Hospital Topics

Venous Graft Surgery in Treatment of Coronary Heart Disease

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Summary

Sixty-seven patients have had aortocoronary venous graft bypass surgery by one surgeon for the relief of symptoms of severe coronary heart disease, including eight emergency operations. The overall operative, hospital, and late mortality was low in patients with favourable myocardial function and no previous myocardial infarction. There was a 7% mortality in patients with a normal preoperative chest radiogram, 8% mortality when the left ventricular end-diastolic pressure was normal preoperatively, and a 5% mortality in patients who had normal left ventricular angiograms. The overall mortality in all elective operations for cardiac pain resistant to medical treatment was 15.8%. 89% of survivors improved; 67% are pain-free. Exercise tolerance in survivors is increased by 135%, atrial pacing results are improved by 10%. Left ventricular end-diastolic pressure is unchanged. Left ventricular function on angiography is improved. The improvement in left ventricular function assessed objectively correlates positively with vein-graft patency, as does freedom from angina pectoris.

Introduction

In the past many operations have been devised for ischaemic heart disease in attempts to revascularize the myocardium, but none has been shown either to reduce symptoms effectively over a long period or to improve left ventricular function or to lengthen prognosis.^{1,2} Recently attention has been turned to direct coronary arterial surgery^{3,4} with the use of autologous vein grafts between the ascending aorta and the distal coronary vessels. The proximal nature of coronary occlusive disease offers a sound pathological basis for this technique.⁵ A high

proportion of venous grafts have been shown to remain patent and to supply blood to the ischaemic myocardium for at least three years.⁶ The apparent success of this operation has led to many being performed.⁷⁻¹⁰ Nevertheless, careful assessment of the results including that of left ventricular function is necessary before its true place in treatment can be defined. Experience with the aortocoronary venous bypass graft operation is reported below, after preliminary communications to the British Cardiac Society.^{11,12}

Patients

Between September 1969 and October 1971 67 patients (59 men, 8 women) aged 24-70 years (mean 50 years) had vein-graft surgery; 57 were referred for surgery on an elective basis because of cardiac pain which was completely resistant to medical therapy. After maximal medical treatment their symptoms were graded according to severity (Table I). Their symptoms had lasted from 6 months to 21 years (mean 5.2 years), and

TABLE I—Angina Pectoris. Symptoms before and after Elective Operation

	Angina Grade*					Total
	0	1	2	3	4	
No. of patients before operation ..	0	0	5	24	28	57
No. of patients after operation ..	32	5	6	3	2	48†

* 0 = Asymptomatic. 1 = Angina on severe exertion. 2 = Angina on moderate exertion. 3 = Angina on slight exertion. 4 = Angina on slight exertion and at rest.
† Nine patients died after operation.

only three had had symptoms for less than one year. Thirty-three patients (49%) had sustained at least one cardiac infarction, and 15 (22%) had had multiple infarctions. Two patients had elective surgery for cardiac failure that was resistant to digitalis and diuretics—as a result of a left ventricular aneurysm in one and mitral regurgitation in the other. The former patient had had symptoms for 10 years and had sustained three cardiac infarctions. The symptoms in the other patient had begun with a cardiac infarction 18 months before surgery.

There were eight emergency operations. Three of these patients were in cardiogenic shock after acute cardiac infarction. In each case the cardiogenic shock had been established for more than four hours and was resistant to adrenergic drugs, and each patient was showing progressive clinical deterioration. Three patients were in intractable heart failure, one due to an acquired ventricular septal defect, and two due to mitral regurgitation. All these patients were within 24 hours of the onset of acute infarction except one with mitral regurgitation who had survived in hospital for three months after an inferior infarction but had suddenly deteriorated. Two patients had emergency

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surgery for rest pain of increasing frequency that was completely unresponsive to full medical therapy, and neither had evidence of cardiac infarction.

