Changes in Maximal Exercise Performance in the Evaluation of Saphenous Vein Bypass Surgery

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SUMMARY
To evaluate the improvement in myocardial oxygen delivery following saphenous vein graft surgery (SVG) for angina pectoris (AP), 46 patients underwent a multistage treadmill test of maximal exercise capacity before and 3–22 (average 8) months after SVG. Variables from exercise testing were correlated with symptomatic response, left ventricular hemodynamics, and graft patency.

Functional capacity (NYHA) improved in 38 (85%), while 27 (59%) had a significant improvement in exercise performance. Functional aerobic impairment (FAI), or the percentage deviation from expected VO\textsubscript{2 max}, improved by a mean of 16% ($P < 0.001$). Maximal systolic pressure-rate product/100$^2$ increased 36 ($P < 0.002$). Twenty of 29 (66%) with presurgical S-T segment depression had a normal response after surgery.

Thirty-three patients were studied for graft patency and had quantitative angiography. Seventeen had all grafts patent and demonstrated a mean improvement of 21% in FAI ($P < 0.0007$). Those with occluded grafts showed no improvement in exercise performance. Sixteen of 22 (73%) with severe exercise impairment showed significant improvement, but only four of 14 (29%) with mild impairment showed a significant improvement. There were no mean changes in left ventricular end-diastolic pressure, cardiac index, contraction plot, or systolic ejection fraction (SEF) in any of the patients. Preoperatively nine had a depressed SEF (<50%), and no improvement in exercise performance could be demonstrated.

Maximal treadmill testing has demonstrated objectively that SVG can improve functional capacity and that it is correlated with graft patency. Ideal surgical candidates appear to be those with severe exercise impairment and unimpaired ventricular performance.

Additional Indexing Words:
Coronary artery disease, Coronary artery surgery, Angina pectoris, Treadmill testing, Coronary arteriography, Left ventricular function

Reports on the use of saphenous vein autografts from the ascending aorta to the coronary arteries claim symptomatic relief from angina pectoris (AP) in patients with severe coronary atherosclerotic disease.\textsuperscript{1–4} At present, the principle indication for surgery is chronic disabling AP. Although surgery has been claimed to cause symptomatic improvement in most patients and has been shown to cause hemodynamic improvement in some selected cases,\textsuperscript{4–6} there have been few studies that use objective end points to assess improvement in a series of patients.

If saphenous vein graft surgery (SVG) does indeed improve myocardial oxygen delivery and relieves angina, then patients limited by angina preoperatively should demonstrate improved exercise performance postoperatively. In addition, the improvement in exercise performance should correlate with the disappearance of ischemic S-T segment changes in the exercise electrocardiogram and should correlate with graft patency.

In this study, we examine the changes in maximum exercise performance in patients who have undergone SVG, to define objectively changes attributable to surgery. Forty-six patients underwent a multistage treadmill test of maximal exercise capacity\textsuperscript{7–20} before and 3–22 months after SVG. Variables from exercise stress testing, including...
maximal pulse rate, blood pressure, functional aerobic impairment (FAI), and S-T segment changes, were correlated with symptomatic response, left ventricular hemodynamics, and graft patency.

Methods

Patient Characteristics

Forty-six patients, 44 male, two female, ages 37–62 years, mean age 50.8 years, were studied prior to elective saphenous vein bypass surgery; all had stable, chronic disabling AP. None of the patients had associated aneurysmectomy or valve replacement. These 46 patients are 92% of the survivors of 60 consecutive operative cases of which seven were operative deaths, three died later prior to study, and four refused reevaluation. The only other criterion for selection was that these patients consented to pre- and postoperative evaluation.

Postoperative studies were performed at 3–22 months (mean 8 months) in order to allow adequate time for recovery from surgery. All patients had stress testing; 33 also had postoperative cardiac catheterization to determine LV function, and selective angiography to determine the patency of the vein bypasses and coronary arteries.

Postoperative medical management was determined on an individual basis. Patients were urged to resume activities as tolerated; only one patient entered a supervised exercise training program.

Clinical Evaluation

Clinical parameters which were evaluated included: pre- and postoperative assessment of functional classification (NYHA), presence of congestive heart failure as determined by symptoms as well as physical examination, and diagnosis of myocardial infarction before and after surgery as determined by compatible history, appropriate enzyme changes, and electrocardiographic Q-wave development. The intraoperative diagnosis of myocardial infarction was based solely on the development of Q-wave criteria for infarction.

