being adopted worldwide (8,9). This review describes the evolution, indications, contraindications, technique, and outcomes of off-pump CABG as well as concerns and controversies ascribed to it.

Evolution

Off-pump CABG is frequently considered a modern technique; however, archives of surgical myocardial revascularization reveal that several revolutionary revascularization procedures were conducted off-pump without the assistance of CPB (*Table 1*). Vineberg procedure involving direct insertion of the left internal mammary artery (LIMA) into the ischemic myocardium was performed without the support of heart lung machine (10). Bailey in 1957 (11) and Longmire a year later (12) described techniques of coronary endarterectomy undertaken without the aid of CPB. Although Favaloro, in 1968, brought into vogue on-pump CABG using long saphenous vein as the conduit for grafting (13), Kolessov had already performed off-pump CABG using LIMA, in 1967 (14). In 1975, Trapp (15) and also Ankeney (16) published their pioneering work of beating heart revascularization of the right and left anterior descending (LAD) coronary arteries. The publication of these landmark reports coincided with standardization of the safety of perfusion techniques and development of methods to protect the myocardium by using cold cardioplegia. The technical benefits of operating on an arrested, flaccid heart in a bloodless field far outweighed the risk of myocardial damage, subsequent to transient disruption of coronary blood flow during off-pump CABG, resulting in abandonment of this technique by most surgeons (17).

In 1990s, the interest in performing off-pump CABG was reinvigorated (18). This resurgence was the result of recognition of the damaging effects of CPB as well as development of devices and strategies to perform beating heart bypass surgery safely. In 2002 off-pump CABG was at

Table 2 Contraindications of off-pump CABG

Absolute contraindications	
	Cardiogenic shock
	Major ischemic arrhythmias
Relative contraindications	
	Small, deep intramyocardial target vessels
	Calcified target vessels
	Poor ventricular function
	Patients with deep pectus excavatum
	Marked leftward displacement or rotation of the heart
	Reoperation

CABG, coronary artery bypass grafting. Reprinted with permission from Springer Nature Customer Service Centre GmbH: Raja SG. editor. Cardiac Surgery: A Complete Guide. Springer Nature, Copyright 2020. doi: https://doi.org/10.1007/978-3-030-24174-2.

its zenith in the United States with almost 23% of CABG procedures performed without pump and this popularity dwindled to 17% by 2012 (19). The adoption rates globally show a large variation and are impacted by availability of novel devices, innovative strategies and emerging publications.

Indications

Major advances in procedural performance and development of innovative devices have enabled beating heart bypass surgery to being offered to an increasing number of patients. Currently off-pump CABG is indicated on its own for treatment of single as well as multivessel coronary artery disease and can be combined with coronary angioplasty (18) and transcatheter aortic valve implantation (20) as a hybrid procedure. Patients with impaired left ventricular function, left mainstem stenosis, advanced age, cerebrovascular accidents, chronic renal failure, chronic obstructive pulmonary disease, sleep apnea syndrome, atheromatous disease of the aorta, acute myocardial infarction (MI), and reoperations are all candidates for off-pump CABG (18). Off-pump CABG has also been done in combination with transmyocardial laser revascularization, carotid endarterectomy, abdominal aortic aneurysm repair, lung surgery, gastrectomy (18) and is a well-described technique to shorten CPB and aortic cross clamp time for patients with coronary artery disease requiring combined valvular surgery (21).

Contraindications

In general, the small number of contraindications of off-pump CABG can be divided into absolute and relative (*Table 2*). Despite significant improvements in procedural performance, display of the target vessels in circumflex territory can be challenging, particularly in a patient with markedly impaired ejection fraction or when the surgeon is still in the early phase of his learning experience. Inability to expose the graftable vessels adequately translates into limited number of distal anastomoses and lack of complete revascularization.

Off-pump CABG due to manipulation-induced hemodynamic instability has a limited role in case of cardiogenic shock with a failing heart. In such a scenario, surgery using the CPB is inadvertent to avoid further deterioration of organ function (22). In the presence of widespread myocardial ischemia, cardiac failure and hemodynamic instability beating heart bypass surgery is best avoided.

