Improved Fat Suppression Using Multi-Peak Reconstruction for IDEAL Chemical Shift Fat-Water Separation: Application with Fast Spin Echo Imaging

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Objective: Iterative Decomposition of water and fat with Echo Asymmetry and Least squares estimation (IDEAL) is a chemical shift fat-water separation method that uses asymmetric echoes and least square fitting in order to achieve the maximum possible SNR performance (1). Most chemical shift fat-water separation techniques including IDEAL use a simple signal model in which fat is modeled as a single resonance peak. Since fat consists of multiple chemically distinct moieties which give rise to at least 6 resonance peaks, these techniques fail to suppress up to 15% of signal arising from fat protons (2). An advantage of IDEAL is that its signal model is easily modified to include multiple fat peaks, so long as the resonance frequencies and relative amplitudes of these peaks are known *a priori* (3). The purpose of this study was to evaluate and quantify improvements in the quality of fat suppression for fast spin-echo (FSE) imaging of the knee using more accurate, multi-peak spectral modeling of fat and IDEAL fat-water separation.

Methods: T_1-weighted FSE sequences (TR/TE=850ms/19.3ms, FOV=14cm, matrix=384x224, slice thickness=3mm, bandwidth=31.25kHz, signal averages=3 for frequency fat-saturation methods and 1 for IDEAL, scan time=4:48 min) and T_2-weighted FSE sequences (TR/TE=5000ms/81ms, FOV=14cm, matrix=384x224, slice thickness=3mm, bandwidth=41.67kHz, signal averages=3 for frequency fat-saturation methods and 1 for IDEAL, scan time=3:35 min) with IDEAL fat-water separation and 2 frequency-selected fat-saturation methods (fat-selective saturation and fat-selective partial inversion) were performed at 3.0T in 10 knees of 5 asymptomatic volunteers using a single channel extremity coil. T_2-weighted FSE sequences with fat-selective saturation and IDEAL fat-water separation were performed at 3.0T on the knees of 10 patients with acute post-traumatic bone marrow contusions using identical imaging parameters and an 8-channel phased array extremity coil. The IDEAL images were reconstructed using a single-peak method and an investigational version of a self-calibrated multi-peak method that more accurately model the NMR spectrum of fat. SNR was measured in various tissues for the sequences performed on the 5 asymptomatic volunteers. Student t-tests were used to compare SNR values. Two fellowship-trained musculoskeletal radiologists ranked the sequences performed on the 10 patients with acute post-traumatic bone marrow contusions according to the following subjective criteria of image quality: 1) quality of fat-suppression, 2) overall tissue contrast, and 3) conspicuity of bone marrow edema. Exact binomial tests were used to compare the ranks given to each sequence.

Results: Multi-peak IDEAL had significantly greater ($p<0.05$) suppression of signal of subcutaneous fat and bone marrow than fat-selective saturation, fat-selective partial inversion, and single-peak IDEAL for both T_1-weighted and T_2-weighted FSE sequences (Figures 1 and 2). For T_1-weighted FSE sequences, multi-peak IDEAL had between 66% and 84% greater suppression of signal of subcutaneous fat and bone marrow. For T_2-weighted FSE sequences, multi-peak IDEAL had between 21% and 81% greater suppression of signal of subcutaneous fat and bone marrow. On subjective analysis, T_2-weighted FSE sequence with multi-peak IDEAL was ranked significantly higher ($p<0.05$) than T2-weighted FSE sequences with fat-selective saturation and single-peak IDEAL for quality of fat-suppression, overall image quality, and conspicuity of bone marrow edema (Figure 3).

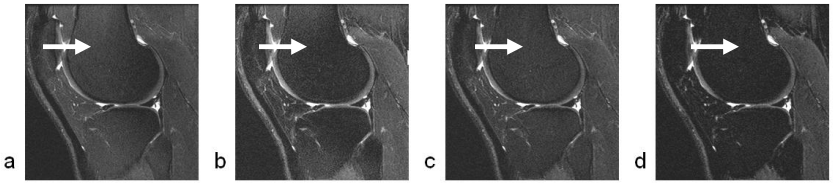

Figure 1: Sagittal T_2-weighted FSE images of the knee in a volunteer performed with a) fat-selective saturation, b) fat-selective partial inversion, c) single-peak IDEAL, and d) multi-peak IDEAL. Note the darker fat in bone marrow (arrows) on the multi-peak IDEAL image.

