Review Article

MYOCARDIAL REVASCULARIZATION

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ABSTRACT

Atherosclerotic coronary artery disease causes more morbidity, mortality and loss of economic capacity than any other group of diseases. The modalities of revascularization of the myocardium have undergone rapid advances with emphasis shifting alternately from medical methods to surgical. Lately interventional cardiology armed with laser technology stands at par with coronary artery bypass grafts.

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KEY WORDS : Coronary artery disease; Coronary artery bypass grafts; Angioplasty.

Introduction

Revascularizing the myocardium jeopardised by atherosclerotic coronary artery disease [1] is an area where cardiac medicine and cardiac surgery are making fascinating advances every year. The scene is changing so rapidly that everytime the subject is reviewed, one is bound to come across something new. And, I am convinced, the best is yet to come. It is interesting to note that till the early seventies, the disease was the domain of physicians when it passed into the hands of cardiac surgeons with coronary artery bypass grafts (CABG). In the eighties physicians made a come back with percutaneous transluminal coronary angioplasty (PTCA). In the nineties, there are advances taking place in the interventional modes of therapy and we have the new breed of the interventional cardiologists sharing the burden with the surgeons. Perhaps the future will be in the hands of the molecular biologist who will find the ultimate answer to the problem of atherosclerosis.

In the old textbooks, it was said that "a man is as old as his arteries" [2]. In the light of present day statistics, one may have to conclude that our arteries may be aging faster than us as the disease is noticed in younger and younger individuals. As for prevalence,

atherosclerotic coronary artery disease is the commonest cause of death in the Western world with one American dying of this disease every minute [3]. As mentioned earlier, all efforts at revascularization, surgical and medical, are mere palliations and do not correct or reverse the basic pathology of atherosclerosis.

The earliest attempt at revascularization was made by Vineberg who in 1951 reported direct implantation of the internal mammary artery (IMA) into the myocardium with some limited success [4]. The efforts of Favalore and Effler (1969) to establish CABG with reversed saphenous vein [5] and those of Green (1972) to achieve the same with IMA were technically made feasible by the early pioneering work of John Gibbon (1953) who, by inventing the heart-lung machine, made open heart surgery a reality. Since the mid-seventies, there has been a relentless rise in the number of CABG operations all over the world. The last 4 years, have for the first time shown a downward trend in the total number of CABGs, especially in the USA, where PTCA has become more common.

CABG

Indications : Fortunately for the surgeon, the blocks in the coronary arteries occur in

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the proximal segments of the epicardial vessels with near normal arteries beyond the obstruction. This makes CABG technically feasible. The intra-myocardial vessels are usually free from disease. At present, indications for CABG in chronic ischaemic heart disease (IHD) are :

1. Coronary artery disease (CAD) with angina on moderate exertion despite adequate medical treatment.
2. Left main coronary artery (LMCA) disease.
3. Proximal left anterior descending artery (LAD) lesion.
4. Two- or three-vessel disease with impaired left ventricular (LV) function (as estimated by ejection fraction or radionuclide studies).
5. Adjuvant to other cardiac procedure e.g. valvular heart disease with co-existing CAD.
6. Acute myocardial infarction with unrelieved pain or haemodynamic deterioration.
7. Unstable angina.
8. PTCA failure.
9. Certain post-infarct complications like mitral regurgitation, ventricular septal defect and LV aneurysm.

Contra-Indications : CABG is contraindicated when IHD has reached the stage of ischaemic cardiomyopathy with congestive cardiac failure and pulmonary hypertension. In such patients, cardiac transplantation is the only answer.

Operative technique : The basic aim of the operation is complete myocardial revascularization by bypassing all vessels 1.5 mm in diameter with > 50% stenosis. The steps of the operation are fairly standardised the world over. They consist of median sternotomy and institution of cardiopulmonary bypass (CPB). Simultaneously, an adequate length of long saphenous vein is harvested. If IMA is to be used, this is harvested before instituting CPB. Systemic hypothermia and

cold cardioplegia are used at the time of anastomosing the conduits to the coronary arteries [9]. Some surgeons prefer intermittent fibrillary arrest to cardioplegia [10]. Proximal anastomoses are usually performed on a beating heart with a side clamp. At the end of the procedure, the heart is weaned off CPB, heparin reversed, haemostasis ensured and the chest is closed with drains. Barring a few modifications, the basic technique has remained unchanged in this operation. However, there have been spectacular advances in areas like myocardial protection, prevention of reperfusion injury, choice of conduits (including the concept of total arterial revascularization), the introduction of aprotinin, and oxygen free radical (OFR) scavengers.

