Magnetic resonance imaging of acute myocardial infarction: gadolinium diethyleneetriamine pentaacetic acid as a marker of reperfusion

RONALD M. PESHOCK, M.D., CRAIG R. MALLOY, M.D., L. MAXIMILIAN BUJA, M.D., RAY L. NUNNALLY, PH.D., ROBERT W. PARKEY, M.D., AND JAMES T. WILLERSON, M.D.

ABSTRACT We examined the effects of a paramagnetic contrast agent, gadolinium diethyleneetriamine pentaacetic acid (Gd-DTPA) on magnetic resonance images of acute myocardial infarction with and without reperfusion. Twenty-two dogs underwent occlusion of the left anterior descending coronary artery (LAD). In 10 dogs (group I) the LAD remained occluded for 3 hr and in the other 12 (group II) for 2 hr followed by 1 hr of reperfusion. Gd-DTPA (0.34 mM/kg) was administered to five dogs in group I at 2 hr and 5 min after occlusion and to seven dogs in group II 5 min after reperfusion. At 3 hr after ligation, the hearts were excised and imaged with spin echo and inversion recovery pulse sequences on a 0.35 Tesla magnetic resonance imager. Reperfused hearts given Gd-DTPA demonstrated a significant increase in contrast between normal and reperfused myocardium as compared with nonreperfused hearts and reperfused hearts not given Gd-DTPA. This enhancement was particularly prominent in the inversion recovery images. Studies performed in vivo in two additional dogs demonstrated similar enhancement with reperfusion with Gd-DTPA in gated spin echo images. Contrast-enhanced magnetic resonance imaging allows the detection of reperfusion early in the course of acute infarction.

Circulation 74, No. 6, 1434-1440, 1986

WITH THE ADVENT of effective means of coronary thrombolysis, it is increasingly important to establish the presence and extent of myocardial reperfusion. Ideally, this assessment would be made noninvasively with high spatial resolution and with the potential for serial evaluations. Nuclear magnetic resonance imaging may fulfill these objectives because it provides images with excellent spatial resolution without the use of ionizing radiation.

Previous studies of myocardial tissue by nuclear magnetic resonance spectroscopy have suggested that changes in tissue relaxation times T1 and T2 caused by infarction may be further increased by reperfusion. However, it is not clear that these changes are sufficient to allow differentiation of reperfused from nonreperfused myocardium on magnetic resonance images. Gadolinium diethyleneetriamine pentaacetic acid (Gd-DTPA), a paramagnetic agent that increases the relaxation rates of hydrogen nuclei, has been demonstrated to enhance contrast between normal and pathologic tissue in humans. Recent studies also indicate that this agent may be a marker of myocardial perfusion. Hence, it might prove to be a useful agent in the demonstration of reperfusion. The present studies were carried out to examine the effect of Gd-DTPA on the appearance of magnetic resonance images of early myocardial infarction in the presence and absence of reperfusion.

Methods

Excised heart studies

Experimental preparation. Twenty-two mongrel dogs weighing 20 to 25 kg were used in this portion of the study. Each dog was anesthetized with intravenous pentobarbital (30 mg/kg), intubated, and ventilated on room air. A left thoracotomy was performed, and the left anterior descending coronary artery (LAD) was isolated. Left atrial and femoral arterial catheters were inserted for measurements of regional myocardial blood flow with radioactive microspheres. Preoclusion blood flow was measured in 15 dogs. The LAD was then occluded in each
animal for 2 hr. Postoclusion flow was measured in dogs receiving microspheres. The animals were then divided into four groups: group IA, no reperfusion, no Gd-DTPA (n = 5); group IB, no reperfusion, Gd-DTPA (n = 5); group IIA, reperfusion, no Gd-DTPA (n = 5); and group IIB, reperfusion, Gd-DTPA (n = 7). In group I, the LAD occlusion was not released. Two hours and 5 min after occlusion, dogs in group IB were given 0.34 mM/kg Gd-DTPA (Mallinckrodt, St. Louis), whereas dogs in group IA were given an equivalent volume of saline. In group II, the LAD occlusion was removed after 2 hr of occlusion. After 5 min of reflow, dogs in group IB were given 0.34 mM/kg Gd-DTPA, whereas dogs in group IIA were given an equivalent volume of saline. Radioactive microspheres were used to measure regional myocardial blood flow after 60 min of reflow in seven dogs in group II (four in group IIA and three in group IIB). At 3 hr after LAD occlusion (1 hr after reperfusion in group II, 55 min after the administration of Gd-DTPA in groups IB and IIB), all animals were killed with a lethal injection of pentobarbital and potassium chloride. The hearts were excised, wrapped in plastic to prevent drying, and imaged.

