DIAGNOSTIC METHODS
MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging to evaluate patency of aortocoronary bypass grafts

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ABSTRACT To assess the efficacy of magnetic resonance (MR) imaging in evaluating graft patency after coronary bypass surgery, 20 patients who had prior surgery (average 5.5 years, range 1.5 to 14) and recent cardiac catheterization because of chest pain were studied. No patient had surgical intervention or change in symptoms in the time interval between catheterization and MR imaging. These 20 patients had a total of 47 grafts, defined as proximal anastomoses: 20 to the left anterior descending or diagonal artery (LAD), 13 to the left circumflex artery marginal branches (LCX), and 14 to the right coronary artery or posterior descending artery (RCA). The patients underwent cardiac and respiratory gated MR scans in a 0.5 tesla magnet with an echo time of 22 msec and two repetitions in a 128 × 256 matrix. In-plane resolution was 2.7 mm. Every patient had a scan in the transaxial plane and some underwent scanning in the sagittal and coronal planes as well. A graft was considered patent by MR when a signal-free lumen was visualized in an anatomic position consistent with that of a bypass graft, had a lumen larger than the native vessels, was seen on more than one slice, and was seen at a level higher than that of the native vessels. If a known graft was not seen it was considered occluded. The scans were interpreted by consensus of two physicians aware of the operative but not the cardiac catheterization data. Twenty-six of 29 patent grafts and 13 of 18 occluded grafts were correctly classified (sensitivity 90%, specificity 72%). Eighteen of 20 (90%) LAD grafts, 11 of 14 (79%) RCA grafts, and 11 of 13 (85%) LCX grafts were correctly classified. When the results from three patients with technically poor studies because of poor cardiac gating were excluded, the overall sensitivity and specificity were 92% and 85%, respectively. This study demonstrates the high sensitivity and moderate specificity of MR for evaluating the patency of coronary artery bypass grafts, particularly LAD grafts.


INCREASING NUMBERS of patients with previous coronary artery bypass surgery develop chest pain due to ischemic or nonischemic causes. In those patients with ischemia this can be due to closure or atherosclerotic narrowing of one or more bypass grafts, or progression of atherosclerosis in native vessels. Noninvasive evaluation of graft patency is thus of obvious potential importance in the management of patients with chest pain after bypass surgery. It may also help to evaluate the need for repeat cardiac catheterization. In 1983 Herfkens et al. first reported imaging a coronary artery bypass graft on a transaxial magnetic resonance (MR) scan of the chest. Since that time other authors have described the visualization of bypass grafts with MR imaging. These preliminary studies demonstrated that MR imaging of patients with a history of coronary bypass surgery was safe and artifacts from implanted metals did not interfere with the interpretation of results. Bypass grafts have also been imaged by cine computed tomography, but this technique requires the injection of radiographic contrast dye and the use of ionizing radiation, which is not needed for graft visualization with MR imaging. With MR imaging vascular structures are well seen with the use of the spin-echo technique. With this type of pulse sequence, rapid flow in the large arteries of the chest appears signal free because excited spins move out of the imaging plane, and slow flowing blood or occluded vessels will not. Currently available MR imaging systems have an in-plane resolution on the order of 2 mm. We reasoned that MR imaging should be able to routinely detect bypass grafts in cardiac gated scans because of its sensitivity
to blood flow in vessels and excellent spatial resolution. The purpose of this study was to validate this hypothesis by studying patients with bypass grafts who had undergone cardiac catheterization to assess the accuracy of MR imaging for the determination of the patency of bypass grafts.

