Original Research

Three-Dimensional Magnetic Resonance Imaging Technique for Myocardial-Delayed Hyperenhancement: A Comparison With the Two-Dimensional Technique

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Purpose: To compare two-dimensional and three-dimensional techniques in the detection of myocardial infarction (MI) and in the grading transmural extent (TE).

Materials and Methods: Twelve patients with clinically proven MI were examined using two-dimensional and three-dimensional techniques with cardiac-gated, breath-hold, T1-weighted gradient echo sequence with an inversion recovery pulse following gadopentetate dimeglumine (Gd-DTPA) at 0.2 mmol/kg. Contrast-to-noise, signal-to-noise, and signal intensity ratios (CNR, SNR, and SIR, respectively) were derived and compared for each technique.

Results: From two-dimensional to three-dimensional, statistical significant difference was found in the mean CNR (11.65 vs. 56.59; P < 0.002), SNR (18.03 vs. 76.90; P < 0.001), and SIR (3.6 vs. 6.36; P = 0.05). Intraobserver agreement (kappa) between two-dimensional and three-dimensional were R1 = 74% and R2 = 90%. Interobserver agreements between the readers were two-dimensional = 77% and three-dimensional = 79%.

Conclusion: Mean CNR, SNR, and SIR are significantly increased in the three-dimensional technique compared to the conventional two-dimensional technique.

Key Words: magnetic resonance imaging; technique; three-dimensional; myocardial infarction; delay hyperenhancement


IN CORONARY ARTERY DISEASE, the distinction of viable and nonviable myocardium is important to guide management of the patient. In addition to traditional techniques for determining myocardial viability such as radionuclide studies, positron-emission tomography, and stress echocardiography, cardiac magnetic resonance (MR) techniques have been applied to identify viable myocardium and distinguish it from myocardial necrosis and scar (1). Cardiac MR imaging (MRI) provides a variety of novel methods for obtaining information on viability (1). Among other techniques, delayed hyperenhancement of the infarcted tissue with gadopentetate dimeglumine (Gd-DTPA) has been emerging as a practical and powerful technique to detect myocardial infarction (MI). While there is still some controversy (2–5), animal (6) and human (7) studies suggest that myocardial delayed hyperenhancement (MDE) indicates nonviable myocardial tissue. Moreover, MDE not only demonstrates how many myocardial segments are infarcted, but also shows the transmural extent (TE) of infarction. The degree of TE is a predictor of segmental functional recovery after revascularization in both animals (8) and humans (9).

The standard application uses a post-Gd-DTPA, cardiac-gated, breath-hold, T1-weighted sequence with an inversion recovery prepulse. The time to inversion (TI) is selected to null the normal myocardium in order to increase contrast between the normal and hyperenhanced nonviable myocardium. Simonetti et al (10) found that this sequence provides the greatest difference in signal intensity (SI) between hyperenhanced and normally enhancing myocardium. However, approximately 15 separate breath holds are necessary to acquire short-axis and long-axis images in the usual two-dimensional implementation, which usually takes 12–15 minutes to complete. In addition to the many end-expiratory breath holds, the potential for variation in TI of myocardium during the study and low signal-to-noise ratio (SNR) are shortcomings of the two-dimensional technique.

The three-dimensional technique has been described and widely used in multiple applications, particularly in vascular imaging (11). Shorter total acquisition time, fewer total breath holds, and higher SNR are theoretical

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advantages of the three-dimensional over the two-di-

MATERIALS AND METHODS

Patient Selection

Twelve patients were included in the study. All the pa-

Imaging Protocol

All the studies were obtained sequentially with the

Three-Dimensional Acquisition

A variable sampling in time (VAST) scheme was used,

Statistical Methods

Two-dimensional vs. three-dimensional methods were

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SI ratio (SIR). The definitions of CNR, SNR, and SIR are given in Table 1. The average CNR, SNR, and SIR were calculated over all 16 segments with available measurements. Comparisons of mean CNRs, SNRs, and SIRs between two-dimensional and three-dimensional techniques were based on two-sided paired Student’s t-tests. Intraobserver (two-dimensional vs. three-dimensional) and interobserver (reader A vs. B) variability in terms of determining the TE of hyperenhancement were also assessed based on the discrete data (0, 1, 2) using percent agreement. A weighted kappa statistic was computed, as well as a kappa (k) statistic, by combining normal vs. enhancing myocardium (14,15) and defined as follows: very good /H11005 0.81–1.00, good /H11005 0.61–0.80, moderate /H11005 0.41–0.60, fair /H11005 0.21–0.40, and poor /H11349 0.20.