Method

Preoperatively the history was taken and a clinical examination was performed. Investigations included an electrocardiogram, chest radiography, blood count, urine analysis, and estimation of serum uric acid, cholesterol, and triglycerides, together with lipoprotein electrophoresis and a Venereal Disease Research Laboratory test. In the elective cases the patients were exercised in the upright position on an Elema-Schönander bicycle ergometer when they were taking the optimal dose of beta-adrenergic blocking drugs. An initial warm-up period of three minutes at 200 kpm/min was followed by a period of rest until the heart rate had returned to normal. The test itself was begun at a work load of 200 kpm/min for three minutes. Lead V5 of the electrocardiogram was recorded at one-minute intervals and at the end of each work load. The work load was increased by 200 kpm/min every three minutes until the onset of angina or until the patient became exhausted. The total work, maximum heart rate achieved, and presence or absence of ST-segment changes in the electrocardiogram were recorded.

During catheterization of the right and left heart, which was performed after discontinuing beta-adrenergic blocking drugs, a standard bipolar pacing catheter was positioned at the junction of the superior vena cava and right atrium from a median antecubital vein. A ventricular catheter was passed retrogradely into the left ventricle either by the Seldinger technique from the femoral artery or by a right brachial arteriotomy. Baseline aortic, left ventricular systolic, and left ventricular diastolic pressures were recorded, each with an electrocardiogram. Atrial pacing was then performed with pressures recorded by using the midthorax as zero reference point. The post "a" wave left ventricular end-diastolic pressure was used and an average reading taken from five consecutive beats. Pacing was begun about 10 beats a minute faster than the resting heart rate and increased at minute intervals by 10 beats a minute to a maximum of 160 beats a minute or until the onset of angina pectoris or the onset of physiological atrioventricular block. Left ventricular systolic and end-diastolic pressures were measured at the end of each interval and at the onset of angina if it occurred. This pacing rate at which the onset of angina occurred was recorded as the pain threshold and ST-segment changes at this rate were noted. When the pressures had returned to the initial levels a cine left ventriculogram was performed in the right anterior oblique position followed by selective cine coronary arteriography by either the Judkins¹³ or the Sones¹⁴ technique.

Postoperative investigations were performed at an average of five months (range 1-13 months) from the date of surgery and included identical exercise, catheterization, atrial pacing, and angiographic studies, with the addition of selective cine angiography of the saphenous vein grafts or an aortogram in the left anterior oblique position if the orifice of a graft was not selectively entered.

SURGICAL TECHNIQUE

All the operations were performed by one surgeon (D.R.). A midline sternotomy was used, and while the chest was being opened one or both long saphenous veins were excised through multiple small skin incisions. After heparinization the ascending aorta and both venae cavae were cannulated and the heart was carefully inspected to detect areas of akinesis. Cardiopulmonary bypass with a pump oxygenator was used and a vent was placed in the left ventricle to decompress the heart. An incision was made in the affected coronary artery as far as possible from the obstructed area and avoiding extensive dissection. The distal

anastomosis between the coronary artery and the vein was performed first; interrupted sutures were used if the arterial lumen was small or irregular, or a continuous stitch if the arterial lumen was large.

The site for the proximal anastomosis on the ascending aorta was selected by draping the vein across the heart, usually after coming off bypass, so as to avoid angulation of the venous graft. After placing a partially occluding vascular clamp on the ascending aorta a small piece of the aortic wall was excised and the proximal anastomosis was then performed using a continuous suture.

Anoxic arrest was sometimes induced by clamping the ascending aorta for up to 15 minutes while the distal anastomosis was made. If a longer period was required it was considered preferable to perfuse the coronary arteries before further anoxic arrest.

When present left ventricular aneurysms were usually well delineated and excision was performed at the junction between the fibrous area and the myocardium. The ventricular incision was then closed and the suture line reinforced with strips of Teflon felt. Either this procedure or imbrication (oversewing) was used for akinetic areas which did not improve after revascularization.

