Bypass Grafting for Occlusive Disease of the Coronary Arteries:

A Report of Experience with 195 Patients

FRANK C. SPENCER, M.D., GEORGE E. GREEN, M.D.,
DAVID A. TICE, M.D., EPHRAIM GLASSMAN, M.D.

From the Departments of Surgery and Medicine, New York University Medical Center, New York City

THE first bypass procedure for coronary artery disease at New York University was performed by Green and Tice in February 1968, anastomosing the left internal mammary artery to the anterior descending coronary artery. This operation followed a long period of laboratory investigation regarding the technic, feasibility, and durability of anastomoses between the internal mammary artery and the anterior descending coronary artery.[6, 8, 15] The first operative procedures were cautiously applied to selected patients, and only 17 bypass operations were done in 1968. The prompt symptomatic improvement, however, encouraged wider use of the technic. Favaloro and Johnson reporting on the use of the saphenous vein for bypass grafting stimulated increased activity in this field.[2, 9]

This report is a description of the total experience with bypass grafting at New York University, representing a group of 195 patients operated upon between February 1968 and November 1970. Over this period of time, several different operative technics have been employed. The internal mammary artery has been used in 67 of the 195 patients, principally by one of us (G. E. G.). The saphenous vein has been used for the other patients because of its accessibility and ease of insertion. However, as this report indicates, significant long term questions remain concerning the relative advantages and disadvantages of different types of bypass grafts.

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Methods

Preoperative Considerations. Most patients were operated upon for severe angina pectoris, often increasing in severity in the few weeks preceding operation. Angina in some patients was virtually disabling, requiring 100 to 200 nitroglycerin tablets per week. Less frequent indications for operation were symptoms of congestive heart failure or a history of multiple myocardial infarctions. Operation was frequently performed for patients in the fourth and fifth decades, with progressive angina and a history of multiple myocardial infarctions, while operation was infrequently done for patients in the sixth decade in whom symptoms were only mild angina. The severity of the coronary disease present in many patients considered for operation is indicated by the fact that several patients scheduled for operation died while awaiting admission to the hospital.

Coronary arteriography was performed in all patients by the Sones technic of direct injection of each coronary ostium. In addition, ventricular function was evaluated by

ventriculography and measurement of end diastolic pressure and ejection fraction. Bypass grafting was employed when angiography found severe stenosis (75 to 80% obstruction) or occlusion of one or more major coronary arteries. Multiple areas of obstruction were usually found. Ventriculography, demonstrating the degree of impairment or destruction of left ventricular muscle, was found the best measurement of both the risk of operation and the likelihood of improvement.

The majority of patients with serious symptoms and the angiographic demonstration of obstruction of a major artery were operated upon. The oldest patient, with an excellent result in the ensuing 6 months since operation, was 73 years of age. The liberal indications for operation are enhanced by the fact that a few of the patients operated upon had developed not only severe congestive failure but also mitral insufficiency, pulmonary hypertension, and tricuspid insufficiency. Contraindications to operation are yet uncertain. Neither the inability to demonstrate a patent arterial segment beyond the area of obstruction, nor the angiographic size of the patent distal vessel were found to be valid contraindications. The ability to opacify a coronary artery beyond the area of obstruction is a function of volume of dye injected and rate of blood flow through collateral circulation. In 80 to 90 per cent of patients, a patent vessel could be demonstrated, but in the remainder, a patent vessel was almost invariably found by dissection at operation. The apparent diameter of the vessel beyond the area of obstruction was similarly found misleading, for the distal artery was often contracted from lack of blood flow and scarring in adjacent epicardium. An artery seemingly 1 mm. or less in diameter on angiography was usually found at operation to dilate readily to 1.5 to 2.0 mm.

The strongest contraindication to operation was extensive destruction of left ventricular muscle in patients 65 to 70 years of age, with congestive heart failure and elevation of left ventricular end diastolic pressure above 25 mm. Hg. Although operation was performed satisfactorily in some such patients, operative mortality was increased and subsequent improvement was not great. Further data are needed in this regard.

Operative Technic. All operations were performed during cardiopulmonary bypass, employing the Temptrol bubble oxygenator with a flow rate near 3 l./M²/min., at a temperature of 30° C. A double bypass was most commonly performed, usually requiring between 2 and 3 hours of perfusion. However, longer periods of perfusion were needed in some patients, even up to 6 hours, and were surprisingly well tolerated. Accordingly, it was not found necessary to modify the operative technic because of the duration of perfusion. The heart was stilled by induction of ventricular fibrillation or by intermittent occlusion of the aorta for 10 to 15 minutes, alternating with 3 to 5 minutes of perfusion. The left ventricle was decompressed with a vent.

Optical magnification was routinely employed and found to be an essential feature of technic. This point should be emphasized, for many surgical groups frequently have not used magnification. Magnification not only facilitated the performance of an anastomosis to a 1–2 mm. artery, but also was of great help in dissection to isolate small distal coronary arteries and to obtain hemostasis from tiny epicardial veins. Ocular loupes magnifying to 4 power were specifically designed for this purpose [13] (Fig. 1). Alternately, the dissecting microscope, magnifying to 16 power, was employed, especially during anastomosis of the internal mammary artery to the anterior descending artery (G. E. G.). Undoubtedly, the routine use of magnification

FIG. 1. Photograph of binocular loupes which have been found essential for operation on coronary arteries. The loupes magnify to 4 power, with a focal length of 16 inches. The binoculars can be individually mounted in spectacles optically corrected for the individual surgeon, permitting ready access to the operative field. (Supplied by George O. Hellinger, D.Os., New York.)

significantly influenced the operative results, for an anastomosis was satisfactorily completed in over 95 per cent of patients. Without magnification, the ability to find the lumen in a distal 1 mm. coronary artery concealed in epicardial fat would have been seriously hampered.

