Accuracy of Serial Myocardial Perfusion Scintigraphy with Thallium-201 for Prediction of Graft Patency Early and Late After Coronary Artery Bypass Surgery

A Controlled Prospective Study


SUMMARY To assess the accuracy of serial myocardial perfusion scintigraphy with thallium-201 (201TI) to predict graft patency early and late after coronary artery bypass surgery, rest and exercise 201TI and coronary arteriography were performed preoperatively and 2 weeks and 1 year after operation. The scintigraphic results were compared with graft patency, symptoms, left ventricular function and physical work capacity in a consecutive series of 55 patients with a total of 154 grafts. Serial 201TI had an 80% sensitivity, 88% specificity and 86% overall accuracy in detecting or excluding graft occlusion, which was predicted by reversible ischemia as well as persistent "new scar" segments. Occluded grafts were correctly localized by 201TI scintigraphy in 61%. Postoperative apical 201TI defects were frequent (two-thirds of cases), and were the result of intraoperative transapical venting of the left ventricle. After coronary bypass graft surgery, ejection fraction at rest was unchanged. Left ventricular end-diastolic pressure and physical work capacity improved significantly. In the presence of new perfusion defects detected postoperatively, physical work capacity was reduced significantly. New 201TI defects in addition to typical or atypical angina provided a high probability of graft occlusion, while in the absence of new 201TI defects all grafts were patent in more than 90% of patients, all of whom had no or only atypical chest pain. We conclude that serial 201TI imaging after coronary artery bypass surgery is an accurate noninvasive method that can be used routinely to assess graft function, to localize spatially occluded grafts and to identify patients with a high likelihood of graft occlusion who may need invasive studies.

THE AIM of coronary artery bypass graft surgery (CABG) is to relieve angina, to improve physical performance and to increase longevity.4-8 Since symptomatic improvement after surgery may not only result from restored myocardial perfusion but may be due to perioperative myocardial infarction9,10 or even a placebo effect,11 follow-up studies are needed to assess objectively operative results. Until recently, graft patency and left ventricular function were studied by left-heart catheterization; but in the last few years, studies using noninvasive radionuclide techniques have been reported.12-18 With these methods, myocardial perfusion and function can be studied separately.19-22

To study graft patency, myocardial perfusion imaging with thallium-201 should be suitable because newly perfused areas after surgery should indicate graft patency.14-16 Most investigations of this technique were based on relatively small numbers of selected patients mainly studied for recurrence of chest pain. Therefore, we have set up a controlled, prospective trial to assess the effect of CABG on symptoms, myocardial perfusion and performance in a consecutive series of patients early and late after surgery, to define sensitivity, specificity and accuracy of serial thallium-201 imaging to detect and localize graft occlusion, and to describe the relationship between thallium-201 results and symptoms, physical work capacity and left ventricular function.

Methods

Patient Selection

Between May 1979 and April 1980, a consecutive series of 79 patients younger than 70 years of age underwent CABG at our hospital. Of these, 15 were excluded because of additional valve replacement, four because of aneurysmectomy and two because of severe peripheral artery disease that did not allow repeat coronary angiograms. Two patients died, one perioperatively and one 2 months postoperatively. One other patient developed a severe psychosis and could not be restudied after surgery. The remaining 55 patients formed the study group.

There were 50 men and five women, average age 54.1 ± 8.4 years. Most patients were operated on because of severe angina refractory to medical therapy. Twelve patients had unstable angina or chest pain at rest, 31 patients suffered from New York Heart Association (NYHA) class III angina, 10 had class II angina and two were in NYHA class I and were operated for prognostic reasons. Twenty-six patients had documented previous myocardial infarction.

Study Protocol

The study protocol included determination of a history of angina, clinical examination, upright bicycle ergometry for ECG recordings, thallium imaging and left-heart catheterization. The studies were performed preoperatively and 2 weeks and 1 year postoperatively.
On the average, postoperative studies were performed on days 15 and 373 after surgery (table 1).

