Myocardial Perfusion as an Indicator of Graft Patency after Coronary Artery Bypass Surgery

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SUMMARY Stress and resting myocardial perfusion were assessed in 38 patients who received 96 grafts. Stress perfusion was evaluated with thallium-201 and resting myocardial blood flow distribution with radiolabeled particles. When both stress and rest perfusion were normal, graft patency was 82% (51 of 62 grafts). Graft patency was also high (81%, 13 of 16) in areas where stress perfusion abnormalities resolved or become less apparent at rest. However, when stress perfusion defects remained unchanged at rest, the graft was likely to be occluded (73%, 11 of 15). Maintenance of normal rest perfusion or improvement of rest perfusion postoperatively was also associated with a high graft patency rate (80%, 35 of 44), whereas the development of new rest perfusion defects postoperatively implied graft occlusion (86%, six of seven).

CORONARY ARTERY bypass grafting to potentially ischemic areas of myocardium is widely used to treat patients with coronary artery disease.1, 2 Because success or failure of such surgery seems largely determined by graft patency, it has become common in many institutions to restudy postoperative patients with a cardiac catheterization. Until recently, a postoperative catheterization appeared to be the only reliable method of assessing graft patency. However, developments in nuclear cardiology imaging techniques have provided reliable methods of evaluating myocardial perfusion.3-6 Thallium-201, the radionuclide most commonly used to assess myocardial perfusion, may provide useful information concerning graft patency in patients who have undergone myocardial revascularization.6, 7

Another useful technique in evaluating myocardial blood flow distribution is the instillation of radiolabeled particles directly into the coronary circulation.8-10 Because two radionuclides are used, it is possible to distinguish the blood flow distribution from grafts and that from the native circulation, thus providing information not always obtainable from thallium studies.11-13 Total myocardial blood flow distribution is indicated by the dual image, which is a combination of both graft and native vessel perfusion. Therefore, the dual or combined image, which is comparable to a resting thallium image,5, 14 can be compared with a stress thallium study to distinguish stress-induced defects from defects that represent fibrosis.15

We assessed both stress and rest myocardial perfusion after myocardial revascularization and correlated postoperative perfusion characteristics with graft patency and native vessel anatomy to predict the success or failure of coronary bypass surgery.

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Methods

Thirty-eight patients undergoing coronary bypass surgery at Ohio State University Hospitals between May 1977 and October 1978 were included in this study. Although our aim was to restudy most patients who had had bypass surgery, many patients were unwilling to undergo another catheterization. Patient selection may therefore be biased toward patients with more advanced preoperative coronary artery disease or with unexplained postoperative symptoms. All patients had stress and rest scintigraphic studies postoperatively, and rest perfusion was evaluated in 22 patients preoperatively. All patients were studied 3–6 months after revascularization. Treadmill exercise studies (Bruce protocol) were performed the day before angiography. Two millicuries of thallium-201 was given intravenously with the onset of chest pain, ECG changes or fatigue. Stress was continued for 1 minute and scintigraphy was performed within 15 minutes after cessation of stress.

Stress ECG changes were considered indeterminate in the presence of resting abnormalities of the ST segments and T waves, digitalis therapy, or if the patient did not achieve at least 85% of the maximal predicted heart rate for age. A stress test was interpreted as positive when the patient developed 1 mm of horizontal ST depression 0.08 second after the J point during or after exercise.

Coronary angiography was performed using the Judkins technique. The decision to perform angiography was made before all scintigraphic studies. Graft patency was confirmed by selective angioigraphy. A graft was considered to be patent when the entire graft and the vessel receiving the graft were angiographically visualized. A graft was considered occluded if the stump was visualized or if the graft was not seen on an aortic root angiogram. Lesions were directly measured from traced images in various views. Measurements were made at the site of luminal narrowing and at a site of the vessel proximal to the narrowing where the lumen did not appear compromised. Lesions were expressed as percent luminal diameter narrowing in the view where the stenosis was calculated to be most critical. Significant lesions were interpreted as 60% stenosis of the luminal diameter of ungrafted vessels, native vessels distal to the site of graft anastomoses, grafts and at anastomotic sites.

Grafts were injected with technetium-99m–labeled, macroaggregated albumin particles and the native circulation with indium-111–labeled particles. Approximately 0.4 mCi of radionuclide was injected into each graft and native vessel. All instillations were performed slowly in the resting state, 3–5 minutes after angiography. Catheter position was confirmed fluoroscopically before and during instillations. No patient had chest pain, electrocardiographic changes, or pressure changes at the time of the instillations. Scintigraphy was performed within 15–30 minutes after catheterization.

