Quantitative Comparison of 2D and 3D MRI Techniques for the Evaluation of Chondromalacia Patellae in 3.0T MR Imaging of the Knee

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Abstract

Introduction: Chondromalacia patellae is a very common disorder of patellar cartilage. Magnetic resonance imaging (MRI) is a powerful non-invasive tool to investigate patellar cartilage lesions. Although many MRI sequences have been used in MR imaging of the patellar cartilage and the optimal pulse sequence is controversial, fat-saturated proton density images have been considered very valuable to evaluate patellar cartilage. The purpose of this study is to quantitatively compare the diagnostic performance of various widely used 2D and 3D MRI techniques for the evaluation of chondromalacia patellae in 3.0T MR imaging of the knee using T2 mapping images as the reference standard.

Methods: Seventy-five knee MRI exams of 69 adult consecutive patients were included in the study. Fat-saturated T2-weighted (FST2), fat-saturated proton density (FSPD), water-only T2-weighted DIXON (T2mD), T2-weighted 3 dimensional steady state (3DT2FFE), merged multi-echo steady state (3DmFFE), and water selective T1-weighted fat-suppressed (WATSc) images were acquired. Quantitative comparison of grade 1 and grade 5 lesions were made using contrast-to-noise (CNR) ratios. Grade 2-4 lesions were scored qualitatively and scorings of the lesions were compared statistically. Analysis of variance and Tukey’s tests were used to compare CNR data. Two sample z-test was used to compare the ratio of MR exams positive for grade 1 lesions noted on T2-mapping and other conventional sequences. Paired samples t-test was used to compare two different pulse sequences.

Results: In detecting grade 1 lesions, FSPD, FST2 and T2mD images were superior in comparison to other sequences. FSPD and FST2 images were statistically superior in detecting grade 2-4 lesions. Although all grade 5 lesions were noted in every single sequence, FST2 images have the highest mean CNR followed by 3DT2FFE images.

Conclusion: FST2 sequence is equal or superior in detecting every grade of patellar chondromalacia in 3.0T MR imaging of the knee in comparison to FSPD, T2mD, WATSc, 3DT2FFE, and 3DmFFE images.

Keywords: Patella, patellar chondromalacia, cartilage, magnetic resonance imaging.
obtained from all individual participants included in the study.

Patients

Between June 2014- March 2015, 100 consecutive adult patients who underwent MR examination of knee were enrolled in the study. Fifteen patients with suspected tumors, previous surgery or implants that would cause artefacts were excluded. Sixteen patients were excluded because of motion of the patients that prevented optimum comparison of MR images. Finally 75 knee MRI exams of 69 adult consecutive patients (31 women and 38 men, mean age, 38 years; range, 21–76 years) were included in the study. Leading clinical diagnosis was patellar chondromalacia in 28 (41%), nonspecific pain in 16 (23%), meniscopathy in 13 (19%), anterior cruciate ligament tear in 5 (6%), and miscellaneous in 7 (10) patients.

MRI Protocol

All images were obtained with a 3T machine (Ingenia; Philips Medical Systems, Best, Netherlands) using a 16 channel transmit/receive dedicated knee coil. Technical data of used MR sequences were given in Table 1. Field of view was 80 mm. Slice thickness was 2 mm with no intersection gap. Resolution was 0.4x0.5 mm. Acquisition times of all 2D and 3D sequences in the study were set between 2 minutes 3 seconds and 2 minutes 15 seconds by adjusting number of excitations and acceleration factor except for T2 mapping sequence. Corresponding T2 mapping sequence (TR 2000/TE 13, 26, 39, 52, 65, 78) were obtained with the same slice thickness, 0.6x0.6 mm resolution with single excitation. Acquisition time of the T2 mapping sequence was 5 minutes and 40 seconds. In these images, orange areas represent normal cartilage whereas yellow, green and blue areas represent cartilage lesions with higher water content in that order.

Qualitative image analyses

All examinations were routinely reviewed by a radiologist with 17 years’ experience excluding the T2 mapping images. Patellar chondromalacia in each knee was graded according to Table 2. Patellar cartilage lesions graded between 2 and 4 were scored between 1 and 5 qualitatively according to ease of separation of the lesion from nearby normal appearing cartilage. Qualitative scorings of the lesions were compared statistically. Then T2 mapping images were reviewed for the detection of such cartilage lesions as the reference standard.