Table 1 shows the actual number of investigations performed. Preoperatively, 14 patients had no thallium scans, 12 because of unstable angina that did not allow exercise testing and two because they were referred directly to operation from outside hospitals. Early postoperative thallium studies could not be performed in three patients because of delayed recovery. At 1 year of follow-up, six patients refused to have another left-heart catheterization, but all patients were studied noninvasively. Except for these few cases, follow-up was complete.

Exercise Testing
A symptom-limited, graded bicycle exercise test was used according to a standard protocol as previously described. On an electronically braked ergometer (Elema-Schönander type 369), the work level was increased 25–50 W every 3 minutes without interruption. The ECG was monitored continuously and a nine-lead ECG (limb leads and leads V1, V5, and V6) recorded at rest, at the end of each stage of exercise and after 1 and 2 minutes of recovery. Changes in ECG were considered to be significant if there was horizontal or downsloping ST depression > 1 mV 80 msec after the J point or any ST elevation; in the presence of digitalis or complete bundle branch block, the ECG was considered to be nondiagnostic. In patients who had nonspecific ST-T-wave changes after surgery and who were not receiving digitalis, an additional ≥ 2 mV of ST depression was required to be considered significant. All tests were performed under individually optimized drug therapy. Because of its antiarrhythmic property, digitalis was given routinely in the early postoperative period. Arm cuff blood pressures were measured at rest and at the end of each work level. Physical work capacity was calculated as total work performed, i.e., watts of each work level times minutes at the corresponding level.

Thallium-201 Scintigraphy
Thallium imaging was performed according to a standard protocol. One to 2 minutes before the termination of exercise or with beginning of symptoms, 2 mCi of thallium-201 chloride were injected intravenously. Recordings of early exercise data started within 5 minutes of the end of exercise. The detector of a mobile scintillation camera equipped with a high-sensitivity, parallel-hole collimator was positioned in the 45° left anterior oblique, anterior and left lateral pro-

ecution. During data collection, the patient was supine to allow comparable repositioning between serial studies except for left lateral views, where he was turned on his right side to eliminate diaphragmatic attenuation. Data were acquired up to an information density of 3000 counts/cm2 over the highest activity area of the heart in each view. Ordinarily, 5–7 minutes were required per view. In all patients, 4-hour delayed (resting) images were obtained in identical projections.

Analog images were recorded with a Polaroid camera for the first few studies and on x-ray film for the remaining patients, without contrast enhancement or computer processing. Each pair of exercise-rest scans was interpreted at the end of the entire study period by three experienced observers without knowledge of other clinical or angiographic information as follows: (1) ischemia — one or more distinct perfusion defects in the exercise images not detectable at rest; (2) scar — perfusion defects unchanged between exercise and delayed resting images; or (3) normal — no perfusion defects. Thallium images were divided into nine segments: anterolateral, apical and inferior in the anterior projection; septal, inferoapical and posterolateral in the 45° left anterior oblique projection; and anterior, apical and inferior in the lateral projection. Defects were anatomically localized as follows: anterior wall and septum corresponding to lesions of the left anterior descending coronary artery (LAD), inferior wall to the right coronary artery (RCA) and posterolateral wall to the left circumflex (LCX) coronary artery. Defects located in the anterolateral wall in the anterior view and in the proximal anterior wall only in the lateral view without concomitant septal defects were related to the major diagonal branches of the left coronary artery. All three observers agreed on the overall diagnosis of preoperative scans in 93% and in the three other cases, a consensus was obtained. This final interpretation was used for analysis of the results. Follow-up images were compared with previous scans, and each study was interpreted to show either no change, new perfusion defects or resolution of perfusion defects compared with preoperative studies.

