Multi-Echo IDEAL Water-Fat Separation for Rapid Imaging of Cartilage

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Introduction: Three-dimensional (3D) MRI is useful to measure articular cartilage thickness and volumes, and detect cartilage lesions. Historically, 3D cartilage imaging has been done with spoiled gradient echo with chemical fat saturation (FS-SPGR) [1, 2]. Other methods of reducing signal from lipid include spectrally selective excitation and chemical-shift based methods. We have developed a chemical-shift based technique for use with 3D-GRE called Iterative Decomposition of water and fat with Echo Asymmetry and Least squares estimation (IDEAL) [3, 4]. Previously, this method required 3 acquisitions to separate water and fat, making scan times relatively long. We have recently developed a multi-echo 3D-IDEAL-GRE method that allows robust water and fat separation in a single acquisition, similar to multi-echo IDEAL-SSFP [5]. We compared cartilage SNR efficiency of multi-echo IDEAL-GRE with fat saturated 3D-SPGR (FS-SPGR) in 6 knees of normal volunteers at 1.5T.

Methods: Six knees (four volunteers) were imaged using a GE Signa TwinSpeed 1.5T MRI scanner and an 8-channel extremity coil. FS-SPGR was done with TR/TE 17.3/3 ms, a 20-degree flip angle, bandwidth of $\pm$ 31.25 kHz and one acquisition for a scan time of 4:44. Multi-echo IDEAL GRE used a TR of 14.7 ms, three echoes of 2.4, 5.4, and 8.4 ms, a 40-degree flip angle, $\pm$ 83 kHz bandwidth, and a scan time of 4:04. All scans were 256x 256, 16 cm field-of-view, 1.5 mm section thickness, and 64 sections. Flip angles were adjusted for good cartilage to fluid contrast. Multi-echo IDEAL-GRE images were reconstructed on-line using the IDEAL method [3]. SNR in each subject was calculated by dividing the average measured signal from 5 regions of interest in the trochlear cartilage by the standard deviation of the noise. SNR efficiency was calculated by dividing the SNR by the square root of the scan time. SNR efficiency values were compared using a student t-test.

Results: IDEAL-GRE produced images with higher cartilage SNR (41.0 $\pm$ 5.2 vs. 36.2 $\pm$ 2.4; $p < .01$) and SNR efficiency than FS-SPGR (41.0 $\pm$ 5.2 vs. 33.3 $\pm$ 2.2; $p < .01$) (Figure 1). All images had excellent depiction of cartilage (Figure 2). The IDEAL-GRE images produced water, fat, and combined images. The multi-echo IDEAL-GRE sequence produced these images in a faster scan than FS-SPGR, and had bright signal from synovial fluid that is helpful to outline cartilage defects [6].

Conclusion: Multi-echo IDEAL-GRE provides a fast, SNR efficient method for examining articular cartilage at 1.5T. Because of the lack of a chemically selective radiofrequency pulse and the use of multiple echoes per TR, multi-echo IDEAL-GRE is more efficient and requires less scan time than FS-SPGR. Fat saturation pulses can take up a large percentage of the TR in FS-SPGR, and can also partially saturate water signal. Multi-echo IDEAL-GRE is highly SNR efficient because it uses a large percentage of the TR for readout, and also achieves an effective signal averaging of three in one TR by using all three echoes efficiently in the water-fat decomposition.

FS-SPGR is also sensitive to both B0 and B1 inhomogeneity, while IDEAL-GRE is not. The ability to provide recombined fat and water images that correct for chemical shift may allow assessment of subchondral bone thickness [7]. Multi-echo IDEAL-GRE can be further accelerated using parallel imaging and partial k-space acquisition. Our results indicate that multi-echo IDEAL-GRE is a highly promising technique for imaging articular cartilage thickness and volume at 1.5T.

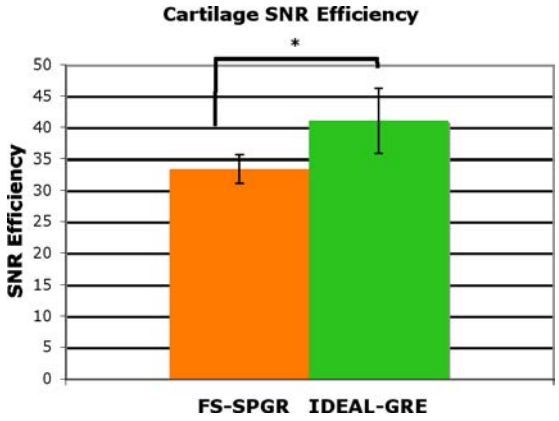

Figure 1: Multi-echo IDEAL-GRE has significantly (*$p < .01$) higher overall cartilage SNR efficiency than FS-SPGR.

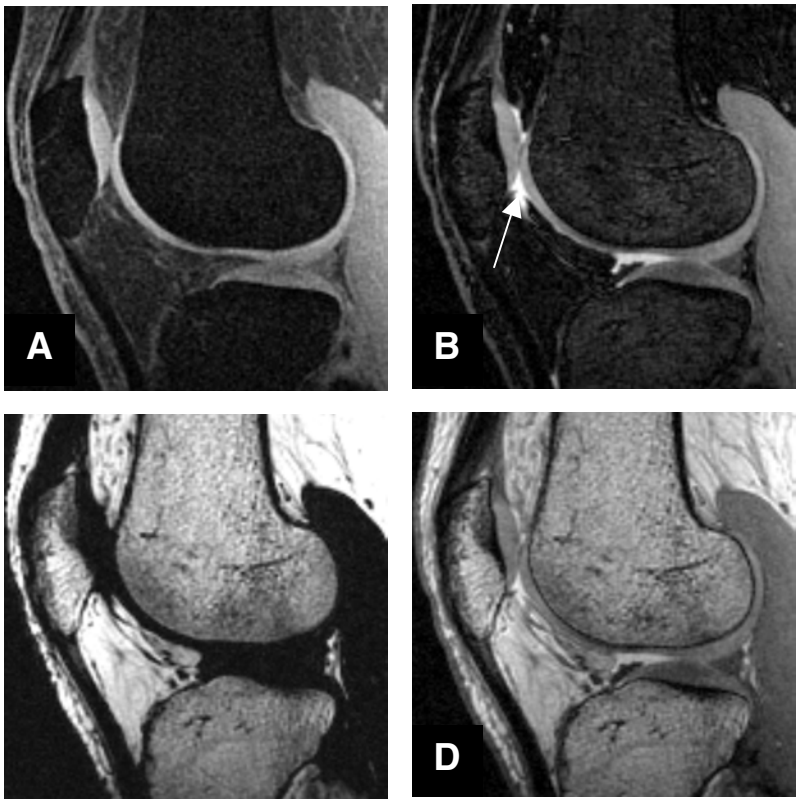

Figure 2: Images from a healthy volunteer. A) FS-SPGR. B) Multi-echo IDEAL-GRE water image with bright synovial fluid (arrow). C) Multi-echo IDEAL-GRE fat image. D) Multi-echo IDEAL-GRE combined image.

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