Quantitative image analyses

All grade 1 lesions noted on T2-mapping images were reviewed with standard sequences. CNR of all grade 1 lesions in all sequences were calculated using the formula:

<table>
<thead>
<tr>
<th>Grade</th>
<th>Outer bridge</th>
<th>ICRS</th>
<th>Modified Noyes</th>
<th>Current study</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
<td>Normal</td>
</tr>
<tr>
<td>1</td>
<td>Softening and swelling, intact surface</td>
<td>Nearly normal (soft indentation and/or superficial fissures and cracks)</td>
<td>Increased T2 signal intensity of morphologically normal cartilage</td>
<td>Increased signal intensity of morphologically normal cartilage</td>
</tr>
<tr>
<td>2</td>
<td>Fragmentation and fissuring of articular cartilage affecting an area of less than 0.5 inches</td>
<td>Abnormal (Lesions extending to &lt;50% of cartilage depth)</td>
<td>Superficial partial-thickness cartilage defect &lt;50% of total articular surface thickness</td>
<td>Lesions extending to &lt;50% of cartilage depth</td>
</tr>
<tr>
<td>3</td>
<td>Fragmentation and fissuring of articular cartilage affecting an area greater than 0.5 inches</td>
<td>Severely abnormal (Lesions extending &gt;50% of cartilage depth, but not through subchondral bone)</td>
<td>Deep partial-thickness cartilage defect &gt;50% of total articular surface thickness</td>
<td>Lesions extending to ≥50% of cartilage depth</td>
</tr>
<tr>
<td>4</td>
<td>Cartilage erosion to bone</td>
<td>Lesions involving subchondral bone</td>
<td>Full-thickness cartilage defect</td>
<td>Lesions involving subchondral bone</td>
</tr>
<tr>
<td>5</td>
<td>Cartilage arthritis</td>
<td>Cartilage arthritis</td>
<td>Full-thickness cartilage lesions</td>
<td>Lesions involving subchondral bone</td>
</tr>
</tbody>
</table>
CNR = \frac{\text{Mean lesion} - \text{Mean cartilage}}{\text{SD air}}

\text{Mean lesion} \text{ is mean signal intensity of the grade 1 cartilage lesion, Mean cartilage is mean signal intensity of normal appearing cartilage nearby the lesion, and SD air is standard deviation of signal intensity of the air. Then all grade 5 lesions noted on each image sequence were evaluated with the same formula to reveal CNR data for those lesions.}

**Statistical analysis**

Analysis of variance (ANOVA) and Tukey’s tests were used to compare CNR data. A \( P \) value less than 0.05 was considered to indicate a significant difference. Two sample z-test was used to compare the ratio of MR exams positive for grade 1 lesions noted on T2-mapping and other conventional sequences. Paired samples t-test was used to compare two different pulse sequences. All statistical analyses were performed with SPSS 20 software (Chicago, Illinois, USA).

**Results**

Fifty-seven grade 1 lesions were noted on T2-mapping images in 49 patients. Fifty-two of these lesions were also noted on both fat-saturated T2-weighted (FST2) and fat-saturated proton-density (FSPD) images. T2-mapping were statistically significantly superior to both FST2 and FSPD images in detecting grade 1 lesions (\( p=0.022 \)). Detection ratio of grade 1 lesions by other sequences remained lower; 48 for T2mD, 36 for 3DT2FFE, 42 for 3DmFFE, and 38 for WATSc images, respectively. Statistical comparison of quantitative CNR data in evaluating grade 1 lesions were given in Table 3. There was statistically significant difference in between groups (ANOVA test, \( p<0.0001 \)). FSPD, FST2 and T2MD images were superior in comparison to other sequences (Tukey’s tests, \( p≤0.03 \)) whereas these sequences were not statistically significantly different from each other (Tukey’s tests, \( p>0.05 \)).

Twenty-seven lesions between grade 2 and 4 were noted on 24 patients on FST2, FSPD, and, while 17 were missed on WATSc images, 3 were missed on 3DT2FFE images, and 2 were missed on 3DmFFE images. Statistical comparison of CNR data in qualitative evaluation of lesions between grade 2 and 4 were given in Table 4. There was statistically significant difference in between groups (ANOVA test, \( p<0.0001 \)). FSPD and FST2 images were statistically superior in detecting such lesions (Tukey’s tests, \( p≤0.024 \)) whereas these two sequences were not statistically significantly different from each other (Tukey’s tests, \( p>0.05 \)).