Imaging. The excised hearts were imaged with a Diasonics MT/S (Milpitas, CA) 0.35 Tesla magnetic resonance imager. All images were acquired with the same 90 and 180 degree pulses and receiver gains. The heart or hearts being imaged were centered in a 30 cm diameter coil and each heart covered approximately 10% of the area of the field of view. The studies in vivo were performed in a standard body coil designed for small adults and children. Spin echo images were obtained with repetition intervals (TR) of 1.0 and 0.5 sec and echo delays (TE) of 28 and 56 msec with a double spin echo, multislice technique. Voxel size in these images was 1.7 x 1.7 x 5 mm. Inversion recovery images (using a spin echo for readout) were obtained with a repetition interval of 1.0 sec, echo delays of 28 and 56 msec, and an inversion time (TI) of 0.420 sec. Voxel size in these images was 1.7 x 1.7 x 7 mm. In five cases, hearts were imaged as pairs (one with and one without Gd-DTPA). In all cases, imaging was complete within 90 min of excision. Then the hearts were sliced transversely in planes similar to the magnetic resonance images and stained with triphenyl tetrazolium chloride (TTC) to serve as a guide in image analysis.

Studies in vivo. To examine whether these changes could be detected in vivo, two animals underwent placement of an LAD balloon occluder and were allowed to recover. The animals were subsequently reanesthetized with intravenous pentobarbital and imaged with a gated, multislice spin echo sequence. The repetition time (TR) was set by the animal’s heart rate and was typically 600 to 800 msec. Images were obtained at echo times (TE) of 28 and 56 msec. Images were obtained before occlusion, 1 hr after occlusion, immediately after reperfusion (before administration of Gd-DTPA), and 1 hr after reperfusion. The hearts were then excised and imaged similar to the hearts in the excised heart study.

Image analysis. The excised heart images were analyzed as follows: Regions of interest (ROIs) of 20 to 30 pixels were selected from the anterior left ventricular wall in the LAD distribution for measurements of signal intensity from ischemic myocardium; ROIs of approximately 40 pixels were chosen from the posterior left ventricular wall for measurements of signal intensity from normal myocardium. The ischemic regions were selected in the following way. The magnetic resonance images were compared with the TTC-stained slices of the heart. In most cases the region of altered signal intensity on the image was similar to the region of abnormal TTC staining. The ROI was drawn on the magnetic resonance image in a region comparable to that found to be abnormal by TTC staining. However, in some cases TTC staining was not clearly abnormal in the region that was obviously abnormal on the magnetic resonance image. In these instances, the ROI was drawn to include the abnormal region on the imaging study. In a few of the inversion recovery images in animals given Gd-DTPA, there was a peripheral region of increased intensity in the ischemic region with a relatively hypointense central region. In these cases, the ROI for the ischemic region was placed in the most intense area of the image for measurement of intensity ratios.

The mean intensity in each ROI was determined for both the 28 and 56 msec echoes of each image. Four ratios were calculated with the intensity data: (1) the ratio of the 56 msec echo intensity to the 28 msec echo intensity in the normal posterior left ventricular wall (I56/I28, normal); (2) the ratio of the 56 msec echo intensity to 28 msec echo intensity in the ischemic LAD distribution tissue (I56/I28, ischemic); (3) the ratio of intensity in the ischemic tissue to the intensity of the normal posterior left ventricular wall for the 28 msec echo (Iischemic/Inormal, 28 msec); and (4) the ratio of intensity in the ischemic tissue to the intensity of the normal posterior left ventricle for the 56 msec echo (Iischemic/Inormal, 56 msec). In the case of the latter ratios (Iischemic/Inormal, 28 msec and Iischemic/Inormal, 56 msec), a value greater than 1 implies that the intensity in the ischemic distribution is greater than that in the posterior left ventricular wall.

