Thallium-201 Myocardial Imaging Before and After Coronary Revascularization
Assessment of Regional Myocardial Blood Flow and Graft Patency

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SUMMARY Twenty patients underwent myocardial imaging with Thallium-201 (201Tl) before and subsequent to coronary artery bypass grafting. All patients had rest and maximal treadmill exercise imaging postoperatively. Eleven of the 20 patients had rest and exercise 201Tl images preoperatively; 9/20 only had rest imaging preoperatively. Postoperative regional exercise perfusion was improved in seven of the 11 patients who had preoperative exercise images, and was associated with regional graft patency in each case.

Thirteen of 20 patients showed no new defect with postoperative exercise imaging. The remaining seven patients developed or had an increased defect with exercise. The patients with no new perfusion defects during postoperative study had 26/30 grafts patent (87%). Patients developing a new perfusion defect with exercise had fewer grafts patent (7 of 13 [54%]; P < 0.03). In these seven cases, a new exercise-induced defect was associated with regional graft closure or residual nonoperated disease. Knowledge of the preoperative coronary anatomy allowed the distinction between ungrafted areas and regional graft dysfunction. We conclude that preoperative and postoperative 201Tl imaging may noninvasively predict graft closure and/or improved regional perfusion with patent grafts.

SINCE ITS INTRODUCTION less than a decade ago, direct aorto-coronary bypass surgery has substantially modified the therapy of patients with coronary artery disease.1, 2 The bypass procedure is reported to relieve angina in 70-80% of patients.3-6 Since symptomatic improvement following surgery may result from a placebo effect7 or from perioperative infarction, improved means for assessing hemodynamics, myocardial blood flow, and graft patency, as well as the symptomatic effects of such surgery, are needed. To date, most studies measuring myocardial blood flow4-11 or cardiac performance12-17 have utilized invasive techniques. Myocardial imaging at rest and exercise is one noninvasive and readily available means of evaluating regional myocardial blood flow.18-20 Reported herein are the results of Thallium-201 (201Tl) rest and exercise myocardial imaging in 20 patients studied before and following coronary artery bypass surgery, and their correlation with angiographic bypass graft patency.

Methods

Patient Selection

All patients at this institution are encouraged to undergo postoperative catheterization without respect to symptoms, and all patients scheduled for surgery are encouraged to have rest and exercise myocardial images. The postoperative patients comprising this study represent the first 20 consecutive patients who fulfilled the following criteria: 1) they were agreeable to and underwent rest and exercise myocardial imaging postoperatively, 2) had at least a resting 201Tl image (9 patients) or a rest and exercise image (11 patients) preoperatively, and 3) had postoperative catheterization to determine graft patency. The benefits and potential risks of repeat catheterization and imaging were explained, and informed consent was obtained from all patients. Preoperative exercise images were not performed in nine patients. Four of these patients had an unstable pain pattern; in five, the exercise study was not performed because of insufficient time and/or isotope prior to surgery. All 20 patients underwent operation for symptomatic angina pectoris.

Cardiac Catheterization

Preoperative coronary angiography was performed by the Judkins technique with 35 mm cine filming in multiple projections. Angiograms were interpreted independently by two observers, and in cases of disagreement a consensus was reached. Lesions with luminal diameter stenosis of greater than 50% were considered to have potential hemodynamic significance. Postoperative evaluation employed selective injection of the proximal graft (45 of 48 grafts) or aortic root aortography (three grafts, two patients) and was performed an average of eight months (range 3-15 months) postoperatively. Grafts were considered closed if they were not visualized on aortography.