I. Myocardial protection : During operation, administration of cold cardioplegic solution at 4°C causing hyperkalaemic arrest, combined with local and systemic cooling has been a valuable adjuvant to all types of open heart surgery including CABG [9]. The basis of this technique is the reduction of metabolic oxygen demand by the myocardium to 50% of normal thus minimising the risk of ischaemic damage [12]. Further refinements in this technique include :

- (a) Retrograde cardioplegia (through coronary sinus) [13].
- (b) Cardioplegia through the grafts to cover areas distal of the obstruction.
- (c) Use of blood cardioplegia as against crystalloid cardioplegia. Blood is a superior vehicle as it can be oxygenated, it acts as a buffer and is a free-radical scavenger [14].
- (d) Use of warm blood at the time of induction of cardioplegia to rid the myocardium of noxious metabolites and reduce the hypothermic injury to the myocardium [15].

II. Reperfusion injury : This has recently attracted a lot of attention after it was recognised that most of the ischaemic damage to the myocardium in fact occurred during reperfusion. Influx of Ca^{++} into mitochondria [16], activation of the complement cascade, release

of oxygen-derived free radicals [17] and the resultant damage to the cell membrane may cause a spectrum of dysfunction from mere "stunning" [30] to the ominous "stone heart". To minimise the chances of such reperfusion injury, pre-operative enhancement of myocardial stores with glutamate and aspartate or with glucose insulin potassium (GIK) solution have been tried [15]. More importantly, the last dose of cardioplegia before release of the cross clamp is carefully constituted with blood at 37°C, physiological pH, low Ca^{++} content and supplemented with glutamate and aspartate. The perfusion is done for the first few minutes at a low pressure of 20 to 30 mm of Hg followed by a period of 50 to 75 mm Hg. Continuous root perfusion at normothermia is continued till ECG returns to normal and only then the cross-clamp is removed. This "hot-shot" and root perfusion routine has improved post-bypass myocardial function to a great extent [15].

III. *Choice of conduits* : It has been proved beyond doubt that IMA is superior to saphenous vein graft (SVG) as a conduit and has a better short and long term patency [18]. Ninety percent of IMA grafts are patent at 10 years as compared to only 55% of SVG grafts. Various factors responsible for this are :

- (a) IMA is usually dissected with its pedicle. This preserves its nutrition and endothelium derived relaxation factor (EDRF) and prostacyclin.
- (b) IMA in its natural position enjoys relative immunity from atherosclerosis.
- (c) Blood flow velocity is better than SVG.
- (d) Volume of flow is better (100 ml/min of SVG 70 ml/min).
- (e) Its calibre more closely approximates the coronary artery.
- (f) Flow is less turbulent than SVG (no valves or varicosities).
- (g) Wall damage due to flow, seen in SVG, is minimal
- (h) Vasomotor activity and other intrinsic vascular mechanisms are preserved.

Because of these factors, greater and

greater use of IMA is being made. Bilateral IMA is often used. IMA may be used as a sequential [22], Y- or free-graft too [23]. Right gastro-epiploic artery has also been used for vessels on the diaphragmatic surface of the heart [24]. Some recent reports mention cases where only arterial conduits have been used [25]. Whatever may be the long term outcome of these, there is no doubt that in younger patients, in diabetics, and in patients with a proximal aorta of poor quality, IMA graft is ideal. As veins go, where the long saphenous is not available or suitable, the short saphenous and cephalic veins have been used [27]. Radial artery free-graft and poly tetra fluoro ethylene (PTFE) grafts have also been used.

IV. *Aprotinine haemostasis* : Haemostasis in CABG is often a problem not only because of the damage to the haemostatic mechanism by CPB but also because of pre-existing platelet dysfunction due to pre-operative aspirin therapy. Discontinuing aspirin for atleast a week restores platelet function and reduces bleeding.