Target vessels that are small in caliber, heavily atheromatous, or deep intramyocardial in location can account for incomplete revascularization (23). Coronary arteries with small caliber or heavy atheroma burden are challenging to graft even when CABG is performed using CPB on an arrested heart. Meticulous endarterectomy of heavily diseased coronary arteries should be carried out on-pump. Comprehensive dissection of an intramyocardial target vessel off-pump predisposes to danger of ventricular puncture and should be undertaken on-pump on a flaccid heart. Hybrid revascularization combining beating heart bypass surgery and coronary angioplasty can be a safer strategy in these challenging patients.

Technique

Off-pump multivessel grafting is performed through a standard median sternotomy (24). Median sternotomy offers the advantage of access to all potential targets, together with an unhindered approach to the left or right internal mammary artery for harvesting, and allows swift establishment of extracorporeal circulation should hemodynamic deterioration occur during off-pump CABG (18).

Dislocation of heart facilitates the exposure of coronary arteries on posterior, lateral, and inferior surfaces and can be accomplished either by the deployment of deep pericardial

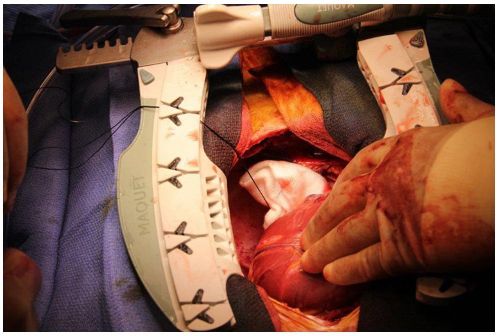

Figure 1 Deep pericardial retraction suture (top left).

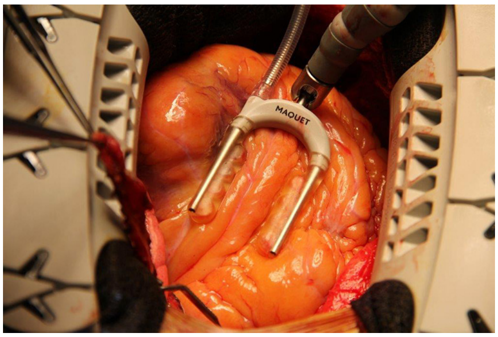

Figure 2 Positioning for LAD artery grafting. LAD, left anterior descending.

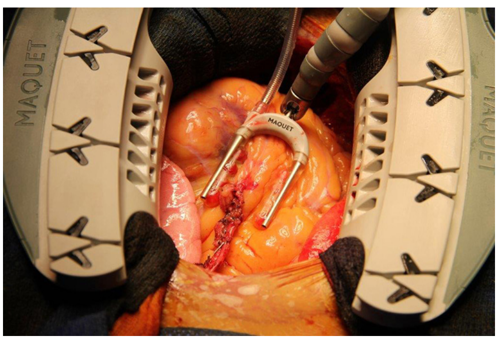

Figure 3 LIMA anastomosed to the LAD artery. LIMA, left internal mammary artery; LAD, left anterior descending.

retraction sutures (*Figure 1*) or the use of stockinet sutured into the oblique sinus (25). Minimal displacement is required to display the LAD artery (*Figures 2,3*), its diagonal branches, or proximal right coronary artery (RCA) and can be achieved by positioning rolled large swabs in the pericardial cavity (26). Placement of pads, slings, pericardial sutures, or a retracting sock (18), either alone or

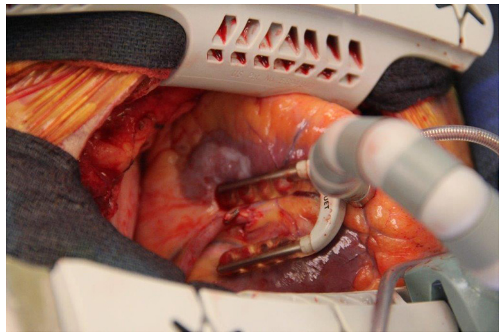

Figure 4 Positioning for obtuse marginal branch grafting (showing vein graft).