Cardiac Catheterization
Left-heart catheterization was performed by the Judkins technique, and cine films of the coronary arteries were obtained in multiple views. Lesions with greater than 50% luminal narrowing were considered hemodynamically significant. Biplane contrast ventriculography and left ventricular pressure measurements were added routinely. Ejection fraction was calculated according to the method of Dodge. Postoperative evaluation included selective injection of contrast material into the proximal grafts or, in two cases where the grafts could not be located, into the aortic root. In two patients, grafts were considered closed because they could not be visualized or showed critical stenosis.

Statistical Analysis
Results are presented as the mean ± SD, except in figure 4, where the mean ± SEM is presented for
graphic reasons. The t test for paired and unpaired samples were used to compare pre- and late postoperative hemodynamic findings.

Results
Preoperative thallium imaging showed defects in all patients studied. Seventeen patients had only ischemic changes and 20 patients had both transient (ischemic) and persistent (scar) defects. In four patients, only regions of scar were detected. On the ECG, 17 patients had Q waves at rest and 21 of 34 patients developed significant ST-T-wave changes during exercise.

Preoperative angiograms revealed luminal narrowing of more than 50% in an average of 2.5 major coronary arteries per patient. Thirty-two patients had three-vessel disease, 16 two-vessel disease and seven one-vessel disease. The number of vein grafts implanted to achieve revascularization was 2.8 ± 0.95 grafts/patient, for a total of 154 grafts. In addition, five patients had an endarterectomy of the RCA.

All 53 patients with preoperative angina experienced symptomatic improvement. One patient had anginal symptoms 2 weeks after surgery, but at that time it was difficult to differentiate between chest pain due to recent thoracotomy and true angina. At the 1-year follow-up, 11 patients (20%) complained of recurrence of typical angina, though of a lesser degree, and 15 patients were considered to have atypical chest pain. Twenty-nine patients (54%) were pain-free.

Angiographic and Scintigraphic Changes After Surgery
Coronary arteriography showed nine occluded grafts in seven patients 2 weeks postoperatively; at 1 year, 18 occluded grafts were visualized in 15 patients, yielding patency rates of 94% and 88%, respectively. Between early and late follow-up studies, only one patient showed obvious progression of coronary artery lesions distal to a graft and in a nongrafted vessel. The fate of proximal lesions often remained unclear due to larger flow in the graft than in the native vessel.

Thallium imaging two weeks after surgery revealed that in 34 of 37 patients (92%), preoperative ischemic thallium segments were no longer detectable. Figure 1 is an example of rest and exercise scans obtained before and after surgery. While there was a clear ischemic perfusion defect in the first study, this defect was no longer apparent after bypass of the coronary lesions. One patient with an ischemic area detected early after operation had an occluded graft. Two other patients had ischemic defects despite open grafts; in one, the defect corresponded to a nongraftable vessel (incomplete revascularization). In addition, two patients with persistent defects before operation had normal scans postoperatively. Four other patients had new, persistent defects (new scar) compared with preoperative studies (fig. 2). In each, at least one graft was occluded. These findings correlated with electrocardiographic and enzymatic evidence of perioperative myocardial infarction. On the other hand, all grafts were patent in 32 of 34 patients without new perfusion defects.

Small but distinct apical defects at rest and after exercise were found in 35 of 52 patients studied noninvasively 2 weeks after surgery. These findings were not associated with symptoms, signs of perioperative infarction or with abnormal coronary arteriography; they could not be called "normal apical thinning." In a majority of these patients, postoperative ventriculograms showed an apical hypo- or akinesis due to perioperative transapical venting. Analysis of the apical area was therefore excluded in postoperative thallium images.

Two weeks after surgery, only seven patients with normal intraventricular conduction were not on digitalis therapy. None of them showed significant ST-T-wave changes during exercise.

