The angular dependence of T1ρ relaxation in normal and abnormal patellae with histological correlation

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INTRODUCTION

Both T1 and T2 have been employed to evaluate articular cartilage degeneration. The magic angle effect in T1 relaxation is well understood. However, the literature regarding T2 relaxation mechanisms is inconsistent. Some researchers reported much reduced or negligible magic angle effect in T1ρ relaxation. For example, Akella et al. reported that spin-lock RF pulses can reduce the laminar appearance. Li et al. investigated the effect of angular orientation on T1ρ and T2 values, and found little angular dependence. Duvvuri et al. suggested that proton exchange between NH and OH groups of proteoglycans and the tissue water might be an important contributor to T1ρ relaxation. Other researchers have reported significant magic angle effect in T1ρ relaxation. For example, Mlynarik et al. found that T1ρ was more orientation and spin-lock field strength dependent in the deep radial zone than in the transitional zone, and concluded that the dominant T1ρ relaxation mechanism at B0 ≤ 3T is dipolar interaction. Menezes et al found that changes in collagen concentration alone could fully account for the variation in T1ρ seen in human tissue. Furthermore, magic angle effects in normal vs. abnormal cartilage are unknown. In this study we aimed to systematically evaluate the magic angle effect on T2 and T1ρ in histological confirmed normal and abnormal cartilage at 3T.

MATERIALS AND METHODS

Eight cadaveric human knee patellae were sectioned into transverse slabs of 5-8 mm thickness and stored in a phosphate buffered saline (PBS) soaked gauze at 4°C prior to MR imaging on a clinical whole body GE scanner. A 3-inch receive only surface coil was used for signal reception. The patella samples were placed in perfluorocetyl bromide (PFOB) solution to minimize susceptibility effects at tissue-air junctions. A single slice at the center of each patella sample was imaged. The imaging protocol was shown in Table 1 (each sample was acquired at six angles relative to the B0 field).

After MRI the patellae slabs were immediately fixed in Z-Fix and sent for histopathology. 2-4 regions of interest (ROIs) per patella were chosen for correlation with histopathology and MRI measurements of T1ρ and T2. Each ROI was given a Mankin score ranging from 0 to 14. Only regions with a Mankin score of equal or less than 7 were used for correlation analysis. Cartilage regions with a Mankin score of less than 2 were considered normal, and regions with a Mankin score higher than 2 were considered abnormal. T1ρ and T2 were determined using nonlinear least square curve fitting of average signal intensities from normal and abnormal regions with three layers (10% superficial, 60% middle, 30% deep) as well as a global ROI for the whole region. Image registration was performed before data analysis to ensure that ROIs were identically located on images obtained at different angles and sequences.

RESULTS AND DISCUSSION

Figure 1 shows selected 2D spiral T1ρ images of a histologically confirmed normal patella at 0° and 40°. The middle and deep layers of articular cartilage showed dramatic signal change with angular orientation. The superficial layers show much less signal change with angular orientation.

Figure 2 shows spiral T1ρ images of another patella with histologically confirmed normal and abnormal regions, which again shows strong magic angle effects.

Figure 3 shows the correlation between T2 and T1ρ and MAPSS T1ρ and histopathological grading. There is a low correlation between T2 and the Mankin score (Rho = 0.29; P = 0.17), a moderate correlation between 2D spiral T1ρ (Rho = 0.47; P = 0.06), 3D MAPSS T1ρ (Rho = 0.42; P = 0.06) and the Mankin score. The low correlation is most likely due to the strong magic angle effects in both the measured T1ρ and T2 relaxation times.

Table 2 shows the magic angle effects in different layers of the normal and abnormal cartilage. T2 values were increased by 156% for normal cartilage, and 104% for abnormal cartilage. 2D spiral T1ρ values were increased by 72% for normal cartilage and 63% for abnormal cartilage. 3D MAPSS T1ρ values were increased by 67% for normal cartilage and 53% for abnormal cartilage. Abnormal cartilage shows a slightly lower (4–10%) magic angle effect.

CONCLUSIONS

T2 and T1ρ in both normal and abnormal cartilage are strongly affected by the magic angle effect, which increased T2 by 100-150% and T1ρ by 60-75%. The increases were much higher than these typically seen in degeneration (usually <30%), leading to a moderate correlation between T2 and T1ρ with histological grading.


Table 1 Imaging protocol for cadaveric human patellae.

<table>
<thead>
<tr>
<th>FOV (cm)</th>
<th>TR (ms)</th>
<th>TE or TSL (ms)</th>
<th>Recon Matrix</th>
<th>Slice (mm)</th>
<th>BW (Hz)</th>
<th>Angular Orientations relative to B0</th>
<th>Scan time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2D Spiral T1ρ</td>
<td>5</td>
<td>2000</td>
<td>0, 10, 20, 40, 80</td>
<td>256×256</td>
<td>2</td>
<td>128</td>
<td>0°:20°:40°:80°:160°</td>
</tr>
<tr>
<td>3D MAPSS T1ρ</td>
<td>5</td>
<td>15</td>
<td>0, 10, 20, 40, 80</td>
<td>256×256</td>
<td>2</td>
<td>62.5</td>
<td>0°:20°:40°:80°:160°</td>
</tr>
<tr>
<td>2D CPMG T2</td>
<td>5</td>
<td>2000</td>
<td>10,20,30,40,50,60,70,80</td>
<td>256×256</td>
<td>2</td>
<td>62.5</td>
<td>0°:20°:40°:80°:160°</td>
</tr>
</tbody>
</table>

Table 2 2D spiral and 3D MAPSS T1ρ and CPMG T2 for the superficial, middle and deep layers, as well as a global ROI in both normal and abnormal cartilage. There is an obvious magic angle effect for both T1ρ and T2. A slightly reduced magic angle effect was observed in abnormal cartilage.