Correction for Multipeak Fat Spectrum When Estimating T2* in the Presence of Fat

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Introduction Simultaneous estimation of water, fat and T2* [1-3] is important in the evaluation of chronic liver diseases such as fatty infiltration and iron overload. We have recently developed a T2*-IDEAL technique [2] by modifying the IDEAL water-fat separation algorithm [4] to account for the effects of T2*. Using this method, water and fat can be separated, free from the effects of T2* decay, and an R2* (=1/T2*) map is estimated simultaneously, free from the alternating constructive/destructive interference of fat. Typically six echoes are acquired with a multi-echo GRE sequence to achieve a good balance of accurate R2* estimation and reasonable scan time [2].

In T2*-IDEAL, water and fat are each modeled as a single resonant frequency in the spectral domain. However, the fat spectrum is well known to exhibit multiple spectral peaks, which are well visualized in the spectrum acquired in subcutaneous fat shown in Figure 1a. As a result, the fat signal does not purely follow an exponential decay, as shown by a 16-echo signal curve in a fat pixel (black curve) in Figure 2b. If only first six echoes were acquired and used for T2* estimation, as in 6-echo T2*-IDEAL [2], a significant under-estimation of T2* results (T2*=8ms, blue curve), which has also been observed in other studies [5]. In this work, we modify the T2*-IDEAL algorithm to model a more accurate fat spectrum. We demonstrate that this enhancement results in substantially improved T2* estimation with no additional echoes needed.

Methods The multipeak T2*-IDEAL approach models the signals from a voxel:

$$s(t) = \left(\rho_w + \rho_f \sum_{p=1}^{P} \alpha_p \cdot e^{j2\pi \Delta f_p t} \right) \cdot e^{j2\pi \psi t}$$, where Δf_p and α_p are the resonant frequency (relative

to water) and the relative amplitude of the pth fat peak ($p=1, \ldots, P$), respectively, with $\Sigma \alpha_p=1$. Both the B_0 field inhomogeneity and the T2* decay are modeled in the "complex fieldmap"

term, $\hat{\psi} = \psi + j R_2*/2\pi$, enabling modification of the IDEAL algorithm [4] to estimate R2*

in addition to water and fat [2]. If the fat spectrum (Δf_p and α_p) is known, water, fat and the complex fieldmap can be estimated by following the conventional T2*-IDEAL algorithm [2] and replacing fat associated weighting from $e^{j2\pi \Delta f_1 t}$ to $\Sigma \alpha_p e^{j2\pi \Delta f_p t}$.

The frequency offsets, Δf_p can be determined from Figure 1a and considered constant. The relative amplitudes, α_p, however may change with sequences with different T1 and T2 weighting. We estimate the α_p of the peak 1-3 directly from the 6-echo source data. Peak 4 is close to peak 1 (52Hz at 3T) and peak 5-6 are small, therefore their effects on 6-echo T2*-IDEAL are assumed small and ignored. The steps are illustrated in Figure 2. First, the signal equation can be reformatted as:

$$s(t) = \left[\rho_w + (\rho_f \cdot \alpha_1) \cdot e^{j2\pi \Delta f_1 t} + (\rho_f \cdot \alpha_2) \cdot e^{j2\pi \Delta f_2 t} + (\rho_f \cdot \alpha_3) \cdot e^{j2\pi \Delta f_3 t} \right] \cdot e^{j2\pi \hat{\psi} t}$$, where water

and the three fat peaks are treated as 4 independent species. It has been shown that the IDEAL algorithm can be extended to estimate multiple species [4]. Therefore, a modified 6-echo T2*-IDEAL reconstruction is performed, resulting in images of the 3 fat peaks ($\rho_f \cdot \alpha_1$, $\rho_f \cdot \alpha_2$, $\rho_f \cdot \alpha_3$). A fat mask is created to select only fat-rich pixels for spectrum calibration. Normalization utilizing $\Sigma \alpha_p=1$ at each pixel leads to three α_p maps. α_p values in each map are averaged over all pixels in the fat mask to form the final estimates of α_p. In the current implementation, this spectrum calibration is performed on only one slice and then used for all slices in the dataset. This algorithm assumes that all fat pixels in the dataset can be characterized by the same spectrum, i.e. Δf_p and α_p are spatially invariant.

