

Serial Nuclear Magnetic Resonance Imaging in Acute Myocardial Infarction

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Recent studies show that proton nuclear magnetic resonance (NMR) imaging can detect myocardial ischemia and acute myocardial infarction (AMI) in animal models¹⁻³ and in humans.⁴⁻⁶ The area of AMI appears as increased signal intensity on the spin-echo NMR images and most likely reflects the regional edema associated with tissue necrosis.¹ Thus, the time course of regional edema and the evolution of infarct healing may be revealed by serial NMR studies. In a recent canine study, Pflugfelder et al⁷ examined the time course of the increased NMR signal intensity associated with AMI. They found that the relative signal intensity increased between the day of AMI and 2 weeks after AMI and subsequently decreased by the 20th day. We examined the early time course of NMR changes in humans.

The 9 patients who were examined in our study consisted of 8 men and 1 woman, aged 38 to 71 years (mean 50). All patients presented with an initial Q-wave AMI, which was anterior in 5 and inferior in 4. Seven patients underwent acute coronary reperfusion using thrombolytic agents or percutaneous transluminal coronary angioplasty at a mean interval of 4.5 hours after initial onset of chest pain. Patient imaging was performed with a 0.35-tesla NMR system using a dual spin-echo pulse sequence electrocardiographically gated to the R wave. The first imaging study was done 3 to 5 days after AMI, after discharge from the coronary care unit. Each patient was restudied 10 to 14 days after AMI, just before hospital discharge. First (SE₁) and second (SE₂) spin-echo images were obtained using transaxial and coronal acquisition planes with the patient in the 30° right anterior oblique position to obtain true long-axis projections through the heart.⁸ Signal intensities of infarcted (I_{infarct}) and remote normal (I_{normal}) myocardium were measured from operator-defined regions of interest (Fig. 1). Each region of interest contained at least 100 voxels

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and generally were 100 to 150 voxels in size. Signal intensity values were expressed as normalized values using the following relation: $I_{\text{infarct}} - I_{\text{normal}} / I_{\text{normal}} \times 100\%$. The inter- and intraobserver variability for intensity measurements in the normal myocardium was 25.8% and 15.0%, respectively, and in the infarcted myocardium, 12.4% and 9.1%. T₂ magnetic relaxation times were calculated from infarct and normal regions according to the formula: $(TE_2 - TE_1) / \text{Log}_e(I_1 / I_2)$, where TE₂ = time to SE₂; TE₁ = time to SE₁; I₁ and I₂ = intensity of SE₁ and SE₂. Mean percent variability of T₂ of fat and skeletal muscle were 9.2% and 24.2%, respectively.

All data are expressed as mean ± standard error of the mean. Statistical analysis was performed using the Student t test. A p value was considered significant at the <0.05 level.

In each patient, an area of increased signal intensity was noted on the initial NMR study in a location corresponding to the electrocardiographic location of the Q-wave infarct. There was some variability in the ease with which the infarct location was identified on visual inspection of the SE₁ and SE₂ NMR images (Fig. 2). The infarct location was sometimes not apparent on certain tomographic projections and was more apparent with others. The electrocardiogram was used to help localize the NMR abnormality for further quantitative analysis.

The intensity values for normal and infarcted regions are shown in Figure 3. For both the SE₁ and SE₂ images the intensity of the infarcted myocardium was significantly greater than that for the remote normal myocardium. This was true both for the early postinfarction studies and the late predischarge studies. When the regional intensity values were normalized, SE₁ was 37 ± 13% on initial study and increased to 51 ± 17% on the predischarge study, but this change did not achieve statistical significance. The SE₂ normalized regional intensity value tended to decrease from acute to predischarge studies, from 89 ± 33% to 53 ±

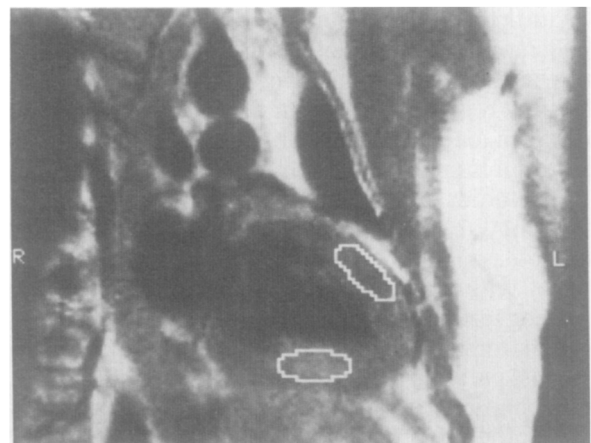


FIGURE 1. Regions of interest are outlined in normal (upper) and infarcted (lower) regions of the left ventricle in a patient with an acute inferior myocardial infarction. Note the increased signal intensity in the inferior (lower) zone.