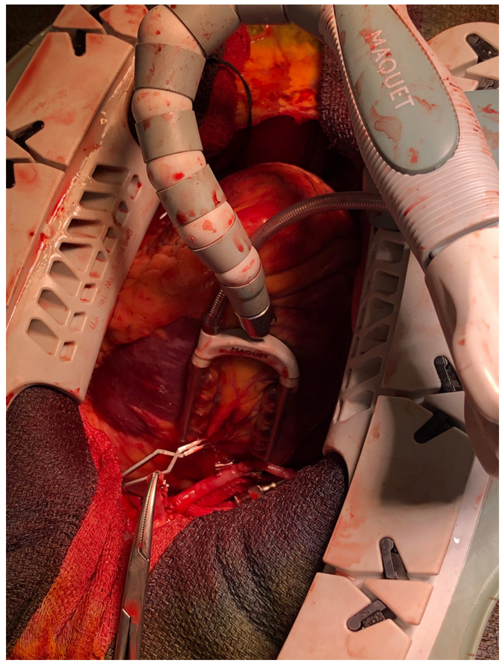

Figure 5 Positioning for posterior descending artery grafting.

in combination, are well-described strategies employed to improve the visibility of the circumflex artery (*Figure 4*), its branches, the posterior descending artery (*Figure 5*), and the posterolateral branch of the RCA. These aforementioned maneuvers luxate and elevate the heart anteriorly ensuring clear view of the target vessels on the inferior and lateral aspects.

Effective and localized stabilization of the anastomotic site enables seamless construction of a good quality anastomosis and is the key to successful off-pump grafting. Pressure or suction stabilizers positioned on the epicardium

Table 3 Strategies to prevent hemodynamic instability

Extensive right pleurotomy
Deep vertical right pericardiotomy
Gentle right decubitus Trendelenburg position
Ischemic preconditioning
Electrolyte optimization
Aggressive management of perfusion pressure
Constructing the proximal before the distal anastomosis
Revascularizing the territory of the LAD before lifting or turning the heart
Avoidance of surgery on the main RCA instead grafting its posterior descending branch
Pacing wires may be prophylactically sited in the right atrium or ventricle to overcome bradyarrhythmia
Prophylactic intra-aortic balloon pump placement for high-risk cases

LAD, left anterior descending; RCA, right coronary artery. Reprinted with permission from Springer Nature Customer Service Centre GmbH: Raja SG. editor. Cardiac Surgery: A Complete Guide. Springer Nature, Copyright 2020. doi: https://doi.org/10.1007/978-3-030-24174-2.

over the selected site of grafting minimize movement of the heart (18). This is a massive improvement from the early days, when reduction in heart rate was achieved with short-acting beta-blockers, diltiazem, or adenosine to create a relatively still anastomotic site (18). A variety of stabilizers have acquired approval with graft patency comparable to that of conventional CABG (27). Regional immobilization is achieved by positioning the stabilizer device on the myocardial surface over the selected spot for grafting.

A bloodless operative field is a fundamental requirement for safe construction of coronary anastomosis. An array of techniques including silastic snares or sutures, clamps, or coronary occluders have been utilized to create a bloodless operative field (18). These strategies also enable preconditioning if needed. Intravascular shunts are widely used due to their well-recognized benefits of preservation of coronary blood flow, avoidance of ischemia, diminished back bleeding, and visualization of suture line to prevent accidental suturing of the arterial back wall (28). Visualization is also improved by employing a surgical blower-mister that helps maintain moisture and increases visibility by gently displacing blood with a controlled flow of saline and carbon dioxide (29).

Anesthetic management

The fundamentals of anesthesia for off-pump surgery are similar to those for conventional on-pump surgery and involve safe induction and maintenance of general anesthesia with a strategy that offers utmost cardiac protection (18). Awareness of the coronary lesions, surgical strategy, and good communication between the surgeon and anesthesiologist is crucial (21). Avoidance and management of ischemia and hemodynamic instability during blockage of native coronary arteries, adequate postoperative pain relief, early emergence, extubation, and ambulation are important considerations. Prevention of hypothermia must be vigorously pursued (18). A cell saver may be utilized to lessen the requirement for homologous blood transfusion in multivessel beating heart bypass surgery. Transvenous pacing leads, defibrillator paddles, and provisions for intra-aortic balloon counterpulsation or emergency circulatory support should be available (18). Routine transesophageal echocardiography and cerebral oximetry are useful adjuncts for enhanced monitoring. Numerous interventions are employed to prevent hemodynamic deterioration and emergency conversion (*Table 3*).

