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The Current and Future Trends in Coronary Artery Bypass Graft Surgery

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Introduction

The roots of current day coronary artery bypass graft surgery (CABG) date back towards the end of 18th century. In 1899, Francois Franck proffered the first surgical treatment for angina pectoris. He believed that ligation of sympathetic pain pathways would result in relief of angina. The internal mammary artery (IMA) formed an area of interest early on, particularly after the report of Fieschi in 1939. He ligated the right IMA at the second intercostal space to increase blood flow to the coronary circuit through smaller anastomotic collaterals from the IMA bed. It was not until the work by Arthur Vineberg in 1946 that the use of the IMA was starting to show promising results. He skeletonized the left IMA and tunneled the artery next to the left anterior descending (LAD) coronary artery. Murray in 1954 suggested that one would need direct anastomosis to the LAD to provide the best results, and like Beck he also favoured the carotid artery. One of the most crucial developments was that of coronary angiography by Mason Sones. He demonstrated the formation of collaterals after the Vineberg operation [1]. In 1910, Alexis Carrel described the principles of CABG for which he was awarded the Nobel Prize in medicine in 1912. In 1953, Dr Gibbon developed the first heart lung machine. Rene favalaro was the first to use venous graft for coronary artery bypass surgery [2].

The Current Scenario

The statistics of 1989 as compared to 1994 and 1999 show a fall in the number of patients undergoing CABG surgeries. As per national hospital discharge survey, 2010, released by CDC, reported that 2,19,000 patients were discharged from hospital post-CABG out of 51.4 million total surgical procedures done the same year in the U.S and U.K. The present day coronary surgery comes with a number of challenges which includes management of diffusely diseased coronaries, to operate on no flow coronaries, management of the ageing population, to compete with ongoing percutaneous interventions (PCI), etc; for which the surgeon has to learn and practice complex procedures with the use of advanced technology. With newer studies and trials showing the efficacy and superior outcomes of CABG on comparison with PCI, there would probably be a rise in the number of patients who will be coming in for surgical revascularization by their own choice in the future.

Indications for CABG

The CABG procedure is indicated for the relief of symptoms (primarily angina) unresponsive to medical treatment or percutaneous transluminal coronary angioplasty (PTCA), particularly when it is likely that this operation will delay unfavorable events (death, myocardial infarction, angina recurrence) longer than other forms of treatment. For angina relief, surgery has often succeeded where medical or interventional therapy has failed or is not recommended. There is general agreement that CABG improves prognosis in the early postsurgical years in those patients with symptomatic left main coronary artery stenosis or stenosis of the three main coronary vessels [3].

Management of Diffusely Diseased Coronaries

The management of diffusely diseased coronaries has been tried over the last decade in various ways to provide blood flow distal to the diseased coronaries. Long segmental LAD reconstruction with or without endarterectomy using the LITA provided excellent long-term outcomes and acceptable early operative results, even in patients with diffusely diseased coronary arteries. An LAD graft anastomosis involving >2 centimeters has been called a plasty and an anastomosis involving >4 centimeters has been called as extensive LAD reconstruction [4]. The technique of LAD reconstruction can be achieved either by endarterectomy, left internal thoracic artery (LITA) patch reconstruction or a saphenous venous patch reconstruction. A long segment arteriotomy is made and the graft conduit is fashioned to it. This technique was much beneficial as it avoids the complications of endarterectomy and at the same time provides revascularization not only to the distal segment but also to the septal branches of LAD which cannot be achieved by a long segment stent. Toshihiro et al. found in their study that freedom from death, cardiac and other cerebrovascular events was 91.5 ± 2.2% at the end of 3 years. The outcomes at the end of 1 year were excellent [4]. This technique has also been performed on other coronaries with the same result.

