

An algorithm for lipid-water separation in the presence of T2* decay

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Introduction: Recently the IDEAL algorithm (Iterative Decomposition of water and fat with Echo Asymmetry and Least square estimation) for fat/water separation has drawn significant attention [1-2]. Compared to conventional Dixon methods, the IDEAL algorithm produces robust lipid and water separation by iteratively searching for the optimal field map. In IDEAL three data sets are acquired with echo-shift combinations that correspond to different phases between lipid and water. The echo-shift combinations are chosen to maximize the theoretical noise performance, or NSA, [3] while keeping the time difference between echo points short enough such that the performance of lipid/water separation is not affected by T2* decay.

Recently two methods were proposed where more than three echoes are collected and are used for lipid/water separation. One method is based on the acquisition of a train of echoes within a gradient echo excitation [4]. The other method is based on a GRASE pulse sequence where the echo-shifted data sets are collected within each SE period as shown in Fig. 1 [5]. The acquisition of more echoes improves the SNR of the individual lipid and water images. However T2* decay may become a problem if the time difference between the first and the last collected echoes is large. For cases where T2* is the same for lipid and water it was shown that the iterative algorithm used in IDEAL can be modified to estimate T2* and correct the errors in lipid/water separation [4]. This condition is only true when susceptibility effects dominate T2*. In vivo, this situation arises mainly when there is iron deposition in tissues. For all other in vivo applications, the T2* values of lipid and water are different (because the T2s of these two species are quite different) and this needs to be taken into account.

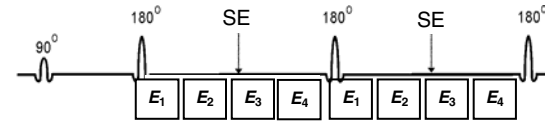


Fig. 1. GRASE acquisition for lipid/water separation

The purpose of this work is to investigate the ability of the Levenberg-Marquardt (LM) [6] algorithm to separate lipid and water signals in the presence of T2 decay.

Theory: Assuming the object being imaged is composed of two species, water and lipid, the signal equation at each voxel is given by

$$s(t_n) = (\rho_w e^{i\phi_w} e^{-t_n/T2_w^*} + \rho_l e^{i\phi_l} e^{-t_n/T2_l^*} e^{iC_s t_n}) e^{i\Phi t_n}$$

There are 7 unknown parameters, the water and lipid spin densities and phase ($\rho_w, \phi_w, \rho_l, \phi_l$), the T2* of both water and lipid, and the field map, Φ . The chemical shift C_s is known. We typically collect complex valued data at 4 time points (as in the GRASE diagram shown in Fig. 1), giving 8 measurements. Since there are more measurements than parameters to be estimated, a least-squares fitting technique like LM can be used. Levenberg-Marquardt uses the Jacobian of the signal equation, which is known analytically in this case, to perform an iterative gradient descent, converging to a local solution of $\arg \min_p \sum_{i,n} (d_i(t_n) - s_i(\bar{p}, t_n))^2$ where \bar{p} is the vector composed of the 7 unknown parameters, d is the collected data, s is

the signal equation model,

$n = 1, 2, 3, 4$ are indexes of the echo shift times, and $i = 1, 2$ represents the real and imaginary components.

The LM algorithm was implemented using MATLAB. In our implementation, the IDEAL algorithm is used to obtain lipid/water parameters that are used as initial conditions in the LM algorithm.

Results: Images of a lipid/water phantom corresponding to echo-shift combinations of $(-5\pi/6, -\pi/6, \pi/2, 7\pi/6)$, $(-3\pi/2, -\pi/2, \pi/2, 3\pi/2)$ and $(-13\pi/4, -3\pi/4, 7\pi/4, 17\pi/4)$ are shown in Fig. 2. These echo-shift combinations correspond to data acquired with GRASE at three different receiver bandwidths (± 125 kHz, ± 64 kHz, and ± 32 kHz, respectively). Thus, the time difference between the first and the fourth echo is 4.5 ms, 6.8 ms, and 17.0 ms, respectively.

The images shown in Figs. 2a-c were processed with the IDEAL algorithm. Note that in (a) the lipid/water separation is excellent but in (c) there is residual lipid signal in the water image (as indicated by the black arrows) and a rim of signal in the lipid image (white arrow) corresponding to unsuppressed water. When data is processed with the LM algorithm, the lipid and water signal intensities are corrected for T2* decay thus lipid/water separation for data acquired with $(-13\pi/4, -3\pi/4, 7\pi/4, 17\pi/4)$ is significantly improved as shown in Fig. 2d.

Conclusion: With the LM algorithm it is feasible to separate lipid and water from data with T2* decay. This allows for the acquisition of more echoes to improve the noise performance of lipid/water separations. In multi-echo acquisition, such as in GRASE, the method enables the acquisition of data with lower bandwidth (and/or higher number of readout points) which in turn also increases SNR (and/or spatial resolution).

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References: [1] Reeder SB, MRM 51:35, 2004. [2] Reeder SB, MRM 54:636, 2005. [3] Pineda AR et al MRM 54:625, 2005. [4] Yu H et al ISMRM 2006, 624. [5] Li et al ISMRM 2006, 739. [6] Marquardt D SIAM J Appl Math 11:431, 1963.

