Coronary Artery Bypass Grafting (CABG): Past Present and Future

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ABSTRACT

Despite increasing competition from percutaneous interventions and other novel methods of non-surgical coronary revascularization, coronary artery bypass grafting (CABG) remains one of the most definitive and durable treatments for severe coronary artery disease. The CABG procedure itself has undergone innovation and evolution in the last few years. This article reviews a brief historical and current perspective of the procedure, modern variations including off-pump, Minimally Invasive Direct Coronary Artery Bypass (MIDCAB) and robotic-assisted CABG. In future, a multifaceted approach is required to sustain coronary revascularization between the surgeon and the interventional cardiologist.

Keywords: CABG, coronary artery disease, surgical systems

INTRODUCTION

Coronary artery bypass surgery (CABG) and percutaneous coronary intervention (PCI) are based on the principle that myocardial ischemia related to coronary artery obstructions can be corrected resulting in relief of the underlying ischemia. CABG is the most common surgical procedure performed on the heart.

Coronary revascularization is built on the foundation of three centuries of research. Stephen Hales performed the first cardiac catheterization in 1711. In 1910, Alexis Carrel described the principles of CABG for which he was awarded the Nobel Prize in Medicine in 1912. In 1953, Dr. John Gibbon performed the first heart-lung bypass and in 1968 Dr. Rene Favaloro first used a saphenous vein graft for coronary artery disease. The internal mammary artery was used for the first time in 1951 when Vineberg (Figure 1) reported an experimental technique to revascularize the cardiac muscle using the internal mammary artery (IMA) directly implanted in the myocardium.[1]

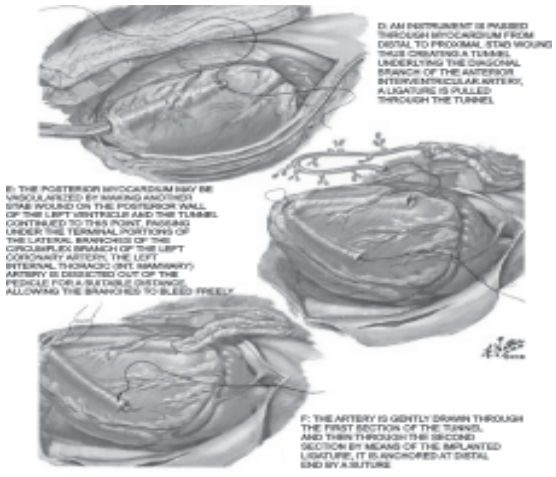


Figure 1: *Veinberg operation done for cardiac ischaemia*

The first CABG in humans using IMA was done by Longmire in 1958.[2] The modern techniques have evolved from the works of Drs. Werner Forssmann, Andre Cournard and Dickinson Richards.

Demikhov performed the first successful coronary artery bypass grafting (CABG) operation in an experiment. Kolesov performed the first successful clinical CABG using suture technique. Furthermore, between February 25, 1964, and May 9, 1967, the Department of Surgery directed by Kolesov was the only center in the world where CABG was systematically performed. Rene Favaloro performed a successful CABG on May 9, 1967, and was the first America's to report this in 1968. Rene Favaloro and his colleagues from the Cleveland Clinic are fairly regarded to be the first in Americans to perform and report successful CABG. It is absolutely true that CABG was revolutionized by the Cleveland Clinic team. In 1968, they performed 171 operations. It was the Cleveland Clinic team that convinced the world. However, the popular belief that the world's first successful CABG was performed and reported by the Cleveland Clinic team is not correct.

The advent of cardio-pulmonary bypass (CPB) machine permitted cardiac surgeons to perform complex operations on the defective heart (Figure 2a,2b). With the refinement of perfusion science, the impact of the pump run on the postoperative recovery of a patient has been lessened considerably since the pioneering days. The drive to reduce the well documented, if somewhat historical, adverse effects of CPB has resulted in attempts to perform coronary artery grafting off-bypass (OPCAB). Kolessov reported the first

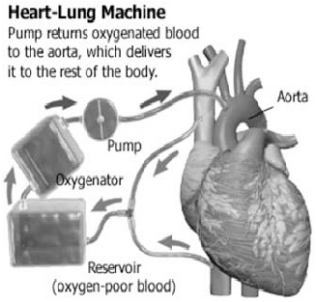


Figure 2a : *Heart lung machine*

Figure 2b : *Mechanics of heart lung machine*

experience with coronary artery surgery on the beating heart in 1967, but the technique was soon abandoned.[3] However OPCAB experienced a revival beginning in the early 1990s with the work of Benetti with the benefits of reduced neurocognitive dysfunction.[4] The current review discusses the present status of CABG, elaborating on the use of various grafts and special patient population. It also highlights the future of CABG.