Methods and subjects

Study population. All patients with a history of coronary bypass surgery who underwent cardiac catheterization after surgery from January 1, 1986, to March 30, 1987, were eligible for entry. A total of 111 consecutive patients underwent cardiac catheterization after coronary artery bypass grafting in this time period. Thirty were excluded because their conditions were unstable and they had undergone repeat coronary artery bypass grafting or had cardiac events such as myocardial infarction, percutaneous transluminal angioplasty (PTCA) of a bypass graft, or death. A further 61 patients either lived too far to return for an MR study, had contraindications for an MR scan (such as a pacemaker or metallic foreign bodies), or did not wish to participate in the study. Twenty patients formed the study population. There were 18 men and two women. The mean age was 59 years (range 43 to 74), and the patients were studied an average of 5.5 years after coronary bypass surgery (range 1.5 to 14). Cardiac catheterizations were performed at the discretion of a patient’s private physician, generally to evaluate chest pain after coronary bypass surgery thought to be ischemic. Three patients had PTCA of native vessels not supplied by a patent bypass graft in the period between cardiac catheterization and MR scanning. The average time between catheterization and MR scan was 3.4 months (range 0 to 11) and the median was 1 month. Only five patients were scanned more than 2 months after catheterization. None of the patients had any change in clinical symptoms in the time between catheterization and the MR scan. Two patients underwent MR scanning immediately before cardiac catheterization.

MR imaging. A superconducting MR imaging system (Picker International Inc.) with a field strength of 5.0 K G (0.5 tesla) was used for all studies. Studies were performed by a spin-echo technique with both respiratory and cardiac gating. Cardiac gating was triggered from the R wave without delay. Respiratory gating was implemented with a bellows wrapped around the upper abdomen. Data collection occurred only at end-expiration. An echo time of 22 msec and two repetitions were used. Pulse repetition times ranged between 500 and 1000 msec, depending on the heart rate (RR interval). The computer matrix consisted of 128 (number of views in the phase encoding direction) × 256 matrix points. Data were interpolated into a 256 × 256 matrix. The field of view was 35 cm, giving an in-plane resolution of 2.7 mm. MR imaging was performed with a multislice technique composed of contiguous 10 mm thick slices, with a minimum of eight slices in the transaxial plane in all patients. All patients underwent imaging in the transaxial plane and most had imaging in the sagittal or coronal planes as well if time permitted. Studies were generally completed in 1 hr.

Angiographic studies. Cardiac catheterization was performed in all patients by the Judkins or Sones technique with standard catheters. All bypass grafts or stumps were selectively visualized in at least two projections. The number of bypass grafts, their origin, and the site of insertion were known for all patients from the surgical operative report at the time of cardiac catheterization and MR imaging.

Data analysis and statistics. Angiographic interpretation was done by the physician performing the catheterization (J. A.). Bypass grafts were visualized by selective angiography at cardiac catheterization and classified as patent, totally occluded, or patent with a greater than 70% luminal obstruction. If a graft could not be identified with certainty, an aortic root injection was done to ensure that a patent bypass graft was not overlooked. Evaluation was done from the origin of the bypass grafts in the ascending aorta to their first insertion in the native coronary artery.

MR studies were interpreted by consensus of a cardiologist (A. A.) and a radiologist (D. T.) unaware of the results of cardiac catheterization but aware of the number and positions of bypass grafts from prior surgical reports. If a consensus could not be reached by the two physicians, the graft was considered not seen and, therefore, occluded. A consensus was not reached about only one graft. The transaxial studies were first examined from the arch of the aorta down to the base of the heart to identify signal-free lumens in the mediastinal fat arising from the ascending aorta and descending toward the heart. A graft was considered patent by MR if three conditions were met. A signal-free lumen of greater diameter than native vessels was considered a patent graft if it was seen on at least two contiguous images, if it was seen in a slice above the origin of native coronary arteries, and if it was in an anatomic position consistent with a bypass graft known to have been placed in that patient. A graft seen only at its exit from the aorta and not further down in the chest was considered to be a stump and therefore occluded. A graft known to have been placed at the time of surgery but not visualized in any projection was presumed to be occluded. The typical anatomic positions of coronary artery bypass grafts in the transaxial projection are shown in figure 1. Images taken in other planes were used to determine if a graft not seen in the transaxial plane could be identified, in which case it would be considered patent.

Only the proximal portions of grafts were included in the statistical analysis since sequential grafts were rarely seen. Data are presented as sensitivity and specificity of MR imaging for classifying bypass grafts as patent or occluded as compared with angiographic classification.