ANALYSIS OF SURGICAL PROCEDURES

Of the 67 patients 18 had a single venous bypass, 44 had two venous grafts, and 5 had three venous bypass grafts. The left anterior descending coronary artery and the main right coronary arteries were the arteries into which venous grafts were most frequently inserted (Table II). A local endarterectomy was necessary in 17 coronary arteries (16 patients) before implanta-

TABLE II—Analysis of the 67 Surgical Procedures

One graft	.. .. .	..	18
Right coronary artery	.. .. .	8	
Left anterior descending coronary artery	.. .. .	6	
Left circumflex coronary artery	.. .. .	4	
Two grafts	.. .. .	..	44
Right coronary artery and left anterior descending artery	.. .. .	34	
Left anterior descending coronary artery and left circumflex coronary artery	.. .. .	6	
Right coronary artery and left circumflex coronary artery	.. .. .	4	
Three grafts	.. .. .	..	5

TABLE III—Additional Surgical Procedures

Enderterectomy	.. .. .	.. .. .	.. .. .	.. .. .
Right coronary artery				12
Left anterior descending coronary artery				3
Left circumflex coronary artery				2
Imbrication or excision of aneurysm				
Infarctectomy				13
Mitral valve replacement				2
Mitral annuloplasty				1
Closure of ventricular septal defect				2
				1

tion of the vein graft (Table III). In 13 patients excision of a ventricular aneurysm or imbrication of akinetic areas in the left ventricle was performed. Infarctectomy was necessary in two of the emergency operations. Mitral valve replacement, mitral annuloplasty, and closure of an acquired ventricular septal defect were the additional procedures in the remaining four patients.

Results

Of the 57 patients who had elective operations for cardiac pain eight died in hospital (14%) and there was one late death, overall mortality 15.8%. Both patients who had elective operations for resistant heart failure left hospital, but one died late. There were four deaths among the eight emergency operations (Table IV)—three in hospital and 1 late.

TABLE IV—Details of the Eight Emergency Operations

	No. of Patients	Mortality	
		Hospital	Late
"Cardiogenic" shock	3	1	0
Resistant myocardial failure .. .	2	1	1
Resistant failure and ventricular septal defect ..	1	1	1
Intractable rest pain .. .	2	0	0

Electrocardiograms.—There were no hospital or late deaths among the 10 patients (15.1%) with normal electrocardiograms. Eighteen patients (27.2%) showed ST-T changes without definite evidence of infarction, and their overall mortality was 11%. Among the 38 (57.5%) with one or more transmural infarctions the overall surgical mortality was 32%. One pre-operative electrocardiogram was missing.

Chest Radiographs.—Forty-six patients (68%) presented with normal chest radiographs, and the overall mortality in this group was 7%. Among the 21 patients with cardiac enlargement the surgical mortality was 52%; in addition 10 of these 21 also showed pulmonary venous congestion, and their overall mortality was 60%.

Blood Investigations.—Levels of serum cholesterol were available for 55 patients and were raised in 19 (34.5%); there were two deaths in this group. Six deaths occurred among the 36 patients with normal cholesterol levels. Full lipid analysis was performed in 26 patients, and 10 (38.4%) were shown to have abnormal patterns classified as Frederickson's type 2, and five as type 4.¹⁶ None of these patients died. Among the 16 with normal patterns, however, there were three deaths. Glucose tolerance tests were performed in 30 patients and were abnormal in 5 (16.7%). Serum uric acid was raised in 2 of the 32 patients not on diuretics. There were no positive Venereal Disease Research Laboratory tests.

Exercise.—Thirty-five patients were exercised before the operation, performing a mean total work of 1,218 kg (range 50-2,400 kg) at a mean maximum heart rate of 113/min (range 75-150/min). Twenty-nine patients stopped exercising because of angina, five because of dyspnoea, and one had dyspnoea and intermittent claudication. Among the 22 patients (63%) who performed more than 1,000 kgm the overall surgical mortality was 9%. Thirteen patients performed less than 1,000 kgm and their surgical mortality was 31%.

Atrial Pacing.—Preoperatively 38 patients were atrially paced.¹⁶ The test was positive in 33, negative in 2 owing to physiological atrioventricular block, and negative in 3 in whom there was no pain or ST change at 160/min. Of the 33 patients with positive tests 29 developed typical angina pectoris and 4 showed only ischaemic ST changes. Left ventricular end-diastolic pressure was recorded in 22 of the 33 patients with a positive test. The left ventricular end-diastolic pressure was raised at threshold pacing rate in 13 patients. The mean threshold rate in positive tests was 132/min (range 90-160/min). Among the 33 patients with positive tests there were three deaths (9%) during or after surgery.

