The Value of Cine Nuclear Magnetic Resonance Imaging for Assessing Regional Ventricular Function

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Previous nuclear magnetic resonance (NMR) imaging studies to assess left ventricular function have used multiple axial planes, which are compromised by partial volume effects and are time consuming to acquire and analyze. Accordingly, an imaging approach using cine NMR and planes aligned with the true cardiac axes of the left ventricle was developed in views comparable with left ventricular cineangiography. Cine NMR imaging was used to assess regional wall motion and was validated by comparison with biplane left ventricular cineangiography. Fifty-nine patients underwent cineangiographic and NMR studies within 72 h. A poor quality NMR study precluded analysis in 4, leaving a study group of 55 patients (mean age 58 ± 12; 17 women).

Cine NMR movie loops were acquired in two long-axis planes: 1) right anterior oblique plane, parallel to the septum, and 2) four chamber orthogonal plane, perpendicular to the septum (this view is comparable to the angiographic left anterior oblique view). To assess regional wall motion, the left ventricle in both cine NMR and cineangiographic images was divided into five segments and graded on a five point grading scale from 3 for normal through 0 for akinesia and −1 for dyskinesia. Regional wall thickening was used qualitatively to aid in the analysis of wall motion. For the 275 segments compared in the right anterior oblique view, agreement was within one grade in 263 (95.6%) of 275 segments, whereas absolute agreement was observed in 171 (62%) of 275 segments. In the left anterior oblique view, of 200 segments evaluated, agreement within one grade was achieved in 184 segments (92%) and agreement was complete in 132 (66%).

It is concluded that biplane cine NMR imaging, using two intrinsic left ventricular long-axis planes, permits noninvasive assessment of regional left ventricular function in views comparable to standard angiographic projections.

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Impairment of regional left ventricular function is a major consequence of myocardial ischemic insult and an important determinant of prognosis (1). Serial wall motion evaluation is useful for assessing the effectiveness of interventional strategies aimed at limiting infarct size (2–5). Thus, a reliable high resolution noninvasive method for wall motion analysis would have important clinical value. Currently available noninvasive imaging methods have limitations in assessing regional wall motion. In echocardiography, optimal image acquisition depends on the skill of the operator and the presence of an adequate acoustic window. With radionuclide methods, limited resolution and overlap of blood-containing structures may confound interpretation (6).

Nuclear magnetic resonance (NMR) imaging is a noninvasive modality that permits acquisition of high resolution images in virtually any tomographic plane (7–10). The development of the gradient echo technique (cine NMR), which uses limited flip angles and short repetition times, has markedly improved temporal resolution (11). This enables sequential frames of the cardiac cycle to be acquired and displayed as a movie loop of the beating heart. The combination of excellent inherent contrast between the blood pool and myocardium and good temporal resolution has made cine NMR a promising method for the evaluation of ventricular function (12, 13).

A major limitation of previous NMR studies in assessing left-ventricular function was the use of planes oriented with respect to external body axes rather than the intrinsic...
cardiac axes (8,9,14,15). These planes transect the myocardium obliquely, leading to the so-called partial volume effects, and thus may not appropriately assess myocardial thickening and regional ventricular function. The recent advent of electronic angulation makes it possible to acquire images in planes that are aligned with the true axes of the heart (16).

The present study reports a cine NMR imaging strategy that uses two intrinsic long axes of the heart to assess regional left ventricular function. This approach was validated by comparison with biplane left ventricular cineangiography in 55 patients.

**Methods**

**Study patients.** Patients undergoing routine cardiac catheterization were screened for eligibility for the study. Exclusion criteria were atrial fibrillation or arrhythmia during left ventricular angiography (making data impossible to analyze), hemodynamic instability and an implanted pacemaker or other ferromagnetic devices (e.g., aneurysm clips). Patients undergoing early coronary angioplasty or coronary artery bypass surgery were also excluded. Thus, 59 patients were candidates and underwent NMR imaging study within 72 h of the cineangiogram. Four patients with poor quality NMR studies were excluded from analysis, leaving 55 patients (38 men and 17 women) for analysis. The mean age of patients in the study was 57 ± 12 (21 to 85) years. Cineangiography was performed for assessment of coronary artery disease in 47 patients, assessment of valvular disease in 4, post-cardiac transplant evaluation in 3 and congestive cardiomyopathy in 1. Of the 47 who underwent cineangiography for the assessment of coronary artery disease, 32 had a history of previous myocardial infarction. Informed consent was obtained from all study patients.

**Cardiac catheterization.** All patients underwent both coronary and left ventricular cineangiography. Cineangiography was performed at a filming speed of 30 frames/s. All patients had left ventricular cineangiography in the 30° right anterior oblique view, whereas 50 patients had an additional cine imaging study in the 60° left anterior oblique projection with 15° craniocaudal angulation.