PRESENT STANDARD OF CARE IN CABG

With a strong foundation, and advancement in technology now CABG has become a standard treatment for severe coronary artery disease, with mortality of only 0.5 to 1.5 % in a normal case (Table 1).

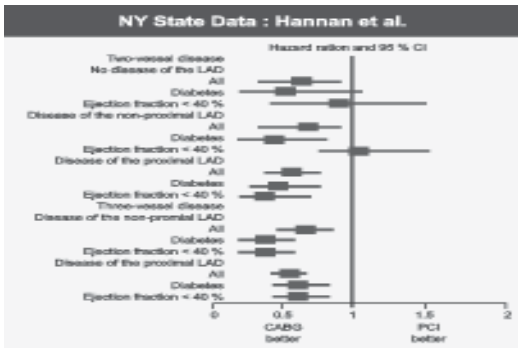
It is first option therapy in following cases of coronary artery diseases.

- Severe triple vessel disease with diabetes
- Left main artery stenosis
- LAD artery ostial stenosis
- Severe triple vessel disease with severe LV dysfunction
- Coronary artery disease with associated procedures like valve repair, replacement, SVR, etc.
- Patients with instent restenosis
- In Indian context, for long term advantage also in double vessel disease, if financial constraints do not exist.

Timing of CABG for Acute Myocardial Infarction (AMI)

a. Patients more than 65 years-After 30 days of AMI
b. Patients less than 65 years-After 7 days of AMI
c. Patients with previous CABG- After 1 year of AMI

Table 1 : *Recent data has shown the advantage of CABG on PCI in triple vessel disease*



PRESENT STATUS OF CABG

a) OPCAB (Beating Heart Surgery/Off Pump Surgery/ MICAS)

Beating heart surgery has been a revolution in the treatment of CAD (Figure 3). It is a preferred technique for old age, renal failure, obese patient, COPD patients, associated carotid artery disease, liver dysfunction etc. In this technique, heart is kept beating and anastomosis on epicardial coronary arteries, is done using heart stabilizing systems like OCTUPUS, GAIDUANT, etc. As there is no need of arresting the heart and using heart lung machine, this has reduced morbidity of the patient and improved recovery of the patient. In the hands of experienced cardiac surgeon, the procedure is done easily with excellent long term results. Off pump requires specific technique and training for complete revascularization.

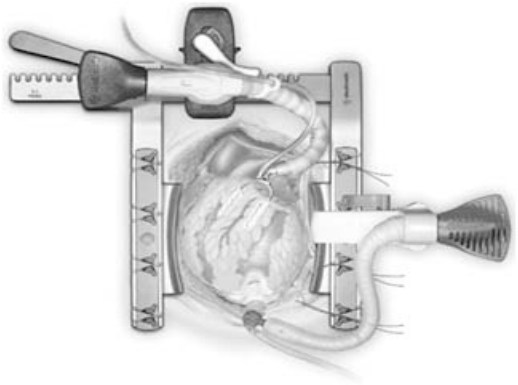


Figure 3 : *Beating heart surgery*

b) Off Pump CABG with Minimally Invasive Conduit Harvesting (OPCRES)

This procedure makes CABG less invasive from head to toe (Figure 4a, 4b, 4c). Here, beating heart CABG is performed along with harvesting of radial artery and saphenous vein through minimally invasive technique thereby reducing the wound infection and associated morbidity.

Figure 4a : *Minimally invasive radial artery harvesting*

Figure 4b : *Traditionally harvested saphenous vein with long scar*

Figure 4c : *Minimally invasive saphenous vein harvesting (current scar)*

c) Total Arterial Bypass (Figure 5)

During CABG arterial grafts are always preferred over venous grafts (Figure 6), for the simple reason that-

- The grafted vessel has to carry arterial blood and not the venous blood. Saphenous veins are tuned to carry venous blood at low pressure.
- The mean coronary arterial pressure is around 40mmHg and this will damage the saphenous venous endothelium more quickly.
- The reocculsion rate at 10 years for venous grafts can reach 60%.
- Long term results of arterial grafts are definitely better than the venous grafts.