There are diverse views with respect to the correct dose of heparin for beating heart bypass surgery, ranging from full heparinization to more moderate doses. It is generally believed that an activated coagulation time >300 seconds is acceptable, and this should be completely reversed upon completion of surgery with an adequate dose of protamine (18).

Outcomes

Since its resurgence, off-pump CABG has faced persistent criticism of skeptics. It has been intensely scrutinized with a massive increase in published research related to this technique over the last two decades. In fact, among techniques of coronary bypass surgery, beating heart bypass surgery is perhaps the most stringently evaluated modality (30). Abundant excellent quality evidence, in the form of large retrospective nonrandomized studies (31-35), single institutional RCTs (36-40) as well meta-analyses and systematic reviews (41-45) (*Table 4*), validates the status of off-pump CABG as a safe and effective technique. Similar outcomes have been reported for on-pump and off-pump CABG by the bulk of published outcomes research. However, erroneous interpretations about imperfect revascularization, diminished long-term graft patency and enhanced need for reintervention causing worse late survival (9) coupled

Table 4 Meta-analysis reporting comparative outcomes of on-pump and off-pump CABG

Author, reference	Year	Studies included	Outcome(s) of interest	Number of patients	Key results
Filardo, (41)	2018	42 RCTs, 31 obs	30-day mortality; 5-year mortality; 10-year mortality	1.2 million	RCTs showed no difference; combined analysis showed OPCAB offers lower short-term mortality but poorer long-term survival
Kowalewski, (42)	2016	100 RCTs	All-cause mortality, MI, cerebral stroke	19,192	Same rate of all-cause mortality and MI Significant reduction in cerebral stroke rate with OPCAB
Luo, (43)	2015	7 RCTs	Mortality, MI, stroke, renal failure, repeat revascularization	9,128	Similar outcomes except significantly higher revascularization rate with OPCAB
Chaudhry, (44)	2014	5 RCTs, 5 RBS, 10 PMS, 12 obs	Mid and long-term survival, repeat revascularization, MI, stroke	52,783	Similar mid-term mortality and morbidity Improved long-term survival with ONCAB
Sedrakyan, (45)	2006	41 RCTs	Mortality, stroke, wound infection, AF, repeat revascularization	3,996	Similar mortality; significantly reduced stroke, AF and wound infection rates with OPCAB; significantly increased repeat revascularization rate with OPCAB

AF, atrial fibrillation; CABG, coronary artery bypass grafting; MI, myocardial infarction; Obs, observational studies; ONCAB, on-pump coronary artery bypass; OPCAB, off-pump coronary artery bypass; PMS, propensity-matched studies; RCT, randomized controlled trial; RBS, registry-based studies.

Table 5 Comparison of off-pump CABG with on-pump CABG in recent RCTs

Trial, reference	30-day mortality	Stroke	MI	Renal failure	Reoperation for bleeding	Similar index of completeness of revascularization	Repeat re-intervention	1-year survival	5-year survival
CORONARY trial, (5)	=	=	=	=	<	Yes	>	=	=
GOPCABE trial, (6)	<	<	<	<	<	No	NM	NA	NA
DOORS trial, (7)	=	=	=	=	=	Yes	NA*	NA	NA
ROOBY trial, (8)	=	=	=	=	=	No	>	<	<
On-off study, (52)	<	<	<	<	<	Yes	NM	NA	NA
The Best Bypass Surgery trial, (53)	=	=	=	=	=	Yes	=	NA	=+

<, less with off-pump CABG; >, more with off-pump CABG; =, same with off-pump & on-pump CABG; NA*, more graft occlusion with off-pump CABG; +, 3-year survival. CABG, coronary artery bypass grafting; MI, myocardial infarction; NA, not available; NM, not measured; RCTs, randomized controlled trials. Adapted with permission from Springer Nature Customer Service Centre GmbH: Raja SG. editor. Cardiac Surgery: A Complete Guide. Springer Nature, Copyright 2020. doi: https://doi.org/10.1007/978-3-030-24174-2.

with ineptitude of RCTs with inadequate sample size to exhibit significant differences in outcomes have encouraged antagonists of beating heart bypass surgery to call for a ban on this strategy (46). Opponents and critics of off-pump CABG are oblivious of the fact that larger retrospective studies (47-51) and recently conducted multi-institutional RCTs that are better powered to statistically compare outcomes have reported improved short-term results with off-pump CABG and comparable late outcomes (5-7,52,53) for both off- and on-pump CABG (*Table 5*).