Myocardial Imaging

All images were obtained within four weeks of preoperative and postoperative catheterization. For the resting study, 2 mCi of 201Tl chloride were injected intravenously following a five-hour fast. Imaging was begun 15 minutes after radiotracer injection, employing an Ohio-Nuclear Series 100 scintillation camera. The camera was peaked with a 201Tl point source, employing a 25% energy window over the photo peak of the mercury X-rays (80 KeV). A Searle Radiographic Model 822017 converging collimator was employed in four patients, and an Ohio-Nuclear Model 14518010 high resolution, parallel hole collimator in the remainder. Three hundred thousand count scintiphotos were obtained in the anterior, 45° left anterior oblique (LAO), and left lateral positions. The camera head
was rotated over the supine, stationary patient to allow comparable repositioning between serial studies. The imaging procedure was identical for the exercise study; however, the radiotracers were injected 40–60 seconds before the termination of a graded, maximal treadmill exercise test. Analog images were recorded with a triple lens Polaroid camera without contrast enhancement or computer processing. Each pair of rest–exercise images was interpreted by two observers unaware of other clinical or angiographic information. The localization and definition of an image defect have been previously described. In brief, an image defect was defined as a discrete region of absent or near absent activity (visually estimated as greater than 50% diminished). The defect was anatomically localized from the LAO view. In this view, the anteroseptal wedge of activity corresponds to the left anterior descending coronary artery distribution, the posterolateral wedge the circumflex coronary artery distribution, and the inferior wedge the posterior descending coronary artery distribution. Following interpretation of the preoperative images, postoperative images were compared directly and each study (rest and exercise) was interpreted to show either no change, new perfusion defects, or resolution of perfusion defects when compared to the preoperative study.

Exercise Testing

Electrocardiographic stress testing was performed utilizing graded treadmill stress to a symptomatic maximum, as described by Bruce. The electrocardiogram was continuously monitored (V5 electrode) and considered positive if 1 mm of flat or downsloping ST-segment depression was observed during or following exercise. Exercise duration was expressed as functional aerobic impairment (FAI), which defines the percentage impairment from predicted maximal oxygen uptake, calculated by comparison to age and sex matched controls. The normal FAI is 0 ± 10% ± 1 SD. The pressure-rate product (PRP) was calculated for each patient at the termination of exercise (systolic blood pressure times heart rate [1/100]).

Results

All 20 patients experienced symptomatic improvement of preoperative anginal symptoms and 16 patients became entirely pain free. Overall, 38 of 48 (79%) bypass grafts were angiographically patent. Of the 11 patients with complete rest–exercise imaging studies preoperatively and postoperatively (group A), two showed no change, one worsened, and eight showed improved regional perfusion in the postoperative study (fig. 1). In the other nine patients with complete postoperative studies and no exercise preoperative study (group B), three had exercise-induced image defects and six did not (fig. 2). Complete exercise, angiographic, and imaging data are summarized in table 1.

I. Regional Myocardial Perfusion: Changes Following Surgery

Improved regional perfusion, defined here as a postoperative decrease in the extent of an exercise-induced image defect or the disappearance of such a defect, occurred in eight of the eleven patients in group A (cases 1–6, 9, and 10 — fig. 1). Six had normalization of preoperative exercise defects and two (cases 3 and 10) showed diminution in the size of the preoperative exercise defect. In all but one patient (case 5), the improved regional perfusion corresponded anatomically to one or more regions supplied by a patent bypass graft (table 1). Figure 3 (case 4) illustrates such a case. This patient had single-vessel coronary artery disease (85% left anterior descending stenosis) and no prior myocardial infarction. His preoperative myocardial image was normal at rest and showed an extensive anterior defect following exercise (upper right, fig. 3). Postoperatively, both the rest and exercise images were normal (lower left and right — fig. 3). The duration of treadmill exercise was longer and the pressure-rate product higher in the postoperative study.

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

**Figure 1.** Group A. The left hand boxes show results of rest (top of box) and exercise (bottom of box) images preoperatively; right hand boxes show postoperative findings. Straight connecting arrows indicate no change between the pre and postoperative images (two patients); upsloping arrows indicate improved regional perfusion in the postoperative exercise study (eight patients) and the downsloping arrow (one patient) indicates worsening postoperative perfusion. $i =$ decreased extent of defect; $MI =$ myocardial infarction.

