

Direct myocardial revascularisation: experience with 9364 operations¹

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Cooley, D A, Wukasch, D C, Bruno, F, Reul, G J Jun, Sandiford, F M, Zillgitt, S L, and Hall, R J (1978). *Thorax*, 33, 411-417. **Direct myocardial revascularisation: experience with 9364 operations.** Between July 1968 and December 1976, 9364 consecutive patients with coronary insufficiency underwent direct myocardial revascularisation using aortocoronary bypass (ACB). Among these patients 8017 had ACB alone, and the remaining 1347 had ACB in addition to correction of other cardiac and vascular lesions. In the series of patients having ACB alone the hospital (early) mortality was 3.9%, but for 2383 surgical patients in 1976 this figure was 2.2%. Operative mortality was higher for women (6.85%) than for men (3.5%), but late survival was about the same for both sexes.

Among surviving patients 88% were improved or symptom-free after undergoing ACB. According to our data, at the end of eight years 80% of the patients will be survivors. These results, when compared with other series of patients treated medically, indicate the superiority of surgical treatment both in terms of symptomatic relief and also in increased life expectancy.

Coronary atherosclerosis and myocardial ischaemia are the leading causes of death in Western societies. Disability from angina pectoris, repeated myocardial infarction, cardiac dysrhythmia, and other symptoms and complications make this disease a heavy burden on modern man in his newly acquired lifestyle. Until the development of heart surgery and the introduction of diagnostic techniques including cineangiography, stress electrocardiography, echocardiography, and myocardial scanning the treatment of arteriosclerotic heart disease was confined to medical measures that were usually only partially effective. While direct reconstruction of congenital coronary artery anomalies was first used in our hospital 14 years ago, (Hallman *et al*, 1965; Cooley *et al*, 1966) the more recent demonstration that direct revascularisation of the ischaemic myocardium due to acquired coronary lesions could be accomplished by using autologous saphenous vein grafts has opened an alternative and more optimistic prospect for patients facing disability, infirmity, and

premature death. This report reviews the results of our experience with myocardial revascularisation during an eight-year period.

Indications for coronary artery bypass

The primary indication for myocardial revascularisation was disabling angina pectoris, although consideration was also given to patients with cardiac failure resulting from ventricular aneurysm, ventricular septal perforation, papillary muscle rupture, mitral incompetence, and uncontrolled dysrhythmia. The indications for operation were mostly the presence of angina pectoris, adequate distal coronary arteries, as shown angiographically, viable myocardium distal to the coronary obstruction, and adequate left ventricular function. In our early experience, evidence of a severely compromised left ventricle, as shown by a raised end-diastolic pressure and reduced ejection fraction, was considered to be a contraindication for operation. Poor left ventricular function when accompanied by angina, however, is no longer considered a contraindication to aortocoronary bypass (ACB)

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unless there is angiographic evidence of diffuse disease in the distal coronary arteries, which would preclude a technically satisfactory anastomosis.

The indication for ACB in patients without angina but with symptomatic left ventricular dysfunction remains controversial. Our present impression is that patients with no angina but with symptoms of heart failure secondary to generalised left ventricular dysfunction, as opposed to the treatable complications of myocardial infarction (that is, ventricular aneurysm, ventricular septal defect, or mitral valve incompetence), benefit little from revascularisation.

A second group of patients in whom operation is indicated are asymptomatic patients with ischaemia on treadmill exercise testing but with angiographic demonstration of proximal occlusive lesions in one or more major vessels, particularly the left main coronary artery. Obstruction of blood flow by an arteriosclerotic plaque depends not only on the degree of stenosis produced but also on the length of the pathological process.

We believe that preinfarction angina constitutes another indication for emergency ACB. Patients with uncontrollable ventricular dysrhythmias associated with myocardial ischaemia also may benefit from emergency revascularisation. The lives of patients experiencing uncontrollable cardiogenic shock after acute myocardial infarction can often be saved by inserting an intra-aortic counterpulsation balloon pump, followed by immediate coronary arteriography and emergency revascularisation.