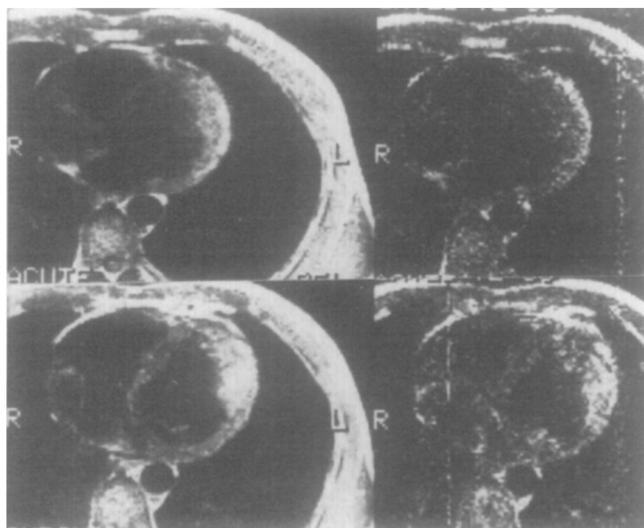


FIGURE 2. First (SE₁, left) and second (SE₂, right) spin-echo nuclear magnetic resonance images in a patient with anterolateral myocardial infarction. Top, acute studies; bottom, predischarge (chronic) studies. The area of infarction appears as an area of increased signal intensity and is easily appreciated on both SE₁ and SE₂ images. There is little change in the signal intensities between the acute and predischarge studies.

17% ($p > 0.05$), but again this change did not reach statistical significance.

The acute T_2 magnetic relaxation time measured 34 ± 3 ms in the remote normal myocardium and was significantly increased in the infarct region (48 ± 4 ms, $p < 0.05$). On the predischarge study, the T_2 relaxation time was prolonged in the remote normal myocardium (51 ± 5 ms, $p < 0.05$). The predischarge T_2 values in the infarct region also were prolonged (72 ± 27 ms). When the T_2 relaxation times were expressed as normalized values, the normalized T_2 relaxation time was $51 \pm 22\%$ during initial study and remained elevated at $33 \pm 39\%$ on the predischarge NMR study. Although there was a trend to some improvement in the normalized T_2 values, this did not reach statistical significance.

Until the present study, the time course of NMR abnormalities associated with AMI in man was unknown. Since these NMR changes may reflect alterations in regional edema and may indicate evolutionary changes in the healing process, further serial studies in humans are important. Our data suggest that serial studies during the early in-hospital phase of AMI show changes in signal intensity ratios and T_2 magnetic relaxation times in the infarct zone which persist, with no statistically significant interval change. This suggests that regional edema in the infarct zone persists for at least 2 weeks after initial infarction.

Most patients in our study underwent thrombolytic or mechanical reperfusion. Reperfusion may have enhanced the regional edema and subsequent NMR abnormality, and thus may have altered the subsequent time course of NMR change. Our data, however, do agree with those of Pflugfelder et al,⁷ who studied dogs for several weeks after complete coronary occlusion without reperfusion. Although they noted a significant

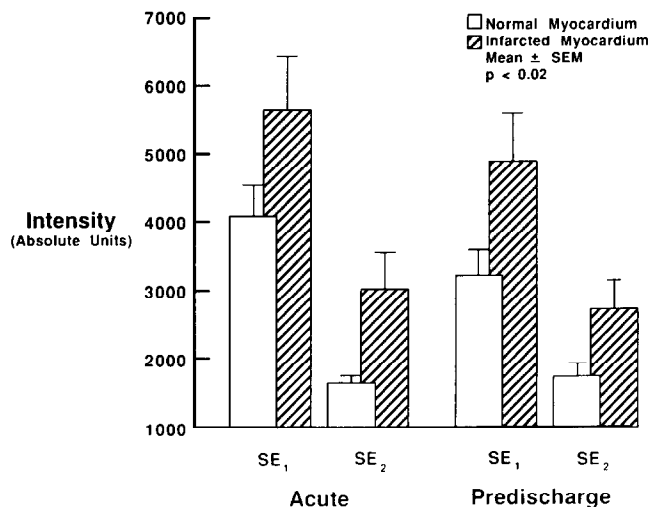


FIGURE 3. Absolute intensity values in normal and infarcted myocardial regions demonstrate the relative increased signal intensity of infarcted tissue on SE₁ and SE₂ images. The change in normalized infarct intensity from initial to predischarge study was not statistically significant.

increase in signal intensity between the initial day of AMI and day 14 after AMI, examination of their data does not indicate significant change in the NMR abnormality.