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

**Figure 2.** The left hand boxes show results of preoperative myocardial image performed at rest; no preoperative exercise image was performed in this group. The right hand boxes show postoperative image results (upper = rest; lower = exercise). Straight connecting arrows indicate postoperative images with no new exercise-induced image defect (four patients). Upsloping arrows indicate resolution of a preoperative defect in the rest image (two patients). Downsloping arrows (three patients) denote the presence of exercise-induced perfusion defect. ETT = exercise tolerance test.
TABLE 1. Clinical, Angiographic, and Imaging Data

<table>
<thead>
<tr>
<th>Patient</th>
<th>Angina</th>
<th>ST</th>
<th>FAI</th>
<th>PRP</th>
<th>RCA/PDA</th>
<th>LAD/Dg</th>
<th>CIRC/OM</th>
<th>Ti-201 Imaging Rest</th>
<th># Vessels &gt;90% stenosis</th>
<th>Grafts</th>
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<td>1) D.A.</td>
<td>Preop</td>
<td>Yes</td>
<td>Yes</td>
<td>&gt;70%</td>
<td>110</td>
<td>100%</td>
<td>90%</td>
<td>95%</td>
<td>Normal</td>
<td>Infere-roapicel</td>
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<td></td>
<td>Postop</td>
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<td>No</td>
<td>30%</td>
<td>272</td>
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<td>90%</td>
<td>95%</td>
<td>RCA, LAD &amp; Circ patent</td>
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<td>2) J.W.</td>
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<td>Yes</td>
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<td>205</td>
<td>90%</td>
<td>90%</td>
<td>90%</td>
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<td>Yes</td>
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<td>90%</td>
<td>Apical</td>
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<td>3) W.B.</td>
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<td>Yes</td>
<td>Yes</td>
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<td>Yes</td>
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<td>5) B.H.</td>
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<td>Yes</td>
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<td>95%</td>
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<td>No</td>
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<td>216</td>
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<td>90%</td>
<td>50%</td>
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<td>6) E.P.</td>
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<td>Yes</td>
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<td>No</td>
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<td>No</td>
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<td>132</td>
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<td>No</td>
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<td>No</td>
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<td>No</td>
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<td>100</td>
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<td>47%</td>
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<td>11) F.T.</td>
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<td>Yes</td>
<td>&gt;70%</td>
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<td>Postop</td>
<td>No</td>
<td>Yes</td>
<td>Dig effect</td>
<td>30%</td>
<td>141</td>
<td>60% LAD 60% Dg</td>
<td>100%</td>
<td>Posterior</td>
<td>&gt;Posterior</td>
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* Demonstrating improved regional perfusion at an increased workload. Exercise duration was similarly improved and pressure-rate product higher, or unchanged, in all patients in the postoperative study, except for one patient with a perioperative myocardial infarction (case 8). In patient BH (case 5), an exercise-induced inferoposterior defect normalized following surgery. This patient's right coronary artery bypass graft was selectively opacified and patent; the circumflex graft could not be selectively identified and neither graft could be seen clearly on aortography. The cir-
<table>
<thead>
<tr>
<th>Patient</th>
<th>Angina</th>
<th>ST</th>
<th>FAI</th>
<th>PRP</th>
<th>RCA/PDA</th>
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<th># Vessels &gt;60% stenosis</th>
<th>Grafts</th>
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<td>No</td>
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<td>190</td>
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<td>LAD patent</td>
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<td>13) G.E.</td>
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<td>No</td>
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<td>222</td>
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<td>90%</td>
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<td>Anterior</td>
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<td>15) J.L.</td>
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<td>Yes</td>
<td>13%</td>
<td>304</td>
<td>60%</td>
<td>90% LAD</td>
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<td>333</td>
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<td>243</td>
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<td>99% Circ</td>
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<td>50%</td>
<td>176</td>
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<td>70%</td>
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<td>19) R.M.</td>
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<td>Yes</td>
<td>100%</td>
<td>171</td>
<td>80% LAD</td>
<td>80% 1st septal</td>
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<td>55%</td>
<td>84%</td>
<td>Dig effect</td>
<td>80%</td>
<td>80% 1st septal</td>
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<td>Inferopapical</td>
<td>Inferopapical</td>
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</tr>
</tbody>
</table>

Table 1. Continued

**Abbreviations:** ST = ST segment depression; FAI = functional aerobic impairment; PRP = pressure-rate product; RCA = right coronary artery; PDA = posterior descending; LAD = left anterior descending; Dg = diagonal; Circ = circumflex; OM = obtuse marginal; ETT = exercise tolerance test; LBBB = left bundle branch block; Dig = digitalis.