Left Ventricular End-diastolic Pressure.—This pressure was measured preoperatively in 54 patients; the mean was 15 mm Hg (range 1-40 mm Hg). In 25 the pressure was normal (<12 mm Hg). The overall mortality was 8%. In 29 patients the pressure was raised, and in these the total mortality was 34%. Among the 17 patients with readings above 20 mm Hg the total surgical mortality was 47%.

Left Ventricular Angiogram.—Left ventricular angiography was performed in 52 patients before the operation. The results were classified into three patterns. (1) Normal function: 19 patients, surgical mortality nil, one late death (5% overall). (2) Localized dyskinesia or aneurysm: 14 patients, no deaths. (3) Poor overall function: 19 patients, nine hospital deaths, one late death, total mortality 52.6%.

Coronary Angiography.—Coronary angiography was performed in 66 patients. Four patients (6%) had disease of only

one artery, and there were no surgical deaths in this group. Among the 14 patients (21%) with disease of two coronary arteries the overall mortality was 7.1%. Forty-eight patients (73%) had disease of all three major coronary arteries; their total mortality for the operative procedure was 25%.

FOLLOW-UP

The survivors were followed-up for 3-27 months (mean 10 months, median 9). Altogether 67% of the survivors were symptom-free and 89% were improved (Table I). Twenty-eight patients had angiography to test the patency of the venous grafts. Sixty per cent of the grafts were entered by catheter for selective angiography and the remainder were shown by aortography. Of the 49 vein grafts in these patients 31 (63%) were patent and 18 were occluded. Nine necropsy vein-graft angiograms in five patients showed six to be patent and three occluded. Thus information regarding venous grafts was available in 55% of survivors of the operative procedure. Five of these grafts were inserted into coronary arteries after endarterectomy in five patients. Of these four were patent, and these patients were asymptomatic, and one was blocked; this patient was not improved symptomatically by the operation.

Electrocardiograms before and after operation were compared in survivors four to six months after the operation so as to allow for operative ST-T changes to have regressed. There was no change in 36 patients. Ten showed some evidence of deterioration judged by the appearance of pathological Q waves or the development of left bundle-branch block or of left axis deviation. Five showed improvement judged by regeneration of R waves where pathological Q waves existed preoperatively or loss of ST-T abnormalities. **Chest radiographs** taken three months after operation were compared with the preoperative records. These showed no change with respect to heart size and pulmonary venous congestion in 47 patients, improvement in five, and deterioration in four.

Exercise studies were recorded in 16 patients before and after operation. Preoperatively their mean total work was 1,316 kg (range 250-2,400 kg) at a mean maximum heart rate of 112/min (range 75-141/min). Initially angina pectoris occurred in 14 patients, with typical ischaemic ST changes in 12. Dyspnoea terminated the test in two patients. Postoperatively these patients performed a mean total work of 3,088 kg (range 350-8,800 kg), representing an increase of 135% at a mean maximum heart rate of 152/min (range 110-200/min), which is an increase of 35%. Typical chest pain occurred in only three patients as the terminating factor in the test, the remaining 13 being

FIG. 1—Exercise performance before and after operation in 12 patients correlated with venous graft patency; 10 patients had two grafts and 2 had one graft.

stopped by dyspnoea and fatigue. Typical ischaemic ST changes occurred in only six patients. Vein-graft angiography was performed in 12 of these 16 patients. Their total work results are shown in Fig. 1, which indicates a close correlation between venous graft patency and improvement. Ten of these patients had two grafts and two had one graft.

The *atrial pacing* test was performed after operation in 17 patients. Fifteen of these had positive tests preoperatively, and only two experienced typical chest pain that terminated the tests postoperatively. Thirteen patients (76%) showed improvement after surgery; venous graft information was available in 11 of these, and all had at least one patent graft. There was no change in the results in three patients, all of whom had at least one patent graft. One patient was significantly worse although his graft was patent. It was also noted that this patient developed left bundle-branch block at operation and was found to have poor left ventricular function at angiography. The maximum pacing rate before operation in the 17 patients was 138/min (range 100-160/min) and after operation 149/min (range 110-160/min). The left ventricular end-diastolic pressure was recorded in eight of the reinvestigated patients at maximum pacing rate: preoperatively the mean was 15 mm Hg (range 0-25 mm Hg) falling to 8 mm Hg (range 0-24 mm Hg) postoperatively. Those who improved most were those who had all grafts patent.