Between 2 weeks and 1 year after surgery, 11 patients developed 13 new defects, i.e., two patients showed both new ischemic as well as new scar defects. In six of eight patients with new ischemic defects and in three of five patients with new scar defects, at least one occluded graft was present. One patient with ischemia due to graft occlusion 2 weeks after surgery had a persistent scar defect in the same area 1 year later. Another patient had new ischemic and scar defects due to rapid progression of coronary disease despite open grafts. In two patients, no obvious reason

![Figure 1. Thallium-201 images immediately after exercise ('exercise') and 4 hours later ('rest') in patient AA before and 1 year after coronary artery bypass graft surgery. Note the anteroseptal and apical ischemia (arrows) preoperatively, which is no longer detectable after surgery in presence of open grafts to the left anterior descending (LAD) and first diagonal (1. DIAG) coronary arteries (snake graft) as well as to the right coronary artery (RCA). Maximal work levels and exercise ECG tracings are shown.](http://circ.ahajournals.org/1019)
One year after CABG, eight patients had ischemic defects; new scar areas were found in five patients. Three additional patients had both ischemic and new scar regions. At least one occluded graft was found in eight of 11 patients with scintigraphic evidence of ischemia and in six of eight patients with new scar areas (fig. 4). Twelve of the 16 patients with new perfusion defects had one or two grafts occluded, resulting in a predictive value of a positive thallium study (new defects) to detect patients with graft occlusion of 75%. On the other hand, only three of 33 patients without new thallium defects compared with previous studies had occluded grafts, yielding a predictive value of a negative thallium study (no new defects) of 91% (30 of 33) and a predictive accuracy of 86% (42 of 49).

Of three patients with ischemic segments without graft occlusion, one had incomplete revascularization (as in the early postoperative study), one had progression of disease as demonstrated by coronary arteriography (ischemic and new scar areas) and one study was considered false positive. Another false-positive result was found in a patient with a new persistent inferior defect. Of six patients without coronary arteriography at the 1-year follow-up, all had patent grafts at early follow-up and none showed new thallium defects at the final study.

One year after surgery, ECGs of 32 patients could be analyzed without drug interference. Three of four patients with new Q waves and two of six with significant ST depression, including one patient with both ECG signs, had at least one graft occluded.

Accuracy in Noninvasive Detection of Graft Occlusion

Based on these results, the sensitivity, specificity and accuracy of thallium imaging for detection or exclusion of bypass graft occlusion could be calculated (table 2). There was a sensitivity of a new perfusion defect (ischemia or new scar) of 80%, a specificity of 88% and an overall accuracy of 86%. If positive thallium scans in patients with incomplete revasculariz-
Patients with open grafts showed a decrease in graft patency over time. Patients with graft occlusion were identified based on clinical symptoms and scintigraphic findings. Eighteen patients had chest pain, and noninvasive localization of occluded grafts was performed using new Thallium-201 imaging. The accuracy of thallium imaging for detecting graft occlusion was evaluated, and the results were compared with those from left-heart catheterization. The table below summarizes the findings:

### Table 3. Combination Symptoms and New Thallium-201 Defects to Detect Coronary Artery Bypass Graft Occlusion (1-year Follow-up)

<table>
<thead>
<tr>
<th>Symptom Combination</th>
<th>n=49</th>
<th>≥1 graft occluded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angina/Tl+</td>
<td>8</td>
<td>7/8 (88%)</td>
</tr>
<tr>
<td>Angina/Tl-</td>
<td>3</td>
<td>1/3 (33%)</td>
</tr>
<tr>
<td>Atyp CP/Tl+</td>
<td>4</td>
<td>3/4 (75%)</td>
</tr>
<tr>
<td>Atyp CP/Tl-</td>
<td>11</td>
<td>1/11 (9%)</td>
</tr>
<tr>
<td>No pain/Tl+</td>
<td>4</td>
<td>2/4 (50%)</td>
</tr>
<tr>
<td>No pain/Tl-</td>
<td>19</td>
<td>1/19 (5%)</td>
</tr>
</tbody>
</table>

Abbreviations: Atyp = atypical; CP = coronary pain; Tl+ = positive thallium scan; Tl- = negative thallium scan.