Surgical technique

The methods used in our revascularisation operation have already been described (Cooley and Norman, 1975). Most operations for myocardial revascularisation were performed utilising ischaemic cardiac arrest under temporary cardiopulmonary bypass with haemodilution techniques. When a localised stenosis of the right coronary artery was the only lesion present, the anastomoses were performed without cardiopulmonary bypass. Since January 1977, a cold (5°C) cardioplegic solution consisting of 500 ml 5% dextrose and 0.45% sodium chloride containing potassium chloride 15 mmol, magnesium chloride 7.5 mmol, sodium bicarbonate 2.5 mmol, and calcium chloride 1.0 mmol has been injected into the ascending aorta after distal cross clamping. After cardiopulmonary bypass was begun by the conventional technique, the heart was arrested and cooled topically. Distal anastomoses were performed with 6-0 monofilament polypropylene sutures using a

continuous suture. Proximal anastomoses were performed with 5-0 sutures after the aortic cross clamp had been released and a partial occlusion clamp had been applied permitting cardiopulmonary bypass to continue and restoring coronary perfusion. The surgeon wears optical loupes (four-power magnification) and wears a headlamp with a fiberoptic light to provide precision in anastomosing small arteries.

To decompress the arrested heart and provide a bloodless field for coronary anastomoses, after the ascending aorta was cross-clamped a special aspirating needle was inserted into the ascending aorta. Suction was applied to this needle and the aspirated blood was returned to the extracorporeal circuit. This method prevents air from entering the cardiac chambers and eliminates the risk of air embolism.

The technique of using sequential grafts (one vein anastomosed side-to-side to two or more arteries) has enhanced the surgeon's ability to revascularise all significant lesions (fig 1). This technique is particularly applicable for multiple lesions in adjacent arteries and in patients having a limited length of available vein and a short ascending aorta, which would make placement of five or six proximal anastomoses technically difficult. Endarterectomy is avoided whenever possible but is sometimes necessary in the occluded right coronary artery.

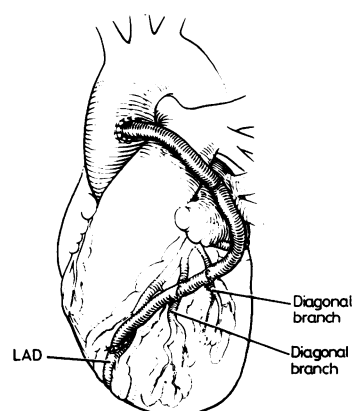


Fig 1 Drawing showing sequential graft from ascending aorta to two diagonal branches (side-to-side) and to left anterior descending coronary artery (end-to-side).

The saphenous vein is carefully removed and all branches are ligated in a manner that does not compromise the main lumen. Distension of the vein is accomplished with heparinised blood since

the vein wall may be injured when a saline solution is used. When the patient has no suitable saphenous veins, the alternative sources of grafts are the veins in the arm. The cephalic veins are more difficult to use because of the lack of smooth muscle layers, but the long-term results have been satisfactory. Internal mammary arteries have seldom been used in this institution and mostly in patients in whom no other vessel was available. Vascular substitutes were used in a few patients who had no vessel available, but the results were not promising. The need for a synthetic or biological tissue substitute for the saphenous vein remains obvious.

Patients and operations

Between July 1968 and December 1976 a consecutive series of 9364 patients with coronary insufficiency had myocardial revascularisation using aortocoronary bypass at the Texas Heart Institute. No patients were excluded from the series because of high risk factors or severity of disease. The series comprised 8017 patients who had ACB alone, and 1347 who had concomitant surgical procedures for the treatment of cardiovascular dysfunction (table 1). In the group with ACB alone 86.7% were men and 13.3% were women (fig 2). Most patients were between 40 and 60 years, and mean age was 54.1 (fig 3, table 2). With increasing experience with myocardial revascularisation the trend has been to bypass every stenotic coronary artery whose structure permitted a satisfactory anastomosis. Thus in the entire series 53.4% underwent three or more bypass grafts (table 3).

Table 1 All cases of coronary bypass surgery (July 1968–December 1976)

Procedure	No of patients
Coronary bypass only	8017
Left ventricular aneurysm resection	536
Aortic valve procedure	326
Mitral valve procedure	209
Other associated procedures	276
Total	9364

Results

EARLY MORTALITY

Early mortality (hospital death) has declined during each year of the study, apparently as a result of increasing technical experience. During 1970, the first year in which significant numbers of operations were performed, early mortality for all patients undergoing ACB alone was 9.7% (17

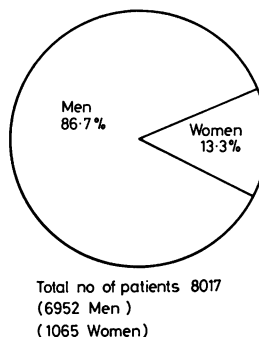


Fig 2 Sex distribution among 8017 patients undergoing ACB (6952 men and 1065 women).