RESULTS
There were 10 males and 2 females with an age range of 41–73 (mean = 55.4). All the patients had myocardial hyperenhancement demonstrated by the two-dimensional technique. Ten infarcts were transmural and two were subendocardial. All infarcts visualized on the two-dimensional scans were visualized on three-dimensional images with no significant difference in the ability to detect the presence of infarction between two techniques. Although in some patients TE of infarction was better delineated on three-dimensional images, this did not change the transmurality between the two techniques in our patient population (Fig. 1). Respiratory motion artifacts were noted in the three-dimensional images in six patients.

The mean imaging time was 12 minutes (±3 minutes) for two-dimensional and 24 seconds (±4 seconds) for three-dimensional techniques. Twelve breath holds of 12–16 seconds were used to complete two-dimensional imaging, while a single breath hold was sufficient for the three-dimensional technique.

Three-dimensional images had an overall lower mean noise and higher signal than the two-dimensional images (Fig. 1). The mean value of CNR was significantly (vs. normal myocardium, P ≤ 0.001; vs. blood pool, P ≤ 0.05) higher for the three-dimensional vs. two-dimensional technique by both readers (Table 2). The mean value of SNR was significantly (P < 0.001) higher for the three-dimensional vs. two-dimensional technique by both readers (Table 3). Using normal myocardium for computing the SIR, the mean value was significantly higher for the three-dimensional vs. two-dimensional sequences by both readers (P < 0.03) (Table 4). However, using the blood pool for computing the SIR, the mean value was insignificant for three-dimensional vs. two-dimensional sequences by both readers.

Table 1
The Definitions of CNR, SNR, and SIR

<table>
<thead>
<tr>
<th></th>
<th>Normal myocardium: myo-n</th>
<th>Hyperenhanced myocardium: myo-e</th>
<th>Blood pool: bp</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNR</td>
<td>(myo-e) - (myo-n) / (noise)</td>
<td>(myo-e) - (bp) / (noise)</td>
<td></td>
</tr>
<tr>
<td>SNR</td>
<td>(myo-e) / (noise)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SIR</td>
<td>(myo-e) / (bp), (myo-e) / (myo-n)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2
Comparison of Mean CNR by Two-Dimensional and Three-Dimensional Techniques

<table>
<thead>
<tr>
<th>Reader</th>
<th>Two-dimensional (mean CNR)</th>
<th>Three-dimensional (mean CNR)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>2.30</td>
<td>15.89</td>
<td>0.05</td>
</tr>
<tr>
<td>B</td>
<td>3.48</td>
<td>23.87</td>
<td>0.02</td>
</tr>
<tr>
<td>A</td>
<td>10.46</td>
<td>61.30</td>
<td>0.001</td>
</tr>
<tr>
<td>B</td>
<td>12.83</td>
<td>51.87</td>
<td>0.002</td>
</tr>
</tbody>
</table>

Figure 1. A 64-year-old male with hyperlipidemia and a strong family history of coronary artery disease. Cardiac MRI was performed two days after clinically proven acute MI. Short-axis delayed hyperenhancement images, obtained with two-dimensional (upper row) and three-dimensional (lower row) techniques, show mid- to apical anterior, anterolateral hyperenhancement with TE consistent with scar. Nonenhancing area (arrow) in the center of the hyperenhancement is a no-reflow region because of profound microvascular obstruction. Note the better delineation of cardiac anatomy and extent of the infarction due to high CNR and SNR on the three-dimensional images.
Three-Dimensional Delayed Hyperenhancement

Three-Dimensional Techniques

Comparison of Mean SNR by Two-Dimensional and Three-Dimensional Techniques

<table>
<thead>
<tr>
<th>SNR</th>
<th>Reader</th>
<th>Two-dimensional (mean SNR)</th>
<th>Three-dimensional (mean SNR)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>myo-e</td>
<td>A</td>
<td>18.16</td>
<td>87.76</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>B</td>
<td>17.90</td>
<td>66.04</td>
<td>&lt;0.001</td>
<td></td>
</tr>
</tbody>
</table>

Intraobserver variability calculations showed 74% and 90% agreement between two-dimensional and three-dimensional for the evaluation of the TE. The kappa statistics were generally moderate based on the three-category data, while the binary kappa was moderate to good (Table 5). Interobserver variability calculations showed similar results, with 77% and 79% agreement between the two readers. The weighted kappa and kappa between the readers were moderate (Table 5).