Exercise Testing

After a standard electrocardiogram and measurement of resting pulse and blood pressure were obtained, a multistage treadmill test of maximal exercise capacity was performed. Patients exercised until they felt compelled to stop because of angina, dyspnea, or other symptoms. During rest, exercise, and recovery they were continuously monitored by electrocardiogram, and S-T segment changes were recorded. Maximum blood pressure, heart rate, and computed maximum pressure-rate product/100 were obtained. Functional aerobic impairment (FAI), or the percentage deviation from expected maximum oxygen consumption, was derived nomographically from the standardized treadmill protocol on the basis of exercise duration and corrected for age, sex, and habitual physical activity as described by Bruce.9,10

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\text{FAI\%} = \left( \frac{\text{Predicted } \dot{V}_O_{2\max} - \text{Estimated } \dot{V}_O_{2\max}}{\text{Predicted } \dot{V}_O_{2\max}} \right) \times 100
\]

The maximum oxygen consumption achieved during exercise may be estimated by the formulae:

In men, \( \dot{V}_O_2 = 8.38 + 2.94 \) (min exercise)

In women, \( \dot{V}_O_2 = 8.05 + 2.74 \) (min exercise)

Angiocardiography

All studies were done with the patients at rest in the supine position, after an intramuscular injection of Valium® (diazepam). Aortic and left ventricular pressures were measured with a fluid-filled catheter-manometer system. All pressures were obtained prior to ventriculography. Either left ventricular biplane, 12 frame/sec filming or single-plane, 60 frame/sec cine filming was performed after injection of 50–60 ml Renovist® (sodium diatrizoate and meglumine diatrizoate). Left ventricular volumes were calculated, using the volume-area method of Dodge. The stroke-volume (SV) was derived by subtracting the end-diastolic volume (ESV) from the end-diastolic volume (EDV), and the systolic ejection fraction (EF) was obtained by using the formula \( \text{EF} = \text{SV}/\text{EDV} \). The cardiac index was calculated from the product of the SV and heart rate divided by body surface area.

Contraction-pattern analysis was performed by drawing and bisecting the longest axis of the end-diastolic film and of the end-systolic film and superimposing the bisected lines of the two films. Contraction-pattern abnormalities were graded: 1 = normal or borderline abnormal; 2 = localized contraction abnormality (<50% of LV involved by akinesis or hypokinesis); 3 = diffusely abnormal (>50% of LV involved by akinesis or hypokinesis); 4 = dyskinesis (definite paradox motion of > 25% of LV wall).12

Selective coronary arteriography and selective catheterization of the vein bypass graft was performed after left ventricular angiography by either the method of Judkins or of Sones. Proximal coronary vessels were graded: normal; <50% stenosis; >50% stenosis, or occluded. Vein grafts were judged as patent or occluded.

Surgery

Reversed autologous saphenous veins were grafted from the ascending aorta to the coronary artery beyond the stenotic lesion, using cardiopulmonary bypass. Early in our series, this anastomosis was completed without ventricular fibrillation or ischemic arrest. At the present time, ventricular fibrillation and aortic cross-clamping are utilized to facilitate the vein-artery anastomosis. The 46 patients received 72 grafts; there were 26 single grafts, 14 double grafts, and six triple grafts.

Data Analysis

Changes in left ventricular end-diastolic pressures (LVEDP), systolic ejection fraction (SEF), cardiac index (CI), maximum heart rate, maximum systolic pressure, maximum pressure-rate product/100, and...
functional aerobic impairment were tested for statistical significance using the Student paired \( t \) test. Severity of functional aerobic impairment (FAI), using 13% as one standard deviation, was adapted from Bruce et al.\(^{10}\) In this study, we considered a change of more than 13% in FAI a significant change. S-T segment depression of 0.1 mv during maximal exercise or recovery was felt to be significant and indicative of myocardial ischemia.

Results

Clinical Profile

When asked, 39 of the 46 patients (85%) felt they had improved symptomatically, while six felt no different, and one felt worse than before surgery. Seventeen are now rated NYHA class I, and 21 are class II (fig. 1). Eighty-three percent improved at least one classification, and 30 (65%) reported complete relief from their angina pectoris (fig. 2).