Fifteen grade 5 lesions in 13 patients were noted in every single MR sequence. All lesions were noted superior to both FST2 and FSPD images in detecting grade 1 lesions (\( p=0.022 \)). Detection ratio of grade 1 lesions by other sequences remained lower; 48 for T2mD, 36 for 3DT2FFE, 42 for 3DmFFE, and 38 for WATSc images, respectively. Statistical comparison of quantitative CNR data in evaluating grade 1 lesions were given in Table 3. There was statistically significant difference in between groups (ANOVA test, \( p<0.0001 \)). FSPD, FST2 and T2MD images were superior in comparison to other sequences (Tukey’s tests, \( p≤0.03 \)) whereas these sequences were not statistically significantly different from each other (Tukey’s tests, \( p>0.05 \)).

**Table 3.** Quantitative comparison of CNR data for grade 1 lesions

<table>
<thead>
<tr>
<th>Sequence</th>
<th>FST2</th>
<th>FSPD</th>
<th>T2MD</th>
<th>3DT2FFE</th>
<th>3DmFFE</th>
<th>WATSc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean CNR</td>
<td>30.9</td>
<td>28.3</td>
<td>22.3</td>
<td>8.4</td>
<td>12.9</td>
<td>8.7</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>24.4</td>
<td>19.0</td>
<td>16.2</td>
<td>6.0</td>
<td>12.8</td>
<td>9.3</td>
</tr>
</tbody>
</table>

\( FST2; \) Fat-saturated T2-weighted, \( FSPD; \) Fat-saturated proton density, \( T2mD; \) Water-only T2-weighted DIXON, \( 3DT2FFE; \) T2-weighted 3D Steady state, \( 3DmFFE; \) Merged multi-echo steady state, \( WATSc; \) Water selective T1-weighted fat-suppressed, \( CNR; \) Contrast-to-noise ratio

There was statistically significant difference in between groups (ANOVA test, \( p<0.0001 \)).
in every single sequence therefore there was no statistically significant difference in detecting grade 5 lesions (p=1). However CNR data showed statistically significantly difference as shown in Table 5 (ANOVA test, p<0.0001). FST2 images have the highest mean CNR followed by 3DT2FFE images. However mean CNR data for these two sequences were not statistically significantly different (Tukey’s tests, p>0.05). Totally 67 of 69 patients were diagnosed having chondromalacia patellae on MR imaging.

### Discussion

Chondromalacia patellae is a very common disorder that cannot be diagnosed on the basis of symptoms or with physical examination (1,2). Although arthroscopy is generally considered reference standard for diagnosis, with current strength of magnets and development in coil production, MRI has become a very promising non-invasive tool in the diagnosis of patellar cartilage lesions. There have been many studies evaluating the capabilities of various 2D and 3D imaging techniques in detecting patellar cartilage lesions however optimal pulse sequence is still controversial (3-8).

In the literature, Outerbridge first described a basic grading system for patellar chondromalacia based on his surgical findings (1). This system has been widely used clinically in its original or revised forms. Noyes introduced another system for grading articular cartilage lesions based on arthroscopic findings (12). His system has also been used and has been modified for using MR classification of chondral lesions. Recently, International Cartilage Research Society (ICRS) developed an arthroscopic cartilage injury grading system (13). Although there have also been some solitary or revised systems from Noyes or ICRS classifications for MR grading of cartilage damage used in clinical practice, there is no widely accepted MR grading system for patellar chondromalacia in the literature (2,5,9,10,14,15). Therefore, in this study, we preferred using a somewhat basic grading system which is given in Table 2 in comparison to other commonly used systems.

Our results suggest that for grade 5 subchondral lesions, diagnostic ability of all 2D and 3D MR pulse sequences in this study were not statistically significantly different. Therefore, these pulse sequences seem equal in detecting grade 5 patellar chondromalacia although mean CNR of these lesions were statistically significantly different and FST2 images had the highest mean CNR. Considering grade 2-4 lesions, FST2 and FSPD sequences are not statistically significantly different whereas these images are superior in comparison to all other pulse sequences. In detecting grade 1 lesions, although mean CNR data is the highest for FST2 images closely followed by FSPD images, FST2, FSPD, and T2mD sequences are not statistically significantly different whereas these pulse sequences seem statistically significantly superior in comparison to 3D pulse sequences. According to our results, FST2 pulse sequence is equal or superior in detecting every grade of patellar chondromalacia in MR imaging of the knee closely followed by FSPD sequence.