Multiple measurements were made in two to four slices in each heart depending on the size of the ischemic region. These values were averaged to obtain a measurement for each heart. To determine the effect of sampling the ischemic region, interobserver variability was evaluated by having two observers (R.P. and C.R.M.) measure ischemic and normal signal intensities for each heart. The ratio Iischemic/Inormal at 28 msec was calculated for each heart and the percentage difference between the two observations was determined to be 2.9 ± 2.5%. Intraobserver variability was calculated by having one observer (R.P.) examine the images at two times 2 weeks apart. The intraobserver variability was 2.0 ± 2.2%.

Blood flow determinations. Regional myocardial blood flows were measured by standard techniques. Microspheres 15 μm in diameter labeled with 85Sr, 46Sc, 57Co, and 95Nb were used in varying order for the multiple flow measurements outlined above. From each heart, the tissue slice that was most similar to an image used in the image analysis was divided into eight subendocardial and eight epicardial samples each weighing approximately 1 g for counting and calculation of regional blood flow. The sample used to measure flow in the central ischemic zone was chosen from the center of the region of abnormal TTC staining or from a region corresponding to the center of the magnetic resonance image abnormality.

Statistical analysis. Results are expressed as mean ± 1 SD. Intensity ratios from different experimental groups were compared by a two-factor repeated measure analysis of variance. In the case of interactions between contrast agent and imaging technique, differences in technique were analyzed with a one-way repeated measures followed by a Newman-Keuls multiple comparison procedure. Within techniques, the effect of contrast agent was evaluated by t tests with a Bonferroni correction for multiple comparisons to control the alpha level for six comparisons jointly at .05.

Results

Imaging results. Typical images obtained in animals in group I and group II with and without Gd-DTPA are shown in figures 1 and 2, respectively. The nonreperfused hearts showed regions of mildly increased intensity in the ischemic regions on spin echo imaging. In the inversion recovery images, there was no difference...
in intensity between the normal and the ischemic regions. In hearts from animals given Gd-DTPA, there was a slight increase in the intensity of the ischemic region relative to normal myocardium in the spin echo and inversion recovery images. In a few of the inversion recovery images obtained after the administration of Gd-DTPA, there was a region of increased intensity peripherally with a relatively hypointense central region.

Typical images from reperfused hearts are shown in figure 2. Spin echo images showed a mild increase in intensity in the reperfused region. Inversion recovery images showed decreased intensity in the reperfused region. In hearts from animals given Gd-DTPA, there was markedly increased intensity in the reperfused regions as compared with the remainder of the myocardium. This contrast was most pronounced in the inversion recovery images.

Typical images from the study in vivo are shown in figure 3. In animals given Gd-DTPA, there was enhancement in the reperfused region when compared with images obtained before Gd-DTPA. Images of the hearts after excision confirm the observation.

Regional myocardial blood flows. Flow was measured in the central region of the ischemic zone in each animal. The results for each group were summarized in table 1. There were no significant differences among preocclusion flows in the four groups of animals. Postocclusion flows were also similar in all groups and significantly less than preocclusion flow in each group. In the reperfused animals, flows after 60 min of reperfusion returned to control levels or above in each animal. There was no significant difference between groups IIA and IIB after reperfusion.

**Effect of Gd-DTPA on contrast between ischemic myocardium and normal myocardium**

*Group I.* Ratios of nonreperfused ischemic to normal myocardial signal intensities are shown in table 2. In spin echo images, animals not given Gd-DTPA demonstrated small increases in the intensity of ischemic tissue in the first echo (4% to 6%) and larger increases in the second echo (12% to 16%). Inversion recovery images in animals not given Gd-DTPA showed little if any contrast between ischemic and normal myocardium. In animals given Gd-DTPA, there was a small increase in image contrast for all imaging techniques as compared with animals not given Gd-DTPA; however, this difference was statistically significant only for the TR 0.5 second spin echo imaging sequence.