A reversed segment of saphenous vein was used for most anastomoses. The vein was removed from the inguinal ligament to the knee through a single longitudinal incision. Anastomoses were performed with a conventional end-to-side technic, selecting a segment of coronary artery beyond the obstruction and incising the anterior wall for 8–10 mm. Following arteriotomy, malleable silver probes, ranging in diameter from 0.5–3.0 mm., were used to dilate gently the artery proximally and distally. Often the coronary artery could be dilated 50–100 per cent beyond the original diameter, greatly facilitating the subsequent anastomosis. The anastomoses were performed with 6-0 Tefdek, using a continuous suture, except at the proximal and distal angles where interrupted sutures were used. An important feature in technic was to minimize dissection of adjacent epicardium from the artery, preferably leaving the coronary artery surrounded by adjacent fat and epicardium and simply incising the anterior wall. During the anastomosis, care was taken to incorporate adjacent epicardium and fat into the suture line, which aided hemostasis.

Usually the distal anastomosis was performed first, and the vein distended with saline to check for any anastomotic leaks. Before anastomosing the other end of the graft to the aorta, a clamp was applied temporarily to the vein proximal to the coronary anastomosis and the vein distended with saline, which permitted selection of an appropriate length of vein graft. Care was taken to choose a graft of enough length to avoid any tension when the heart filled with blood following bypass.

Considerable attention was given to the method of aortic anastomosis, and the ideal technic is not yet certain. Vein grafts to the left coronary artery were attached to the left anterolateral surface of the aorta, usually by occluding the aorta distally, making a 6–8 mm. transverse or oblique incision, and subsequently removing a 3–4 mm. wedge of aortic wall. The anastomoses were constructed with interrupted and continuous sutures of Tefdek, attaching the

FIG. 2. Operative photograph demonstrating double coronary bypass graft employing two segments of saphenous vein. The graft supplying the left anterior descending coronary is anastomosed proximally to the left anterolateral wall of the ascending aorta while that one extending to the distal right coronary is placed on the right anterolateral wall.

vein graft to form an obtuse angle with the aorta, as opposed to a right angle or an acute angle (Fig. 2). Theoretically an obtuse angle has less turbulence of blood flow than an anastomosis performed at an acute angle. The overlying pericardium was often incised over the vein graft to prevent adhesions which subsequently might develop between the pericardium and epicardium and compress the graft.

Green performed the vast majority of the 67 internal mammary anastomoses which were done. The internal mammary artery was used for anastomosis to the anterior descending coronary in 75 to 80 per cent of patients operated upon by him. It was used if it was at least 2 mm. in diameter at the level of the fifth interspace, and had a free flow of blood greater than 80 ml./min. from the transected end, when allowed to bleed freely into a medicine cup. The internal mammary was first mobilized with a 1 cm. pedicle of surrounding soft tissue up to the subclavian artery. The anastomosis was end-to-side, performed with a dissecting microscope (10–16×) (Fig. 3). The anterior descending coronary artery was first incised for 3–4 mm. and the anastomosis then constructed with a continuous suture of 9-0 nylon. Usually, the internal mammary artery was transected directly and not opened obliquely with a longitudinal incision. With double or triple bypass grafts, the internal mammary artery was anastomosed to the anterior descending and the saphenous vein to the other coronary arteries (Figs. 4 and 5).

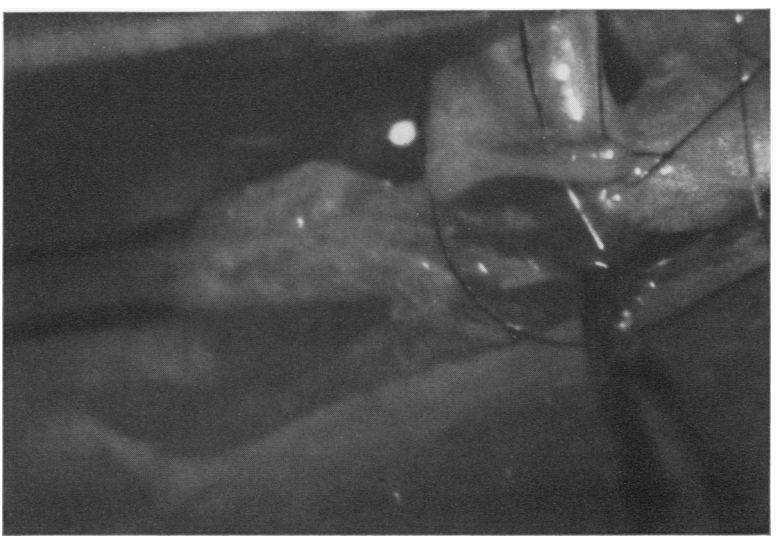

FIG. 3. Operative photograph demonstrating the microsurgical anastomosis between the internal mammary artery and the distal left anterior descending coronary. The photograph was obtained through the operating microscope at 16 magnifications. One-half of the anastomosis has been completed with a continuous suture of 9-0 monofilament nylon. The second side is completed in the same manner.

Adjunctive Procedures. Myocardial scars of significant size, usually 4–8 cm. in length, were often excised (Fig. 6). Such scars could readily be defined by palpation. An incision centrally placed in the scar was extended to the margins, excising the scar near its juncture with normal muscle. Closure was performed with heavy mattress sutures of Dacron, buttressed through strips of Teflon felt and reinforced with continuous sutures. Left ventricular myocardium which appeared normal but did not contract was *not excised*, however, for such areas were often found to contract well following revascularization.

Significant mitral insufficiency was present in several patients and confirmed by angiography. At operation the mitral valve surprisingly often appeared normal except for unimpressive scars in the papillary muscles. The mechanism of insufficiency apparently is caused from impaired contraction of the left ventricle at the origin of the papillary muscles. Rupture chordae tendineae were not found, nor was the mitral annulus greatly dilated. Repair by annuloplasty was performed in some patients, with a significant early failure rate. Prosthetic replacement is currently the preferred technic. Prosthetic replacement of the tricuspid valve was performed, in addition, in two patients with advanced cardiac failure and pulmonary hypertension when bypass could not be stopped after replacement of only the mitral valve. Cardiac function was improved significantly following tricuspid replacement, but both patients died from low cardiac output within the first 4 days after operation.