cumflex graft was considered closed, although the image improvement may, in fact, indicate patency. One patient (case 10) had improved perfusion by imaging in the region of a patent left anterior descending graft, and a persistent defect in the region supplied by an 80% stenotic graft. The single patient who showed worsening of the postoperative rest and exercise images (case 8) had sustained an enzyme and ECG Q wave documented anterolateral myocardial infarction (he was the only patient with a perioperative myocardial infarction in this series). All three of his grafts were patent; however, the lateral wall served by the circumflex graft was akinetic. Two patients showed no change in the preoperative and postoperative images. In one (case 11), the exercise-induced posterior defect corresponded to disease of the circumflex artery which was diffusely diseased and had not been grafted. The other had entirely normal images...
preoperatively and postoperatively (case 7). Thus, in the group of patients with complete preoperative and postoperative studies, improved regional perfusion was associated with patency of at least one bypass graft to the given region, except patient 5, in whom graft patency may be uncertain. The single patient with worse postoperative perfusion had an associated operative myocardial infarction (case 8). Hence, those four patients with persistent postoperative exercise defects had either: 1) failure to graft the involved region or stenotic grafts (cases 3, 10, and 11), or 2) operative infarction (case 8).

II. Prediction of Graft Patency

In the nine patients in group B (complete postoperative exercise images, cases 12–20), four had normal rest and exercise images postoperatively and two showed rest defects unchanged by exercise. Three of the nine patients had a rest defect which increased with exercise postoperatively. Three of the four patients with pre-infarction angina had had defects present on the rest image which resolved or improved following surgery (table 1, cases 13, 14, and 17). Although preoperative exercise images were not available for direct comparison in these cases, postoperative exercise defects developed exclusively in arterial beds supplied by occluded grafts (cases 16 and 18), or in one patient with both an occluded graft and a stenotic right coronary artery which had not been grafted (case 19 — fig. 4). Two patients (cases 16 and 18) developed new defects in the postoperative rest image. These patients had nonpatent grafts to the involved regions, but had not had enzyme or ECG evidence of perioperative myocardial infarction.

Overall, the presence of an exercise image defect in the postoperative study was associated with lowered graft patency rates. Excluding cases 8 and 10 (operative myocardial infarction and stenotic graft), 7 of 13 (54%) grafts were patent in those five patients with postoperative exercise-induced defects. Among the 13 patients without postoperative exercise defects, a significantly greater proportion of grafts were patent (26 of 30, 87%; \( P < 0.03 \) by chi square test). For the entire group, the presence of a postoperative exercise defect predicted graft closure and/or residual ungrafted disease. Considering the location of the postoperative exercise image defect, it was possible in each case to associate it with either graft failure (cases 16, 18, and 19) or residual ungrafted disease (cases 3 and 11). The resolution of exercise ST depression per se did not predict graft patency. Eighty-three percent (5/6) of grafts were patent in the three patients in whom preoperative ST depression was normalized postoperatively (cases 1, 4, and 5), compared to 87% (14/16) patent grafts in the remaining seven patients (cases 2, 3, 7, 8, 9, 10, and 12). (The ST response could not be analyzed in cases 6 [left bundle branch block] and 11 [digitalis effect].)

Discussion

Although direct coronary revascularization surgery has revolutionized the care of patients with coronary atherosclerosis, objective, noninvasive measurements of its possible effects on myocardial performance and regional myocardial blood flow have been limited. Such techniques are necessary for both early and serial assessment of the effects of bypass surgery. Cardiac catheterization can determine graft patency, but its invasiveness and risk prohibit serial
Also, under usual circumstances, myocardial performance can be measured in only the basal state. Most reports conclude that resting left ventricular hemodynamics are unaffected by coronary artery bypass surgery.\textsuperscript{18-17} Measurements of exercise or pacing stressed regional contraction,\textsuperscript{19, 17} or pulmonary artery wedge pressure have demonstrated postoperative improvement.\textsuperscript{12} However, techniques such as these are not available for general use.

Patient symptomatology alone clearly does not predict successful surgery. DiLuzio et al.,\textsuperscript{7} for example, reported relief of angina in five patients sustaining asymptomatic perioperative infarction with all grafts occluded. Similarly, Benchimol et al.\textsuperscript{24} reported 12 patients in whom all grafts had closed — all had symptomatic improvement and eight of 12 patients had disappearance of angina. Perioperative infarction could be identified in only four of the 12. Exercise stress testing is a noninvasive and more objective means of evaluation than patient symptoms, and improved exercise duration, pain relief, and disappearance of ST depression have generally correlated with bypass graft patency in large series of patients.\textsuperscript{6, 28} However, for the individual patient, such studies may be imprecise. Block et al.\textsuperscript{29} studied 23 patients with all grafts occluded and found improved exercise duration in 57%, loss of exercise angina in seven of 18 (39%), and normalization of ST segments in five of 14 (36%).

