Chemical species separation with simultaneous estimation of field map & T_2* using a k-space formulation

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INTRODUCTION: Since the original two-point Dixon approach [1], fat-water separation techniques have been considerably improved with new methods, such as three-point and multi-point Dixon, extended two-point Dixon and Iterative Decomposition of water and fat with Echo Asymmetry and Least-squares estimation (IDEAL) [2]. A more complete signal model is presented in [3], where each pixel is modeled with a single T2* value, generating a T2* map for the entire object. In the existing *k*-space decomposition methods [4,5] the field and T2* maps are obtained in the image domain and then demodulated from the acquisitions. In these methods, the phase accumulation due to field inhomogeneity and the signal decay during the readout are not taken into account. In this work we propose a new method for Field Inhomogeneity, R2* and Species estimation using a variable Time map (FIRST). Unlike current methods, FIRST accounts for the phase accumulation due to field inhomogeneity and for the signal decay during the readout. Thus, it is able to correct the artifacts caused by chemical shift and field inhomogeneity. Moreover, the T2* map is calculated in the undisplaced positions.

$$S(t) = \sum_{m=1}^{M} \int_{\mathbf{r}} \rho_m(\mathbf{r}) \cdot e^{-t/T_2^*(\mathbf{r})} e^{-i2\pi((\psi(\mathbf{r})+\Delta f_m)\cdot t + \mathbf{r}\cdot k_\mathbf{r})}\, d\mathbf{r} \qquad \textbf{(1)}$$

$$\min_{\substack{\boldsymbol{\rho}_m \in \mathbb{C}^N \\ \tilde{\boldsymbol{\psi}} \in \mathbb{C}^N}} \left\| S_q^a - \sum_{m=1}^{M} \sum_{\mathbf{r}} \rho_{m,\mathbf{r}} \cdot e^{-i2\pi(\Delta f_m + \tilde{\psi}_\mathbf{r})\cdot q} \cdot e^{-i2\pi \mathbf{r}\, k_\mathbf{r}} \right\|_2 \qquad \textbf{(2)}$$

METHODS: The proposed MR signal model in *k*-space is shown in Eq. 1. The readout time *t* is considered for field inhomogeneity (ψ) and chemical shift (Δf_m). Furthermore, the T2* signal decay during the readout is also considered. The estimation is achieved by minimizing the difference between the acquired signal and an accurate signal model of each *k*-space position. The discrete minimization functional is shown in Eq. 2, where T2* decay is included in the complex part of the field variable ($\tilde{\psi}$). The signal model is fitted to the acquired signal (S_q^a), where *q* is the discrete readout time. Estimates for the unknowns are generated directly in image space. Similar to previous methods, it does not need specific echo time combinations, allowing the use of short echo time sequences.

EXPERIMENTS: A conventional 2D gradient echo sequence with cartesian trajectories was performed in the thigh and head of two healthy subjects. All images were obtained using a Philips Intera 1.5T scanner (Philips Healthcare, The Netherlands). Four acquisitions were obtained with the following parameters: matrix size 256x256, TE = 4.6, 4.8, 6.2, 7.5 ms, slice thickness = 10 mm, TR = 150 ms, FOV = 18 cm with sampling bandwidth of 13.8 kHz (217 Hz/pixel). The images were processed to obtain estimates of fat and water with FIRST and T2*-IDEAL [3] algorithms. The water-fat frequency shift was assumed to be -3.5 ppm, or -217.1 Hz at 1.5T. Images for fat, water and in-phase combination (water plus fat) were generated in addition to field and T2* maps. Both methods were implemented in Matlab (The MathWorks, Natick), with FIRST requiring an algorithm suitable for a non-linear objective function with linear constraints (the interior-point algorithm was chosen). The ranges for both methods for field inhomogeneity and R2*=1/T2* were set to -150 to 150 Hz and 0 to 350 1/s, respectively. Our final implementation consisted of two steps. The first step consists in estimating the species and the field map without considering T2* decay. In the second step we re-estimate the species and the field map but now calculating a T2* map. The estimates for the species and field map are used as the starting point of the second step. Bounds for all variables were provided, creating a convex feasible set. For T2*-IDEAL the field map was filtered with a gaussian filter of size 3x3 and sigma = 1.5 in order to achieve better water-fat separation.

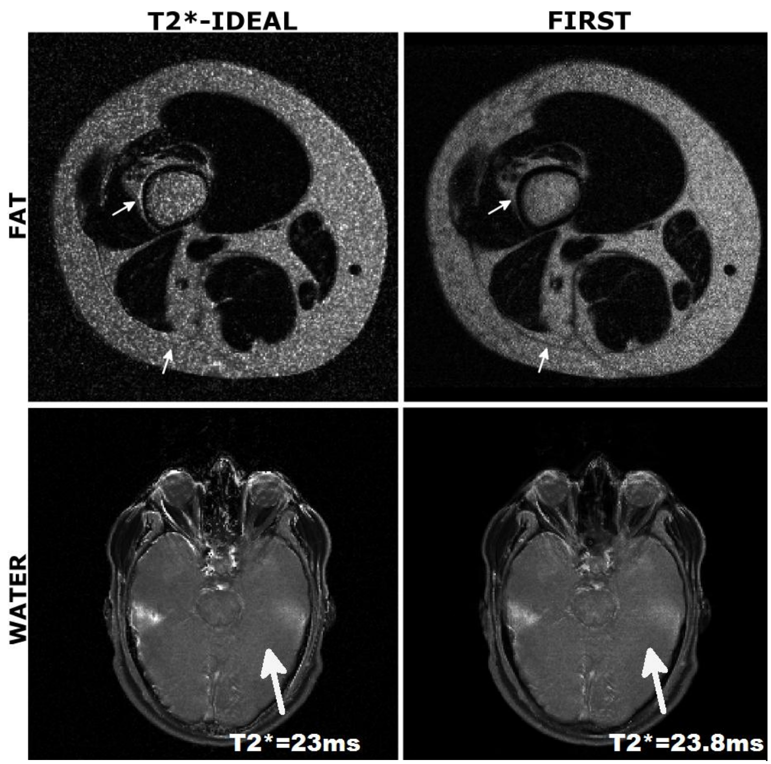

Figure 1: Water magnitude images in the thigh estimated with T2*-IDEAL (left) and FIRST (right). An intensified signal band is observed with IDEAL in areas where fat and water usually overlap when performing cartesian acquisitions. These artifacts are corrected with the proposed algorithm.

RESULTS: Fig 1, shows the results obtained with T2*-IDEAL and FIRST for water and fat magnitude images. The arrows show erroneous signal accentuation with T2*-IDEAL, which FIRST succeeds to correct. Similar values for T2* decay are obtained with both methods.

CONCLUSION: Our *k*-space-based approach calculates simultaneously estimates of species, field inhomogeneity and T2* maps. By considering a variable time map, the field and T2* maps are correctly estimated. Additionally, the proposed method corrects image-space displacement and of species due to chemical shift and field inhomogeneity. As shown in the results, this technique achieves accurate and reliable water-fat separation, outperforming existing methods.

References: [1] Dixon, WT. Radiology, 153(1), 1984. [2] Reeder, SB. Magn Reson Med, 51, 2004. [3] Yu, H. J Magn Reson Imaging, 26, 2007. [4] Brodsky, EH. Magn Reson Med, 59(5), 2008. [5] Wang, K. J Magn Reson Imaging, 31(4), 2010.