### Noninvasive Localization of Occluded Grafts

The accuracy of thallium imaging for correct localization of occluded grafts is outlined in Table 4. Of six patients with occluded grafts to the LAD, five had new perfusion defects in the anteroseptal region. Four of these patients with an occluded graft to the RCA had a new defect in the inferoposterior wall. There was only one occluded graft to a marginal branch of the LCx that was not detected in the lateral area. Thus, noninvasive localization of occluded grafts was successful in 11 cases. Six occluded grafts (61%) were correctly localized by thallium scintigraphy.

### Relation Between Postoperative Thallium Imaging and Left Ventricular Performance

Ejection fraction as assessed during left-heart catheterization did not change significantly between measurements before (58.1 ± 13.0%) and 1 year after CABG (57.8 ± 13.8%, NS). Left ventricular filling times were also evaluated, but no significant differences were noted.

### Table 4. Localization of Occluded Grafts by New Thallium-201 Perfusion Defects (1-year Follow-up)

<table>
<thead>
<tr>
<th>Pt</th>
<th>Age (years)</th>
<th>Total grafts</th>
<th>Occluded grafts</th>
<th>New thallium-201 defect localization</th>
</tr>
</thead>
<tbody>
<tr>
<td>EG</td>
<td>58</td>
<td>3</td>
<td>RCA</td>
<td>Inferior</td>
</tr>
<tr>
<td>MK</td>
<td>44</td>
<td>2</td>
<td>RCA</td>
<td>Inferior</td>
</tr>
<tr>
<td>MS</td>
<td>59</td>
<td>3</td>
<td>LAD, Marg</td>
<td>Anteroseptal</td>
</tr>
<tr>
<td>HM</td>
<td>44</td>
<td>3</td>
<td>Diag</td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td>67</td>
<td>4</td>
<td>LAD, RCA</td>
<td>Anterior, posterior</td>
</tr>
<tr>
<td>HS</td>
<td>51</td>
<td>3</td>
<td>Diag</td>
<td>Anterolateral</td>
</tr>
<tr>
<td>AB</td>
<td>57</td>
<td>2</td>
<td>LAD</td>
<td>Anterior</td>
</tr>
<tr>
<td>WL</td>
<td>60</td>
<td>4</td>
<td>RCA</td>
<td>Anterior</td>
</tr>
<tr>
<td>TM</td>
<td>58</td>
<td>5</td>
<td>RCA</td>
<td></td>
</tr>
<tr>
<td>MW</td>
<td>59</td>
<td>3</td>
<td>Diag</td>
<td>Anterolateral</td>
</tr>
<tr>
<td>AZ</td>
<td>67</td>
<td>3</td>
<td>LAD</td>
<td>Inferolateral</td>
</tr>
<tr>
<td>PS</td>
<td>62</td>
<td>3</td>
<td>LAD</td>
<td>Septal</td>
</tr>
<tr>
<td>GM</td>
<td>54</td>
<td>2</td>
<td>LAD</td>
<td>Anterior</td>
</tr>
<tr>
<td>AB</td>
<td>59</td>
<td>3</td>
<td>RCA, Diag</td>
<td>Inferoposterior</td>
</tr>
<tr>
<td>WN</td>
<td>45</td>
<td>3</td>
<td>RCA</td>
<td>Inferior</td>
</tr>
</tbody>
</table>

Abbreviations: Diag = first diagonal branch of the left coronary artery; LAD = left anterior descending coronary artery; Marg = marginal branch of the left circumflex coronary artery; RCA = right coronary artery.
pressure decreased at the same time, from 20.2 ± 6.7 to 16.2 ± 8.4 mm Hg (p < 0.05). In contrast to these small changes at rest, left ventricular performance during symptom-limited exercise as assessed indirectly by physical work capacity improved significantly (p < 0.001) between preoperative and 1 year postoperative measurements, whereas no significant change between tests before and 2 weeks after surgery was found. Physical work capacity 1 year after surgery in patients with new thallium defects returned to preoperative levels and was significantly lower than that in patients without new perfusion defects (fig. 5).