Twenty-six of the 46 had had a myocardial infarction prior to surgery. Seven patients (15%) developed a myocardial infarction between the time of surgery and discharge from the hospital. Three of the infarctions occurred among the group who had had a prior myocardial infarction (fig. 2).

Three patients had symptoms of congestive heart failure preoperatively, which were not changed by surgery, and two additional patients developed congestive heart failure. Three patients had murmurs and angiographic evidence of mitral regurgitation; these were unchanged by surgery (fig. 2).

Changes in Exercise Performance

All but two patients had preoperative exercise stress tests. The two who did not were New York Heart Association class IV and were unable to start exercise without precipitating angina. All 46 had postoperative treadmill stress testing.

Highly significant improvement was noted in the group as a whole (table 1). Functional aerobic impairment improved by 16% from a preoperative mean of 50% to a postoperative mean of 34%, \( P < 0.001 \). Maximum pressure-rate product/100 also showed a significant improvement of 36 units \( P < 0.002 \) (fig. 3). Postoperatively, there were 13 patients with normal FAI and 18 with only mild impairment, as opposed to three and 11 respectively, preoperatively. Twelve of these with normal or mild aerobic impairment postoperatively had been in the group with severe functional aerobic impairment before surgery. FAI improved a significant amount in 29 (59%) patients (fig. 4).

Evaluation of S-T segment changes induced by exercise on the treadmill showed that 32 (73%) had S-T segment depression of 0.1 mv or more before surgery; only 12 retained it after surgery. One patient who did not have S-T segment depression preoperatively developed it after surgery with an improved test. He did not have an intraoperative infarction and angiographically one graft was patent and one occluded. Six subjects were on

![Figure 1](http://circ.ahajournals.org/)

*Changes in New York Heart Association classification after saphenous vein graft surgery.*

![Figure 2](http://circ.ahajournals.org/)

*Changes in clinical parameters after saphenous vein graft surgery. MI = myocardial infarction; CHF = congestive heart failure; MR = mitral regurgitation.*

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Changes after saphenous vein graft in cardiovascular responses to exercise. FAI% = percentage functional aerobic impairment; Max P · R/100 = maximal pressure-rate product/100.

digitalis and S-T segment changes could not be evaluated (fig. 5). The four patients noted to have cardiac arrhythmia with exercise postoperatively were the one patient with preoperative atrial fibrillation, one who developed intermittent QRS prolongation, and two who developed three successive PVCs during exercise or recovery.

Whereas 38 (85%) had chest pain consistent with angina pectoris at the time of exercise testing as their limiting symptom before surgery, only nine (20%) were limited by chest pain after surgery. Again, only one patient who was not limited by chest pain on the treadmill before surgery became limited by pain after surgery at a decreased performance level. He had had no infarction but one of the two grafts was occluded. Other limiting symptoms were: dyspnea in 15 patients, eight of whom had improved performance; one instance of claudication with improved performance, and in 21 fatigue or leg weakness, a usual response to maximal exertion (fig. 6).

Factors Influencing Improvement

Graft Patency

Patent vein grafts were clearly associated with improved exercise performance. The 33 patients who had a postoperative cardiac catheterization were subdivided by graft patency to determine the effects of successful vs unsuccessful surgery on
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Figure 4
Change in functional aerobic impairment after saphenous vein graft surgery. Each 13% equals 1 SD from normal.

Figure 5
Changes in electrocardiographic responses to exercise after saphenous vein graft surgery.

Figure 6
Changes in the limiting symptoms with exercise after saphenous vein graft surgery.

functional improvement and hemodynamic variables (table 1, fig. 7). Postoperatively, 17 patients had all grafts patent, seven had some grafts patent, and nine had all their grafts occluded. Seventy-three percent of the patients had at least one patent graft. There were 33 patent grafts and 18 occluded grafts, for a graft patency rate of 66%.