Only one arterial implant has been performed in the last year, in a patient in whom the anterior descending coronary artery was buried in a myocardial tunnel and could not be found at operation. In the vast majority of patients, an anastomosis has been performed to a small distal artery, often only 1 mm. in diameter; so no indication for an implant has been found. However, a significant question is the long-term patency of anastomoses performed to coronary arteries as small as 1 mm. in diameter.

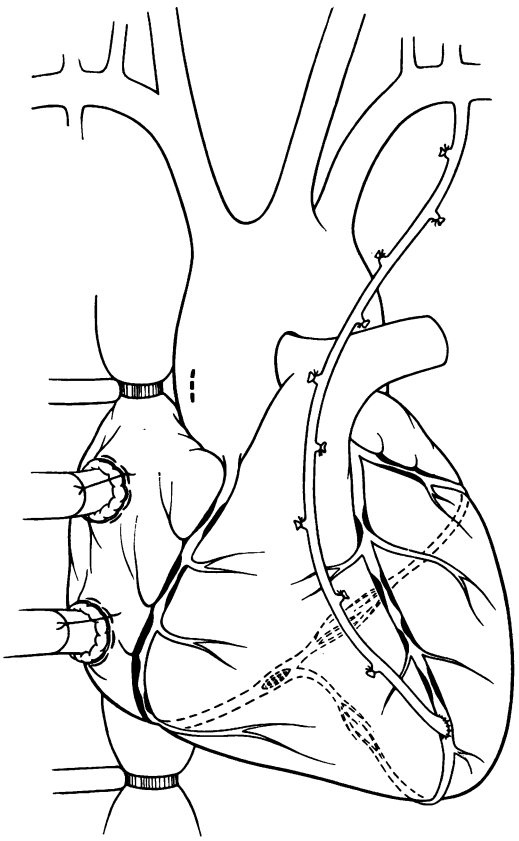

FIG. 4A. Diagrammatic illustration showing the completed internal mammary-anterior descending anastomosis. The arteriotomy site on the right coronary artery, opposite the origin of the posterior descending branch, is indicated. The preferred site for incision of the aorta is also illustrated, selecting an area on the lateral surface of the aorta to avoid angulation of the graft.

Following bypass, flow rates were separately measured in each graft with an electromagnetic flowmeter. The significance of such measurements is uncertain, for rate of blood flow varies with many factors, the most significant being diameter of the distal coronary artery and the systemic blood pressure. The average rate of blood flow was 40 to 80 ml./min. per graft, ranging from as small as 20 to 30 ml./min. to as high as 100 to 120 ml./min.

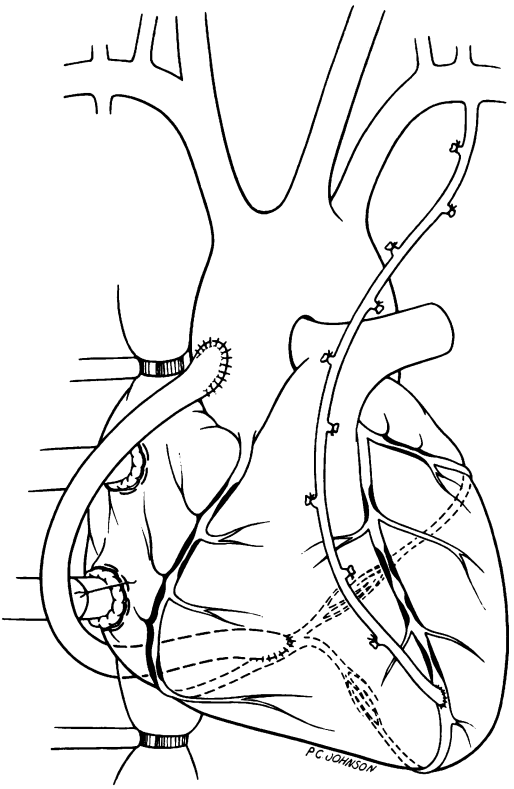

FIG. 4B. Illustration showing completed bypass grafts, with the saphenous vein segment inserted between the aorta and the distal right coronary. Performing the anastomosis far distally on the right coronary permits direct perfusion into both the posterior descending branch and the continuation of the right coronary onto the posterior surface of the left ventricle. The vein graft normally is about 6 inches in length.

Left atrial pressure was measured routinely before and after bypass. In some patients with severe failure and a mean left atrial pressure of 30–35 mm. Hg, a decrease to 15–20 mm. Hg occurred after bypass, presumably due to an immediate improvement in cardiac function following bypass grafting.

Small polyvinyl catheters, inserted through a #16 gauge needle, were routinely left in the left atrium and pulmonary artery for postoperative monitoring. Pacemaker wires were routinely implanted in the right atrium and right ventricle for postoperative control of arrhythmias.

Postoperative Management. Following operation particular attention was given to adequacy of cardiac output, ventilation, and arrhythmias. Assisted ventilation was usually performed through an indwelling endotracheal tube for several hours. If ventilation was required for longer than 12–18 hours, a tracheostomy was performed, but this was not frequently necessary.

Left atrial pressure was monitored constantly on an oscilloscope through the polyvinyl catheter previously implanted in the left atrium. Oxygen saturation of mixed venous blood, an indicator of adequacy of cardiac output, was measured through samples obtained from the indwelling catheter in the pulmonary artery. Oxygen tension in mixed venous blood usually was kept above 30 mm. Hg. This was accomplished by elevation of left atrial pressure by appropriate transfusion of blood. The degree to which the left atrial pressure was elevated varied with the left atrial pressure present before

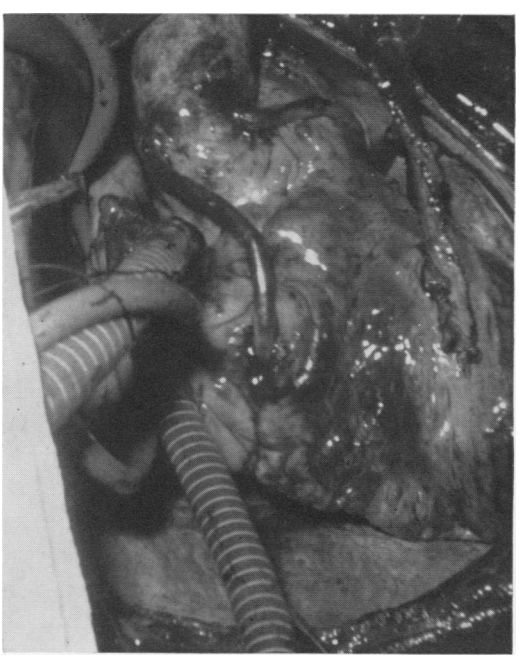

FIG. 5. Operative photograph showing a completed triple bypass graft employing the internal mammary artery and two segments of saphenous vein. The internal mammary artery has been anastomosed to the distal left anterior descending coronary artery while the two vein segments, anastomosed proximally to the ascending aorta, are employed to bypass the right and circumflex coronary arteries.