Images were obtained in the anterior, 45° left anterior oblique and left lateral views for both thallium and the particles in all patients. Imaging was performed with a high-resolution camera and a low-energy, parallel-hole collimator using a 1000 information density set over the left ventricle. Analog images without computer enhancement were independently reviewed by two experienced observers who had no knowledge of clinical data. Major interobserver variation occurred in less than 5% of cases and was resolved by consensus.

Specific perfusion areas of the myocardium have been shown to correspond to the distribution of the native coronary circulation. Therefore, myocardial blood flow distribution was assessed for the grafts according to the distribution pattern expected of the native vessels that received the grafts. Grafts to the left anterior descending artery would be expected to provide perfusion to the interventricular septum and anterior wall, circumflex grafts to the posterior and posterolateral walls and right coronary artery grafts to the inferior wall. Perfusion defects were interpreted as areas of absent or discernibly decreased activity. Exercise perfusion defects were felt to represent ischemia only when decreased areas of perfusion were noted with stress compared with the rest scan. Exercise perfusion defects that remained unchanged at rest were considered to represent fibrosis.

The thallium and particulate scans were first interpreted independently. Thallium images were then compared with the dual particulate images to assess whether the stress defects represented ischemia or fibrosis. Because dual isotopes were used to assess rest perfusion, we compared corresponding areas on both the stress and rest studies in order to determine whether myocardial blood flow distribution was due to graft or native vessel perfusion. Statistical analysis was accomplished with a 9600-B computer using chi-square analysis and standard programs.

Results

Postoperative Perfusion and Graft Patency

Ninety-six grafts were inserted into 101 vessels that had at least 60% stenosis of the luminal diameter. Seventy grafts were patent and 26 were occluded at the time of postoperative catheterization. Of the native vessels grafted, all had at least 60% luminal diameter narrowing proximal to the site of graft anastomoses and 70 appeared to be totally occluded proximally. Therefore, the grafted vessels were highly dependent on graft blood supply.

Both stress and rest myocardial perfusion were normal in 62 areas of myocardium that received grafts (fig. 1A). Fifty-one of these areas were supplied by patent grafts and 11 by occluded grafts. The sources of perfusion to those areas with occluded grafts were patent native vessels in seven cases, collateral vessels in three and undetermined in one. Figure 2 is an example of normal stress and rest perfusion. The angiogram revealed a patent snake graft to the diagonal branch and left anterior descending artery, and a patent graft to the right coronary artery.
Although perfusion was normal, a snake graft to the circumflex and obtuse marginal was occluded. Figure 3 is from the same patient and shows only the left anterior oblique view. The small perfusion abnormality in the distribution of the graft is filled in by the native posterolateral vessel, as the graft to this artery is occluded. The perfusion distribution of the native left anterior circulation is completely absent, and is totally dependent on graft perfusion.

Sixteen areas of myocardium received grafts where stress perfusion was normal but rest perfusion was normal or improved (fig. 1B). Thirteen patent grafts provided blood flow distribution to areas with improved resting perfusion. However, rest perfusion improved in three instances when the grafts were occluded. The sources of the rest perfusion were a patent native vessel, a collateral vessel, and both a patent native vessel and collateralization.

Figure 4 is an example of a patient who developed two perfusion defects with stress. These defects are most likely ischemic, as rest perfusion is substantially better in both areas. Grafts to the left anterior descending and posterolateral arteries are patent and both provide resting myocardial blood flow distribution to the areas that become ischemic with stress. In this case, the patent grafts seem able to provide adequate perfusion at rest but not with stress.

Perfusion was abnormal both with stress and rest in 15 areas (fig. 1C). Eleven of 15 grafts to these areas were occluded, but four grafts remained patent. In each of these four instances, the ECG indicated the presence of a myocardial infarction. There were three situations in which stress perfusion was normal but defects were seen at rest (fig. 1D). Two grafts were found to be patent and one was occluded.