**NMR Imaging.** Studies were performed on a 1.5 tesla NMR imaging system (Philips Medical Systems of North America). Three orthogonal spin echo scout images (transaxial, sagittal and coronal) were acquired to define the cardiac axes. Then two orthogonal cardiac long-axis imaging planes were determined as follows: 1) *Right anterior oblique plane*—a single angulated plane parallel to the interventricular septum intersecting the apex and the mid mitral valve (Fig. 1). 2) *Four chamber view*—a double angulated plane perpendicular to the interventricular septum, orthogonal to the right anterior oblique plane (Fig. 2). The latter appears similar to the echocardiographic four chamber view and comparable to the cineangiographic left anterior oblique view.

Cine NMR imaging variables were as follows: slice thickness 8 mm, flip angle 45° to 50°, echo time 12 to 15 ms, 4 measurements, 16 frames, resolution matrix 128 interpolated to 256. Repetition time (mean 37 ms; range 32 to 50) and acquisition time (mean 7 min) varied with heart rate. NMR imaging studies were displayed as a cine loop of 16 phases.

**Wall motion analysis.** To assess regional wall motion in the right anterior oblique view, the left ventricle in both cine NMR and cineangiographic studies was divided into five segments according to the Coronary Artery Surgery Study classification (17). The NMR four chamber view was compared to the cineangiographic left anterior oblique view. Because the latter angiographic projection is variably foreshortened (although the NMR plane is not), the apical segment is usually not visualized in the cineangiographic study. Therefore, the apical segment was not included in the analysis, leaving four segments for comparison in the left anterior oblique view (Fig. 3). NMR and cineangiography
Figure 2. Nuclear magnetic resonance (NMR) images, four chamber view: a double angulated plane perpendicular to the septum and orthogonal to the right anterior oblique plane. This plane is achieved by angulating a sagittal (top left) and a coronal (top right) scout imaging study. This imaging plane intersects the apex and mitral and tricuspid valves (bottom right). The cine NMR tomographic plane is shown at bottom left.

Figure 3. Segments used for comparison of wall motion between cineangiography and NMR (based on the Coronary Artery Surgery Study [CASS] classification). Right anterior oblique (RAO) view: AB = anterobasal; AL = anterolateral; A = apical; D = diaphragmatic; PB = posterobasal. Left anterior oblique (LAO) view: AS = apical septum; BS = basal septum; IL = inferolateral; LA = left atrium; PL = posterolateral.

were assessed by independent observers unaware of patient data.

Segmental motion was assessed qualitatively from the cine displays and scored on a five-point scale: normal = 3, mild hypokinesia = 2, moderate to severe hypokinesia = 1, akinesia = 0 and dyskinesia = -1 (18). Cineangiograms and NMR images were compared on a segment by segment basis. Total segment score (defined as the sum of scores for all segments in a given view) was calculated for each patient.

Statistical analysis. Agreement between segmental scoring for the two techniques was assessed by chi-square analysis. To assess for the possible existence of a systematic difference between the two methods, we compared the mean segmental scores for all segments using a paired t test. Inter- and intraobserver variation were expressed by the component of variance. Correlation of the total segment score for the different techniques was performed by using a least square linear regression analysis. Probability values <0.05 were considered significant.

Results

Wall motion abnormality scoring. Representative examples of NMR images in the different views are illustrated in Figures 4 to 6. NMR imaging demonstrated regional wall motion abnormalities in 43 (95%) of 45 patients who had an abnormal cineangiogram. Normal wall motion by NMR imaging was detected in 9 (90%) of 10 patients who had normal wall motion by cineangiogram.

Segment by segment comparison is summarized in Figure 7. In the right anterior oblique view, agreement was within one grade for 263 (95.6%) of 275 segments, whereas agreement was absolute for 171 of the 275 segments. In the left anterior oblique view, agreement was within one grade on 184 (92%) of the 200 segments, whereas agreement was absolute on 132 of these segments (66%) (Fig. 8).

The differences of mean segmental score for cineangiography and NMR imaging are shown in Figure 9. There were significant differences in mean segmental score for the anterolateral and anterobasal (right anterior oblique view) and
inferolateral and basal septal (left anterior oblique view) with the NMR score being significantly higher in each case.

Total segment score (sum of segmental scores in each patient) demonstrated a good correlation between NMR imaging and cineangiography for both the right anterior oblique view ($r = 0.90, p < 0.01$) and the left anterior oblique view ($r = 0.85, p < 0.01$) (Fig. 10). The combined biplane segment score also demonstrated good correlation ($\text{NMR} = 0.77(\text{angio}) + 5.34, r = 0.90, p < 0.01$) with the NMR score consistently higher than the cineangiographic (angio) score.