In contemporary CABG practice referrals of patients with high-risk profile are on the rise. The advantages of off-pump CABG are evident for patients at high risk for complications attributed to CPB usage and aortic handling. Current publications have reported improved outcomes with off-pump CABG for higher-risk patients (52-56) (*Table 6*).

Table 6 Studies reporting outcomes of off-pump and on-pump CABG in high-risk patients

Author, reference	Year	Study type	Patient characteristics	Primary endpoint	Number (ONCAB, OPCAB)	Key outcomes
Lemma, (52)	2012	RCT	EuroSCORE ≥6	Composite[a]	195, 216	Significantly more on-pump patients experienced primary end point
Møller, (53)	2010	RCT	EuroSCORE ≥5	Composite[b]	176, 163	No major differences
Barandon, (54)	2008	Case series	EuroSCORE >9	Early mortality, ICU stay, MI, stroke, RRT	–120	Early mortality 3%, ICU stay 2.7 days, MI 0.8%, stroke 0.8%, RRT 7%
Marui, (55)	2012	PSM	Division into tertile based on PROM	30-day mortality, cardiovascular events	1,377, 1,091	Similar 30-day mortality, more 30-day stroke rate in high-risk ONCAB tertile
Vasques, (56)	2013	PSM	Age ≥80 years	Early mortality, ICU stay, MI, stroke, 5-year survival	56, 56	All outcomes similar except lower stroke rate with OPCAB

[a], Composite primary end point included operative mortality, MI, stroke, renal failure, reoperation for bleeding and adult respiratory distress syndrome within 30 days after surgery; [b], composite of adverse cardiac and cerebrovascular events (i.e., all-cause mortality, acute MI, cardiac arrest with successful resuscitation, low cardiac output syndrome/cardiogenic shock, stroke, and coronary reintervention). CABG, coronary artery bypass grafting; RCT, randomized controlled trial; ICU, intensive care unit; MI, myocardial infarction; ONCAB, on-pump coronary artery bypass; OPCAB, off-pump coronary artery bypass; PROM, predicted risk operative mortality; RRT, renal replacement therapy; PSM, propensity score modeling.

Due to changing patient profile in the current era, off-pump CABG remains a beneficial strategy for patients considered high-risk for conventional CABG.

Concerns

Occlusion of grafts is one of the key factors determining clinical prognosis after CABG. Substantial concern has been expressed by clinicians regarding the increasing technical complexity of off-pump coronary revascularization that might affect quality of anastomoses and graft patency (57). The 15-year patency rate for conventional on-pump CABG is >97%. Any new revascularization method must be compared against this benchmark (58). Inferior graft patency after off-pump CABG is attributed to a sharp learning curve, hindrance caused by cardiac movement or pulmonary excursions, and anastomotic suturing on a moving target (58).

Interestingly, majority of the concerns about suboptimal anastomotic quality and inferior graft patency over the years have been principally ascribed to two RCTs (8,59). Shroyer *et al.* (8) reported lower patency rate on 12-month angiography and higher composite adverse outcome rate (death from any cause, nonfatal MI, and any reintervention procedure) for off-pump than for on-pump CABG at 1 year. Limited surgical experience of 53 participating surgeons most likely accounted for the undesirable high conversion rates to on-pump CABG (12%) and lack of complete revascularization (18%) with poor outcomes for the off-pump CABG cohort. In addition, 60% of the cases were performed by relatively inexperienced residents which could have affected graft patency. Simultaneous utilization of endoscopic vein harvesting (EVH) in 1,471 patients (on-pump =907 and off-pump =564) in the Veterans Affairs (VA) Randomized On/Off Bypass (ROOBY) trial (8) was another potential confounder that impacted graft patency. On follow-up angiography, 41.3% patients in the EVH group had one or more occluded saphenous vein grafts compared with 28.0% in the open vein harvesting (OVH) group (P<0.0001). Overall patency of saphenous vein graft was markedly worse at 74.5% in the EVH group in comparison to 85.2% in the OVH group (P<0.0001) (60). Since ROOBY trial was enrolling at a time when practice of EVH was still in its infancy, the suboptimal vein graft patency due to EVH can be ascribed to learning curve and lack of experience of the vein harvesters. The learning curve for EVH results in poor conduit quality that has been held responsible for early graft failure, blunted positive remodeling, and greater negative remodeling (61).

