Making SENSE of Chemical Shift: Separating Species in Single-Shot EPI using Multiple Coils

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Introduction: We present a method for separating chemical shift in single-shot EPI using multiple coils. Chemical shift causes severe artifacts in long echo-train EPI. While this is often mitigated using spectral excitation or saturation, these methods are sensitive to B0 and B1 inhomogeneities. We propose simple and robust alternative. The basic idea is, that chemical shift artifacts are inconsistent with the coil sensitivities. For example, fat would have shifted image and shifted sensitivity maps with respect to water. By finding a solution consistent with these two sets of maps, separation is achieved. This approach is an extension of the PAGE method by Kellman et al. [1,2]. Results are presented using maps obtained from a pre-scan showing high quality images without the need of knowing the field inhomogeneity. In addition, we present a fully automated joint estimation scheme based nonlinear inversion that does not require prior knowledge of the sensitivities.

Theory: Given the measured data, y, the reconstruction is defined as the solution of an inverse problem. Our forward model is separated water and fat images. The water image, I_w, is multiplied by the sensitivities, C, and Fourier transformed, F. The fat image, I_f, is multiplied by the sensitivities, C, Fourier transformed, F, and modulated by phase, Φ, corresponding to the chemical shift and the k-space acquisition timing. This can written as

$$y = F C I_w + \Phi F C I_f \ .$$

Given the coil sensitivities, this can be solved directly or iteratively for both images. An extension can be using joint estimation for both, images and sensitivity maps [3,4]. In this case, a mask has to be included restricting the FOV to the support of the image to avoid some ambiguity in areas where there is no signal.

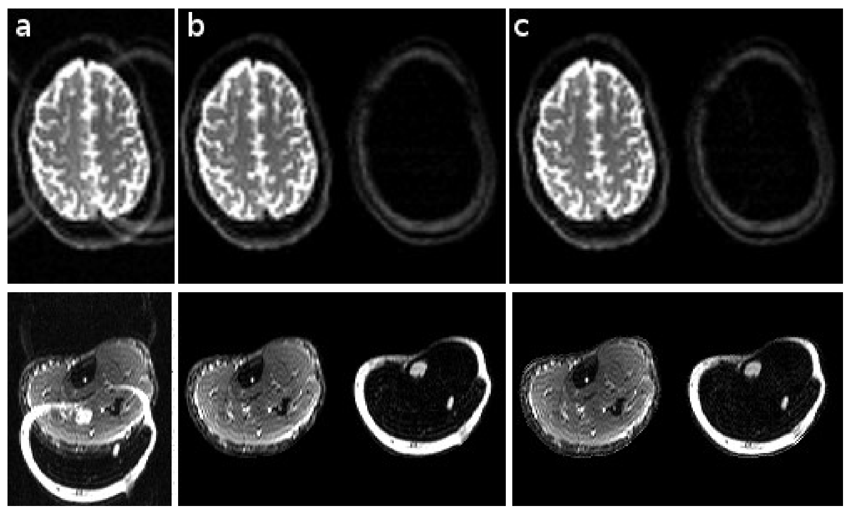

Figure 1: *Images from a human brain (top) and a human (leg) acquired with EPI and reconstructed with a) Fourier transform b) proposed linear inverse reconstruction using known sensitivities c) proposed non-linear reconstruction*

Methods: Single-shot EPI scans have been performed for a human brain (TE = 78.4 ms, ΔTE = 0.752 ms, 35 mm FOV, 4 mm slice thickness, 128x48 matrix) and a leg (TE = 71.1 ms, ΔTE = 1.008 ms, 20 mm FOV, 5 mm slice thickness, 128x96 matrix) using eight channel receive coils at 1.5 T. Coil sensitivity maps have been determined using a fat suppressed scan. The proposed algorithm has been implemented in Matlab and used to reconstruct water and fat images from the acquired data using either explicit knowledge of the sensitivities or using a non-linear inverse reconstruction [4].

Results and Discussion: Figure 1 shows images from a human brain (top) and a human leg (bottom). While the image reconstructed by Fourier transform has a shifted fat ghost (a), the proposed reconstruction methods (b,c) are able to separate the signal into components from water (left) and fat (right). The use of the nonlinear reconstruction to estimate the sensitivities gives comparable results as the method using explicit coil sensitivities and eliminates the need for a pre-scan. Figure 2 shows g-factor maps corresponding to the images of the human leg. It describes the noise amplification in the water and fat images during the reconstruction.

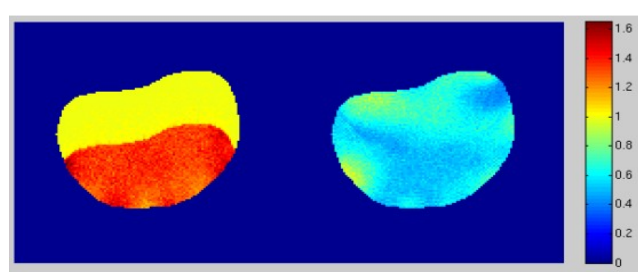

Figure 2: *g-factor maps corresponding to the water (left) and fat (right) images of the human leg.*

References:

1. Kellman P et al., NMR in Biomed 2006;19:352-361
2. Flask CA et al., Proc. 12th ISMRM, 2004:269
3. Ying L et al., Magn Reson Med 2007;57:1196-1201
4. Uecker M et al., Magn Reson Med 2008;60:674-682