*Group II.* Reperfusion after 2 hr of ischemia significantly altered tissue contrast as well as the pattern of response to Gd-DTPA. Ratios of reperfused ischemic to normal myocardial signal intensities are shown in table 3. In spin echo images of animals not given Gd-DTPA, increases in signal intensity similar to those in group I animals were observed. Inversion recovery images, however, demonstrated a ratio less than 1, which indicates reduced intensity in this region (see figure 2). This ratio was significantly different from the intensity ratios observed in the spin echo images. In animals given Gd-DTPA, there was a marked increase in contrast, particularly in the TR-0.5 sec and the inversion recovery images. Depending on the imaging sequence used, the reperfused LAD regions were 28% to 65% more intense than normal myocardium after the administration of Gd-DTPA.

**Influence of Gd-DTPA on the intensity of second echo images as compared with first echo images.** Table 4 com-
FIGURE 2. Images of hearts from group II (reperfusion). Similar to figure 1, panels A and B show images obtained with a spin echo sequence. A, Image of a heart from an animal not given Gd-DTPA; B, image of a heart from an animal that received Gd-DTPA. Panels C and D show inversion recovery images of the same hearts. Prominent enhancement is apparent in the reperfused region in images B and D. The white arrow indicates a relatively hypointense central area on the inversion recovery image without Gd-DTPA.

The ratio of the second echo to first echo intensity for normal myocardium and ischemic myocardium regardless of whether or not reperfusion was present. The ratio was greater in all ischemic groups with or without reperfusion than in normally perfused tissue. In addition, in animals given Gd-DTPA this ratio was not significantly decreased in any group.

Influence of Gd-DTPA on signal intensity in normally perfused myocardium. Five pairs of hearts were imaged simultaneously, with one heart receiving Gd-DTPA and the other not receiving Gd-DTPA, allowing direct comparison of image intensity under identical imaging conditions. Table 5 lists the effect of Gd-DTPA on the signal intensity of normally perfused myocardium. The results are expressed as the ratio of signal intensity in normal myocardium receiving Gd-DTPA to the signal intensity in normal myocardium not receiving Gd-DTPA. Gd-DTPA caused a significant increase in the intensity of normal myocardium in both inversion recovery and in spin echo TR-0.5 sec images as compared with spin echo TR-1.0 sec images. This effect was present in both first and second echo images.

The ratio of second to first echo signal intensity was increased in all ischemic regions regardless of the presence or absence of Gd-DTPA. With the spin echo

FIGURE 3. Images obtained in vivo with a gated spin echo imaging sequence (TR approximately 700 msec). The 28 msec echoes are shown in the top row and the 56 msec images are shown in the bottom row. A, Images obtained before occlusion; B, images 2 hr after reperfusion; C, images obtained 3 hr after initial occlusion (i.e., 1 hr after beginning reperfusion, 55 min after the administration of Gd-DTPA); D, images of the excised heart approximately 15 min later (TR 500 msec).
images for TR = 1.0, the mean I_56/I_28 in normal myocardium was 0.50 ± 0.02 compared with 0.56 ± 0.04 in the ischemic region (n = 20, p < .01). For TR = 0.5, the mean I_56/I_28 for normal myocardium was 0.50 ± 0.02 compared to 0.56 ± 0.04 in the ischemic region (n = 22, p < .01). With the inversion recovery images, the mean I_56/I_28 for normal myocardium was 0.48 ± 0.02 compared with 0.51 ± 0.03 (n = 22, p < .01).

Discussion

The data obtained in this study lead to three important conclusions: (1) Gd-DTPA enhances the contrast between normal and acutely ischemic myocardium, (2) this enhancement is markedly augmented with reperfusion, suggesting that Gd-DTPA may be useful as a marker of reperfusion after temporary coronary arterial occlusion, and (3) inversion recovery pulse sequences may be useful in the evaluation of myocardial ischemia particularly when used with paramagnetic contrast agents.

