High resolution 3D cartilage imaging of the knee at 3T in five minutes using IDEAL-SPGR and parallel imaging

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Introduction: Accurate imaging of cartilage morphology requires high resolution, high SNR images with good fat suppression, and good contrast between cartilage and synovial fluid, all within a reasonable scan time. Traditionally, the gold standard imaging sequence for cartilage morphology evaluation in the knee has been three-dimensional spoiled gradient echo with fat saturation (FS-SPGR) [1]. The IDEAL method (Iterative Decomposition of water and fat with Echo Asymmetry and Least-squares estimation) [2] provides robust fat/water separation with greater signal-to-noise ratio (SNR) efficiency and less sensitivity to field inhomogeneity than fat saturation. IDEAL-SPGR has been previously shown to provide improved SNR compared to FS-SPGR at 1.5T [3], however scan times were relatively long. The purpose of this work is to combine IDEAL with parallel imaging at 3.0T to provide high resolution, high SNR cartilage imaging within five minutes, an acceptable scan time to be added to routine clinical protocols.

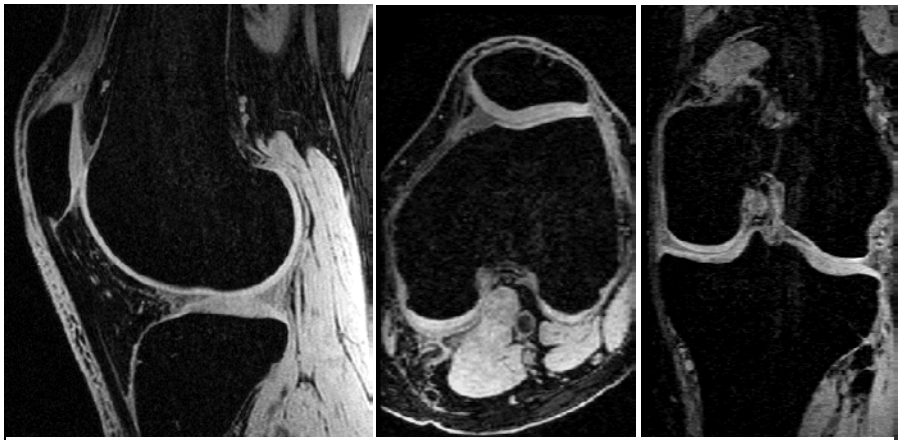

Figure 1: Full knee coverage with 0.3 X 0.7 x 1.0mm resolution provides high quality multiplanar reformatted images using IDEAL SPGR.

Methods: Eight knees (four volunteers) were imaged on a 3.0T MRI scanner (TwinSpeed, GE Healthcare, Waukesha, WI) using an eight channel extremity coil (In Vivo, Orlando, FL). FS-SPGR imaging was performed with TR/TE 14.8/4.6 ms, a 9-degree flip angle and one average for a scan time of 5:00. Other scan parameters included: 512x224 matrix, 16 cm field-of-view, 1mm section thickness, 90 sections, and acquisition bandwidth of +/-41 kHz. Voxel resolution was 0.3x0.7x1.0mm^3. Imaging parameters were identical for IDEAL, except TR was 10.8ms and three TE increments of 4.6, 5.4, and 6.1ms were used, which have been shown to provide the best possible SNR performance [4]. IDEAL imaging also used a SENSE [4] based parallel acceleration method (ASSET) with an acceleration factor of 2.22. The flip angle for IDEAL-SPGR was 8-degrees, and the total scan time was 4:59. Flip angles were calculated as the Ernst angle and cartilage T1 of 1200ms [6]. For IDEAL, separate fat, water, and recombined images were reconstructed using an on-line reconstruction algorithm.

SNR was measured from regions of interest in the patellar cartilage, femoral condyle cartilage, muscle, and fluid. The SNR measurements for IDEAL SPGR were performed using the difference method [7] based on two identical acquisitions to ensure accurate SNR measurement in the parallel imaging context. SNR for FS-SPGR images was performed using conventional SNR measurement techniques with one ROI in the image and the noise ROI in a region outside the body. SNR and contrast-to-noise ratios (CNR) values were compared using a student t-test.

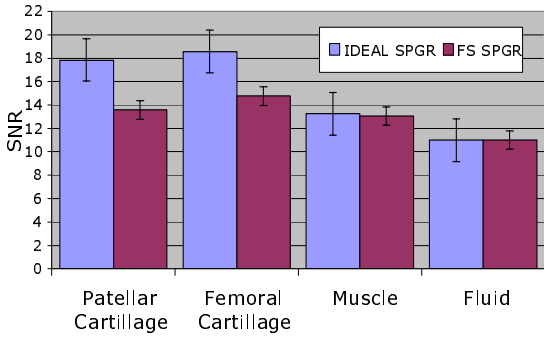

Figure 2: Mean calculated SNR values for each technique.

Results: IDEAL SPGR at 3.0T with parallel imaging demonstrated a 31% improvement ($p<0.05$) in patellar cartilage SNR when compared to FS-SPGR with the same resolution and imaging time (Fig 2). Femoral cartilage SNR also improved by 26% ($p<0.05$). SNR in muscle and fluid was similar for both techniques. CNR between patellar cartilage and synovial fluid was 6.8 for IDEAL SPGR compared to 2.6 for FS-SPGR, a 168% improvement ($p<0.05$) which is illustrated by figure 3.

Discussion: The combination of IDEAL-SPGR at 3.0T with parallel imaging allows high resolution (0.3x0.7x1.0mm^3) cartilage imaging in about five minutes. IDEAL provides superior SNR performance, which is a result of improved sequence efficiency from the elimination of a fat-saturation pulse, and the optimization of echo shifts which produce the best possible SNR performance of the water-fat separation method. In addition, IDEAL demonstrated dramatic improvement in cartilage/fluid CNR. This is best explained by the shortened TR of IDEAL, creating improved T1 contrast between fluid and cartilage; the fluid is better suppressed at shorter TR because of its long T1. In addition to its benefits for clinical evaluation of cartilage morphology, the combination of high resolution, high SNR and improved fluid-cartilage CNR also offers potential for improved segmentation and volumetric analysis studies[8]. Finally, unlike FS-SPGR, IDEAL also provides separate fat, in-phase and out-of-phase images with no additional scan time penalty.

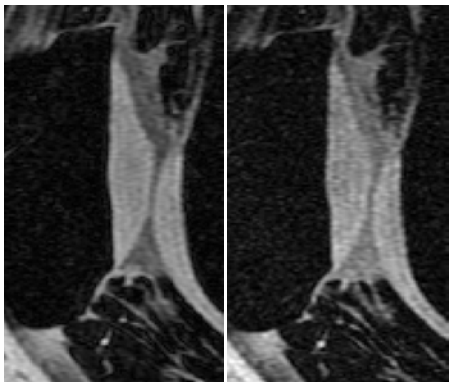

Figure 3: Magnified images illustrate improved cartilage SNR and cartilage/fluid CNR of IDEAL SPGR (left) compared to FS SPGR (right).

Conclusion: IDEAL-SPGR at 3.0T with parallel imaging allows sub-millimeter resolution cartilage imaging in five minutes with higher SNR and improved cartilage/fluid contrast compared to FS-SPGR.

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