Discussion

The present study, performed prospectively in a consecutive series of 55 patients, demonstrated that CABG relieved angina in most patients and improved myocardial perfusion and physical performance. Recurrence of chest pain was associated with more new perfusion defects due to graft occlusion or progression of underlying disease and a lower physical work capacity.

A majority of patients suffering from angina pectoris experience marked symptomatic improvement after CABG. Due to graft occlusion and progression of disease, this improvement decreases over time. Repeat follow-up studies are necessary to assess the different factors responsible for persistence or recurrence of chest pain. Cardiac catheterization has been used to determine graft patency, but its invasiveness and risk prohibit serial studies. Furthermore, left ventricular performance can usually be measured only in a basal state. Therefore, routine repeat studies have been restricted to selected patients with recurrent angina. However, to assess the overall operative result in an unselected series of patients early and late after surgery, noninvasive and easily repeatable methods are needed to evaluate bypass graft function. The aim of our investigation, therefore, was to define the accuracy of noninvasive thallium imaging to detect and localize or exclude bypass graft occlusion in a consecutive series of patients studied preoperatively as well as early and late after operation and to relate these scintigraphic findings to changes in symptoms and left ventricular performance.

Previous studies in selected patients after CABG using potassium-43, rubidium-81 and thallium-201 have demonstrated that improved postoperative myocardial perfusion predicted graft patency and that failure to improve was associated with graft occlusion or perioperative infarction. Since most of the reported patients were only studied after surgery, emphasis was put on ischemic perfusion defects to indicate graft occlusion. In the present investigation, all patients had at least two and a majority even three successive scintigraphic studies (preoperatively and early and late postoperatively). Therefore, not only new or persistent ischemic defects, but also new defects in resting images (new scar) could be identified as indicators of graft occlusion. Early after operation, such new scar areas were only found in patients with other signs of perioperative myocardial infarction, but new persistent defects could also appear between serial postoperative studies, indicating graft occlusion. Comparison between early and late follow-up scans showed that thallium imaging has a high predictive value to detect late postoperative bypass graft occlusion, too.

In two patients, persistent scar defects before operation disappeared early after operation, indicating that severe, prolonged ischemia with delayed reperfusion may have mimicked preoperative persistent defects in these patients. In addition, reduction in heart size early after CABG due to diuretic therapy (fig. 1) may have influenced the interpretation of some of these defects. Nevertheless, the initial interpretation of preoperative scans was not changed in view of follow-up findings.

A symptom-limited exercise test was used before as well as early and late after surgery because it was felt that symptomatic limitation to physical performance was the only acceptable criterion for stopping the tests in view of the changing clinical and therapeutic status of these patients over time. The insignificantly lower physical work capacity 2 weeks after surgery compared with preoperative studies may be explained by early consequences of operation and bed rest. Im-

![PHYSICAL WORK CAPACITY](image)

**Figure 5.** Physical working capacity before and 2 weeks and 1 year after coronary artery bypass graft surgery (left, all 38 patients with three successive tests) and its relation to new thallium perfusion defects (TL +) 1 year postoperatively (right, all 49 patients with complete 1-year follow-up). Total work performed (watt × min) was not significantly lower early after surgery than before, but increased significantly up to late follow-up. At this time, patients with new thallium defects performed no better than before surgery and significantly worse than those without new perfusion defects.
Improvement in physical performance seen in patients with favorable operative results and persistently or newly depressed working capacity in patients with new perfusion defects support the view that symptom limitation is important if exercise tests are to be compared in changing clinical settings.