Comparative results of *left ventricular end-diastolic pressure* before and after surgery were recorded in 16 patients. The mean pressure preoperatively was 12.5 mm Hg (range 7-20 mm Hg). Postoperatively the mean was 14.1 mm Hg (range 5-35 mm Hg). Vein-graft information was available on all these patients, and the correlation between these pressure readings before and after operation and vein-graft patency is shown in Fig. 2. Of the 31 grafts placed 20 were found to be patent and 11 occluded.

FIG. 2—Left ventricular end-diastolic pressure (L.V.E.D.P.) before and after operation in 16 patients correlated with venous graft patency; 1 patient had three grafts, 13 had two grafts, and 2 had one graft.

Three patients had no patent graft. In only two patients did a normal reading before operation become abnormal postoperatively; both had at least one patent graft, but one was in transient atrial fibrillation during the preoperative study, which may have made the left ventricular diastolic pressure artificially low. In no patient did an abnormal reading become normal. Of these 16 patients two had grade 2 angina pectoris, five had grade 3, and nine had grade 4 preoperatively. After the operation 13 patients were asymptomatic, and one from each preoperative grade was not improved. These were the three patients with no patent grafts. In all three, however, the pressure remained within the normal range.

Fourteen patients had *left ventricular angiograms* after the operation. The distribution of these patients within the classification described above before and after the operation is shown

TABLE V—Ventricular Function. Findings on Left Ventricular Angiography before and after Operation

	Grade*			Total
	1	2	3	
No. of patients before operation	5	6	3	14
No. of patients after operation	7	6	1	14

* 1 = Normal left ventricular function. 2 = Localized left ventricular dyskinesia or aneurysm. 3 = Poor overall left ventricular function

in Table V. Two of the patients had no patent graft but left ventricular function had not deteriorated. One patient deteriorated and a fresh infarct was noted postoperatively on his electrocardiogram. Before the operation there were two patients with grade 2 angina pectoris, two with grade 3, and 10 with grade 4. After the operation 11 were asymptomatic, and in one grade 2 angina persisted and in two grade 4 angina persisted. The three latter patients, who did not benefit from the operation, showed no change in left ventricular function and none had patent venous grafts.

Postoperative *coronary angiography* was performed in 27 patients, and the findings were compared with the preoperative results and with the vein-graft patency information. There were 31 patent grafts in this group, and of these eight grafted arteries showed deterioration of the original disease proximal to the graft. One showed improvement and 22 no change. There were 17 occluded grafts, and of these eight grafted arteries showed deterioration proximal to the graft; none showed improvement and nine were unchanged.

Discussion

The results show a low overall mortality in patients with resistant angina pectoris and favourable left ventricular function as evidenced by the absence of previous infarction on the electrocardiogram, normal heart size on chest radiography, normal left ventricular end-diastolic pressure, and normal left ventricular function on angiography. Similar findings have been noted by others.^{7,9} Rees *et al.*¹⁷ presented a detailed study of patients with normal angiographic ejection fractions, confirming the favourable short-term prognosis in this group. Many patients in this series, however, showed evidence of severely reduced left ventricular function.

Our policy was to accept patients for a new surgical technique only if they were severely disabled and had had optimal medical treatment, which we consider to be glyceryl trinitrate, when required, plus propranolol in doses up to 400 mg a day (or other beta-blocker in equivalent dosage), and in the case of emergency operations only if the prognosis without treatment seemed hopeless. Thus these patients would be expected to have severe coronary heart disease by any criteria. This is borne out by the long duration of symptoms, the high incidence of previous myocardial infarction, cardiac enlargement and pulmonary venous congestion, poor exercise tolerance, raised left ventricular end-diastolic pressure, reduced left ventricular function on angiography, and high incidence of disease of all three major coronary arteries. When several of these risk factors occur in one patient, as is frequent, the surgical prognosis is less favourable.