Inter- and intraobserver variability. Interobserver variance was 13% for the right anterior oblique view and 10.9% for the left anterior oblique view. The intraobserver variance was 12.3% and 9.8%, respectively, for the same views (values are expressed as coefficient of variance). Observer scores never differed by more than two grades for any segment.

Figure 4. Cine NMR right anterior oblique imaging (top) compared with cineangiography (bottom) in a patient with recent inferior myocardial infarction. Severe inferior hypokinesia is prominent in both the NMR images and the cineangiogram. Left, End-diastole. Right, End-systole.

Figure 5. Comparison of NMR right anterior oblique imaging (top) with cineangiography (bottom) in a patient with anterior myocardial infarction. Anterior and apical akinesia are comparable in both views. Left, End-diastole. Right, End-systole.
Figure 6. NMR imaging, four-chamber view, in a patient with extensive anterior myocardial infarction. Pronounced akinesia of the distal septum and apex is noted with hypercontraction of the proximal septum. Left, End-diastole. Right, End-systole.

Discussion

Noninvasive assessment of regional ventricular function. A knowledge of regional left ventricular function is critical for diagnosis and management of patients with ischemic heart disease (1), documentation of the temporal changes in ventricular remodeling after myocardial infarction (19) and evaluation of the effectiveness of reperfusion strategies (2-5). Thus, a need exists for a reliable noninvasive method for serial wall motion analysis.

Current noninvasive imaging modalities have limitations in fully assessing regional left ventricular function. Whereas echocardiography permits real-time imaging in a variety of planes, reliable assessment of wall motion can be difficult due to poor acoustic windows and inadequate discrimination of endocardial borders, especially in the long-axis view (20,21). Radionuclide methods, although widely accepted for wall motion analysis, suffer from relatively low resolution in left ventricular border recognition, limitation of views due to overlying right ventricular and left atrial blood pools and inability to assess wall thickness (6). Ultrafast (cine) computed tomography requires injection of contrast material and is limited in the ability to acquire angulated views (22).

NMR techniques to evaluate ventricular function. Earlier cardiac NMR imaging studies were performed with the spin-echo pulse sequence in standard axial views (i.e., transaxial, sagittal and coronal) (7-10,12). These early studies demonstrated the potential of NMR imaging to tomographically assess regional wall motion (14,23,24). However, the spin-echo approach has a limited time resolution (50 to 100 ms/frame) and typically requires long acquisition times (average 30 to 40 min for eight phases).

In 1986, Haase et al. (11) introduced an alternative imaging strategy, the gradient echo technique, i.e., cine NMR imaging in the present study. This approach improved temporal resolution and reduced acquisition time. In contrast to the spin-echo approach, cine NMR imaging depicts the blood pool with increased signal intensity so that a cine loop resembles contrast left ventricular cineangiography. Furthermore, visual interpretation of wall motion is greatly improved.

Figure 7. Comparison of segmental wall motion assessment between NMR imaging and cineangiography (CATH). The hatched squares represent complete agreement between the two imaging techniques. Abbreviations as in Figure 3.
facilitated by the more readily achieved cinematic display. As shown by Pflugfelder et al. (15), the gradient-echo technique also can be used to visually assess the dynamic changes in systolic wall thickening, another property to facilitate regional wall motion evaluation (25,26).

Previous studies that used standard nonangulated planes were somewhat compromised because of the oblique position of the left ventricle relative to external body axes and the substantial patient to patient variability in cardiac position (8-10,23,24). The standard axial approach results in varying degrees of left ventricular foreshortening with partial volume effects, which may lead to errors in assessing wall thickness and thickening (15,23,24,27). Furthermore, in transaxial planes the NMR image is often parallel to the inferior wall of the heart, making wall motion analysis of the inferior and apical segments difficult or sometimes impossible. It is intuitively evident that imaging using planes oriented with respect to the intrinsic cardiac axes should improve the precision of regional left ventricular function analysis (27-30).

**Intrinsic axis imaging using a spin-echo pulse sequence was first described by Dinsmore et al. (28).** By rotating the patient 30° around the z axis (the long axis of the body) and using a plane that transects the apex and mid-aortic valve, they were able to achieve a view that resembles the right anterior oblique ventriculogram. Akins et al. (29) using a similar technique defined the long axis of the left ventricle as a line intersecting the mid-mitral valve and the apex. Similar single long-axis methods have been described by others (16,31). However, for improved assessment of wall motion, at least two long-axis planes should be examined (30). In the present study, a second plane, orthogonal to the right anterior oblique view and thus perpendicular to the septum was employed. This plane allowed evaluation of the septum and posterior wall and further assessment of the apex. No previous studies have analyzed wall motion using cine NMR views oriented with respect to the intrinsic axes of the heart.
Another approach using spin-echo pulse sequences and short-axis imaging has also been described (32,33). Although this technique appears useful for visualizing wall thickening, its current application for the assessment of wall motion is confounded by several factors. First, because of partial volume effects, analysis of apical wall motion is not possible. Second, because the left ventricle frequently shortens along its long axis and the NMR tomographic plane remains fixed, different portions of myocardium will be evaluated during systole and diastole. Third, this approach requires long scanning and analysis times. Improved application of this technique should be possible by utilizing slice-tagging techniques (34). These recently reported methods could enable imaging of the same myocardial slice throughout the cardiac cycle.