CPB also affects platelet function adversely in many other ways besides reducing their available number. Aprotinin (Trasylol) derived from bovine lung, used before and during CPB, has resulted in marked reduction of blood loss and blood requirement even in prolonged open heart procedures, probably though platelet protection and other mechanisms [28].

V. *Oxygen free radial scavengers* : OFR have been recognised as the culprits in ischaemic myocardial damage [29]. Oral administration of OFR scavengers, like allopurinol, in the immediate pre-operative period have been shown to improve post-operative myocardial function [30].

VI. *CABG without CPB* : Dr. Buffolo of Brazil has introduced the concept of performing CABG in selected poor risk cases on the beating heart, without CPB [32]. He has reported excellent results. In India, Dr Nasser at Srichitra Institute Trivandrum has performed this operation a number of times.

VII. *Transmyocardial revascularisation* :

Mehmood Mirhoseini has pioneered this procedure with the help of a high power CO₂ laser called heart laser. Reptilian hearts have direct channels from the LV cavity leading into the myocardium. Similar channels occur in the human embryo and may persist in some cases of hypoplastic left heart syndrome. Based on this principle, 35 to 50 millisecond duration pulses of laser are delivered to the left ventricle to create 1 mm diameter channels, 15 to 30 in number, from epicardium to endocardium. This is done on a beating heart through a left thoracotomy. The laser openings on epicardium seal spontaneously but the rest of the channels remain patent. The procedure is under trial and long term results are awaited [33].

Results of CABG

Mortality due to CABG operations in the West has gone up from below 2% to above 3% in the last few years because of selection of older patients with more extensive disease and poorer LV function [34]. Peri-operative infarct rate is around 2.5%. Post-operative cerebrovascular events occur in 2% cases.

Long term results based on coronary artery surgery study (CASS) [35,36] are depicted in Table 1.

TABLE 1
Long term results of CABG (based on CASS)

Period	% Survival	% free from angina	% free from MI	% for re-operation
1 year	95	95	—	—
5 years	90	83	95	2.7
10 years	70	60	—	11.4
15 years	60	—	64	20.0

Re-operation is more difficult due to problems of dissection, injury to heart, damage of functioning grafts and difficulties in myocardial protection - hence the increased mortality of upto 7%.

Prognostic indices in CABG are becoming more and more important as patients, referring doctors, and health administrators - for

their own reasons - would like to have an objective assessment of the risk. Higgins *et al* (1992) have evolved a scoring system [37] as depicted in Table 2.

TABLE 3

Factor	Score
Emergency operations	6
Serum creatinine > 1.68 mg/dL	4
Severe LV impairment	3
Re-operation	3
Mitral regurgitation	3
Age > 74 years	2
Prior vascular surgery	2
COPD	2
Diabetes	1
Cerebrovascular disease	1

Mortality and morbidity rises rapidly beyond the score of 5 (Fig 1).

PTCA

No account of revascularisation will be complete without a discussion of PTCA. In the present management protocol of IHD, PTCA is placed ahead of CABG and is finding wider and wider application with results improving all the time. Started initially by Gruntzig in 1974, the procedure is gathering momentum steadily. In 1988 nearly 30% cases of IHD were treated by PTCA. The present indications for PTCA are [38] :

Fig. 1 : Mortality and morbidity pattern as per Higgins's score.

1. Angina on moderate effort despite medical therapy.
2. Post-myocardial infarction angina.
3. Positive stress test.

The relative contraindications are :

1. High risk anatomy (eg. LMCA stenosis).
2. Diffuse and extensive disease.
3. More than 50% stenosis.
4. Severe LV dysfunction (EF < 25%)
5. Absence of on-site surgical backup.

Results of multivessel PTCA

Multivessel PTCA carries with it a mortality risk of 0.4-2.8%. In about 2.5% cases PTCA 'crashes' due to dissection or occlusion of the vessel and requires emergency CABG. The re-stenosis rate is still fairly high at 25% in 3 months and 30% in 6 months.

The newer developments in PTCA include laser angioplasty, coronary atherectomy (incl Rotablator), stents and finally PTCA with percutaneous cardio pulmonary support (PCPS).

I. *Laser angioplasty* [39] : Atherosclerotic plaque can be vaporised to CO₂ and H₂O with pulsed lasers. Still in the experimental stage, efforts are on to modify the laser delivery system so as to minimise the risk of thermal injury and vessel - wall perforation.