This series has been studied objectively in great detail. Subjectively, our results compare closely to those of others,^{1,8} showing that 89% of patients are improved by the operation. Objectively, exercise tolerance improved dramatically and correlated closely with venous graft patency. Improvement with training did not influence these patients, as they were not given an opportunity to train. It was considered that the preoperative assessment performed on optimal beta blockade and the postoperative assessment made without drugs would in itself not favour improvement in exercise tolerance. Thus the significance of the postoperative improvement is emphasized. Nevertheless,

the increase in maximum heart rate also noted postoperatively may be due solely to the withdrawal of beta blockade. Furthermore, the tests were performed in most cases early in the post-operative course, and it was likely that many patients would further improve with time.

Atrial pacing tests showed appreciable improvement and corroborated venous graft patency. This test has been shown to have a close degree of reproducibility;¹⁶ the improvement shown falls clearly outside these limits. Left ventricular end-diastolic pressure was shown not to have changed significantly. The results of left ventricular angiography showed convincing improvement in five out of 14 patients studied, with four remaining normal. Spencer *et al.*⁸ claimed no improvement in patients with poor overall left ventricular function preoperatively; the experience reported here does not support this claim. They also showed that left ventricular function remains poor despite venous graft patency. In this series, however, the improvement always correlated with venous graft patency.

The vein-graft patency rate in the present patients at a mean of five months postoperatively was similar to those reported by others^{19 20} at one year. Hence most vein-graft occlusions occur in the early postoperative phase and the late occlusion rate is low.^{6 19 20}

During this series surgical techniques improved, and the reinvestigations reported are those on patients operated on early in the series. The more recent studies show an increasing patency rate. It is of importance that in this series most patients had widespread coronary artery disease, suggesting that peripheral run-off was at times not completely adequate, which would of course militate against prolonged graft patency. Vein graft flow rates at surgery are not reported here, but these measurements are now being performed routinely. Many reports^{7-9 19 20} suggest that flow rates of less than 25 ml/min in a venous graft at surgery indicate a strong likelihood of early occlusion. Clinically it is usually obvious that there is venous graft patency because the patient has a rapid and uncomplicated post-operative course without angina pectoris. Many workers^{7-9 19 20} perform vein-graft angiograms before discharging the patient from hospital and find this information useful in the subsequent clinical management. Endarterectomy in the artery grafted and a recognizable lipid disorder do not appear to play a part in graft occlusion at the present stage of our analysis.

On theoretical grounds a patent vein graft to a coronary artery which has a significant proximal stenosis will reduce or abolish the pressure gradient across that stenosis, enhancing the likelihood of coronary arterial occlusion at that site. Our present results do not support this conclusion. But it is not known at what stage postoperatively such vein grafts become occluded, and it is therefore possible that proximal coronary arterial occlusion may have occurred during the period that the venous graft was patent

and that this was subsequently followed by occlusion of the graft. The rate of advance of proximal disease of coronary arteries in this series over the short mean period of five months was higher than that reported by Bewis and associates.²¹ Their patients, however, showed less severe coronary arterial disease.

Benefit has been shown in terms of the relief of symptoms and objective improvement of left ventricular function correlating with venous graft patency at an early stage after the operation. Reports suggest that there is a progressive late occlusion rate of vein grafts.^{8 20} Only time and continuing careful analysis will decide if the long-term results offer improvement in prognosis.

We thank those physicians who referred patients for treatment, and colleagues for permission to report details of patients under their care.

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Any Questions?

We publish below a selection of questions and answers of general interest

Combating Cockroaches

What is the best way to combat an invasion of cockroaches in an urban house?

Two kinds of cockroach infest dwellings in Britain. In former days, the black beetle (*Blatta orientalis*) was most common. It is mahogany brown, a wingless floor creeper up to 1 in (2.5 cm) long. More recently, the German cockroach (*Blattella germanica*) has become more prevalent, especially in large, centrally-heated buildings (hospitals and other institutions

and sometimes large blocks of flats). This animal is yellowish brown, up to ½ in (12.7 mm) long, and, unlike the black beetle, it can climb up walls. This ability, combined with its faster rate of breeding, makes it a most troublesome pest in certain conditions.

Apart from the warmth of central heating systems, the wall-piercing pipes, often enclosed in ducts or cases, provide excellent harbourages in which the insects spend the daytime and from which it is difficult to dislodge them. For this reason it is desirable to seal up cracks and crevices wherever possible, especially round hot water pipes entering rooms.