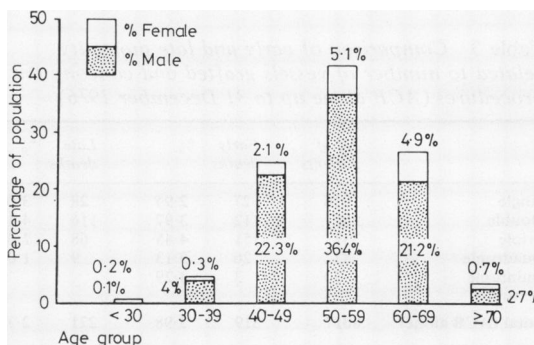


Fig 3 Age distribution among 8017 patients undergoing ACB.

deaths among 175 patients). During 1976, early mortality in patients undergoing ACB alone declined to 2.2% (52 deaths among 2383 patients). Early mortality in the 8017 patients undergoing ACB alone was 3.98% (319 deaths among 8017 patients) (table 3). Early mortality among 1347 patients undergoing associated procedures was 12.4%, and the mortality of the entire series was 5.2% (table 3).

During the period of this study it soon became apparent that women with coronary artery occlusive disease represented a significantly higher risk as shown in table 4 which shows an early mortality rate of 6.85% in women compared with 3.54% in men. The higher early risk in women, however, did not extend into the late follow-up since the late mortality was the same for both sexes (table 4).

The actual number of bypasses performed reflects the extent and severity of the coronary disease and degree of myocardial fibrosis and ventricular dyskinesia. The number of vessels bypassed is therefore related to the early mortality. In both men and women the early mortality was higher when three or more arteries were bypassed.

Table 2 Distribution of patients by number of grafts performed (July 1968–December 1976)

Age group	No of arteries bypassed					Total
	Single	Double	Triple	Quadruple	Quintuple or more	
15–19		1				1
20–24		1				1
25–29	6	5	3	1		15
30–34	21	24	30	11		86
35–39	44	107	90	25		266
40–44	113	268	263	59	5	708
45–49	158	473	494	117	9	1251
50–54	191	639	732	164	20	1746
55–59	169	564	658	175	18	1584
60–64	115	424	590	152	12	1293
65–69	82	244	385	90	9	810
70–74	15	61	107	36	1	220
75–79	2	10	19	2	1	34
80–84			2			2
Total	916	2821	3373	832	75	8017

Table 3 Comparison of early and late mortality related to number of vessels grafted and concomitant procedures (ACB alone up to 31 December 1976)

	No of patients	Early deaths	%	Late deaths	%
Single	916	27	2.95	28	3.06
Double	2821	112	3.97	116	4.11
Triple	3373	151	4.48	68	2.02
Quadruple	832	26	3.13	9	1.08
Quintuple	70	3	4.29		
Sextuple	5				
Total (ACB alone)	8017	319	3.98	221	2.76
With LV aneurysm	536	50	9.33	39	7.28
With aortic procedure	326	61	18.71	22	6.75
With mitral procedure	209	25	11.96	29	13.88
With other	276	31	11.23	10	3.62
Total (ACB with associated procedures)	1347	167	12.40	100	7.42
Total	9364*	486	5.19	321	3.43

*9364 patients had 9446 ACB procedures including second operation.

These patients were a higher risk group because they had more diffuse disease and required more prolonged surgical procedures. Late mortality, however, occurred less often in those patients in whom more complete revascularisation was performed (table 4). This supports our conviction of the importance of bypassing all diseased vessels.

Comparison of early mortality by age of patients at the time of operation showed a greater risk with advanced age (fig 4). An exception to this trend, however, was the higher early mortality in women between 40 and 49 years compared to the older women.

SYMPTOMATIC RESULTS

A long-term assessment of symptoms up to eight years after operation in 4491 patients in whom

Table 4 Comparison of early and late mortality related to sex and number of vessels grafted (ACB alone up to 31 December 1976)

	No of patients	Early deaths	%	Late deaths	%
Men					
Single	696	19	2.73	23	3.30
Double	2426	83	3.42	104	4.29
Triple	3003	121	4.03	60	2.00
Quadruple	756	20	2.65	8	1.06
Quintuple or more	71	3	4.23		
Total	6952	246	3.54	195	2.80
Women					
Single	220	8	3.64	5	2.27
Double	395	29	7.34	12	3.04
Triple	370	30	8.11	8	2.16
Quadruple	76	6	7.89	1	1.32
Quintuple or more	4				
Total	1065	73	6.85	26	2.44
Total (men and women)	8017	319	3.98	221	2.76