In the present investigation, the accuracy of noninvasive thallium imaging to detect or exclude patients with bypass graft occlusion was 86%. This high degree of accuracy was achieved because ischemic segments and those suggestive of new scar formation were shown to predict graft occlusion when analyzed by serial studies. Since new or nongraftable coronary artery lesions also produced abnormal thallium scans, the overall accuracy of thallium imaging was even higher. Comparing graft vs regional thallium uptake sensitivity for the localization of occluded grafts, 11 of 18 occlusions could be predicted correctly. Changes in serial thallium scans as observed in patient MK (fig. 3) may help to identify which graft is occluded, although the relative nature of thallium uptake prohibits a 100% region-by-region sensitivity. This finding corresponds to the results reported in patients who do not undergo CABG.21-26, 33, 34 With newer quantitative analyses, the sensitivity of regional detection of coronary lesions or graft occlusion by thallium imaging may improve even more.

Small but discrete apical areas without thallium uptake at rest or after exercise were seen after operation in two-thirds of patients and could be related to the intraoperative technique of transapical venting of the left ventricle. This method obviously produces some myocardial damage in the apical region which may be detected by thallium scintigraphy.

Some interesting aspects were provided by relating thallium results to postoperative symptoms. In the presence of new thallium defects, more than 85% of patients had angina pectoris due to occluded grafts (sensitivity of thallium imaging alone 80%, of typical angina pectoris 73%; NS). On the other hand, in absence of new thallium defects, more than 90% of patients without chest pain had all grafts patent. The most important contribution of thallium imaging, however, was in the difficult group of postoperative patients with atypical chest pain. Here, a new thallium defect was strongly suggestive of graft occlusion; without this finding, the grafts were patent in more than 90% of patients. Thallium scintigraphy, therefore, seems to help identify patients with open grafts despite atypical chest pain postoperatively who may require future invasive study. Table 3 reveals that even in patients with known coronary artery disease, after CABG surgery, sensitivity and specificity of thallium imaging to detect or exclude graft occlusion depends on pretest probability for such a finding.35, 36

Recurrent of chest pain after CABG surgery is related to incomplete revascularization, further progression of coronary artery disease and graft closure.30-32 In our patients with quite severe coronary artery disease (average of 2.5 vessels involved/patient), complete revascularization was attempted (average of 2.8 grafts/patient). A somewhat higher rate of graft closure might be expected with such a surgical strategy. Still, the 1 year, patency rate of 88% is well within the range reported in the literature.3, 29, 37

With improved patency rates, relief of symptoms alone has only limited value in predicting successful surgery.9-11 Because of nonspecific postoperative changes, bundle branch block and the frequent use of digitalis therapy, the exercise ECG was of limited help in the present investigation as in previously reported follow-up studies.38, 39 According to the reported results, noninvasive thallium scintigraphy is a valuable tool for the assessment of bypass graft function, especially when used to perform serial studies.

The effect of CABG on left ventricular function has not been consistent. Some studies have shown improvement of wall motion in regions of left ventricular dysfunction,40-42 but others have failed to demonstrate amelioration of resting left ventricular performance after surgery.17, 18, 43, 44 These discrepancies may partly be explained by the variability of parameters of left ventricular function, such as filling pressure and ejection fraction, which are not only related to the extent of myocardial revascularization but also to preload and afterload which may vary significantly from day to day owing to patient baseline state and medication.45 With postoperative improvement of myocardial perfusion during exercise as found in the present investigation, global and regional left ventricular function after surgery might at least be expected to improve during exercise.46 This could be shown recently in studies using pre- and postoperative radionuclide ejection fraction measurements during exercise.17, 18 In the present investigation, these reports were supported indirectly by the improvement in overall myocardial performance during exercise as assessed by physical work capacity. After CABG, resting ejection fraction did not change, while physical work capacity increased significantly, as noted by others.47, 48 In addition, at the 1-year follow-up, patients with new perfusion defects performed significantly worse than those without such findings. Thus, improvement in physical performance (during exercise) is dependent on a successful surgical result as demonstrated by thallium scintigraphy.

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