Results In-vivo scans were performed using a multi-echo 3D-SPGR sequence with informed consent and permission from our Institutional Review Board. Figure 1c compares results from conventional T2*-IDEAL to multipeak T2*-IDEAL in a healthy volunteer. The R2* map from conventional T2*-IDEAL demonstrated an under-estimated T2* of 10ms in fat. With the multipeak correction, T2* measured in the same area is 26ms, more consistent with expected values [6]. Figure 3 demonstrates the clinical impact of the multipeak correction in a patient scan. The conventional T2*-IDEAL resulted in a moderately reduced T2* of approximately 15ms in liver, suggesting the presence of mild iron concentration [7]. However, the patient also has over 30% fat in liver, which could result in artifactual T2* shortening. With the multipeak correction, the estimated T2* increased to 22ms, a normal T2* value in liver [7]. In addition, with the multipeak correction, the fat-signal fraction measured in liver increased from 35% to 41%, likely due to appropriate inclusion of the signal from spectral peaks of fat.

Discussion and Conclusion We have shown that multiple peaks of fat confound the ability to estimate fat and T2* simultaneously, and that a more accurate signal model for fat is needed. In this work, the fat spectrum is estimated directly from the source data, eliminating the need for assumptions about the fat spectrum that may vary between different datasets. However, the possible intra-data spectrum variation in different fatty tissues is not modeled. In conclusion, we have described a new multipeak signal model for simultaneous water, fat and T2* estimation, improving the accuracy of the R2* mapping and fat quantification.

References
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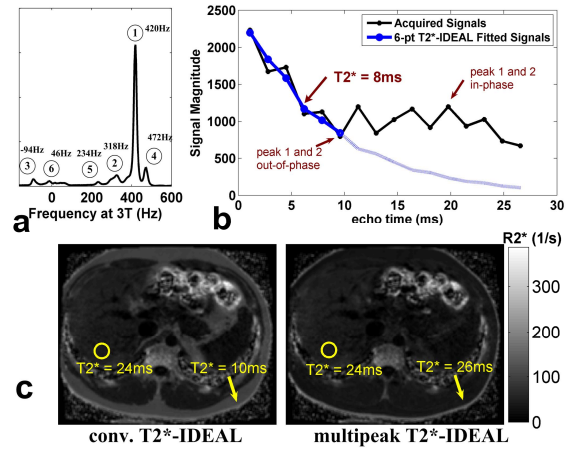[7]. Westwood et al, JMRI 2003;18(1):33-39.

Figure 1: Illustration of the T2* under-estimation effect due to the fat side peaks. a: a typical fat spectrum. b: a 16-echo signal curve (black) and T2*-IDEAL fitted signals using the first six echoes (blue) c: R2* maps estimated from 6-pt T2*-IDEAL without and with the multipeak correction.
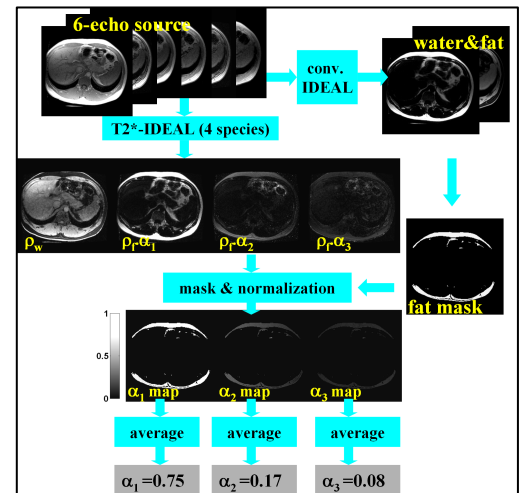

Figure 2: Illustration of the spectrum self-calibration algorithm to estimate the relative amplitudes directly from the six-echo source data.
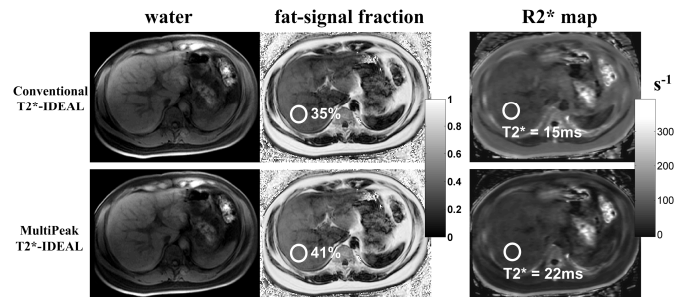

Figure 3: Results from a liver patient scan. Conventional T2*-IDEAL suggests moderately shortened T2*. With multipeak correction, it is evident that the shortened T2* is caused by the T2* under-estimation effect from the liver fat content.