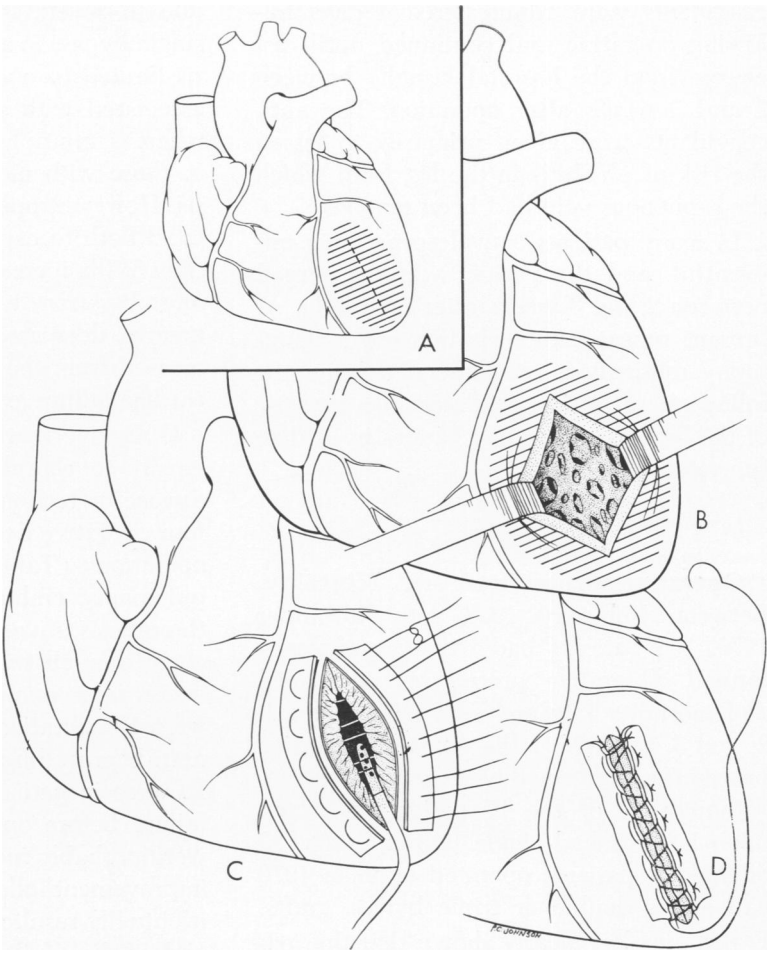

FIG. 6A. Illustration of adynamic area in the anterior apical portion of the left ventricle, a site frequently involved by myocardial infarction. These adynamic areas are best identified by left ventriculography, demonstrating absence of contraction or paradoxical ballooning of the area during systole. At operation, these areas can be identified easily by inspection and palpation. There is a notable absence of contraction, and on palpation a sharp distinction can be felt between the scar in the "adynamic" area and the normally contracting ventricular muscle.

B. Following incision of the scar, palpation of the junction of the scar and the muscle can indicate the areas that should be excised. Normally, there is a sharp delineation between the noncontractile scar and the adjacent contracting ventricular muscle.

C. Closure is initially begun with heavy mattress sutures placed through strips of Teflon felt.

D. Closure is completed by additional continuous sutures for hemostasis. Air is displaced from the ventricle at the time with an appropriate vent. Functional improvement is best indicated by a decrease in left ventricular end diastolic pressure.

operation. For example, a patient in severe congestive failure with a preoperative left atrial pressure of 30–40 mm. Hg would require a much higher left atrial pressure following operation to maintain an adequate cardiac output than would one whose preoperative left atrial pressure was only 10–15 mm. Hg. Maintenance of an adequate cardiac output was clearly the single most essential feature in postoperative care. If cardiac output was not adequate following elevation of left atrial pressure to a satisfactory level, a dilute infusion of catecholamines, either epinephrine or isoproterenol, 1–2 mcg./min., was given for 24 to 48 hours.

Arrhythmias were the single most frequent complication following operation and they were unpredictable. They occurred despite adequate cardiac output, adequate ventilation, normal blood gas concentrations, and careful attention to administration of digitalis and potassium. Hence, constant monitoring of the electrocardiogram on an oscilloscope was essential. The majority of arrhythmias responded promptly to treatment, but a variety of therapy often was required. These included infusions of lidocaine, procaine amide, potassium, digitalis, Propranalol, or electrical cardioversion. Digitalis was used for signs of cardiac failure but was not given routinely. Anti-

coagulants were administered 4 days following operation and continued until discharge from the hospital, usually between 2 and 3 weeks after operation. The anticoagulants were given primarily to lessen the risk of phlebitis in the leg from which the saphenous vein had been removed.

In many patients convalescence was uneventful, and the patient was discharged between 2 and 3 weeks after operation. At present repeat catheterization and angiography routinely is recommended 6 months following operation to determine patency of the bypass grafts and changes in cardiac function.

Results

Operative Procedures and Mortality. Between February 1968 and November 1970, 195 patients had bypass grafts performed. Operative procedures performed and mortality rate are shown in Tables 1, 2, and 3. In Table 1 the types of operative procedures performed each year are shown. Although 13 of the 17 patients operated upon in 1968 had single bypass grafts, 83 of the 129 patients operated upon in 1970 had either double or triple bypass grafts. Experience has clearly shown that the majority of patients require multiple bypass grafts.