The Ageing Population

As per society of thoracic surgeons (STS) database, coronary surgery increased from 0.7% to 1.6% in nonagenarians. Cardiac operations are successful in most of the octogenarians with increased hospital mortality and longer hospital stay. The operative mortality was 10% and the 5 year survival rate was 65.8 ± 8.8% [5]. Operative mortality and complication rates associated with cardiac surgical procedures are highest with nonagenarians and centenarians. But, with careful patient selection, a majority of these patients have a lower risk of CABG related mortality approaching that of younger patients. The operative mortality was 11.8% in patients > 90 years age and 7.1% in patients aged 80-89 years [6]. A careful scrutiny is to be undertaken which can range from stress thallium test to cardiac MRI to determine the myocardial viability, along with other investigations that aid the surgeon for an appropriate selection of the elderly patients.

Conduits in CABG

The conduits that are being used today in CABG include arterial conduits (Left and right internal thoracic arteries, radial artery, gastro-epiploic artery) and venous conduits (great saphenous vein). Studies have shown that the patency of arterial grafts is better than venous grafts over 5-10 year period [7]. Steven Goldman et al. have conducted a trial to compare the patency of IMA and SVG grafts over a 10 year period. This VA Cooperative Studies Trial defined 10-year SVG patency in 1,074 patients and left IMA patency in 457 patients undergoing coronary artery bypass grafting (CABG). Patients underwent cardiac catheterizations at 1 week and 1, 3, 6, and 10 years after CABG. Patency at 10 years was 61% for SVGs compared with 85% for IMA grafts (p- 0.001). If a SVG or IMA graft was patent at 1 week, that graft had a 68% and 88% chance, respectively, of being patent at 10 years. The SVG patency to the left anterior descending artery (LAD) (69%) was better (p 0.001) than to the right coronary artery (56%), or circumflex (58%). Recipient vessel size was a significant predictor of graft patency, in vessels 2.0 mm in diameter SVG patency was 88% versus 55% in vessels 2.0 mm (p- 0.001) [8]. A systemic review and meta-analysis by Thanos Athanasiou et al; suggest that the RA is a superior conduit compared with SV for CABG when considering the medium-term (1-5 years) (OR 2.06) and long term (>5 years) (OR 2.28) patency rates. Taking into account that the ultimate goal of CABG is to achieve complete revascularization with conduits that remain patent and functional for the duration of the patient's lifetime, we can confidently state that if the patient's life expectancy is >5 years and there is no contraindication to RA use, this conduit should be used in preference to the SV [9]. A number of clinical trials and observational studies have demonstrated a significant benefit of statin treatment on vein graft patency. Statins reduce vascular oxidative stress in SVGs, improve NO bioavailability and reduce vascular inflammation, all critical components of SVGs failure. In addition, statins have systemic antithrombotic and anti-inflammatory effects therefore, their administration may prevent acute SVGs failure post CABG [10].

Bilateral Internal Thoracic Artery Grafting

The concept of bilateral internal mammary artery usage in CABG has proven results of its superiority. The usage of bilateral internal thoracic arteries also has better outcomes [11]. Malcolm et al. have done 30 year follow up for patients who received bilateral internal thoracic artery. 1107 consecutive diabetic patients underwent coronary artery bypass grafting with either SIMA (n=646) or BIMA (n=461) grafting. Optimal matching with the propensity score was used to create matched SIMA (n=414) and BIMA (n=414) cohorts. Cross-sectional follow-up (6 weeks to 30.1 years; mean, 8.9 years) determined long-term survival. There was no difference in operative mortality, sternal wound infection, or total complications between matched SIMA and BIMA groups (operative mortality, 10 of 414 [2.4%] versus 13 of 414 [3.1%]; P>0.279; sternal wound infection, 7 of 414 [1.7%] versus 13 of 414 [3.1%]; P>0.179); total complications, 71 of 414 [17.1%] versus 71 of 414 [17.1%]; P>1.000). Late survival was significantly enhanced with the use of BIMA grafting (median survival: SIMA, 9.8 years versus BIMA, 13.1 years; P>0.001). Use of BIMA was found to be associated with late survival on Cox regression (P>0.003) [12]. Compared with SIMA grafting, BIMA grafting in propensity score-matched patients provides diabetics with enhanced survival without any increase in perioperative morbidity or mortality. As per a review study done by Ali and colleagues using 12 papers concluded that skeletonisation of LIMA increases the length of conduit by around 3 cm and may also increase flow and conduit diameter. Skeletonisation should be the technique of choice for diabetics in whom BIMA harvest is desired, but at the expense of an extra 15-20 min per operation.