The 17 patients with all patent grafts had a highly significant improvement in FAI, with a mean improvement of 20% (P < 0.0007). Maximum pressure-rate product/100 improved by mean of 51 (P < 0.003). Maximum heart rate similarly improved. Of these 17 patients, 11 (65%) had an improvement in FAI of more than 13%, while six had no significant change. Of these six, one patient's FAI was normal prior to surgery, one had a severely depressed ejection fraction of 28% preoperatively, and four had a myocardial infarction in the intraoperative period. In spite of patent grafts, no significant changes were noted in maximum systolic pressure or in the hemodynamic variables of left-ventricular end-diastolic pressure, systolic ejection fraction, or cardiac index.

In the seven subjects who had at least one patent graft and at least one occluded graft, no mean significant changes were noted in any of the exercise hemodynamic variables. Three people showed an improvement in FAI > 13%, four showed no significant change.

All the grafts were occluded in nine patients, seven of whom had had only one graft. In this group, there was no evidence of significant improvement in exercise parameters, or in LVEDP, SEF, or CI. Five showed no change in FAI; two
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had significant deterioration in FAI and had associated myocardial infarctions. One patient with an occluded graft has an improved FAI but still has angina and S-T segment depression. One patient with occluded grafts and a myocardial infarction is now asymptomatic and shows significant improvement in FAI.

**Functional Aerobic Impairment**

The degree of improvement in exercise performance was directly proportional to the degree of preoperative impairment. Preoperatively, 22 patients had severe impairment (FAI > 54%), 16 (73%) of these patients had a significant improvement of more than 13% in FAI. Two others improved between 10 and 13%. Seven of 10 patients (70%) with moderate impairment of FAI showed a significant improvement in FAI, but of the 14 cases with no or mild impairment in FAI, significant improvement was demonstrated in only four. Two of these four had all grafts patent, and the graft status of the other two is unknown. In the 10 cases with no or mild impairment before surgery who failed to show significant improvement in FAI, there were four who had all grafts patent and two with at least one patent graft.

Only two patients in the series showed significant deterioration in FAI. These were referred to earlier as having both occluded grafts and intraoperative myocardial infarction.

**Systolic Ejection Fraction**

Patients with preoperative impairment of ventricular function did not show significant improvement in exercise performance. Thirty-three patients had preoperative angiograms which were satisfactory for assessment of systolic ejection fraction. In 24 patients, SEF was > 50% and in nine it was < 50%. Those whose ejection fraction was normal preoperatively had a mean improvement in FAI of 18% (P < 0.001) and maximum pressure-rate product/100 improved by a mean of 39 (P < 0.0001), and a similar improvement in maximum heart rate (fig. 8). Other variables did not change significantly.

The nine patients with abnormal ejection fractions as a group had no significant improvement in exercise performance or in hemodynamic variables. Two patients had improvement in their ejection fractions, one from 28 to 47% with all grafts patent, and one from 43 to 51% with two of three grafts patent. Nevertheless, neither had a significant improvement in FAI. Three of the nine patients had a significant improvement in FAI, one of whom had no change in ejection fraction, and two in whom the postoperative ejection fraction is unknown.

SEF decreased in 10 patients, of whom three, all with patent grafts, showed improved FAI. Six, four of whom had patent grafts, had no change in FAI. One of the four with patent grafts had an intraoperative myocardial infarction. Thus changes in postoperative ventricular function had little relationship to changes in postoperative exercise performance.

**Contraction Pattern**

Normal contractile patterns were associated with greater exercise improvement. Thirty-two patients had matched pre- and postoperative contraction plots available. Of these, 22 remained the same, seven deteriorated, and three improved (fig. 9). These changes could not be attributed to differences in time of follow-up, 8 months for those deteriorating, and 9 months for those improved. Five of seven with deterioration of contraction plot had an intraoperative myocardial infarction.
Figure 8
Changes after saphenous vein graft surgery in functional aerobic impairment in terms of normal and abnormal preoperative systolic ejection fraction. SEF > 50% = normal systolic ejection fraction; SEF < 50% = abnormal systolic ejection fraction; FAI% = percentage functional aerobic impairment.

Thirty-one patients had normal or borderline abnormalities of contraction, preoperatively. FAI improved by a mean of 14% \((P < 0.0003)\) and maximum pressure-rate product/100 improved by a mean of 35 \((P < 0.002)\) in these 31 patients.

Prior to surgery, seven patients had localized abnormalities (grade III) of their contraction plot and failed to show a significant mean improvement in exercise performance after surgery. Three improved their FAI, three showed no change, and one deteriorated.