The mortality rates at different periods of time are summarized in Table 2. The overall operative mortality has remained near 10 per cent. The relationship between operative mortality and the number of bypass procedures performed is shown in Table 3. Single bypass procedures in 67 patients were associated with an operative mortality of 5 per cent, while double bypass procedures in 103 patients had an operative mortality of 11 per cent. Paradoxically, eight triple bypass procedures were associated with no operative mortality. The lack of a close relationship between number of bypass procedures and mortality is due to several factors. Performance of a single bypass in a patient with atherosclerosis limited to one major coronary artery is associated with a very low operative risk, whereas multiple procedures are required in those with more extensive atherosclerosis. However, operative mortality is also related both to experience and patient selection. With increasing experience operative mortality from technical complications has greatly decreased, but mortality has increased from the inclusion of patients with cardiac failure as well as angina pectoris.

Operative mortality has been due principally to complications of cardiovascular disease or technical complications. In 1969 four operative deaths occurred following 49 operations (Table 2). These were due to pulmonary embolism, superior mesenteric thrombosis, myocardial infarction, and tracheostomy obstruction with arrhythmia, all occurring in one patient each. In 1970 there were 10 operative deaths following 129 operative procedures (Table 2). Three of the 10 were in patients with advanced cardiac failure before operation, and in retrospect were probably inoperable. There were little improvement following operation, and death eventually resulted from low cardiac output and cardiac failure several days to weeks following operation. Two other deaths occurred in patients who had had a myocardial infarction in the 2 days immediately preceding operation; bypass procedures were performed under semi-emergency circumstances. Two deaths resulted from unexpected arrhythmias in patients seemingly recovering uneventfully following operation. Two patients succumbed from neurologic complications following bypass, and one death occurred in the operating room from cardiovascular complications.

In the 129 bypass operations performed in 1970, additional procedures were performed in 24 patients. These included excision of a left ventricular aneurysm in 15 patients, aortic valve replacement in five,

mitral annuloplasty or replacement in five, and tricuspid valve replacement in two. Multiple adjunctive procedures were performed in some patients, such as resection of ventricular aneurysm and mitral valve annuloplasty.

Late Results: Mortality and Symptomatic Improvement. Eleven of 17 patients survived operation in 1968 (Table 2). Subsequently, two of these died, one from hepatitis and one from myocardial infarction 6 months following single bypass to the right coronary artery. Of nine living patients, seven are asymptomatic and two have slight angina. Five of the nine patients have been restudied with angiograms several months to 1 year after operation, finding a patent graft in each.

In 1969, 45 of 49 patients recovered following operation (Table 2). Five of these have died. One death occurred from myocardial infarction 18 months following operation and clearly was due to progressive coronary disease. Originally, only a right coronary bypass graft was performed in this patient. Angina recurred 15 months later. Angiography showed a functioning right bypass graft but also showed progressive disease in the left coronary system. Operation was being considered when sudden death occurred.

The other four deaths probably were all related to ineffective bypass grafts. In one patient an internal mammary-anterior descending anastomosis was very difficult to perform because of an anomaly of the anterior descending. The angina persisted and was associated with death a year later, presumably from myocardial infarction, although no postmortem examination was obtained. In two patients double bypass grafts thrombosed in the first 3 months after operation, one of whom had been operated upon previously for bilateral internal mammary implantation, and had unusually severe pericardial adhesions. With the occlusion of the grafts, severe angina promptly reappeared, with progression to a fatal outcome within a few days. One other patient had a similar clinical history of sudden recurrence of angina, rapidly increasing in severity and progressing to a fatal outcome within 4 days, suggesting occlusion of double bypass grafts, but a postmortem examination was not performed.

Of the 40 living patients, 34 are either asymptomatic or have negligible cardiac symptoms. Six patients remain symptomatic; four have mild angina; and two have continued cardiac failure, little improved by operation. Of the four with mild but not disabling angina, two initially had only a graft to the right coronary artery and the other two developed complications in one of two grafts inserted, leaving only one functioning graft.

In 1970, 119 of 129 patients recovered from operation. Two of these died, one sev-

TABLE 1. *Operative Procedures*

Year	Total	Single Bypass	Double Bypass	Triple Bypass
1968	17	13	4	0
1969	49	21	26	2
1970	129	46	77	6
Total	195	80	107	8

TABLE 2. *Operative and Late Deaths after Bypass Grafting in 195 Patients*

Year	No. Pts.	Operative Deaths	Late Deaths	Survivors
1968	17	6	2	9
1969	49	4	5	40
1970	129	10	2	117

TABLE 3. *Operative Procedure and Mortality—178 Patients—1969–1970*

Operative Procedure	No. Patients	Survivors	Op. Mort.
Single bypass	67	64	5%
Double bypass	103	92	11%
Triple bypass	8	8	0

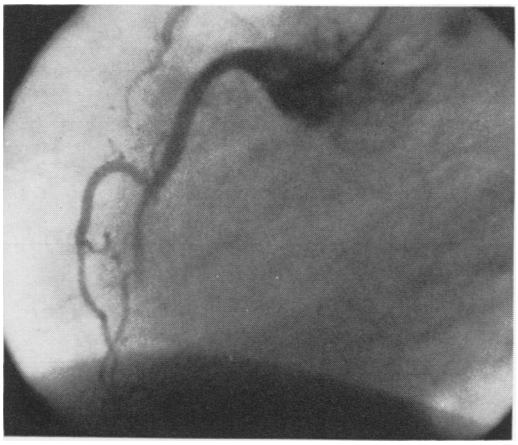

FIG. 7A. Preoperative angiogram demonstrating the total obstruction of the right coronary artery (left anterior oblique projection) in the midportion of the vessel.

eral months after operation from cerebral thrombosis unrelated to the cardiac disease. The other death was due to thrombosis of both saphenous vein grafts within a few weeks after operation, in a manner similar to two patients who died in 1969. Reoperation and regrafting, at which time extensive adhesions with obliteration of the grafts were found, was unsuccessful. In the group of 117 surviving patients, six patients continue to have a slight degree of angina, although greatly decreased in intensity. Only one patient subsequently has had myocardial infarct, which occurred 5 months after operation. The status of the double bypass grafts in this patient is unknown, although they were patent 2 weeks after operation.