Previous studies have shown that magnetic resonance imaging can detect regions of myocardial infarction on the basis of changes in tissue relaxation times T1 and T2, probably related to changes in tissue water content.7-8 However, early in infarction, changes in tissue water content, although present, are less prominent.9 Spectrometric measurements of excised tissue have demonstrated changes in T1 3 hr of ischemia with relatively smaller changes in T2.1 These changes were only slightly greater in hearts imaged after 3 hr of occlusion and 1 hr of reperfusion. The results of our study also indicate that relaxation times are prolonged by acute ischemia. An increase in the ratio of second echo to first echo intensity (I_56/I_28) is a reflection of an increase in tissue T2.

### TABLE 2

**Influence of Gd-DTPA on contrast between nonreperfused and normal myocardium**

<table>
<thead>
<tr>
<th>Imaging technique</th>
<th>No Gd-DTPA</th>
<th>Gd-DTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE, TR 1.0, TE 28</td>
<td>1.06 ± 0.06</td>
<td>1.16 ± 0.03</td>
</tr>
<tr>
<td>SE, TR 1.0, TE 56</td>
<td>1.16 ± 0.06</td>
<td>1.31 ± 0.08</td>
</tr>
<tr>
<td>SE, TR 0.5, TE 28</td>
<td>1.04 ± 0.03</td>
<td>1.12 ± 0.03</td>
</tr>
<tr>
<td>SE, TR 0.5, TE 56</td>
<td>1.12 ± 0.07</td>
<td>1.26 ± 0.02</td>
</tr>
<tr>
<td>IR, TR 1.0, TI 0.420, TE 28</td>
<td>1.00 ± 0.04</td>
<td>1.07 ± 0.07</td>
</tr>
<tr>
<td>IR, TR 1.0, TI 0.420, TE 56</td>
<td>1.04 ± 0.06</td>
<td>1.16 ± 0.10</td>
</tr>
</tbody>
</table>

I_{56}/I_{28} = ratio of signal intensity in the ischemic region to the signal intensity in the normally perfused myocardium; SE = spin echo; IR = inversion recovery; TR = repetition interval (sec); TE = echo time (msec); TI = inversion time (sec).

n = 5 for each value.

^Different from no Gd-DTPA, p < .05.

### TABLE 3

**Influence of Gd-DTPA on contrast between reperfused ischemic and normal myocardium**

<table>
<thead>
<tr>
<th>Imaging technique</th>
<th>No Gd-DTPA</th>
<th>Gd-DTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE, TR 1.0, TE 28</td>
<td>1.06 ± 0.06 (n = 4)</td>
<td>1.28 ± 0.05 (n = 6)</td>
</tr>
<tr>
<td>SE, TR 1.0, TE 56</td>
<td>1.17 ± 0.17 (n = 4)</td>
<td>1.43 ± 0.11 (n = 6)</td>
</tr>
<tr>
<td>SE, TR 0.5, TE 28</td>
<td>0.98 ± 0.03 (n = 4)</td>
<td>1.36 ± 0.09 (n = 6)</td>
</tr>
<tr>
<td>SE, TR 0.5, TE 56</td>
<td>1.08 ± 0.11 (n = 4)</td>
<td>1.52 ± 0.12 (n = 6)</td>
</tr>
<tr>
<td>IR, TR 1.0, TI 0.420, TE 28</td>
<td>0.91 ± 0.09 (n = 4)</td>
<td>1.45 ± 0.17 (n = 6)</td>
</tr>
<tr>
<td>IR, TR 1.0, TI 0.420, TE 56</td>
<td>0.93 ± 0.03 (n = 4)</td>
<td>1.60 ± 0.22 (n = 6)</td>
</tr>
</tbody>
</table>

Abbreviations as in table 2.

^Different from no Gd-DTPA, p < .05.

^Different from TR 1.0 or 0.5 no Gd-DTPA, p < .05.