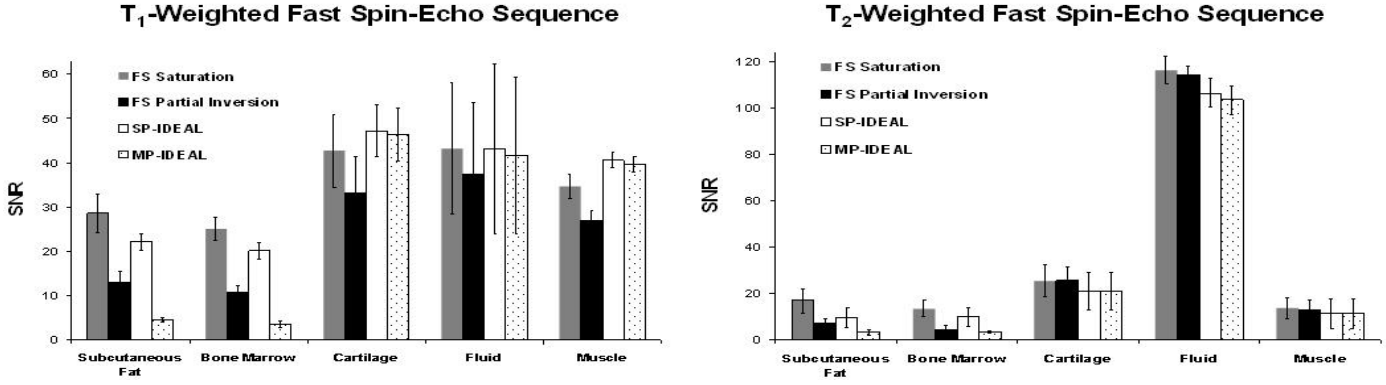

Figure 2: Mean SNR with standard deviations of subcutaneous fat, bone marrow, cartilage, fluid, and muscle for the T_1-weighted and T_2-weighted FSE sequences performed with fat-selective (FS) saturation, fat-selective (FS) partial inversion, single-peak (SP) IDEAL, and multi-peak (MP) IDEAL. Note the greater suppression of signal in subcutaneous fat and bone marrow for the multi-peak IDEAL T_1-weighted and T_2-weighted FSE sequences

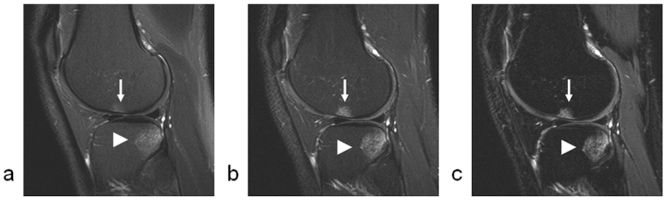

Figure 3: Sagittal T_2-weighted FSE images of the knee in a patient with acute post-traumatic contusion performed with a) fat-selective saturation, b) single-peak IDEAL, and c) multi-peak IDEAL. Note that the bone marrow edema within the lateral femoral condyle (arrows) and lateral tibial plateau (arrowheads) are more conspicuous on the multi-peak IDEAL image.

Conclusion: Multi-peak IDEAL fat-water separation provides improved fat-suppression for both T_1-weighted and T_2-weighted FSE imaging of the knee when compared to single-peak IDEAL and two widely used frequency-selected fat-saturation methods. The greater suppression of signal within bone marrow and subcutaneous fat may improve the conspicuity of pathologic conditions as demonstrated in our patients with post-traumatic bone marrow contusions.

References: 1) Reeder, et al. Mag Reson Med 54:583, 2005. 2) Brix, et al. Magn Reson Imaging 11:977, 1993. 3) Yu, et al. Mag Reson Med 60(5):1122, 2008.