In the total group of 129 patients operated upon in 1970, 11 were operated upon principally for symptoms of progressive cardiac failure of severe degree. Three of these who died following operation due principally to continued cardiac failure have been mentioned previously. Two of the 11 remain seriously disabled from continuing cardiac failure with little improvement from bypass grafts which have been demonstrated to be patent on repeat angiography. In the other six patients, significant improvement occurred, but all continue to require careful medical therapy because of symptoms of cardiac failure.

Postoperative Angiography. Postoperative angiograms have been performed at different periods of time in 24 patients following venous bypass grafts (Tables 4, 5, 6, and 7). A total of 37 grafts were inserted in these 24 patients; 31 of the 37 have been demonstrated to be patent. Five were studied between 1 and 2 years after operation, and eight between 8 and 12 months after operation (Tables 4 and 7) (Fig. 7). It was noteworthy that on elective postoperative angiography no patient was found to have thrombosed both double bypass grafts. This occurred in three patients within several weeks after operation. All three died within a short period of time, despite reoperation in two of the three. Occlusion of one of two grafts inserted was found in five patients (Table 4).

Postoperative angiograms were performed in 21 patients at varying periods of time after internal mammary-left coronary anastomoses (Table 5) (Fig. 8). Three patients were studied twice (Table 5). The patency

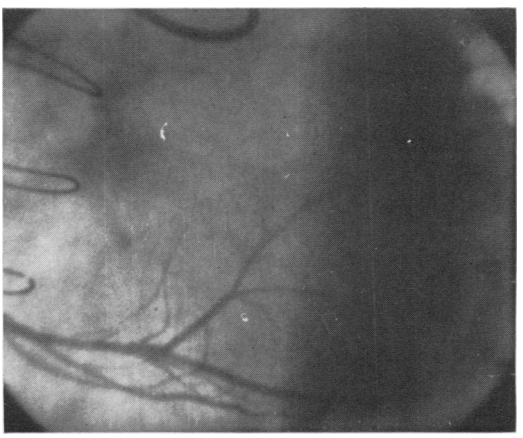

FIG. 7B. Postoperative angiogram in the same patient with opacification of the saphenous vein graft to the distal right coronary artery, demonstrating filling of terminal branches and the posterior descending artery.

rate was surprisingly high, 96 per cent (Table 6). Thirteen of the angiograms were performed within the first 5 months after operation, three in the subsequent 6 months, and eight between 1 and 2 years after operation. The durability of the small internal mammary-left coronary anastomosis has been equally surprising and encouraging.

Discussion

Criteria of Operability and Inoperability. The results indicate clearly that a bypass graft is technically feasible in the majority of patients with occlusive disease of the coronary arteries. The operability rate probably is greater than 90 per cent, especially if operative magnification is employed to perform anastomoses to vessels as small as 1 mm. in diameter.[5] Similar conclusions regarding operability have been reported by Johnson and Morris.[9, 12] Berger has recently described a postmortem study of 300 hearts with coronary atherosclerosis in which patent segments were found distal to the area of obstruction in between 80 to 90 per cent of patients, varying with the extent of obstruction present.[1] Similar findings in a smaller series were reported earlier by Green.[7, 14] The implications of this astonishingly high operability rate are far-reaching, for it is estimated that, at present, at least 20 per cent of American males develop myocardial infarction before 60 years of age.

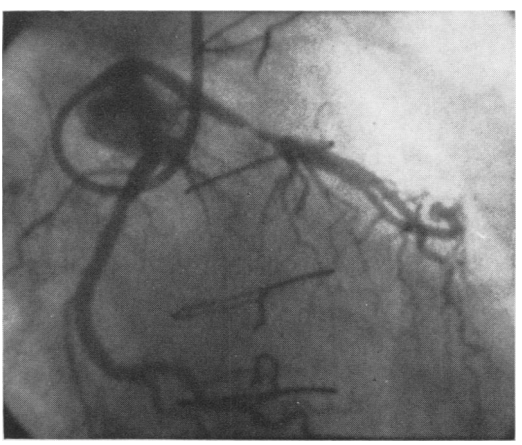

FIG. 7C. Preoperative angiogram of the left coronary artery (right anterior oblique projection) demonstrating severe obstruction in the proximal left anterior descending artery with poor filling of the distal segment.

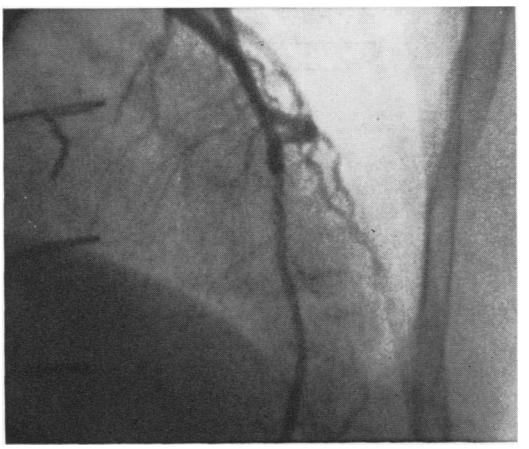

FIG. 7D. Postoperative study of the same patient demonstrating the saphenous vein bypass graft to the left anterior descending artery. There is excellent runoff into the distal portion of the vessel.

The fact that bypass grafts are technically feasible in the vast majority of patients with coronary artery disease creates a serious question of indications and contraindications to operation. Until more long-term data are available, operation should be restricted to those with serious symptoms, such as progressive angina, multiple myocardial infarctions, or early symptoms of congestive failure. Decisions concerning operation is greatly influenced by the location of the coronary disease. Symptoms associated with severe stenosis of a major coronary artery, with the likelihood of occlusion and infarction in the near future, is a far more urgent indication for operation than similar symptomatology in a patient with multiple areas of occlusion in small coronary tributaries.