In summary (fig. 1), the graft patency rate was 81% (51 of 62) when both stress and rest perfusion were normal. Thirty-one stress defects were detected. In the 16 instances where resting perfusion was normal, graft patency rate was 82% (13 of 16). In the 15 instances where stress defects persisted at rest, the graft occlusion rate was high (73%, 11 of 15). The combination of normal rest perfusion and occluded grafts did occur in 18% of cases (14 of 78 grafts). In these instances, per-
Pre- and Postoperative Changes in Rest Perfusion

The resting postoperative blood flow distribution patterns of 51 grafts were compared with the preoperative distribution patterns in the 22 patients who had preoperative particulate studies (table 1). Postoperatively, rest perfusion remained normal in 30 areas, appeared improved in 14 areas and worsened in seven areas. In the 44 areas with normal or improved postoperative perfusion, 35 grafts were patent and nine were occluded. Seven of the nine areas with occluded grafts maintained normal perfusion after revascularization and two actually appeared to improve perfusion. Dual particulate scintigraphy showed that the sources of myocardial blood flow to these normally perfused areas with occluded grafts were persistently patent native vessels in five instances, collateral vessels in three, and both collateral and native vessels in one. The seven areas where perfusion was invariably due to a persistent native vessel or collateral vessels. On the other hand, abnormal rest perfusion was occasionally demonstrated with a patent graft, as seen in four of 15 areas, and could be attributed to an old infarction.

Preoperative Angiographic Surveillance

Of the 32 patients undergoing angiographic surveillance postoperatively, 21 had thallium studies during stress. Eighteen of these 21 patients had at least one area of inducible ischemia demonstrated with thallium. Sixteen of the 18 patients with inducible ischemia had new perfusion abnormalities by postoperative stress thallium. These new abnormalities included new perfusion defects in three patients and improvement in one. Postoperatively, a sixth patient developed a positive stress ECG and a positive stress thallium study, and the remaining four patients had no evidence of new perfusion abnormalities by thallium. Overall, 13 patients had significant new perfusion abnormalities postoperatively. These new perfusion abnormalities included a new perfusion defect in 11 patients and improvement in two. The remaining two patients had no evidence of new perfusion abnormalities postoperatively.

Table 1. Postoperative Changes in Rest Perfusion and Graft Patency (51 Grafts in 22 Patients)

<table>
<thead>
<tr>
<th>Perfusion</th>
<th>Patent grafts</th>
<th>Occluded grafts</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal or improved (44)</td>
<td>35</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Worse (7)</td>
<td>1</td>
<td>6</td>
<td>p &lt; 0.05</td>
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Discussion

Postoperative Stress and Rest Perfusion

Thallium-201 is a monovalent cation that provides useful information regarding myocardial perfusion.5-9 Whether a stress perfusion defect represents ischemia or fibrosis may be determined by performing a resting thallium study several days after stress.10, 11 by performing a redistribution scan,21, 22 or by assessing resting perfusion at the time of cardiac catheterization with the particulate method.12, 13 The large number of patients now undergoing coronary revascularization procedures emphasizes the need for safe and reliable techniques to assess the results of bypass surgery in the postoperative period. Several studies have indicated that rest and stress thallium testing may be used to assess graft patency in this group of patients.6, 7, 23, 24 Although we evaluated deteriorated postoperatively were associated with six occluded grafts.

Postoperative Stress Perfusion and ECG Changes

The results of postoperative stress ECG changes are described in figure 5. In the five patients who developed ischemic ECG changes, thallium studies showed new perfusion abnormalities in four, and all had significant coronary lesions. Sixteen patients had no ischemic ECG changes during stress. One of these patients developed a new perfusion defect and had a positive coronary angiogram as well. Fifteen of the 16 patients had no evidence of new perfusion abnormalities with stress, although six had significant anatomical lesions. The stress test was indeterminate for ischemia in 17 patients. Overall, 13 patients had significant coronary lesions but negative or indeterminate stress ECG changes and no new perfusion abnormalities with thallium. Eight of these 13 patients had a myocardial infarction on the resting ECG. In the 21 patients in whom it was possible to interpret stress ECG, the sensitivity of the test in detecting significant coronary lesions was low (36%, four of 11) but the specificity was high (90%, nine of 10).
resting perfusion with the particulate method, thus necessitating catheterization, much of the information obtained could be obtained with resting thallium studies or redistribution scans. However, because coronary angiography is necessary to validate graft patency, the use of radiolabeled particles, in addition to assessing rest perfusion, permits differentiation between the myocardial blood flow distributions of grafts and native vessels.