II. *Directional atherectomy* [40] with side-cutting or end-cutting catheters is considered superior to balloon angioplasty as the atherosclerotic plaque is excised in this system.

III. *Rotablator* [41] is a further refinement of this system. Here fine diamond chips are mounted on a metal burr revolving at 100,000 rpm, pulverising the atheroma into fragments of 25 microns. The fragments thus washed down the distal coronary circulation are well-tolerated. Rotablation is usually combined with PTCA.

IV *Coronary stents* [42,43] : Self-expanding or balloon expandable stents are placed in a segment of coronary artery opened by PTCA to support the treated vessel in the open position and prevent re-occlusion. Anti-coagu-

lation, with heparin for 2 weeks and later coumarin for 8 weeks, is required to prevent thrombosis.

V. *PTCA with PCPS* : Applications of PTCA were considered risky in cases with severe left ventricular dysfunction or those with ongoing ischaemia because of danger of circulatory collapse during the procedure. To enable PTCA in such cases, a system of percutaneous CPB support has been introduced [44]. Thus PTCA with PCPS is finding application not only in such cases but also in high risk CABG cases with non-cardiac contra-indications to surgery. It is technically simple with catheters of 18-20 F being introduced through the femoral artery and vein to establish CPB with a membrane oxygenator and a simple pump. The PCPS is usually required for much shorter periods than conventional CPB. Early results in 16 patients with poor LV function (ejection fraction 25 to 39%) done at GB Pant Hospital, New Delhi are very encouraging with no mortality [46].

In view of all these developments, how does CABG compare with PTCA? A very difficult question to answer. The last word (as of date) has been said by the Emory angioplasty vs surgery trial, (EAST) [47]. In this single-centre, prospective, National Institute of Heart-sponsored trial started in 1987, it has been shown that multivessel CAD, randomised to CABG or PTCA, showed no difference in mortality or combined clinical end-point at 3 years or in cost of therapy. However, the CABG group had more complete revascularisation and the PTCA group required a repeat procedure more often. The same EAST study had earlier (1990) shown the following observations [34] :

TABLE 4
Changing treatment pattern in EAST study

	1981	1988
No of patients	1704	1717
Treated medically %	51	41
Treated with CABG %	44	29
Treated with PTCA %	5	30

TABLE 5

Changing treatment and patient selection pattern observed in EAST study (figures in %)

	CABG '81	CABG '88	PTCA '81	PTCA '88
Age 65 years	28	45	15	35
LVEF 50%	24	30	10	15
Single vessel	18	4	11	46
Triple vessel	65	56	1	30
Overall mortality	2.1	3.8	—	0.8

PTCA in LMCA

Encouraged by these trends, O'Keefe et al attempted PTCA in LMCA stenosis in a number of elective and emergency cases [48]. Undoubtedly the most lethal form of CAD, LMCA stenosis carries a high mortality of about 50% with medical therapy and has been regarded as an undisputed indication for surgery. O'Keefe's results have not been very encouraging as it showed a high mortality and high re-occlusion rate.

A passing glimpse at the acute phase of the disease show that here too there have been dramatic improvements. Early thrombolytic therapy by the IV route (intra-coronary if detected during cardiac catheterisation) [49], with streptokinase [50], APSAC [51], (anisoylated plasminogen streptokinase activator complex) or recombinant tissue type thromboplastin activator (RTPA) improves survival if instituted within 4 to 6 hours of onset.

Complications are local or intracranial haemorrhage (0.5%) and allergy. There are a number of contra-indications like proven peptic ulcer, bleeding diathesis, recent trauma, major surgery or head injury (within 6 weeks), stroke, pregnancy, previous streptokinase therapy, and liver dysfunction with portal hypertension.

Angioplasty

Emergency PTCA in evolving acute MI either as a primary procedure or following failed thrombolysis has been tried with high success rates [53].

Surgery in acute myocardial infarction [54], has been carried out in selected centres with a mortality of around 2% and good long term results. Though acceptable in an emergency situation where the necessary infra structure is available, these are controversial modalities and no definite consensus has emerged on this issue except that in coronary occlusion occurring during cardiac cath or PTCA, emergency CABG is inescapable [55].

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