“Dixon” Water-Fat Separation for Musculoskeletal Imaging with Fast Spin-Echo at 3T

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Introduction: Fast spin-echo (FSE) imaging is used routinely for most musculoskeletal (MSK) imaging protocols. Spectrally selective fat-saturation pulses are routinely used. However, non-uniform fat-saturation is common because of B_o and B_1 inhomogeneities, which worsen at higher field strengths. Alternative FSE fat-suppression methods include short tau inversion recovery (STIR) (1), and spectral-spatial pulses (2,3). STIR suffers from low signal to noise ratio (SNR) and requires additional time for inversion pulses, and spectral-spatial pulses are sensitive to field inhomogeneities.

We have recently described an iterative least-squares Dixon water-fat separation algorithm in combination with FSE that allows the calculation of water and fat images at arbitrary and short TE increments (4). This is beneficial for FSE Dixon imaging because shorter TE increments reduce the minimum time between refocussing pulses (echo spacing) to minimize blurring from long echo trains (5). This work compares the iterative least-squares “Dixon” fat-water separation method combined with FSE with conventional T2W FS-FSE in 10 knees of healthy volunteers at 3T.

Methods: Whole knee image acquisition was performed at 3.0T (Signa vH/i, GEMS, Milwaukee, WI) in 10 knees from 5 healthy volunteers (avg. age 32.8, range 26-40, 3 M, 2 F) . Informed consent was obtained prior to imaging and the study was approved by our IRB. We used a modified T2W fast-spin echo pulse sequence to acquire three images with echo shifts of –600us, 0, and 600us from the center of each spin-echo. This shift is slightly lower than the optimum of 750us. A lower value was chosen because this reduced the echo spacing to minimize blurring from long echo train lengths, with minimum penalty to SNR performance (4). Automated shimming routines and a standard single element extremity coil was used for all imaging. Echo time shift was changed for each TR to interleave measurements and reduce misregistration artifacts from potential motion between images acquired at different echo shifts.

For comparison, conventional fat-saturated (FS) T2W-FSE images were acquired at the same locations in all patients. Imaging parameters for both sequences included: 25-28 sagittal images, TR=5s, BW=±31kHz, FOV=16cm, slice=2.5mm, N_x=512, N_y=256, echo train length=10. Total scan time for one knee was 5:05min with both sequences. The effective TE (TE_{eff}) was 39ms for the Dixon acquisition and 42ms for conventional FS-FSE; differences in TE_{eff} were caused by slight differences in echo spacing between the two sequences. Three signal averages (NSA) was used for the FS-FSE technique to facilitate comparison of SNR between the two sequences, for constant scan time. Of note, the lack of fat-saturation pulses in the Dixon approach allowed the acquisition of 10% more slices than in conventional FS-FSE, within the same scan time.

Images were reconstructed with an on-line program based on the iterative least-squares algorithm (4). For each method, we measured the SNR of cartilage and gastrocnemius muscle, and contrast-to-noise ratio (CNR) between cartilage and joint fluid. Images were scored by consensus by two experienced radiologists on 4-point scales (0-3) for both fat-suppression and diagnostic quality. A paired Student *t*-test was performed to compare quantitative measurements (SNR, CNR). Qualitative fat-suppression and diagnostic quality scores were compared with a Wilcoxon paired signed rank test. To evaluate statistical significance $p<0.05$ was used for both quantitative and qualitative analyses.

Results: Overall, image quality for both techniques was excellent. Fig. 1 shows example images from one volunteer. Note the subtle shading of signal in the posterior aspect of the femur in the fat-saturated image. This effect is not seen on the calculated water image from the Dixon decomposition. Table 1 lists the SNR measurements for muscle, cartilage, and the CNR for cartilage and fluid, as well as the qualititative fat-suppression and diagnostic quality scores. All measurements were statistically similar except SNR of muscle and the FS score, both of which were higher for Dixon-FSE ($p<0.05$).

The average diagnostic quality was slightly lower for FSE-Dixon, although the difference was not statistically significant. The primary cause of this difference appears to be higher severity of flow related ghosting artifacts from the popliteal artery.

	SNR Muscle	SNR Cartilage	CNR Cart/Fluid	FS Score	DQ Score
Dixon-FSE	13.7±3.5*	13.7±3.7	22.4±7.3	2.8*	2.4
FS-FSE	12.0±3.5*	14.4±2.7	24.2±7.1	2.1*	2.7

Table 1: Comparison of SNR, CNR, Fat-Suppression (FS) Score, and Diagnostic Quality (DQ) Score for Dixon-FSE compared to FS-FSE for 10 knees. *Statistically different ($p<0.05$).

Discussion: Excellent fat-suppression, significantly better than conventional FS-FSE imaging was achieved with Dixon-FSE imaging. Except for SNR measurements in muscle, all SNR and CNR measurements were comparable for both methods, with the same scan time. Higher SNR in muscle was attributed to suppression of normal muscle by the fat-saturation pulse in regions of B_o inhomogeneity. Ghosting artifacts from the popliteal artery, which appear to be stronger in the Dixon-FSE images Further work is needed to evaluate whether this difference is real and, if real, to develop potential remedies.

The need to acquire three echoes lengthens the minimum scan time considerably for the Dixon method. However, this method is highly SNR efficient and the additional scan time required for this method is reflected in the SNR of the calculated water and fat images; the two methods had comparable SNR performance. For high-resolution imaging, as was used in this study, standard clinical protocols often require NSA=3; in this scenario, no additional time is needed for the Dixon method. Indeed, the lack of fat-saturation pulses with the Dixon method increased the maximum slice coverage from 28 to 31, without increasing changing total scan time. The effects of blurring from lengthened echo spacing was not observed in this study, although the increase in echo spacing (1.2ms) was short compared to the echo spacing 14ms . This effect may worsen at longer echo train lengths or with higher bandwidth acquisitions when the baseline echo spacing is shorter.

An additional benefit of Dixon imaging is that source images and fat images are also available to the diagnosing physician. For low bandwidth imaging, chemical shift correction of fat images can be made before recombination with water images to produce images free of chemical shift displacement artifacts.

Use of parallel imaging may be helpful to reduce total scan time for rapid imaging protocols. Further evaluation of this method in patients in the detection and diagnosis of pathology will also be required.

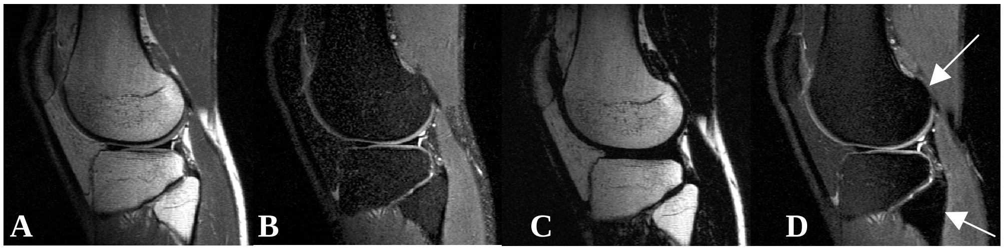

Figure 1: Source (a), calculated water (b), calculated fat (c) FSE Dixon images, compared with a FS-FSE image (d) from the same slice. Excellent image quality is seen with both images; however, shading can be seen in the posterior aspect of the lateral femoral condyle and proximal fibula (arrows).

References:

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