Present study of cine NMR. The present study demonstrates that long-axis biplane cine NMR provides a reliable means for evaluating wall motion in views comparable to those of cineangiography. Qualitative segmental wall motion analysis by NMR agreed well with cineangiography. Ninety-five percent of the left ventricular segments in the right anterior oblique view and 92% of the segments in the left anterior oblique view were in agreement within 1 grade (Fig. 8). However, small systematic differences were noted in the anterolateral and anterobasal segments of the right anterior oblique view, and the inferolateral and basal septal segments of the left anterior oblique view. These discrepancies may be explained by the inherent differences in the two techniques, i.e., cineangiography is a projective technique whereas NMR imaging is a tomographic technique. In the right anterior oblique view, the cineangiogram depicts a projection of the entire left ventricle and overlapping structures, whereas the NMR tomograph depicts the actual borders of the ventricular plane examined (Fig. 11). Thus, the two techniques frequently do not demonstrate the precise segment of the ventricular wall (14). The NMR four chamber view is a true long-axis view with no foreshortening. In contrast, the 60° left anterior oblique angiographic view is variably foreshortened as it is generally not possible to attain a sufficiently steep craniocaudal angle necessary to image the maximal profile of the left ventricle. The inferolateral and basal-septal segments are most likely to be affected by the varying degree of cineangiographic foreshortening in this view, and it was these segments that were demonstrated to have a higher contractile NMR score (Fig. 12).

The total segment score in a given view was used to overcome to some degree a possible misregistration of the segments between the two techniques. This strategy resulted in a good correlation for both the right anterior oblique and left anterior oblique views (0.90 and 0.84, respectively, p < 0.001). The results for inter- and intraobserver variance in NMR images are similar to those previously reported (18) for observer variance in the assessment of radionuclide and cineangiography.

General limitations of cardiac NMR imaging. The strong magnetic field used in NMR imaging and the narrow bore of the magnet preclude imaging of patients with an implanted pacemaker or other ferromagnetic devices (e.g., aneurysm clips) or patients with claustrophobia. Also, hemodynamic monitoring of unstable patients in the environment of the magnet is currently difficult. Because acquisition of cardiac NMR images requires a stable cardiac rhythm, significant variation in RR interval such as occurs in patients with atrial fibrillation can significantly degrade image quality. A current limitation of NMR imaging is its cost. However, strategies are being developed to reduce acquisition (35) and analysis times, making this technique more cost-effective.

Limitations of the present approach. The main limitation of the present study is the use of a projective method (cineangiography) to validate a tomographic technique (14). This has already been discussed and may explain the lack of agreement observed in some segments. An assumption in this study was that the long axis of the left ventricle does not change substantially between systole and diastole. This potential source of error was minimized by the technique used to align the planes. Scout images acquired in both systole and diastole were used to assure that the imaging plane remains centered in the ventricle throughout the cardiac cycle.
Evaluation of the inferior wall (right anterior oblique view) may occasionally be complicated by motion artifact and difficulties distinguishing between the myocardium and diaphragm. In these circumstances, observation of myocardial thickening may facilitate interpretation. Also, using only two tomographic planes of the left ventricle may overlook small portions of the left ventricle that would not be overlooked (except at the apex) by a short-axis tomographic method. Future improvement with faster imaging sequences and better algorithms for analysis may permit combination of these two approaches (e.g., long- and short-axis imaging), to provide a complete assessment of regional wall motion in an acceptable imaging period.

**Conclusions.** Cine NMR imaging, using the long-axis approach, is comparable with left ventricular cineangiography as a means of assessing regional wall motion. The combination of two perpendicular tomographic planes aligned with the intrinsic left ventricular long axis permits adequate assessment of all segments including the inferior wall and apex, which are poorly assessed with use of the previously reported transaxial NMR imaging approach. Furthermore, acquisition and analysis times are relatively short, making this NMR technique attractive for clinical use.

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**References**

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**Figure 12.** Comparison of the nuclear magnetic resonance four chamber view (left) with angiographic left anterior oblique view (right). The alignment of basal septum and the inferolateral segments (arrows) is most likely to be affected by the varying degree of cineangiographic foreshortening. RV = right ventricle. Other abbreviations as in Figure 11.
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