DISCUSSION

It has been demonstrated that both acute and chronic myocardial infarcts exhibit delayed hyperenhancement (6). The mechanism that leads to late delayed hyperenhancement in infarction is still the subject of discussion. It is postulated that both increased volume of distribution and slow contrast washout are responsible for MDE (1,16–21). The recent addition of an inversion recovery prepulse led to significant improvement in image quality to differentiate normal myocardium from nonviable myocardium (10). In this cardiac-gated, sequential two-dimensional approach, each slice is acquired individually during an end-expiratory breath hold, each lasting 12–16 seconds. Complete evaluation of the heart in the short axis requires about 12 separate breath holds. Usually the study is completed in 9–15 minutes, depending on the patient’s tolerance. During this long acquisition period, the gadolinium concentration in myocardium decreases, resulting in nonoptimum nulling. Many breath holds for MDE are less likely to be tolerated by the majority of patients with acute coronary syndromes. In addition, the two-dimensional technique is low in SNR, potentially limiting identification of the extent of the infarction.

The three-dimensional approach permitted the imaging of the whole heart in one breath hold, which makes the study more tolerable for the patient and more practical for the imaging team. The T1 relaxation time of the myocardium is nearly constant during three-dimensional acquisition. With the three-dimensional technique, images were acquired with less mean noise level, resulting in significantly increased CNR and SNR compared to the two-dimensional technique. Mean CNR and SNR were increased in three-dimensional images by fivefold and fourfold, respectively, compared to two-dimensional images, due to increased signal as well as decreased noise level. Increased SNR and CNR led to better delineation of the extent of the infarction in some cases, although there was no significant difference in the ability to detect MI and TE. The difference in SIR using the blood pool was insignificant between the two techniques. It resulted from similar SI of enhancing myocardium and blood pool. This could potentially create difficulty in the detection of thin subendocardial infarctions. However, SIR using normal myocardium was significantly increased in the three-dimensional technique, suggesting that not only the noise was less in three-dimensional images, but also the SI of the enhancing myocardium was increased over the nulled myocardium. Breathing motion artifacts seen on some three-dimensional images are likely due to patients fatigue, since three-dimensional images were obtained after the completion of the two-dimensional images. We believe if only three-dimensional images had been acquired, the patients would have tolerated the relatively longer but single breath hold with less difficulty, resulting in less motion artifacts. End-expiratory breath hold has been shown to provide less variability in the location of the heart due to diaphragmatic motion and is used for cardiac MRI (22). Since all the slices were obtained in one breath hold, end-expiratory breath holding to optimize image registration is not necessary. An end-inspiratory breath hold, which is more tolerable for some patients, can be used. However, greater-than-20-second breath holds still may not be tolerated by many patients. In the future, the acquisition time can be reduced by the use of a parallel imaging technique, resulting in more tolerable scanning times, especially considering the improved SNR of the three-dimensional technique.

In conclusion, MDE images with the three-dimensional technique produce less noise and more signal. Mean CNR, SNR, and SIR are substantially increased with the three-dimensional technique compared to the conventional two-dimensional technique. Three-dimensional images are comparable with two-dimensional images in terms of detection of TE. The whole heart can be imaged in one breath hold with the three-dimensional technique, compared to 12 breath holds in the two-dimensional technique, which makes cardiac viability imaging practical for routine daily use. With better understanding of the three-dimensional technique and properly adjusted study protocols, this new technique promises to have an important impact in clinical imaging.

<table>
<thead>
<tr>
<th>SIR</th>
<th>Reader</th>
<th>Two-dimensional (mean SIR)</th>
<th>Three-dimensional (mean SIR)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>bp</td>
<td>A</td>
<td>1.21</td>
<td>1.27</td>
<td>0.22</td>
</tr>
<tr>
<td>B</td>
<td>1.42</td>
<td>1.60</td>
<td>0.19</td>
<td></td>
</tr>
<tr>
<td>myo-n</td>
<td>A</td>
<td>3.39</td>
<td>5.78</td>
<td>0.03</td>
</tr>
<tr>
<td>B</td>
<td>3.81</td>
<td>6.94</td>
<td>0.03</td>
<td></td>
</tr>
</tbody>
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REFERENCES