CABG Vs PCI

The debate between percutaneous coronary interventions (PCI) and CABG has always interested the medical fraternity. But off late the SYNTAX trial [13] and the FREEDOM trial [14] have proven beyond doubt that the long term outcomes of surgical revascularization are better than PCI using stents or balloon angioplasty. The recurrence of myocardial infarction was remarkably lesser after surgical revascularization. The SYNTAX trial is an elaborate and extensive study with 1800 patients randomized from 85 centers in the Europe and the United States, this has been the largest randomized controlled study of PCI versus CABG. The principal finding of SYNTAX was that patients treated with PCI by DES were more likely to reach the primary end point of the study at 12 months after randomization: 17.8% suffering one of death (all causes), stroke, MI, or repeat revascularization compared with 12.4% of patients treated by CABG. Therefore, the conclusion of the study was that CABG remains the standard of care for patients with 3VD or LMD. There was, however, a statistically significant excess of strokes after CABG compared with PCI (2.2% versus 0.6%). The principal driver of the higher primary end point event rate in the PCI group was an excess of repeat revascularizations (13.5% versus 5.9%), consistent with all previous studies comparing CABG with PCI, even in the DES era [13]. The FREEDOM trial enrolled 1,900 patients with diabetes and angiographically confirmed multivessel coronary artery disease (83% with three-vessel disease) with stenosis of more than 70% in two or more major epicardial vessels involving at least two separate coronary artery territories. The 5-year rates in the CABG group vs the PCI group were; Primary outcome-18.7% vs 26.6%, P = .005, Death from any cause-10.9% vs 16.3%, P = .049, Myocardial infarction-6% vs 13.9%, P < .0001, Stroke-5.2% vs 2.4%, P = .03. The secondary outcome (death, nonfatal myocardial infarction, nonfatal stroke, or repeat revascularization at 30 days or 12 months) had occurred significantly more often in the PCI group than in the CABG group at 1 year (16.8% vs 11.8%, P = .004), with most of the difference attributable to a higher repeat revascularization rate in the PCI group (12.6% vs 4.8%, P < .001). The major advantage of CABG over PCI is the ability to achieve complete revascularization. Diabetic patients with coronary artery disease tend to have diffuse, multifocal disease with several stenotic lesions in multiple coronary arteries. While stents only treat the focal area of most significant occlusion, CABG may bypass all proximal vulnerable plaques that could potentially develop into culprit lesions over time, truly bypassing the diseased segments [14]. These trials have proved the benefit of surgical revascularization over PCI in patients with diabetes mellitus.

Off Pump vs On Pump CABG

The conflict regarding the superiority between off-pump and on-pump CABG is also yet to be proved as each one comes with its own set of complications and advantages. Randomized control trials have shown no difference between the two. The ROOBY trial randomized 2203 patients to off-pump versus on-pump CABG. Follow-up angiography was obtained in 685 off-pump (62%) and 685 on-pump (62%) patients. Angiograms were analyzed (blinded to treatment) for Fitz Gibbon classification (A-widely patent, B-flow limited, O-occluded) and effective revascularization. Effective revascularization was defined as follows: All 3 major coronary territories with significant disease were revascularized by a Fitz Gibbon A-quality graft to the major diseased artery, and there were no new post-anastomotic lesions. Off-pump CABG resulted in lower Fitz Gibbon A patency rates than on-pump CABG for arterial conduits (85.8% versus 91.4%; $P<0.003$) and saphenous vein grafts (72.7% versus 80.4%; $p<0.001$). Fewer off-pump patients were effectively revascularized (50.1% versus 63.9% on-pump; $P<0.001$). Within each major coronary territory, effective revascularization was worse off pump than on pump (all $P<0.001$). The 1-year adverse cardiac event rate was 16.4% in patients with ineffective revascularization versus 5.9% in patients with effective revascularization (P 0.001) [15].