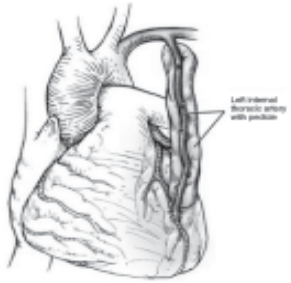


Figure 5 : *Schematic presentation of LIMA to LAD graft*

Figure 6 : *Graft patency after CABG*

LIMA AS A GRAFT

Internal mammary artery (IMA) is the gold standard graft and specifically the pedicle IMA practically rarely gets closed. Free IMA and free radial artery have a patency rate of 80-85% at the end of 15 years. Venous graft patency rate at the end of 10 years is 50%.

Left Internal Mammary Artery (LIMA) is the most commonly used arterial graft. (Figure 7) This is usually anastamosed with LAD. The lumen of LAD & LIMA are more or less equal and they match well in character also. Finally, the most important feature of LIMA is that it is a live graft. LIMA's proximal origin from subclavian is left intact, so LIMA acts as a live vessel with it's vasa vasorum intact, with no interruption in the secretion of the endothlium derived relaxing factor (EDRF-Nitric oxide). This makes LIMA an excellent graft, self protected against reocclusion. *One may call it a drug eluting graft!* LIMA patency rate at 10 years is nearly 90 %, besides depending on many factors , like diabetes, age, gender, surgical technique. Sequential LIMA grafts, free LIMA grafts (which loses the advantage of being a live graft) have relatively lower patency rates. LIMA and RIMA Y graft is the best option for young non diabetic non obese patient for long term survival.

Other arteries used in CABG *(Figure 7)*

Other arteries that could be used are radial artery, right internal mammary artery, and gastro epiploic artery. The patency rates of all these arteries are more or less similar to free LIMA.

Only problem with the arterial grafts is, they are very dynamic and hence can go into spasm in undesirable conditions. In unstable patient, severe LV dysfunction, old age, arrhythmia prone, coronary lesion less than 70-80%, and on the right coronary artery, venous grafts are better and advisable as they are passive conduits and they donot go into spasm. Use of saphenous venous graft in this situation is advisable

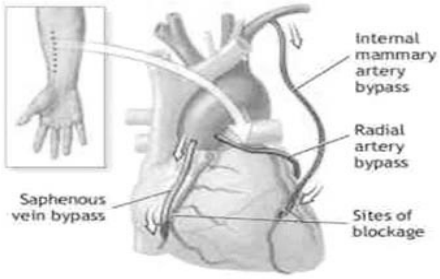


Figure 7 : *Various arterial grafts*

CABG IN SPECIAL CONDITIONS

A) Diabetics with CAD

CABG is the best known form of intervention for diabetics with mutivessel coronary artery disease. Long term results get better with:

1) Early detection and surgery
2) Aggressive control of diabetics
3) Aggressive use of statins
4) Use of arterial grafts

Effect of incomplete revascularization in diabetics may be more severe in view of:

- More diffuse and distal CAD
- Poor collateral development
- Microcirculatory dysfunction in diabetic patients

B) CABG in LV Dysfunction

Ischemic dilated cardiomyopathy occurs due to massive myocardial infarction (Figure 8) leading to scar formation and

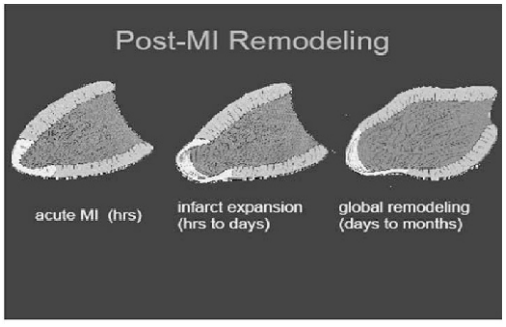


Figure 8 : *Post MI remodeling of heart and aneurysm formation*

remodeling of heart with aneurysm formation and mitral valve regurgitation. CABG in LV Dysfunction is indicated in-

1) Significant (50%) left main coronary artery stenosis.
2) Significant (greater than or equal to 70%) stenosis of the proximal LAD and proximal LCX.
3) 3-vessel disease

Results of CABG in LV Dysfunction

LVEF greater than 50% was associated with 1.9% mortality rate whereas less than 20% LVEF was associated with 6.7% mortality rate. The 5 year Survival rate is shown in table 2.