Our data further emphasize limitations of using magnetic relaxation times to characterize myocardial ischemia and injury in humans. T_1 relaxation times were not calculated because additional pulse sequences would have been necessary, which would have led to unacceptable patient study times, almost 2 hours. In our experience, T_1 times calculated from cardiac studies have been too variable to be clinically useful. The T_2 times were calculated from signal intensity values as previously described. The fact that the T_2 values increased significantly in the remote nonischemic myocardium in our study population suggests that T_2 relaxation times as calculated in the present study may have only limited value. Our data suggest that T_2 times in patient studies need to be interpreted cautiously until the specific determinants of T_2 are better understood and until improved methods for its calculation are developed.

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Angiographic Demonstration of Congenital Intercoronary Communication in Normal Adults

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Prominent anastomoses between the right and left coronary arteries, which are present during fetal life, persist into the postnatal period and diminish in caliber by the 8th month.¹ Recent anatomic studies indicate that the normal adult heart contains a profusion of small interconnecting vessels less than 200 μ in diameter.² Their angiographic demonstration in living humans with normal coronary arteries is probably precluded by minimal or no flow across them and by limitation of resolution of imaging systems. We report angiographic documentation of a prominent intercoronary connection between a dominant right and non-dominant left circumflex coronary arteries in 3 normal adults.

During the last 10 years, 6,400 coronary arteriographic studies have been performed in our laboratory. Normal arteriograms recorded from 600 patients investigated for atypical chest pain, cardiomyopathy and valvular heart disease were examined and 3 subjects were identified who had the intercoronary connection described in this report.

Clinical features are summarized in Table I. The studies were carried out using the transfemoral technique with standard 7Fr catheters. There was no pressure damping during selective placement of the catheter tip in either coronary ostium. Multiple oblique and hemiaxial views were obtained.

In all 3 cases injection into the normal right coronary artery resulted in prompt visualization of the left circumflex artery through a prominent straight connection, at or near the level of the crux, measuring after correction for magnification 1.5, 1.1 and 1.6 mm in caliber, respectively. In cases 1 and 2 the left circumflex artery was visualized in its entirety (Fig. 1A and 2A). Additionally, in case 2 the retrograde filling progressed to partially visualize the left main and the

left anterior descending arteries. In case 3 retrograde filling of the distal left circumflex artery only was observed (Fig. 3A).

During injection of the left coronary artery a minimal amount of contrast medium crossed the connection to partially fill the right coronary artery in case 1 (Fig. 1B) and not in cases 2 and 3. To account for this apparent discrepancy one may propose that both the force of injection and the velocity of flow in the left coronary artery would suffer some degree of dispersion because of its larger vascular capacity. A selective injection into the left circumflex artery probably would have resulted in full visualization of the right coronary artery. Angiographic luminal integrity of the left coronary arterial system is evident in all 3 cases. (Fig. 1B to 3B).

The prominent straight connection between 2 major nonobstructed right and left circumflex coronary arteries identified in each patient, at or near the level of the crux, is incontrovertible. It is clearly different from the inter- and intracoronary anastomoses seen in the course of occlusive coronary artery disease. Acknowledged for many years in most patients with obstructive coronary artery disease, these anastomotic channels consist of 1 or more small, tortuous channels of differing sizes and lengths, carrying a variable amount of flow and functioning only upon the demand of a severe perfusion gradient.³ Only on rare occasions have they been found to be of somewhat larger caliber.

Presence of large anastomotic connections in the absence of obstructive coronary artery disease, as seen in these 3 cases, is extremely rare. A careful literature search revealed only 3 previously reported cases^{4,5} with intercoronary connection strikingly similar in all details to that reported here. In 1 of the 2 cases described by Hines et al,⁴ a 67-year-old man, extensive obstructive coronary pathology was also present. In

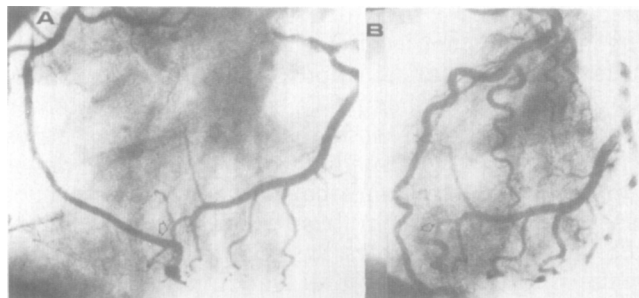


FIGURE 1. Case 1. **A**, selective injection of the right coronary artery, left anterior oblique view, demonstrating retrograde filling of entire left circumflex artery via a 1.5-mm-diameter connection at level of crux (arrow). **B**, selective injection of the left coronary artery, left anterior oblique view, demonstrating visualization of distal right coronary artery via the existing connection (arrow).

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