The three cases with either diffuse hypokinesia (grade IV) or dyskinesia (grade V) demonstrated two with significant improvement in FAI and one without change.

Myocardial Infarction in the Intraoperative Period
Myocardial infarction occurred in seven patients during the intraoperative period. There were no significant mean changes \((P > 0.05)\) in the hemodynamic or exercise variables in this group. However, three patients showed a significant improvement in FAI, two of whom had all grafts patent, and one had all grafts occluded. Two of the
patients with patent grafts and infarction had no change in FAI. In two with occluded grafts and infarction, FAI deteriorated significantly. There were no mean significant changes in LVEDP, SEF, or CI. No relationship was found between intraoperative myocardial infarction and subsequent S-T changes with exercise.

Discussion

Evaluation of surgery for the treatment of angina pectoris is a difficult task; the multiplicity of factors such as bed rest after surgery, subsequent myocardial damage, and patient and physician desire for improvement complicate all attempts to evaluate this method of treatment. Numerous procedures, including sham operations, are reported to cause symptomatic improvement in 80-90% of patients with angina pectoris. Indeed, 85% of our patients reported symptomatic improvement; however, in only 50% could this improvement be objectively documented by function testing. If relief of angina is to be used as a criterion for assessing the success of SVG, then the patient's assurance that he feels an improvement should be supported by objective improvement in cardiovascular function. Although postoperative arteriography verifies the patency of vein grafts, it is not a quantitative test of functional improvement. For these reasons, a multistage treadmill test of maximal exercise capacity was employed as an objective measure of the functional results of saphenous vein graft surgery.

Analysis of maximal exercise test results takes into consideration several variables related to cardiovascular function. Maximal oxygen consumption ($\dot{V}O_{2max}$) is the product of maximal heart rate, stroke volume, and arteriovenous difference in oxygen content. As FAI is derived from the relationship between predicted and estimated $\dot{V}O_{2max}$ in a given patient, it will be altered by changes in the components of $\dot{V}O_{2max}$. Improvement in myocardial blood flow by SVG should be demonstrable in alterations in maximum HR and maximum SV. Certainly heart rate is improved, but observations from this laboratory (Lapin ES, Murray JA, Bruce RA, Winterscheid L: Unpublished data) suggest that SV is unchanged and arteriovenous difference widens.

The maximum pressure-rate product, a major determinant of myocardial oxygen consumption, increased in the presence of patent grafts and improved performance while evidence of myocardial ischemia, angina, and S-T segment depression diminished, suggesting functional effectiveness of the additional myocardial blood flow. Fifty-nine per cent of these patients showed significant improvement in their FAI and pressure-rate product, and a higher percentage lost their S-T segment depression and lost their anginal pain (fig. 10), suggesting relief of myocardial ischemia.

Are these favorable changes in objectivity observed physiologic variables due to some other unapparent intervention? This appears unlikely because repetitive maximal exercise testing gives remarkably consistent results in healthy subjects who are seemingly affected only by age and physical training. In 67 healthy men and women retested hours to days apart, the measured $\dot{V}O_{2max}$ was reproducible with a correlation coefficient of 0.990. The placebo effect of surgical therapy likewise appears to be an unlikely explanation, for this was not noted in the patients of this series whose grafts were found all to be occluded or following internal mammary artery implantation operations in similar patients.

The clinical significance of an improvement in FAI of 14%, 1 sd, can be appreciated if this change is translated into oxygen consumption and equated with the physical tasks which may be accomplished. The average patient in our study had a preoperative FAI of 50%, or a maximum $\dot{V}O_2$ of 21 cc/kg/min. Fourteen per cent improvement in FAI increases $\dot{V}O_2$ by 5 cc/kg/min. This amount of O2 consumption allows a person to engage in such occupational activities as light carpentry, painting, welding, driving a truck, or such recreational activities as golf, dancing, doubles tennis, raking leaves, without symptoms, whereas previously these activities would have caused symptoms.