Contraindications to operation are yet being determined. Excluding the small

TABLE 4. *Postoperative Angiograms in 24 Patients after Venous Bypass Grafts*

No. Patients	Time of Study	Results
5	1–2 years	4 patent; 1 of 2 grafts occluded in 1 patient
8	6–12 mos.	6 patent; 1 of 2 grafts occluded in 2 patients
11	0–6 mos.	8 patent; 1 single graft occluded; 1 of 2 grafts occluded in 2 patients
Total patients: 24 Total grafts: 37		Patent: 31 (84%)

TABLE 5. *Twenty-four Postoperative Angiograms in 21 Patients after Internal Mammary-Left Coronary Anastomosis*

No. Patients	Time of Study (Months)
2	24
1	18
5	12
1	9
2	6
4	4
6	3
1	2
2	0.5

23 of 24 anastomoses patent (96%)
3 patients studied twice.

TABLE 6. *Postoperative Angiography*

Type of Graft	No. Grafts	Patency Rate (%)
Internal mammary	24	96
Saphenous vein	37	84

TABLE 7. *Postoperative Angiography* (Time of Study)

Type of Graft	0–5 mos.	6–11 mos.	1–2 yrs.
Internal mammary	13	3	8
Saphenous vein	11	8	5

number of patients in whom the location of the occlusive disease makes the bypass operation unattractive, the strongest contraindication is extensive destruction of left ventricular muscle. This is seen most prominently with advanced congestive failure, often refractory, with an end diastolic pressure of 20 to 40 mm. Hg. On ventriculography contractility in such ventricles is greatly impaired. At operation multiple areas of scarring from numerous myocardial infarctions are found. Although more data are needed, it is clear that improvement following operation is limited. In those with extensive destruction of muscle and intractable congestive failure, cardiac homotransplantation is probably the only possible therapy, especially when further advances in immunology make control of the rejection process more certain. Hopefully, in many patients earlier operation may forestall such extensive destruction of left ventricular muscle.

Emergency Operations for Pre-infarction Angina? With the recognition that the majority of patients with severe angina have obstruction of a major coronary artery which can be treated with a bypass graft, the emergency evaluation of patients with so-called "pre-infarction angina" becomes of increasing importance. The ability to delineate a severe form of angina pectoris associated with a grave risk of myocardial infarction within hours or days is necessary. In such patients, a logical form of therapy currently being evaluated by several groups, including our own, is the performance of emergency angiography, followed by immediate bypass grafting if a major area of obstruction is found. This approach assumes even greater importance because of the fact that operative procedures performed once myocardial infarction *has occurred* have thus far been associated with a very high mortality, despite excision of the area of infarction and bypass grafting. Hopefully the intense studies currently

being performed by several groups will develop an effective form of surgical therapy even for those patients with established myocardial infarctions.

Operative Mortality. The operative mortality has remained near 10 per cent in this series, principally from liberal inclusion of patients with cardiac failure and destruction of left ventricular muscle. Such seriously ill patients have been operated upon to determine the limits of operability for this disease. From the data now available, it seems probable that patients with severe cardiac failure and extensive destruction of left ventricular muscle may be operated upon with a mortality between 10 and 20 per cent, but the degree of improvement is limited and may be negligible in some. Patients with simple angina pectoris, a left ventricle of normal size, normal contractility, and normal end diastolic pressure belong in an entirely different category and should be reported separately. The risk of operation in such patients is surprisingly small, well under 5 per cent.[3, 10, 11, 16] In this group the principal factor influencing mortality is the extent of the occlusive disease, involving one, two, or three major coronary arteries. This unexpected low mortality almost surely is due to the immediate improvement in coronary blood flow to ischemic myocardium. This corresponds well with the decrease in end diastolic pressure in some patients from 20 to 30 mm. Hg before operation to 10 to 20 mm. Hg immediately after operation, despite the trauma from an operative procedure several hours in duration.

An important influence on operative mortality separate from the extent of the coronary disease existing before operation, is precise postoperative care. As described earlier, the essential features are maintenance of an adequate cardiac output, adequate ventilation, and constant monitoring to detect arrhythmias. Because of the constant threat of arrhythmias, constant observation of the cardiac rhythm on an oscilloscope 24 hours a day, similar to the management in a coronary care unit following a myocardial infarction, is essential. With such vigilance, arrhythmias may be promptly detected and treated. Hopefully further studies in this area will permit more effective prevention of arrhythmias which currently occur with astonishing frequency.

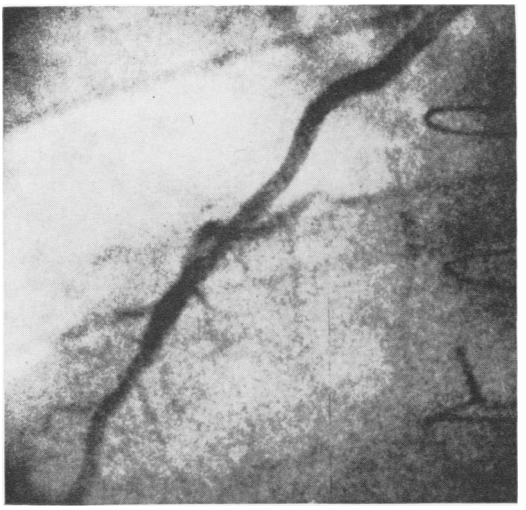

FIG. 8. Postoperative angiogram demonstrating an internal mammary-anterior descending coronary artery bypass at one year after operation. The vessel sizes can be seen to be similar. There is good runoff to the distal vessel as well as retrograde flow to the point of obstruction proximal to the anastomosis.

Long-Term Patency of Bypass Grafts. The most important question at present is the patency of bypass grafts 1, 2, and 3 years following operation. The patency rate of 84 per cent in the 37 venous grafts studied by angiography in this series is similar to the early patency rates reported by other groups.[9] However, in this series eight grafts were studied between 6 and 12 months after operation, and only five more than a year after operation. Although the numbers are much too small to be significant, the absence of any chronic changes in vein grafts studied to date, such as progressive stenosis, is encouraging. Within the next 2 years, the patency rates 1 to 3 years

after bypass grafting should become well defined, and will greatly help resolve the current indecision about indications and contraindications to operation.

