Removal of Olefinic Fat Signal in Body Diffusion-Weighted EPI Using a Dixon Method

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Introduction

Body fat produces a complex set of peaks in the MR signal. Diffusion-Weighted (DW) body MR imaging is typically performed using EPI with chemical shift-based fat suppression, e.g., spatial-spectral (SS) excitation pulses. SS pulses effectively suppress the main fat peak (methylene protons, ~1.4 ppm) as well as other secondary peaks with similar chemical shifts. However, they fail to suppress the signal due to the olefinic protons (~5.4 ppm), which is spectrally close to the water peak (see Fig. 1). In the presence of DW gradients, the water signal is greatly attenuated, causing the slow-diffusing olefinic fat signal to become significant. Additionally, the chemical shift artifact (CSA) in EPI results in the subcutaneous fat signal often overlapping the region of interest (i.e., muscle), complicating the interpretation of DW images [1]. DW-EPI acquisitions usually require multiple averages to attain sufficient SNR. However, averaging does not alleviate the bias introduced by the presence of olefinic fat signal. Therefore, robust separation of water and olefinic fat is desirable. In this abstract, we propose a method for Dixon-based separation of water and olefinic fat signal in DW-EPI.

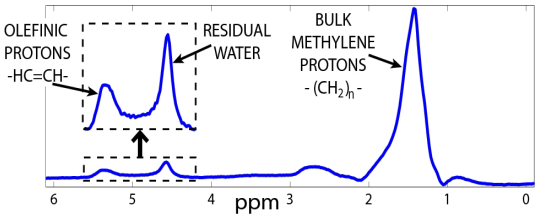


Fig. 1: *In vivo* spectrum, including water and several fat peaks.

Methods

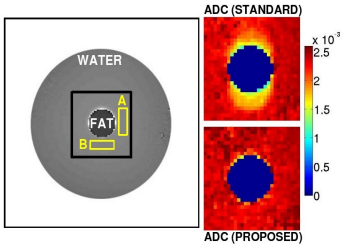
We propose to substitute the averaging in spin echo or stimulated echo DW-EPI by a Dixon acquisition [2,3], where "Dixon shifts" are obtained by shifting the refocusing pulse. In the proposed acquisition, the measured signal magnitude at location *x*, using a Dixon shift Δt, can be modeled as:

$$|s(x;\Delta t)| = \left| W(x)e^{j2\pi f_B(x)\Delta t} + F(x-\Delta x)e^{j\varphi_F(x-\Delta x)}e^{j2\pi[f_F+f_B(x-\Delta x)]\Delta t} \right|, \quad (1)$$

where $W(x)$ is the magnitude of the water signal, $F(x)$ is the magnitude of the olefinic fat signal, $\varphi_F(x)$ is the phase of the fat signal, $f_B(x)$ is the frequency offset due to B_0 field inhomogeneity, f_F is the chemical shift of the olefinic fat signal ($f_F \approx 94$Hz at 3T), and Δx is the displacement introduced by the CSA. In this work, the water and fat components $W(x)$ and $F(x)$ in Eq. (1) (as well as the nuisance parameter $\varphi_F(x)$) are separated using a Rician maximum likelihood fitting procedure directly on the magnitude signal. Use of magnitude signal is important, since phase is often distorted in body DW images due to motion. Ambiguities are resolved by initializing the fitting procedure using parameters derived from the *b=0* images (which also allow estimation of $f_B(x)$), where the phase was observed to be reliable.

Results and Discussion

DW-EPI data were acquired on a fat-water phantom, using *b=0* and *b=800* s/mm^2. The standard DW-EPI acquisition used *6* averages, whereas the proposed Dixon acquisition used *6* values of Δt (each with a single average), equally spaced between -3.0ms and 7.0ms. In the standard acquisition, regions showing both fat and water (see Fig. 2, where olefinic fat was displaced by 6 pixels due to the CSA) resulted in an underestimation of *18%* in the ADC estimates. This error was largely corrected with the proposed method.



ADC (x10^{-3}mm^2/s)	Region A	Region B
Proposed – 6 TEs	**2.402 ± 0.051**	**2.308 ± 0.064**
Standard – 6 ave	**2.399 ± 0.040**	**1.977 ± 0.199**

Fig. 2: Phantom results. Region A contains only water, and region B contains both water and olefinic fat (which appears displaced due to CSA). The proposed method results in more accurate ADC estimates in region B, with moderate increase of the standard deviation in region A.

In vivo data were acquired from the thigh region of one volunteer, using a single-shot stimulated echo EPI sequence [4] with *b=0* and *b=540* s/ mm^2, and *6* values of Δt, equally spaced between *0.0*ms and *10.0*ms. Results are shown in Fig. 3. The acquired images contain significant olefinic fat contribution (see arrows). The proposed method results in uniformly good suppression of the olefinic fat signal. Noise performance was analyzed using the Cramer-Rao (CR) bound [5], by computing the effective number of signal averages (NSA, see Fig. 4).

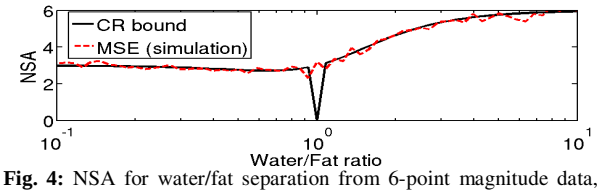


Fig. 4: NSA for water/fat separation from 6-point magnitude data, for varying water/fat ratios. The degeneracy of the CR bound for water/fat ratio 1 does not affect practical estimation performance.

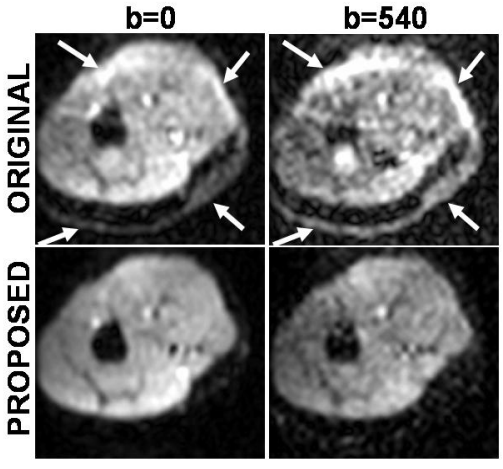


Fig. 3: In vivo DW-EPI thigh images. Olefinic fat signal is clearly visible in the original images (single average). The proposed method removes the fat signal and results in improved ADC estimates, as well as improved SNR due to the effective averaging.

Conclusions

The combination of DW, SS pulses and EPI makes olefinic fat signal significant in MR images, complicating the estimation of diffusion parameters. The proposed method addresses the problem using a Dixon method, and should prove useful for many applications in body DW imaging.

References: [1] Damon BM, Magn Reson Med, 60:934-944, 2008. [2] Dixon WT, Radiology 153:189-194, 1984. [3] Hwang K et al., ISMRM 2008, p. 2293. [4] Karampinos D et al., ISMRM 2008, p. 2590. [5] Pineda A et al., Magn Reson Med 54:625-635, 2005.