### Table 4. Qualitative comparison of grade 2-4 lesions.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>FST2</th>
<th>FSPD</th>
<th>T2MD</th>
<th>3DT2FFE</th>
<th>3DmFFE</th>
<th>WATSc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean CNR</td>
<td>4.25</td>
<td>4.33</td>
<td>3.55</td>
<td>1.1</td>
<td>1.33</td>
<td>0.89</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>0.46</td>
<td>0.47</td>
<td>0.96</td>
<td>0.49</td>
<td>0.67</td>
<td>1.37</td>
</tr>
</tbody>
</table>

FST2; Fat-saturated T2-weighted, FSPD; Fat-saturated proton density, T2mD; Water-only T2-weighted DIXON, 3DT2FFE; T2-weighted 3D Steady state, 3DmFFE; Merged multi-echo steady state, WATSc; Water selective T1-weighted fat-suppressed

There was statistically significant difference in between groups (ANOVA test, p<0.0001).

### Table 5. Quantitative comparison of CNR data for grade 5 lesions.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>FST2</th>
<th>FSPD</th>
<th>T2MD</th>
<th>3DT2FFE</th>
<th>3DmFFE</th>
<th>WATSc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean CNR</td>
<td>67.4</td>
<td>40.8</td>
<td>40.7</td>
<td>47.6</td>
<td>13.8</td>
<td>54.2</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>28.4</td>
<td>21.9</td>
<td>20.5</td>
<td>21.4</td>
<td>8.5</td>
<td>18.3</td>
</tr>
</tbody>
</table>

FST2; Fat-saturated T2-weighted, FSPD; Fat-saturated proton density, T2mD; Water-only T2-weighted DIXON, 3DT2FFE; T2-weighted 3D Steady state, 3DmFFE; Merged multi-echo steady state, WATSc; Water selective T1-weighted fat-suppressed, CNR; Contrast-to-noise ratio

There was statistically significant difference in between groups (ANOVA test, p<0.0001).
There were many studies in the literature searching for the optimal image sequence in detecting cartilage lesions. Although fat-saturated proton density or intermediate weighted images have been generally considered very valuable to evaluate patellar cartilage with high spatial resolution and good CNR in a reasonable scan time the search for a better sequence has been continued (3,4,8). In the last decade, many 3D sequences were extensively investigated in detecting cartilage lesions in comparison to conventional 2D images however their diagnostic ability were not considered superior (6-8). More recently, isotropic 3D sequences with fat-suppression have been targeted in the search for optimal image sequences. Although there were some promising results, their exact value has not been well documented yet (16,17).

Although most of the studies in the literature have arthroscopic or surgical reference standards, their primary goal was to compare these sequences qualitatively with multiple observers and inter- and intraobserver reliability tests while comparing them to arthroscopic findings (5,6,8). To the best of our knowledge, such quantitative comparison of CNR data regarding patellar chondromalacia have never been documented. Therefore, our study seems unique since we performed quantitative comparison of abovementioned sequences in grade 1 and grade 5 lesions which arthroscopy might not be considered as the reference standard for making the diagnosis. Besides, T2mD sequence has never been studied before in detecting patellar cartilage lesions. We also set almost equal acquisition times by adjusting number of excitations and acceleration factor for all 2D and 3D sequences to provide a fair comparison which many of the studies in the literature did not.

This study has some limitations. First, we do not have arthroscopic examinations as reference standard. However, this study largely depend on quantitative comparison of images and we used T2 mapping sequence as the reference standard for lesion detection. Besides, arthroscopic evaluation might not detect grade 1 lesions with intact articular surface as well as grade 5 subchondral lesions. Second, we...
lack a fat-suppressed isotropic 3D sequences in comparison. However, these isotropic 3D sequences provides different temporal resolution than other conventional 2D and 3D images and therefore similar comparison with standard sequences is challenging. Besides, comparatively long acquisition times makes a fair comparison unlikely. Finally, although this study mainly depends on quantitave comparison, we lack interobserver reliability testing for detecting grade 2-4 lesions.

In conclusion, FST2 sequence is equal or superior in detecting every grade of patellar chondromalacia in 3.0T MR imaging of the knee in comparison to FSPD, T2mD, WATSc, 3DT2FFE, and 3DmFFE images. Newer isotropic 3D fat-suppressed proton density or intermediate weighted sequences might be considered as possible alternatives and be further studied.

References