An important technical point is the fact that occlusion of a venous graft may occur from several causes. This has been clearly evident from our own observations as well as experiences reported by others. Early occlusion may result from anastomosis to a small, diseased coronary artery, 1–2 mm. in diameter, following which the rate of blood flow is too small to prevent thrombosis. Exactly what rate of flow is "too small" is not certain, but may be in the range of 15 to 25 ml./min. A second cause of obstruction of a graft can evolve in the first few weeks following operation when dense pericardial adhesions may compress, kink, and obstruct a functioning graft. This clearly has occurred in at least three of the patients described in this series and most probably in a fourth; in each instance occlusion of both bypass grafts occurred with resulting severe angina, quickly progressing to death within a few days despite reoperation in two patients. The rapidity of development clearly was indicated by the course of the other two patients, both of whom promptly were readmitted to the hospital for study but succumbed before angiograms were performed. The cause of such extensive pericardial adhesions, in the absence of gross infection, is uncertain. An important point for laboratory investigation is whether a bypass graft is best left lying freely in the pericardial cavity or whether the pericardium should be incised, or excised, and the grafts surrounded by adjacent mediastinal fat.

Finally, late occlusion of grafts may occur from progression of coronary atherosclerosis or simply from proliferation of intima at the site of either the aortic or coronary anastomosis. Undoubtedly, turbulent blood flow occurs where the vein graft is attached to the aorta. The degree of turbulence may be influenced by the angle at which the graft is connected, varying from an acute to a right or even an obtuse angle. This point is entirely theoretical at present. At the distal anastomosis the discrepancy in size between the large saphenous vein and the small coronary artery also creates turbulent flow of blood. To date progressive stenosis at the distal anastomosis has not been recognized on serial angiograms, but this remains an uncertain point.

In this regard a critical question is the long-term difference in patency between internal mammary-coronary anastomoses and venous-coronary anastomoses. As shown in Table 6, postoperative angiograms have found the surprisingly high patency rate of 96 per cent in 24 anastomoses studied, eight of which were studied more than one year after operation. Whether the high patency rate is due to the use of an artery rather than a vein as a graft, or to a better match between the size of the two vessels is uncertain. This area remains, however, an important one for future study.

To recapitulate, the fact that the ideal method for bypass grafting is yet uncertain should be emphasized. The leading technical questions are the method of performance of the anastomosis between the aorta and the saphenous vein, whether the saphenous vein should be left freely in the pericardial cavity or not, and the relative merits of the internal mammary artery as compared to the saphenous vein.

Influence of Bypass Grafts on Coronary Artery Disease. The data described in this report, as well as reports from several other groups, indicate that bypass grafting promptly and effectively relieves angina in the majority of patients. Persistence or recurrence of angina has almost always been found due to either occlusion of a previously inserted graft or to coronary disease in other major coronary arteries which were not grafted initially. With the diffuse distribution of coronary disease in the majority of patients, a double graft will

usually be needed. How often a triple bypass will be required is yet being determined, but clearly triple bypass grafts can be performed with a low mortality (Table 3).[4]

The most crucial question for the future is whether *any patient* will die from coronary disease in whom double bypass grafts are functioning adequately. Death may, of course, occur if the bypass grafts become occluded, but to date in this series no cardiac death has yet occurred in a patient in whom two bypass grafts have been inserted and have remained patent. This question is perhaps most important in determining the long-term role of bypass grafting for coronary arterial disease.

Summary

1. Between February 1968 and November 1970 a total of 195 patients were treated with bypass grafts for occlusive disease of the coronary arteries. Operation has been feasible in over 90 per cent of patients with severe coronary disease. Most operative procedures were performed for severe angina pectoris, but in the past year several patients were operated upon for refractory congestive heart failure. A single bypass was performed in 80 patients, a double bypass in 107, and a triple bypass in eight. The internal mammary artery was used for anastomosis in 67 patients, usually to the left anterior descending coronary artery. The saphenous vein was used for the other anastomoses. Additional operative procedures, such as excision of a myocardial scar or ventricular aneurysm, mitral annuloplasty, mitral, aortic, or tricuspid valve replacement, were performed in 15 to 20 per cent of patients.

2. The overall operative mortality has remained near 10 per cent, principally from liberal inclusion of patients with extensive destruction of left ventricular muscle and advanced congestive failure. Operative mortality for single bypass procedures was 5 per cent for 67 patients in 1969–1970, and 11 per cent for 103 patients with double bypass grafts. The risk of operation has been related principally to the presence of left ventricular failure before operation as well as the extent of the coronary occlusive disease.

3. Nine late deaths have occurred in the 175 patients discharged from the hospital Two of the nine deaths were unrelated to coronary artery disease. The other seven deaths were all associated with inadequate bypass grafts. They resulted from thrombosis of double bypass grafts or from left coronary atherosclerosis in patients in whom only the right coronary artery had been operated upon. It is significant that *no* deaths have occurred in patients with functioning double bypass grafts.

4. Angina pectoris in the majority of patients operated upon (85 to 90%) has either disappeared or is of minimal severity. Recurrence of severe angina has almost always been associated with occlusion of a graft or progression of disease in a patient originally treated with a single bypass graft. Severe cardiac failure has been improved in some patients with bypass grafting, but others have shown little benefit. The value of bypass grafting for severe congestive heart failure with extensive destruction of the left ventricle is yet uncertain.

5. Thirty-seven venous grafts have been studied in 24 patients at varying periods of time following operation, finding a patency rate of 84 per cent. Five of the grafts were studied between 1 and 2 years following operation. Twenty-four angiograms were performed following internal mammary anastomoses, finding a patency rate of 96 per cent. Eight of these were done between 1 and 2 years following operation.

6. Two important future questions are the long-term patency of bypass grafts, comparing venous and arterial grafts, and the protection from myocardial infarction and death afforded by functioning bypass grafts.

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