Figure 10

Changes in functional classification subjective and objective data. NYHA = New York Heart Association classification; FAI = functional aerobic impairment; ETT = exercise tolerance test.
Graft patency is a critical factor in improvement. Only the group of patients with all patent grafts had a significant mean improvement in function. As a group, those with some grafts patent had no significant change. Nevertheless, FAI in three improved >13%. Those who failed to improve may have had coronary lesions which were still critical. Unfortunately, there is no way of determining which coronary lesion or combination of lesions are critical ones in any given patient. Nine patients with occluded grafts would be predicted to have derived no benefit from surgery. Eight of nine had symptomatic improvement. Two of these patients were functionally improved, but one still has angina and S-T segment depression while the other is asymptomatic following a myocardial infarction. The other seven are either the same or worse on exercise testing. Only the one patient lost his S-T segment depression.

Optimally, the patients with all grafts patent who did not have an impaired ventricular performance, and who did not have a myocardial infarction subsequent to surgery should demonstrate improved exercise performance; conversely those with all grafts occluded who did not have an intraoperative myocardial infarction to account for change in pain pattern should have no improvement in exercise performance. Twelve of 15 patients with ideal conditions showed improvement on exercise testing while five of six patients with occluded grafts and no myocardial infarction failed to improve. Thus this test of exercise performance was correct 80% of the time in selecting those with good operative result with a specificity of 83%. Similarly, failure to improve exercise performance in the absence of a myocardial infarction should signify at least some grafts occluded with a high degree of specificity. Unfortunately the group of patients with only some grafts patent cannot be screened this way for the reason discussed earlier.

The most sensitive predictor of improvement in our series appears to be the severity of preoperative limitation. Seventy-three per cent of those patients who had a severe (>54%) functional aerobic impairment improved. By comparison, only 29% of those with normal or mild impairment showed a significant improvement. Because there are no data at present to show that SVG prevents myocardial infarction or prolongs life, the major indication for surgery appears to be disabling angina, as assessed by objective testing.

Patients with abnormal left ventricular performance at rest, as manifested by a depressed SEF or by an abnormal contraction pattern, failed to improve after surgery. Our two patients whose SEF improved failed to show a significant improvement in their FAI. Unfortunately, more patients had SEF and contraction patterns that deteriorated than the converse suggesting more myocardial damage occurred than was detected by ECG observations for myocardial infarction.

In spite of an increase in exercise performance in our patients, there were no postoperative changes in LVEDP, cardiac index, contraction pattern, and ejection fraction. This may not be an unexpected finding, since angina pectoris is an exertional syndrome and resting values are normal or only mildly abnormal in most patients. Those patients whose hemodynamic values were abnormal failed to demonstrate improvement in either the hemodynamic or exercise variables. It has been shown by others that patients with congestive heart failure fail to improve with SVG. Indeed, the more severe the pump failure as manifested by widened A-Vo2 difference and depressed ejection fraction, the higher the operative mortality. Therefore, SVG surgery appears to offer little to those patients with poor ventricular performance.

Age appeared to be no contraindication to surgery although we did not offer surgery to anyone over the age of 65. Those over the mean age of 51 years preoperatively improved as much as did our younger patients.

The complication rate among survivors is significant. Fifteen per cent (seven) had myocardial infarctions during their hospitalization. Other groups report 8–11% in larger series. This does not necessarily correlate with graft patency. Of those studied, three had all grafts occluded and two had all patent; three of these subjects had significant progression of exercise limitation. Our late graft closure rate of 33% is similar to that of other authors reporting 32% in a group of 88 patients and 22–27% in a group of 317 patients.

The question of undergrafting as it affects our results is relevant. Grafts were anastomosed in each patient to patent distal coronary arteries 1 mm in diameter and larger. Multiple grafts to the same vessel were not done, and no patient had more than three grafts. Perhaps a more aggressive approach with more than three grafts and multiple grafts into the same vessel would have improved our results.

Multistage maximal treadmill testing before and after surgery has demonstrated objective data that aortocoronary vein bypass grafting can improve functional capacity and that it is correlated with...
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graft patency. The magnitude and extent of improvement is greater than the results of internal mammary artery implantation using similar testing.\textsuperscript{16, 17} Ideal patients appear to be those with a severe exercise impairment, but without evidence of impaired ventricular performance manifest by congestive heart failure, depressed ejection fraction, or abnormal left ventricular contraction pattern. Those patients without significance exercise limitation obviously cannot improve and there is no evidence to suggest that SVG prolongs life or prevents infarction. Depressed ventricular performance and graft occlusion appear to interfere with postoperative improvement.

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