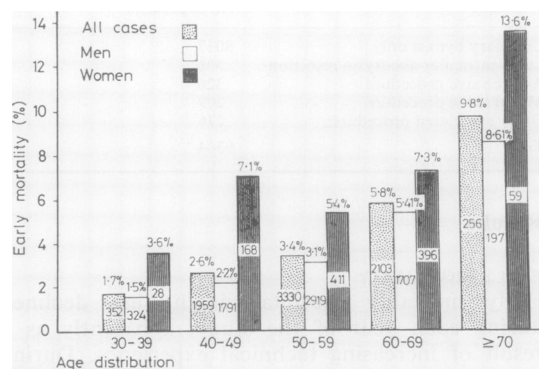


Fig 4 Comparison of early mortality according to age distribution.

Table 5 Symptomatic results in patients surviving operation up to 31 December 1976

	No of patients	Asymptomatic (%)	Improved (%)	Same (%)	Worse (%)	Died (%)
Single	604	30.0	54.1	6.5	4.8	4.6
Double	1798	27.9	56.3	5.7	3.7	6.4
Triple	1751	38.1	53.7	2.6	1.7	3.9
Quadruple	313	43.1	51.1	1.9	1.0	2.9
Quintuple or more	25	56.0	44.0	—	—	—
Total	4491	33.4	54.6	4.3	2.9	4.8

follow-up could be obtained was made. This showed that 88% of patients remained asymptomatic or significantly improved, 4.3% were symptomatically unchanged, 2.9% worse, and 4.8% had died during the period of follow-up (table 5). Significantly, the symptomatic results improved when more complete revascularisation was performed. When four vessels were revascularised, 94.2% of patients remained asymptomatic or significantly improved, and all 25 patients who underwent five or more bypass grafts remained in these categories (table 5).

CAUSES OF DEATH

Among 540 early and late deaths, myocardial failure or infarction and arrhythmias were the most frequent causes (table 6).

Table 6 Causes of death

Cause	Early deaths*	Late deaths†
Myocardial infarction	93	77
Myocardial failure	90	41
Arrhythmias and cardiac arrest	93	28
Stone heart	2	—
Pulmonary embolism	7	1
Cerebrovascular accident	13	21
Renal failure	5	1
Haemorrhagic shock	1	—
Surgical coagulopathy	1	—
Pneumonia	6	6
Pneumothorax	2	—
Hepatic failure	1	—
Diabetic keto-acidosis	1	—
Dissecting ascending aortic aneurysm	1	—
Ruptured abdominal aortic aneurysm	—	2
Acute abdomen	2	1
Haemorrhage from anticoagulants	—	1
Malnutrition	—	1
Car accident	—	1
Suicide	—	4
Murder	—	1
Unknown or undetermined	1	35
Total	319	221

* Among 8017 patients undergoing ACB alone up to 31 December 1976.

† Among 4491 patients undergoing ACB alone in whom follow-up could be obtained up to 31 December 1976.

LONG-TERM SURVIVAL

Survival curves for the surgically treated patients were calculated by the life table method of Cutler

and Ederer (1958). These actuarial curves, which include operative and hospital mortality, showed that 80% of all patients undergoing ACB alone were alive at eight years (fig 5).

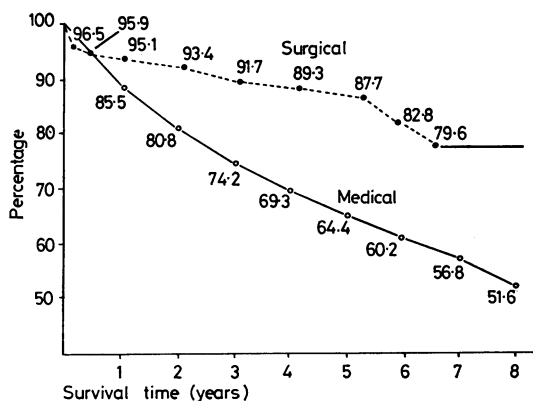


Fig 5 Actuarial curves showing survival of entire series of patients undergoing ACB alone and comparing survival with the series treated medically by Brusckke *et al* (1973).