The trial by Khan *et al.* (59) is the other frequently cited randomized trial that castigates off-pump CABG for poor graft patency. This trial reported decreased graft patency at 3 months in the off-pump group. However, critical analysis of this trial reveals that relative inexperience of the trial surgeons, comparatively low dose of intraoperative heparin, the lack of dual antiplatelet therapy usage postoperatively, and reliance on old fashioned stabilization devices with suboptimal exposure contributed to poor graft patency (4,62).

Controversies

Lack of complete revascularization due to fewer grafts is a controversy that has haunted off-pump CABG since its resurgence. The criticism regarding incomplete revascularization is no longer credible in the contemporary era due to availability of state of the art technology to safely perform multivessel off-pump CABG. Grafting of target vessels in the circumflex and RCA territories is not insurmountable any more. In fact, the more recently conducted randomized trials report at least comparable completeness of revascularization (5-7,52,53). Moreover, it is crucial to emphasize that completeness of revascularization and number of grafts are not synonymous. The index of completeness of revascularization [number of grafts performed divided by the number of grafts needed (number of graftable vessels with angiographically significant stenoses)] is a more rational way to deal with the controversy surrounding lack of complete revascularization (63).

The relative experience with each technique of the reporting center(s) and surgeon(s) influences revascularization rates reported by various studies comparing off-pump and on-pump CABG. Low volume off-pump CABG centers will report similar rates of complete revascularization in the early as well as late phases of off-pump experience emphasizing the significance of learning curve as well as case load. Contribution of cases from low volume off-pump centers can therefore influence the final completeness of revascularization rate reported by multicenter RCTs. The ROOBY trial illustrates this phenomenon (64). Nearly 4,000 isolated CABG procedures are performed annually in the VA system at 42 cardiac surgery facilities (65). During the enrollment phase of the ROOBY trial only 7 of the 42 centers could be rated as high-volume off-pump CABG centers because they performed at least 50 off-pump cases annually (66). As the learning curve for off-pump CABG is perceived to be between 50 and 75 cases (67) it does not come as a surprise that the ROOBY trial reports incomplete revascularization with off-pump CABG.

Long-term all-cause mortality is reported to be worse after off-pump CABG. Late mortality rates are negatively influenced by incomplete revascularization and lower graft patency (68). Takagi *et al.* (69) recently published a meta-analysis of 11 randomized trials comparing ≥1-year all-cause mortality after off-pump and on-pump CABG. Mortality was significantly increased by a factor of 1.37 with off-pump relative to on-pump CABG (RR: 1.373; 95% CI: 1.043–1.808). The ROOBY trial (8) emerged as a strong contributor to the pooled estimate as revealed by the sensitivity analysis in this meta-analysis. The inferior survival of off-pump cohort could be attributed to the previously mentioned criticisms of the ROOBY trial. It is important to mention that long-term outcomes, including late mortality data, for majority of the more contemporary trials (5-7,52,53) are still awaited.

It is anticipated that once information on long-term outcomes is available for contemporary RCTs (5-7,52-53), that deployed advanced technology for stabilization and exposure and had comparable index of completeness of revascularization for off-pump and on-pump CABG, these contentious issues will be addressed.

Conclusions

Despite abundant published evidence substantiating the benefits of off-pump CABG, apprehension prevails regarding the safety, effectiveness, and similarity of completeness of revascularization of off-pump CABG compared with on-pump CABG. Off-pump CABG is a challenging technique with a steep learning curve that accounts for all the concerns and controversies attributed to this technically demanding strategy. Appropriate patient selection, individualized grafting strategy, peer-to-peer training of the entire team, and graded clinical experience are some of the interventions that can facilitate safe negotiation of the learning curve of off-pump CABG. Off-pump CABG is an attractive strategy for treating high-risk patients and next generation of cardiac surgeons must receive structured training to perform off-pump CABG so as to deal with increasing numbers of high-risk patients that are being referred for surgical myocardial revascularization.

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

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