For the individual patient in our series undergoing rest and exercise myocardial imaging (group A), improved regional perfusion predicted graft patency (except case 5, in whom patency may be uncertain). Conversely, the presence of a postoperative exercise defect always predicted: 1) regional graft occlusion or stenosis, 2) operative infarction, or 3) native coronary artery disease which had not been grafted (groups A and B). These findings support the value of postoperative imaging among patients in whom preoperative imaging has not been obtained. That is, since the coronary anatomy has been defined preoperatively, this knowledge in conjunction with postoperative rest and exercise myocardial imaging may allow prediction of graft closures. In patient RM (case 19 — fig. 4) for example, the occluded right coronary artery was associated with an old inferior myocardial infarction and an inferior defect on the preoperative and postoperative rest images. The presence of an additional postoperative anteroseptal defect with exercise correctly predicted closure of one of the two grafts supplying this region (LAD graft patent, first septal graft occluded — fig. 4). Since this patient could not be exercised preoperatively, changes in regional perfusion could not be determined, but the postoperative presence and location of perfusion defects and the knowledge of the coronary anatomy correctly predicted graft occlusion. It should be emphasized that the failure to develop an exercise image defect must be interpreted conservatively. About 30% of patients with angiographically proven coronary artery disease do not develop exercise image abnormalities.\textsuperscript{27, 28} This phenomenon was observed in the present study, in that one patient (case 7) with three-vessel coronary artery disease had entirely normal preoperative rest and exercise images. Similarly, cases 9, 13, and 15 had normal postoperative exercise images, although each had nonpatent grafts and/or ungrafted disease.
The results of the present study support those originally reported by Zaret et al.\textsuperscript{26} employing preoperative and postoperative imaging with \textsuperscript{4\textit{K}}K, and Lurie et al.\textsuperscript{29} with \textsuperscript{81}Rb. Zaret demonstrated that improved postoperative regional perfusion predicted graft patency and that failure to improve was associated with graft occlusion, operative infarction, or patent grafts supplying inadequate distal beds. Thallium-201, a monovolatile cation, was employed in the present study. The reproducibility of exercise image defects with this agent has been established.\textsuperscript{31} Image quality with \textsuperscript{201}TI is improved over earlier agents; \textit{in vivo} myocardial-to-background ratios are higher,\textsuperscript{26, 30}\textsuperscript{29} and diagnostic quality images can be routinely obtained on standard scintillation cameras. Myocardial uptake of such ions is a well recognized phenomenon,\textsuperscript{15, 28} and the uptake of \textsuperscript{201}TI resembles that of \textsuperscript{4\textit{K}}K. Experimentally, myocardial distribution of \textsuperscript{201}TI resembles that of \textsuperscript{4\textit{K}}K. Similarly, the 88\% extraction fraction of \textsuperscript{201}TI (the fraction extracted by the myocardium during a single circulation) remains constant under conditions of increased blood flow and oxygen demand induced by pacing.\textsuperscript{36} These experimental studies strongly support the thesis that exertional defects represent regional malperfusion. Conversely, the disappearance or regression of postoperative exercise image defects supports improved regional blood flow. The postoperative pressure-rate product, when compared to the preoperative value, was increased or unchanged among patients showing improved regional perfusion. The same or a higher pressure-rate product, reflecting similar or increased myocardial oxygen demands,\textsuperscript{34} suggests that greater postoperative \textsuperscript{201}TI deposition was achieved by improved regional blood flow via the bypass graft.

In summary, rest and exercise myocardial imaging preoperatively and postoperatively may demonstrate and spatially localize improved or worsened regional blood flow and assess graft function.

References

Thallium-201 myocardial imaging before and after coronary revascularization:
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Circulation. 1977;56:830-836
doi: 10.1161/01.CIR.56.5.830
Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
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Print ISSN: 0009-7322. Online ISSN: 1524-4539

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