Minimally Invasive Cardiac Surgery (MICS)

Over the past decade, minimally invasive cardiothoracic surgery (MICS) has grown in popularity. Minimally invasive direct coronary artery bypass (MIDCAB), the Mc Ginn technique, MICS-CABG is synonyms of this technique. This growth has been driven, in part, by a desire to translate many of the observed benefits of minimal access surgery, such as decreased pain and reduced surgical trauma, to the cardiac surgical arena. With innovations in perfusion techniques, refinement of transthoracic echocardiography and the development of specialized surgical instruments and robotic technology, cardiac surgery was provided with the necessary tools to progress to less invasive approaches [16]. The studies on MICS-CABG have shown that the duration of hospital stay is lessened, providing good cosmesis, being reasonably cost effective and achieving revascularization which is no different from the conventional technique [17]. MICS-CABG is an off-pump technique of bypass grafting via a left hemi thoracotomy with an incision of 5-8 centimeters only. Earlier this was tried only for single vessel disease to graft LIMA to LAD. This has now been carried on to multi-vessel diseases to graft other diseased coronaries, which requires more refined skills and dedicated instrumentation. The percentage of MICS-CABG compared to conventional method is a very meagre number, but with surgeons taking up the task of improvising themselves and striving to adapt these newer techniques, we hope to see a rise in the number of MICS CABG in the upcoming future.

Robotics in Cardiac Surgery

This is the generation of minimal and key-hole surgeries. Conventional methods are trending towards more complex and technology aided techniques, i.e the robot assisted coronary surgery. This is the next level of performing surgical revascularization by making 2-3 tiny non-rib spreading incisions and completing the procedure with the help of robotic arms and high definition real-time imaging. The Da Vinci Si HD Surgical System (Intuitive Surgical, Inc.) allows the surgeon to gain access to the heart via four half-inch incisions made in the intercostal space. These incisions are subsequently used for the introduction of robotic instruments and a videoscope. Seated at a robotic console, the surgeon can see into the patient's chest via high-definition, 3D optics. The console is connected electronically to the bedside robot, allowing the surgeon to manipulate the robotic instruments and the scope as if they were hand-held surgical instruments. A skilled operating team is necessary for the rapid exchange of the robotic surgical instruments [18]. A recent prospective, multicenter trial of robotically assisted totally endoscopic coronary artery bypass (TECAB) demonstrated this procedure to be safe, with angiographic patency, morbidity and mortality equivalent to traditional CABG procedures [19]. But due to the high costs of instrumentation and specifically trained and skilled personnel requirement, robotics is still not in realization in many centers and can be a probable technique in future.

Hybrid Procedures

Hybrid coronary revascularization combining minimally invasive coronary surgery and percutaneous coronary intervention (PCI) allows sternal preserving treatment of multivessel coronary disease. The main principle of the technique includes placement of mammary artery graft to the left anterior descending coronary artery (LAD) and performance of PCI in non-LAD target vessels. This requires the combined set-up of a catheterization lab and an operating room. Three major protocols have been used: (1) PCI prior to TECAB, (2) TECAB and PCI in one session, and (3) TECAB prior to PCI. The results are very encouraging and seem to be equivalent to conventional approaches in selected patients. Prospective randomized trials comparing hybrid closed chest revascularization, with conventional PCI or CABG, may shed light on outcomes and provide us with the ideal candidate for this procedure [20]. This technique has good results, but studies are yet to prove its benefits.