### TABLE 4

**Influence of Gd-DTPA on the ratio of second to first echo intensity**

<table>
<thead>
<tr>
<th>Imaging technique</th>
<th>Tissue</th>
<th>No Gd-DTPA</th>
<th>Gd-DTPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE, TR 1.0</td>
<td>Normally perfused</td>
<td>0.52 ± 0.01 (n = 9)</td>
<td>0.49 ± 0.02 (n = 11)</td>
</tr>
<tr>
<td>SE, TR 1.0</td>
<td>Ischemic</td>
<td>0.56 ± 0.05 (n = 9)</td>
<td>0.55 ± 0.02 (n = 11)</td>
</tr>
<tr>
<td>SE, TR 0.5</td>
<td>Normally perfused</td>
<td>0.52 ± 0.02 (n = 10)</td>
<td>0.50 ± 0.02 (n = 12)</td>
</tr>
<tr>
<td>SE, TR 0.5</td>
<td>Ischemic</td>
<td>0.56 ± 0.04 (n = 10)</td>
<td>0.55 ± 0.02 (n = 12)</td>
</tr>
<tr>
<td>IR</td>
<td>Normally perfused</td>
<td>0.48 ± 0.01 (n = 10)</td>
<td>0.48 ± 0.02 (n = 12)</td>
</tr>
<tr>
<td>IR</td>
<td>Ischemic</td>
<td>0.50 ± 0.03 (n = 10)</td>
<td>0.52 ± 0.03 (n = 12)</td>
</tr>
</tbody>
</table>

I_56/I_28 = ratio of the intensity in the second echo image to the intensity in the first echo image for that region of myocardium; other abbreviations as in table 2.
TABLE 5
Influence of Gd-DTPA on signal intensity of normally perfused myocardium

<table>
<thead>
<tr>
<th></th>
<th>First echo image</th>
<th>Second echo image</th>
</tr>
</thead>
<tbody>
<tr>
<td>SE, TR 1.0</td>
<td>1.00 ± 0.11^A</td>
<td>0.92 ± 0.12^A</td>
</tr>
<tr>
<td>SE, TR 0.5</td>
<td>1.12 ± 0.09^B</td>
<td>1.04 ± 0.12^B</td>
</tr>
<tr>
<td>IR</td>
<td>1.35 ± 0.11^C</td>
<td>1.27 ± 0.11^C</td>
</tr>
</tbody>
</table>

Abbreviations as in table 2.

A Different from TR 0.5 and IR, p < .05.

B Different from TR 1.0 and IR, p < .05.

C Different from TR 1.0 and TR 0.5, p < .05.

Ischemic regions, both with and without reperfusion, showed an increase in this ratio in spin echo images. However, there was no significant difference between the value in reperfused and nonreperfused regions. Hence, early in infarction it appears that differences in relaxation times between reperfused and nonreperfused regions may be small and difficult to differentiate with standard magnetic resonance imaging as performed in this study.

In view of these limited differences in T1 and T2, it is reasonable to suggest that a blood-borne contrast agent might aid in the differentiation between reperfused and nonreperfused ischemic myocardium. Gd-DTPA is a paramagnetic contrast agent that acts to reduce tissue relaxation times. Previous studies of the use of Gd-DTPA in the setting of infarction and acute coronary occlusion have concentrated on the effects of Gd-DTPA on relaxation times in the first 1 to 5 min after injection. Wesbey et al. found that hearts with 24-hr-old infarction excised 90 sec after the injection of Gd-DTPA demonstrated significant decreases in both T1 and T2 relaxation times consistent with the delivery of Gd-DTPA to the normally perfused region. Infarced myocardium was not affected in the first 90 sec and increased contrast between infarcted and normally perfused myocardium was shown to be due to a prominent effect on T2 in the normal region with a consequent decrease in normal myocardial signal intensity. In hearts excised 5 min after injection of Gd-DTPA, there was greater T1 shortening in the infarced region consistent with redistribution of the agent into the infarcted region. In hearts with acute coronary occlusion, McNamara et al. demonstrated that 1 min after injection of Gd-DTPA there were alterations in tissue relaxation times, suggesting that it was a perfusion marker.

