Comparison of New Methods for Magnetic Resonance Imaging of Articular Cartilage

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Introduction

Magnetic resonance imaging is the most accurate non-invasive method of diagnosing cartilage lesions. However, MRI of articular cartilage still suffers from inadequate spatial resolution and lengthy scan times. Both of these limitations could be improved by using a method that provides higher signal-to-noise ratio (SNR) of cartilage images. The goal of this work is to investigate new high-SNR imaging sequences and to compare them with currently-used methods.

In addition to high image SNR, cartilage imaging demands contrast between cartilage and structures such as synovial fluid and bone. This is usually provided by T2 contrast and fat suppression respectively.

In MRI, there has recently been a renewed interest in steady-state free-precession (SSFP) imaging, also known commercially as True-FISP, FIESTA or balanced FFE. SSFP provides a high SNR-efficiency, and the suppression to provide contrast between cartilage and bone marrow.

Recent studies have shown that steady-state sequences provide clear cartilage depiction and contrast for cartilage imaging. SSFP provides a high SNR-efficiency, and low synovial fluid signal, but bright cartilage signal.

In this study, a 3D echo-planar DEFT sequence provides volume coverage.

Methods and Results

SNR-efficiency is the ratio of SNR to the square-root of total imaging time.

For each of the six pulse sequences, we selected the sequence parameters to maximize the SNR efficiency. Next we adjusted the TR and TE to maximize contrast between cartilage and synovial fluid while keeping the SNR efficiency within 5% of the maximum. For this optimization, we assumed T2 = 800 ms for cartilage and 2500 ms for synovial fluid. For the steady-state sequences the TR was averaged over a +/- 30 Hz bandwidth. Table 1 shows the optimal sequence parameters for each pulse sequence, and Fig. 1 shows the simulated relative SNR-efficiency for these parameters.

Using a 1.5 T MRI scanner and a 3" surface receive coil, we scanned in vivo volunteer cartilage. The improved SNR-efficiency can be traded-off to reduce scan times or to provide higher resolution.

<table>
<thead>
<tr>
<th>Sequence</th>
<th>TR (ms)</th>
<th>TE (ms)</th>
<th>FOV (x,y,z)</th>
<th>Matrix Size</th>
<th>Slice Thickness</th>
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<td>8</td>
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<tr>
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<td>22</td>
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<td>DEFT-SPGR</td>
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<tr>
<td>FS-SSFP</td>
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<td>256 x 256 x 256</td>
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<td>256 x 256 x 256</td>
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</tr>
</tbody>
</table>

Table 1. MRI Sequence Parameters

Discussion

Results of this study show that steady-state imaging techniques are strong candidates for in vivo imaging of articular cartilage. The following points describe how each sequence compares to the group as a whole.

FSE - Large 3D image resolution, but may have lower SNR-efficiency, due to this blurring. Measurements from FSE images over-estimate the cartilage SNR efficiency, due to this blurring.

SPGR - fast imaging, but poor contrast between cartilage and synovial fluid. Although 3D, SPGR is relatively slow.

DEFT - improves contrast compared with FSE, but the sequence is complex to implement and currently not performing well as a pulse sequence.

Steady-State Techniques - All provide higher SNR and CNR efficiency with rapid imaging, but sensitivity to resonant frequency shifts.

FS-SSFP - about 40% faster than FEMR or LCSSFP and only half as sensitive to resonant frequency shifts (green arrows). Some transient artifacts, as well as fat-suppression will be improved in future developments. A shorter TR could be used to further reduce sensitivity to off-resonance.

LCSSFP - slower, but simpler than FS-SSF. Provides images centered on bone-marrow without additional scan time.

FEMR - cartilage, and synovial fluid. May have a higher SNR-efficiency, but less CNR efficiency.

Conclusions

We have shown, both in simulations and in vivo images that steady-state imaging methods provide significantly higher SNR efficiency and CNR efficiency for imaging articular cartilage. Fat-saturated SSFP imaging provides the highest SNR-efficiency combined with the lowest minimum scan time of all sequences tested. Combined with improved coil design, this sequence could significantly improve the resolution and scan time of clinical knee imaging without sacrificing volumetric coverage.

References