Research on SVG External Stenting

Low patency rates of saphenous vein grafts remain a major predicament in surgical revascularization. Still in experimental phase, being tried on animal veins (sheep), the results seem to be promising. Yanai Ben-Gal et al. have developed this new innovation to increase the longevity the venous grafts. The expandable SVG external support system was found to be efficacious in reducing SVGs non-uniform dilatation and neointimal formation in an animal model early after CABG. Of the fourteen animals studied, three died peri-operatively (unrelated to device implanted), and ten survived the follow-up period. Among surviving animals, three grafts were thrombosed and one was occluded, all in the control group ($p = 0.043$). Quantitative angiographic evaluation revealed no difference between groups in immediate level of graft uniformity, with a coefficient-of-variance (CV%) of 7.39 in control versus 5.07 in the supported grafts, $p = 0.082$. At 12 weeks, there was a significant non-uniformity in the control grafts versus the supported grafts (CV = 22.12 versus 3.01, $p < 0.002$) [21]. This novel technology may have the potential to improve SVG patency rates after surgical myocardial revascularization.

The Role of ECMO in Cardiac Surgery

The indication of ECMO is refractory cardiogenic shock despite adequate filling volumes, large-dose inotropes and intra-aortic balloon pump support. Average duration of ECMO was 7.5 - 6.7 days. Twenty-seven (53%) patients could be successfully weaned from ECMO. The 30-day and 3-month mortalities were 49% (25/51) and 65% (33/51). The in-hospital mortality was 67% (34/51 patients). Seventeen (33%) patients could be successfully discharged. Fifteen (29%) patients were still alive at 1-year outpatient department (OPD) follow-up. ECMO provides a good temporary cardiopulmonary support in patients with postcardiotomy shock [22].

The Instrumentation

Apart from the common instruments that are used for cardiac surgeries, certain instruments have indeed changed the perspective of it. The introduction of cardiac stabilization devices have made off pump coronary revascularization much easier without which it would be difficult to perform a distal anastomosis over a beating heart. Starfish and octopus are some of the stabilization devices, which also have undergone various modifications to the present day in-usage devices. The innovations like the proximal anastomotic device have made it safe and easy to perform proximal anastomosis in aorta that are calcified of atheromatous (grade III, IV or V) with mobile elements where it is not safe to use a conventional clamp. Intra-operative graft flow assessments are also being increasingly used now a days. Graft patency verification is increasingly recognized as an important component of coronary artery bypass grafting. Conventional angiography remains the gold standard technique for assessing graft patency, it is rarely available in the operating room. Most commonly used modalities for graft patency assessment, intraoperative fluorescence imaging and transit-time flow-metry susceptible to "false positive" images. C. Herman et al. have shown that transient time flow meter (TTFM) measurements intra-operatively resulted in 0.9% graft revision with a majority having a correctable problem. In addition, we have shown that patients with a measured graft PI higher than five, that is not revised surgically, are more likely to experience in-hospital adverse events defined as prolonged ventilation, re-operation, postoperative PCI, peri-operative MI and mortality with an odds ratio of 1.8 (1.1-2.7). This would suggest that TTFM may be used not only to identify grafts with problems but a predictive tool to identify patients at increased risk of adverse events postoperatively [23]. Specific instrumentation for MICS, robotics and hybrid procedures has been developed too. With the present day research and advances, we hope to get even better innovations to perform these complex and skilled procedures with speed and ease.

The Future Prospects

The world is fast growing and technology even faster. Procedures are more trending towards minimally invasive and robotic assisted. Upcoming surgeons should be encouraged to learn and adapt these techniques as the patient demand is the smaller incision with better outcomes. Coronary revascularization techniques have also undergone many changes over the past decades and are ever improving to adapt and satisfy the patient population without compromising in the results.

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