OLEFINIC FAT SUPPRESSION IN SKELETAL MUSCLE DTI WITH COMBINED 6- AND 2-POINT DIXON

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Purpose: Quantitative MRI methods used in skeletal muscle such as Diffusion Tensor Imaging (DTI) require robust fat suppression [1]. This is particularly important in patients with muscular dystrophies, where significant fat infiltration of the muscle tissue is a common pathological feature. Presence of olefinic fat, often not suppressed by standard fat suppression methods, can have a large influence on quantitative DTI measurements [1]. Two methods were proposed to eliminate the olefinic fat signal in muscle tissue. Williams et al. [1] use spectral fat saturation. While usable in many applications, this technique reduces water signal by approximately 10% [1] and is susceptible to main magnetic field (B_0) inhomogeneities. Hernando et al. [2] use a chemical-shift encoded method. While more robust against B_0 inhomogeneities, it requires complex data acquisition, which enforces the use of longer echo times or causes loss of resolution in phase domain as a result of partial Fourier acquisition while using potentially unstable reconstruction with model fitting.In this study we propose an adapted method based on the latter approach which offers clinically acceptable resolution with shorter TE and significantly simplified reconstruction.

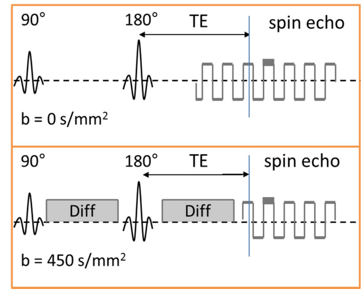

Fig. 1 Sequence diagram. Only magnitude data is needed from diffusion-weighted acquisition, allowing partial Fourier to compensate for the duration of diffusion gradients.

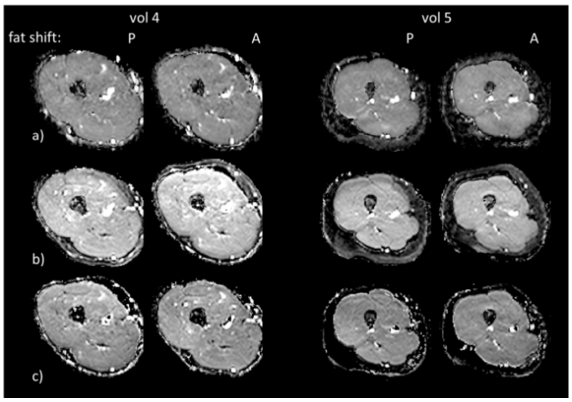

Fig. 2. Sample of DTI parameters (MD) calculated from images with olefinic fat suppression with a) fat saturation+SSGR, b) SSGR only, and c) Dixon + SSGR. Main fat is suppressed with SPAIR + SSGR in all acquisitions. To compare areas with and without presence of fat, fat shift direction is switched between A and P. Visual inspection shows good fat suppression.

Methods: Acquisitions were performed on a 3T Philips Ingenia system. 5 healthy volunteers were scanned (upper leg, unilateral), and informed consent was obtained from all participants. A standard spin-echo planar imaging DTI sequence with Spectrally Adiabatic Inversion Recovery (SPAIR) and Slice Selection Gradient Reversal (SSGR) fat suppression was modified to allow chemical-shift encoding. Diffusion-free (b=0) images were acquired with 6 shifted echoes (-1.05 ms to 9.38 with step of 2.08 ms). Diffusion-weighted images (b>0) were acquired with 2 shifted echoes (0 ms and 5.2 ms: in- and out-of-phase water-olefinic fat signal). b>0 acquisitions were repeated twice for purposes of signal averaging, and partial Fourier phase encoding was used (factor 0.69) to reduce TE. No partial Fourier was used in b=0 acquisition while keeping TE the same in both b=0 and b>0(Figure 1). Other typical acquisition parameters were: TE 50 ms, TR 3000 ms, 12 slices, voxel size 2 x 2 x 6 mm, b-value of 450 s/mm^2 , 6 diffusion directions. To further reduce TE, parallel imaging was used (SENSE, factor 1.7). For validation purposes, each acquisition was repeated with different fat shift directions, anterior (A) and posterior (P). Acquisition with similar parameters was performed in 2 volunteers using the triple fat suppression (triple fs) method proposed in [1].

In the reconstruction, initial olefinic fat separation was performed with 6-point IDEAL [4] tuned to the resonant frequency of olefinic fat (90 Hz at 3 T) on b=0 images. b>0 magnitude images were reconstructed from in-phase and out-of-phase magnitude images. Ambiguity between water and fat [3] was resolved using a fat fraction map generated from reconstructed b=0 images and corrected to include diffusion weighting. Mean Diffusivity (MD) was calculated from reconstructed images and compared in a region of overlap in vastus lateralis.

Results: Sample images reconstructed with the proposed method are shown in Fig. 2, along with images using only SPAIR and SSGR, and triple fs. Visual inspection shows successful olefinic fat suppression, which is confirmed in quantitative measurements in water-fat overlap region (Table 1). Difference in MD calculated with and without overlapping fat in the Dixon-based method shows improvement compared to SPAIR+SSGR only, and comparable to triple fs in the 2 volunteers where this method was included. Dixon methods displays slightly higher standard deviation, possibly due to the method's susceptibility to motion, particularly close to the edge of the tissue: movement between Dixon acquisitions will prevent fat signal on the edge from cancelling out, resulting in large misestimation of MD.

Method/Dir	Vol 1	Vol 2	Vol 3	Vol 4	Vol 5
triple fs A	---------------	---------------	---------------	1.74 ± 0.15	1.70 ± 0.13
triple fs P	---------------	---------------	---------------	1.74 ± 0.14	1.75 ± 0.12
SPAIR SSGR A	2.27 ± 0.15	2.03 ± 0.19	1.98 ± 0.22	2.24 ± 0.24	2.04 ± 0.20
SPAIR SSGR P	2.23 ± 0.18	2.09 ± 0.17	2.07 ± 0.14	2.39 ± 0.19	2.14 ± 0.14
Dixon A	1.71 ± 0.19	1.53 ± 0.19	1.54 ± 0.15	1.88 ± 0.20	1.67 ± 0.18
Dixon P	1.68 ± 0.46	1.49 ± 0.37	1.49 ± 0.28	1.82 ± 0.32	1.61 ± 0.25

Table 1. Quantitative measurements (MD) in a small water-fat overlap region in the vastus lateralis, averaged over 12 slices for each volunteer and shown for both fat shift directions. Difference between A and P measurements in the proposed (Dixon) method is comparable to triple fat suppression and generally lower than SPAIR + SSGR only. In addition, SPAIR+SSGR appears to overestimate MD. Higher standard deviation in Dixon can be attributed to sensitivity of the method to motion near the edges.

Discussion: Use of Dixon for olefinic fat suppression results in greater robustness of the method against B_0 inhomogeneities and potentially allowing for acquisitions with larger field of view than the triple fs method. It also offers much better resolution compared to method proposed by Hernando et al. as well as simplified and more stable reconstruction, at the cost of being more susceptible to motion around the edges of the imaged area.

Conclusion: We demonstrated an improved approach to suppressing olefinic fat signal in muscle DTI which in comparison with previously described methods allows for shorter echo times and potential robustness to B_0 inhomogeneities typical of Dixon methods, while simplifying the reconstruction process and maintaining good standard of quantitative results.

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References: [1] Williams et al. 2013, JMRI 38:1292-7; [2] Hernando et al. 2011, MRM 65:692-701; [3] Glover 1991, JMRI 1:521-530