In our study, both normal rest and exercise perfusion indicate a high graft patency rate (fig. 1A). However, 11 of 62 grafts in this group of patients were occluded. Although normal perfusion in the presence of occluded grafts has been reported,\textsuperscript{6, 7} the reason for this apparently paradoxical finding is unknown. One likely explanation might be the low sensitivity of the perfusion studies: Stress thallium testing has been reported to be only 56–85% sensitive in detecting significant coronary lesions in nonoperated patients.\textsuperscript{4–19, 20}

A few patients may have well-developed collaterals that supply adequate perfusion to areas of the myocardium where grafts are occluded,\textsuperscript{13} as in three of our patients. We have previously shown that such perfusion may originate from patent grafts in other areas of the heart.\textsuperscript{13}

A perfusion defect with exercise was not a reliable sign of graft occlusion (figs. 1B and 1C), although Ritchie et al.\textsuperscript{6} reported that the presence of a postoperative exercise defect predicted either graft occlusion, stenosis or native-vessel disease. Our results indicate that if a stress perfusion defect resolves or is less extensive at rest (fig. 1B), the likelihood of graft patency is high (82%, 13 of 16), whereas if a stress defect remains unchanged at rest (fig. 1C), the graft is most likely occluded (73%, 11 of 15). The ECG revealed an infarction in the four areas where grafts remained patent despite abnormal rest and stress perfusion.

Although the techniques used in this study preclude quantitative measurement of blood flow through grafts, the data pertaining to the grafts in figures 1A and 1B suggest that grafts may have differing physiological capabilities with respect to providing blood supply to the myocardium. A large number of patent grafts seem able to provide adequate perfusion with rest and stress, but others are able to maintain normal resting perfusion only. Because the patent grafts and distal native vessels appeared free of significant lesions in both groups of grafts, mechanisms other than obstructive lesions may be responsible for the different perfusion characteristics of these two groups of grafts (figs. 1A and 1B). Additional possible explanations might include differences in the caliber of the vessels receiving the grafts distal to the anastomotic site, angiographically undetected lesions, variations in surgical techniques, and the presence of varying degrees of myocardial fibrosis in areas receiving grafts. In three areas, stress perfusion was normal but defects were seen at rest (fig. 1D). There are two potential reasons for this paradoxical observation. Because the resolution of the particulate scans is superior to thallium,\textsuperscript{16, 18} it is possible that the thallium study was not sensitive enough. On the other hand, the streaming phenomenon may occasionally be a problem with particles and the resting defects might represent artifacts.

Pre- and Postoperative Changes in Rest Perfusion

The results of the postoperative changes in rest perfusion in the patients who had preoperative rest studies imply that improved perfusion or maintenance of normal perfusion in the postoperative period indicates a high graft patency rate (table 1) and that the development of new resting defects postoperatively strongly suggests graft occlusion. These results are consistent with both Ritchie\textsuperscript{6} and Zaret,\textsuperscript{26} who found that improved postoperative stress perfusion indicated graft patency.

Nine areas with improved or normal postoperative perfusion were associated with nine occluded grafts. Blood flow to these areas appeared to originate from either collateral or native vessels. We have reported this observation regarding collateral flow in other patients,\textsuperscript{12, 13} and have found that in certain instances collateral flow may originate from grafts in other areas of the heart.\textsuperscript{12} In five situations, persistently patent native vessels continued to provide blood flow despite graft occlusion. This is surprising, because these vessels appeared to have significant stenosis. However, it is possible that the blood flow rates through these vessels were sufficient to maintain resting perfusion despite the lesions seen on the angiogram. The results described in this study relate to qualitative assessment of regional blood flow distribution patterns, and comments regarding blood flow rates are merely speculative.

Postoperative Stress ECG Studies

The poor sensitivity of the stress ECG alone in predicting graft occlusion emphasizes the need for using other measures to evaluate postoperative patients. Greenberg et al. also reported a relatively low sensitivity of the stress ECG as a predictor of postoperative lesions.\textsuperscript{7} A major problem in our study is the high number of indeterminate tests, which precludes the identification of patients with significant postoperative disease by stress ECG alone. Most of these indeterminate studies were due to resting ECG changes or inability of the patient to reach an adequate heart rate. Therefore, postoperative stress and rest perfusion studies seem to be much more reliable indications of graft occlusion than the stress ECG alone, particularly when the patient population includes a high incidence of indeterminate stress tests.

Conclusion

Both normal stress and rest myocardial perfusion indicate a high graft patency rate. Assessment of rest perfusion should be performed in conjunction with stress testing, because stress defects that improve or disappear at rest are usually associated with patent grafts and defects that persist are generally associated...
with occluded grafts. The physiologic capabilities of patent grafts vary; the majority can provide normal exercise and stress perfusion, whereas others can provide normal rest perfusion only. Maintenance of normal perfusion or improvement of rest perfusion postoperatively also indicates a high graft patency rate, whereas worsening rest perfusion postoperatively strongly suggests graft occlusion. Finally, stress perfusion studies may add significant, useful information to the stress ECG, which when used alone has a relatively low sensitivity in detecting significant disease postoperatively.

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References

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