Table 2 : *5 year - survival rate*

LVEF	0.31~0.35	0.26~0.30	<0.25
5 year-survival rate with CABG	73%	70%	62%
5 year-survival rate with medical treatment	60%	50%	43%

CABG will help in poor LV patients by improvement in the EF by reperfusion of the hibernating myocardium, reversing the remodelling process, limiting the permanent myocyte loss by repeat infarcts and ameliorating proarrhythmic tendencies and sudden cardiac death.

CABG in LV Dysfunction

- Yale series has shown good improvement in the EF and symptomatic status, with mortality of 2.8%, in patients with no demonstrable evidence of ischemia.
- Patient with low EF with severe proximal triple vessel disease and adequate targets, should be subjected to surgery
- No EF is categorically too low
- No LV is categorically too big
- Objectively demonstrable ischemia is not essential
- Only RV dysfunction subset and redo cases should be taken up very cautiously.

However, CABG alone will not suffice to treat this patient in some subsets who have LV aneurysm and or mitral regurgitation, as they may still remain symptomatic in the form of dyspnoea and heart failure symptoms post operatively. This patient requires CABG + surgical ventricular restoration (LV aneurysm repair) + mitral valve repair.

Surgical Ventricular Restoration (SVR) is a surgery where dilated and remodeled left ventricle is given normal shape, size and orientation of the myocardium. It is basically plastic surgery of the heart. This removes the noncontractile scarred myocardium, restoring the only contracting myocardium again.

SVR (Table 3 and 4) reduces the myocardial wall stress and hence-

- Reduces myocardial oxygen consumption
- Improves myocardial efficiency
- Improves myocyte orientation and slippage
- Alters the neurohormonal milieu

Table 3 : *Results following SVR*

	Before	After	P
EF %	34 ± 8.6	40.5 ± 9.5	.001
LVEDV ml	161 ± 58.6	121 ± 34.7	.001
LVESV ml	108 ± 45.2	79 ± 34	.001
MI > 2+ %	20	4	.001
Asynergy Score	15.8 ± 2	10 ± 4	.001
LVEDP mm	19 ± 7	15 ± 6	.04
Wall Stress	86.8 ± 31	65 ± 20	.001

Table 4 : *Pre and post operative Quality of Life*

PRE-AND POST-OPERATIVE QUALITY OF LIFE

	PRE-OP	POST-OP
Medications*		
Beta Blockers	✓	✓
Ace Inhibitors	✓	✓
Diuretics	✓	✓
Anti-coagulants	✓	✓
Statins	✓	✓
Coronary artery dilator - nitrate	✓	✓
Anti-arrhythmia	✓	✓
Potassium	✓	✓
Hospitalization Admissions	6 in 3 yrs.	0
Change in Symptoms	Inability of perform daily activities, shortness of breath inability to sleep laying down, servere and constant chest pain	Patient now able to walk, climb staris, perform more daily activities for extended periods without dyspnea on exertion or dizziness, only rare occasional chest pain

*In most cases, dosages were lowered post-operatively.

Recently published reports of STITCH trial have shown the morbidity benefit and symptomatic improvement and reduced repeat hospitalization with exceptable mortality. These patients are high risk patients and they stand a chance of sudden cardiac death due ventricular arrythmias in follow up also. Ideally this patient should have AICD.

C) Redo CABG

In the present era the number of reoperative cases is on a rise. With the present day technology redo procedures have became safe however re sternotomy is a high risk of procedure, needs expertise and patience in surgery, and use of specialized instrumentations.

- Risk increases with the presence of patent LIMA or other graft flowing
- Haemostasis is exhaustive
- Heart is densely adherent and hence making difficult
- Bleeding and its complication.

D) CABG in High Risk Patients

CABG in high risk patients with multiple comorbid conditions depicts about 5-15% mortality worldwide. Diabetes and hypertension are not considered as comorbid conditions. Other comorbid conditions are obesity, gross obesity, renal failure and post renal transplant, old age like octogenarians and

septugenerians, COPD, carotid artery disease and stroke, ventricular dysfunction, LV aneurysm, functional severe MR and biventricular failure.