Results

An example of a typical MR scan is shown in figure 2. Eight contiguous slices are shown as a collage from the inferior most portion of the left ventricle to the ascending aorta at the level of the pulmonary artery bifurcation. Note the two structures designated in different images by the triangles. The white triangle is the graft to the right coronary artery (RCA) and the black is the graft to the left anterior descending artery (LAD). Both grafts can be followed through the higher slices until they insert into the ascending aorta. In the fourth panel a sequential portion of the LAD graft inserting into the first diagonal can also be seen. The native RCA (open arrow) and native left coronary (black arrow) can also be seen. Note that despite artifact from the sternal wires, the images of the heart and bypass grafts are not obscured. Artifact from sternal wires was always greater in the sagittal plane but did not obscure the images of the ascending aorta or the bypass grafts.

The 20 patients had a total of 47 proximal aortotomies and 62 total bypass grafts. At cardiac catheterization all 47 proximal aortotomies were visualized; 29 were widely patent, 17 were totally occluded, and one was 99% obstructed. The latter vessel was classified as
obstructed. Fourteen grafts were to the RCA or posterior descending artery, 20 were to the LAD or diagonal branches, and 13 grafts were to the left circumflex artery (LCX) or marginal branches.

In figure 3 graft patency as determined by angiography and MR imaging is shown. Twenty-six of 29 patent grafts and 13 of 18 occluded grafts were correctly classified for an overall sensitivity of 90% and a specificity of 72%. Table 1 details the MR determination of bypass graft patency by the anatomic site of each graft. Eighteen of 20 (90%) LAD grafts, 11 of 14 (79%) RCA grafts, and 11 of 13 (85%) LCX grafts were correctly classified.

In three patients image quality was significantly worse than in the others because of poor cardiac gating due to low R wave amplitude in the limb leads. The grafts could be seen in these patients on images superior to the base of the heart in the mediastinum where there was less motion artifact. These scans were also interpreted but with less confidence at the time of interpretation than the others. These three patients had a total of eight grafts. If these patients are included, 24 of 26 patent grafts and 11 of 13 occluded grafts were correctly classified for a sensitivity of 92% and a specificity of 85%. When these three patients are excluded from the analysis, all 16 LAD grafts, eight of nine (89%) LCX grafts, and 11 of 14 (79%) RCA grafts were correctly classified.

Discussion

This study demonstrates the high sensitivity and moderate specificity of MR scanning in the evaluation of patency of coronary artery bypass grafts. Technically adequate images could be obtained in all patients and artifacts from sternal wires, surgical clips, or other graft markers did not interfere with interpretation. There were no complications associated with these metal implants or the MR imaging process. In our experience the transaxial scan was the most useful for visualizing bypass grafts, particularly in the slices above the heart where confusion with the native coronary vessels would not occur. The LAD graft was the most obvious and most often correctly identified.

In some patients it was difficult to differentiate the native RCA from the RCA graft at the level of the myocardium (twice the native RCA was interpreted as a patent graft). Since most cardiovascular surgeons place the origin of the RCA graft most inferiorly on the ascending aorta, it was sometimes difficult to clearly identify it above the origin of the native coronary arteries. The LCX graft was, on occasion, difficult to distinguish from the coronary sinus at the level of the left ventricle. Other authors have commented on structures that may be confused with bypass grafts or native coronary arteries, including the pericardial reflections, coronary veins, and postsurgical defects in the pericardium. Gomes et al. commented on the importance of following bypass grafts through successive images from the position near native coronary

TABLE 1
Angiographic and MR patency by graft location

<table>
<thead>
<tr>
<th>Grafted artery</th>
<th>LAD (n = 20)</th>
<th>RCA (n = 14)</th>
<th>LCX (n = 13)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patent by angio and MR</td>
<td>12</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Occluded by angio and MR</td>
<td>6</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Patent by angio but occluded by MR</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Occluded by angio but patent by MR</td>
<td>1</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Correctly classified by MR (%)</td>
<td>90</td>
<td>79</td>
<td>85</td>
</tr>
</tbody>
</table>

angio = angiography.
arteries up to their origin in the proximal aorta to avoid misinterpretation of low signal structures from coronary bypass grafts.