Discussion

The reduction in early mortality from 9.7% to 2.2% during the period of this study is encouraging and emphasises the importance of increased surgical experience and improved techniques, particularly the use of cold cardioplegia, topical cardiac hypothermia, and the greater technical precision provided by optical magnification and high intensity illumination. The early mortality rates have improved, even though our indications for ACB have been broadened to include those patients who have angina pectoris in the presence of poor ventricular function (ejection fractions less than 0.2). As a rule only those patients with angina pectoris who have angiographic evidence of diffuse coronary arteriosclerosis that would preclude technically satisfactory grafts are refused operation (Wukasch *et al*, 1977a). When higher risk patients are excluded from the series, early mortality is in the range of 1%, the mortality con-

sidered acceptable for most elective major surgical procedures. For example, in a recent consecutive series of patients from Holland that excluded acute emergency cases, 268 underwent coronary bypasses with one death (0.4% mortality).

The higher early mortality in women compared with men is striking. Particularly notable is the fact that early mortality has been reduced considerably in male but not in female patients (Wukasch *et al*, 1976). A possible explanation for this difference may be that when women develop coronary insufficiency, the metabolic derangement is more severe, thereby producing more diffuse lesions. In addition, it has been our impression that the coronary arteries in women tend to be smaller, more friable, and more often intramyocardial in location than in men, thereby making satisfactory anastomoses technically more difficult. Curiously, for reasons that are not apparent, the higher early mortality in women did not extend to late mortality, which was about the same for men and women. Once the female patient has survived operation, patency rates of the grafts in women are the same as in men. Support for the concept that a more severe metabolic derangement exists in women who develop coronary artery occlusive disease (CAOD) is suggested by their relative higher early mortality between 40 and 49 years. Most women in this age group are premenopausal and should still have been protected from developing CAOD. Apparently the arteriosclerotic process superseded the possible hormonal protection. Another factor to be considered is the higher incidence of diabetes among women.

The importance of complete revascularisation of all stenotic coronary arteries is shown by the lower late mortality in those patients in whom this was achieved. We consider the improved long-term survival outweighs the slightly higher early mortality associated with the more prolonged surgical procedure required for multiple bypass grafts. Additionally, our experience has shown that complete revascularisation of all lesions producing more than 50% luminal stenosis is a major factor in reducing the need for subsequent revascularisation procedures (Wukasch *et al*, 1977b). Moreover, the results clearly indicate better long-term symptomatic relief with more complete revascularisation.

Actuarial curves using Cutler's methods (Cutler and Ederer, 1958) showed that 92% of patients in our surgical series were alive at three years and 80% at eight years after operation. Although it may be unrealistic to compare dissimilar and non-randomised control studies, our surgical cases were compared with the series of Brusckhe *et al* (1973)

(angiographically proved coronary insufficiency treated medically). The comparison was significant with a P value of less than 0.001 according to the combined test of significance described by Cochran (1954). Thus among patients treated surgically 80% were alive after eight years, whereas of those treated medically, only 52% were alive at eight years (fig 5).

A recently published Veterans' Administration Co-operative Study (Murphy *et al*, 1977) of randomised patients with stable angina pectoris (one group receiving medical and the other surgical treatment) questions the efficacy of coronary artery revascularisation in prolonging life (Braunwald, 1977). That study reported that 87% of medically treated patients were alive compared with 88% treated surgically three years after diagnosis. In our series of patients, which included patients with both stable and unstable angina and many risk factors excluded from the Veterans' study, 92% of 8017 patients were alive three years after operation. The Veterans' Administration Co-operative Study follow-up extends to three years only, but if their actuarial curves are projected to eight years, only 65% of medically treated patients will be alive, compared with 80% in our surgically treated patients. The difference in the projected eight-year survival of 65% in the Veterans' study (Murphy *et al*, 1977) and the 52% survival in the group of Brusckhe *et al* (1973) may be due to excluding some patients in the former series who had occlusion of the left main coronary artery. Another study made at the Veterans' Hospital, Houston, Texas (Mathur and Guinn, 1975) showed a superiority of surgical over medical treatment of myocardial ischaemia in terms of quality of life and early death.

Addendum

The numbers of patients in whom accurate information could be obtained for the determination of symptomatic results and calculation of survival curves differ. Follow-up information concerning symptoms was obtained from 4491 patients. Clearly, the 540 patients who had died were excluded. We do not consider it useful to include the 1145 patients who had been operated on within the past six months in determining symptomatic results. Therefore these patients were also excluded. In addition, there were 431 patients about whom we have received information as to whether they were dead or alive, and therefore could include them in the survival curves, but about whom we had not received an accurate assessment of their symptoms.

In summary a long-term follow-up concerning survival was obtained in 6617 of the 8017 patients (82.54%).

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