This CABG in high risk group is possible now days because of following reasons:

a) Improvement in CABG technique like Beating Heart CABG (OPCAB, OTCAB), improvement in the CPB technology, improvement in heart protection during CABG, better invasive monitoring technology, minimally invasive CABG and advancement in heart failure surgery.

b) Better perioperative management with better cardiac drugs, evaluation of the patient in totality and availability of Trans Esophageal Echo and other imaging modalities.

c) Good post operative care with fast tracking.

d) Cardiac surgery has became a team work with involvement of Anasthetist- Intensivist, Perfusionist , Nephrologist, Critical care specialist, Neurologist, Pulmonologists , Physiotherapist, Hematologists, etc.

Table 5 : *Complications of coronary artery bypass graft surgery*

Complication	Percent (%)
Operative mortality	2-4
Peri-operative myocardial infarction	2-4
Tachy-arrhythmias	40
Brady-arrhythmias	1-4
Bleeding	4-6
Neurological complications	2-4
Infection	1
Acute renal failure	30
Pleural effusion	90
Phrenic nerve damage	1
Low cardiac output	Negligible
Intercostal nerve damage	Negligible
Aortic dissection	Negligible
Thrombocytopenia	Negligible
Early readmission	Negligible

FUTURE OF CABG

In the past decade, the face of Surgical Coronary Revascularization has been changed by a number of advances, most notably, the development of minimally invasive techniques, including minimally invasive direct coronary artery bypass (MIDCAB) and totally endoscopic, robot-assisted coronary artery bypass grafting (TECAB) (Figure 9).

Figure 9 : *Future of CABG*

a) Hybrid Revascularization

This is the upcoming concept that is prevalent in European countries where through small left thoracotomy LIMA to LAD graft is done on beating heart and in the same sitting angioplasty is done for right coronary artery and left circumflex artery . Hence a patient of triple vessel disease is treated and can be sent home in 2-3 days and can resume normal routine work in 15-20 days. Still long term results are awaited.

b) Robotic Surgical Systems and Totally Endoscopic Robot Assisted CABG

Robotic surgical systems have permitted the manipulation of surgical instruments through limited thoracic incisions. The Da Vinci surgical system consists of two primary components: the surgeon's viewing and control console and the surgical arm unit that positions and maneuvers detachable surgical endo wrist instruments. Shortly after its clinical introduction in 1998, the Da Vinci system was first used for endoscopic internal mammary artery (IMA) harvesting. Success with endoscopic IMA harvest paved the way for the development of a TECAB operation, while initially restricted to single-vessel, LIMA-LAD revascularization, cases of alternative vessel and multiple bypasses have now been reported. A number of technical issues related to TECAB have prevented its widespread acceptance and deployment. The learning curve is significant, which has translated into long operating room and CPB times. In addition, conversion rates to conventional sternotomy remain high and are often related to difficulty with remote-access perfusion or inadequate intra-thoracic working space.

c) Minimally Invasive Direct Coronary Artery Bypass (MIDCAB)

The LIMA is harvested either under direct vision or with robotic assistance and a small anterior thoracotomy is made in the fourth intercostals space (ICS) and an OPCAB, hand sewn LIMA-LAD anastomosis is performed under direct vision. This eliminates the need for femoral cannulation and cardiopulmonary bypass, thus reducing procedural times as compared to TECAB. (Figure 10)

Figure 10 : *Minimally invasive CABG for single vessel disease*

d) Anastomotic Devices

Another area of technological innovation has been the development of anastomotic devices for both the proximal and distal anastamosis. A few such systems are currently available which include the St. Jude Symmetry Aortic Connector and the Cardica C-Por, PAS-Port Anastomotic Systems with the Converge Anastomotic Coupler.

CONCLUSION

Ideal coronary revascularization should always be complete revascularization irrespective of surgery or PCI. Complete revascularization is not a subject of competition between these two treatment strategies; rather an important factor in the decision-making process. With increased use of arterial grafts, increased experience with drug-eluting stents and other new devices in interventional cardiology, coupled with the widespread adoption of better secondary-prevention measures such as use of statins, the results that have been described previously are important but may not be as pertinent today. Minimally invasive and robotic CABG is paving the way for near out-patient coronary surgery. The future is likely to see a multifaceted approach to complete and sustained coronary revascularization with increasing cooperation between the surgeon and the interventional cardiologist.

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