There are several ways spin-echo MR imaging to detect bypass grafts may be improved. Oblique imaging became available on our MR imager only at the end of our study and was used in two patients. If the coronal imaging plane is rotated approximately 45 degrees into a left anterior oblique orientation so that the imaging plane is aligned with the long axis of the heart parallel to the septum it is possible to appreciate the proximal portions of the bypass grafts as they come off the proximal aorta. This orientation is also useful for following the LAD graft since it approaches the native LAD in the interventricular groove. Thinner image slices might also improve the ability to separate a bypass graft from an adjacent structure such as a native coronary artery. Five to seven millimeter thick slices

**FIGURE 2.** Eight contiguous transaxial slices from a typical patient from the most inferior portion of the left ventricle to the ascending aorta at the level of the pulmonary artery bifurcation. The white triangle points to the RCA graft and the black triangle points to the LAD graft. The open arrow points to the native RCA and the black arrow points to the native LAD. LV = left ventricle; RV = right ventricle; AA = ascending aorta; PA = pulmonary artery.

**FIGURE 3.** Graft patency as determined by angiography and MR.
may be helpful in improving resolution by diminishing partial volume averaging. As the sampling volume is reduced, signal decreases, and the signal-to-noise ratio will decrease, possibly leading to poorer image contrast. This may be counteracted by increasing the number of image averages. Further investigation will be needed to determine the optimal slice thickness and the possible benefits of oblique imaging.

In this study we considered grafts known to have been placed at the time of surgery that were not seen by MR as occluded, although it is possible that if flow through a native graft is slow it will not have the typical appearance of a signal-free lumen. Blood vessels are visualized with the spin-echo technique by the appearance of a signal-free lumen because the spins of moving blood that are pulsed move out of the imaging plane. With slower flow from a stenosis this may not occur. Paulin et al. discussed this as a reason why they were unable to visualize the right coronary orifices in two patients with diseased native right coronary arteries. In the present study three of 29 grafts patent by angiography were not seen by MR and considered occluded. In two of these cases the studies were technically poor and the other case represented the only disagreement of interpretation. In our study population only one graft had a stenosis and was not seen by MR imaging. The remaining grafts were either widely patent with apparently good flow or occluded. This may reflect the fact that all the patients in the study were referred for cardiac catheterization because of chest pain. These patients probably have more severely obstructed or occluded grafts than asymptomatic patients. As such it was not possible to evaluate the influence of a stenosis, and possibly reduced blood flow, in a graft on the ability to visualize that graft with MR. We suspect, however, that a more proper way of describing the inability to visualize a bypass graft with MR spin-echo imaging would be to say the graft is either occluded or has reduced flow. Further investigation will be required to assess the influence of graft stenosis on spin-echo MR images.

A noninvasive modality that can accurately evaluate patency of coronary artery bypass grafts is of potential clinical significance. Graft patency has been postulated to be related to long-term survival. However, graft closure is not a rare event; studies have shown that within 6 months of operation 10% of bypass grafts in patients not treated with platelet-inhibiting agents are occluded, and at 1 year 25% of grafts in untreated patients are occluded. Patients presenting with chest pain cannot be presumed to have only graft closure, since when they are studied 5 to 7 years after coronary bypass grafting the incidence of graft closure versus progression of native coronary artery disease in ungrafted vessels is approximately equal.

Information on coronary artery bypass graft patency has significant implications for the management of patients with recurrent angina pectoris, often affecting the decision for repeat catheterization, reoperation, or medical therapy. Since obstructive disease in the LAD is a much stronger predictor of prognosis than disease in other vessels, continued medical therapy in patients with chest pain after bypass surgery and a patent graft to the LAD may be warranted unless symptoms are severe. The high accuracy of correctly classifying LAD grafts (18 of 20) is thus of particular clinical importance. The use of MR imaging in conjunction with stress testing may offer a rational approach to these patients, allowing better patient stratification for cardiac catheterization.

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References


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