The fact that significant redistribution of Gd-DTPA into a region of infarction occurs within 5 min of injection limits the time available for imaging if one is interested in the initial distribution of the agent. In other imaging techniques, such as radionuclide and computed tomographic (CT) scanning, it has proved useful to examine the distribution of the agent after redistribution. Contrast in this case is dependent on the differential clearance of the agent from abnormal and normal myocardium. In animals studied 4 days after infarction, we have previously observed contrast between normal and infarcted myocardium, peaking approximately 1 hr after injection of 0.34 mM/kg Gd-DTPA, consistent with delayed clearance of Gd-DTPA from the region of infarction. This late enhancement is similar to that seen in CT studies of infarction using iodinated contrast agents. However, as compared with CT studies, the time of peak contrast and its duration appear to be different. This may be related to several factors, including (1) differences in the concentration of Gd-DTPA used in this study as compared to the concentration of iodinated contrast material used in CT studies, (2) the differential effects on image intensity caused by changes in T1 and T2 under various imaging conditions, and (3) differences in the distribution and clearance of Gd-DTPA as compared with iodinated contrast material. In this report, we performed imaging 55 min after the injection of Gd-DTPA and found enhanced contrast between ischemic and normal myocardium. This enhancement was modest in nonreperfused myocardium but marked in the regions of reperfusion.

Gd-DTPA appeared to have little effect on the ratio of second to first echo intensities of normal and ischemic myocardium at the dose used in this study. This suggests there was little effect on tissue T2 relaxation times. Hence, the predominant effect appeared to be on tissue T1 relaxation. This is supported by the fact that the relatively T1-weighted imaging sequences, spin echo TR-0.5 and inversion recovery, showed the greatest contrast.

The intensity changes seen in the inversion recovery images obtained with Gd-DTPA suggest that this type of imaging may be useful in the evaluation of ischemia and reperfusion. In nonreperfused hearts there was increased intensity in the periphery of the ischemic region (figure 1), suggesting delivery of Gd-DTPA to the border of the ischemic region without delivery centrally. This pattern is similar to that seen with iodinated contrast material and technetium pyrophosphate, reflecting residual blood flow to the region. In comparison, reperfused hearts given Gd-DTPA showed marked uniform enhancement of the ischemic region. Recently, a method for obtaining gated inversion recovery images has been described, suggesting a po-
tential role for such $T_1$-weighted images in cardiac evaluation.

There are two concerns that arise with regard to the application of this technique in man. First, the dose of Gd-DTPA (0.34 mM/kg) used in this study is higher than that presently used in studies of the central nervous system in man (0.1 mM/kg). It is probable that the effect observed in this study is dose related. Hence, it would be necessary to evaluate the effects of this lower dose or to establish the safety of the higher dose used in this study before this technique can be used in man. Second, the hemodynamic effects and possible effects of this compound on infarct size were not evaluated in this study. At present, the hemodynamic effects of Gd-DTPA in patients or animals with acute infarction have not been evaluated.

In conclusion, we found in a canine preparation that early during myocardial ischemia, it may be difficult to distinguish reperfused from nonreperfused myocardium on the basis of intrinsic changes in tissue relaxation times with standard magnetic resonance imaging. However, in hearts imaged 1 hr after the administration of Gd-DTPA, there was markedly enhanced contrast with reperfusion. Hence, the use of Gd-DTPA may be helpful in defining the degree and extent of reperfusion in the setting of acute myocardial infarction by means of magnetic resonance imaging.

We acknowledge the technical assistance of Dorothy Gutekunst, Judy Behrens, Cindy Miller, and Frank Gorishek.

References

Magnetic resonance imaging of acute myocardial infarction: gadolinium diethylenetriamine pentaacetic acid as a marker of reperfusion.
R M Peshock, C R Malloy, L M Buja, R L Nunnally, R W Parkey and J T Willerson

Circulation. 1986;74:1434-1440
doi: 10.1161/01.CIR.74.6.1434

Circulation is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231
Copyright © 1986 American Heart Association, Inc. All rights reserved.
Print ISSN: 0009-7322. Online ISSN: 1524-4539

The online version of this article, along with updated information and services, is located on the World Wide Web at:
http://circ.ahajournals.org/content/74/6/1434

Permissions: Requests for permissions to reproduce figures, tables, or portions of articles originally published in Circulation can be obtained via RightsLink, a service of the Copyright Clearance Center, not the Editorial Office. Once the online version of the published article for which permission is being requested is located, click Request Permissions in the middle column of the Web page under Services. Further information about this process is available in the Permissions and Rights Question and Answer document.

Reprints: Information about reprints can be found online at:
http://www.lww.com/reprints

Subscriptions: Information about subscribing to Circulation is online at:
http://circ.ahajournals.org//subscriptions/