Temperature and B0 Field Measurment Bias of Multi-echo Fat-Water Fitting Algorithms

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Introduction

Multi-echo fat-water separation techniques, such as IDEAL[1], have been shown to be effective in measuring temperature changes in fatty tissue[2]. These techniques often make assumptions that allow them to linearize the model in order to simplify the computation of a solution. However, the assumptions made typically preclude the addition of additional terms, such as individual T2* decays for water and fat, that would more accurately model the physical changes occurring in tissues due to their inherent nonlinearity. This can result in the addition of significant bias to the measurement of the temperature and the B0 field offset, both important parameters to monitor during therapeutic heat applications (tumor ablation, hyperthermia). In this work, the bias of a linearized multi-peak IDEAL algorithm (without T2* decay) and a new nonlinear fitting algorithm approach is characterized using Monte Carlo simulations.

Methods

The nonlinear approach assumes that the MR signal is composed of water (1 peak) and fat (3 peaks) contributions and is of the form:

$$s(n) = \left(A_w e^{\frac{-TE(n)}{T2_w^*}} e^{2\pi i \alpha \nu \Delta T} + A_f e^{\frac{-TE(n)}{T2_f^*}} \left(\beta_1 e^{2\pi i TE(n)\varphi_{fw\,1}} + \beta_2 e^{2\pi i TE(n)\varphi_{fw\,2}} + \beta_3 e^{2\pi i TE(n)\varphi_{fw\,3}}\right)\right) e^{2\pi i TE(n)\psi} + \varepsilon \qquad (1)$$

where A_w and A_f are the TE = 0 amplitudes at the TR of interest for water and fat signal contributions. $T2^*_w$ and $T2^*_f$ are the T2* values for water and fat, α is the PRFS thermal coefficient (0.01ppm/°C), ν is the imaging frequency, φ_{fwn} are the frequency differences between the fat and water peaks at a "baseline" temperature(T_b), ψ is the signal offset due to B0 frequency shift, and ε is Gaussian noise with mean=0 and variance=σ_ε^2. β_i is the relative ratio of the area of each fat peak compared to the area of all fat peaks combined, with summed values adding up to 1. ΔT is the temperature change from base temperature T_b, and n is the echo number. A Levinberg-Marquardt nonlinear fitting algorithm was used to fit for ΔT and ψ values assuming that all other variables in s(n) were held fixed (A_w=4, A_f=6, $T2^*_w$=$T2^*_f$=40ms, ψ=-12.5Hz, f = 63.87MHz, φ_{fw1}=-222Hz, φ_{fw2}=-175Hz, φ_{fw3}=33Hz, β_1=0.82, β_2=0.11, and β_3=0.07).. A standard IDEAL algorithm, without the T_2^* terms, was also applied to the data to get ψ values while ΔT was calculated as the difference in phase angle between the water and fat signals at time N as compared to their phase angle at time 0. Bias values were calculated in a 36x21 matrix of starting conditions based on "starting TE" (range 18-22 ms) and "echo separation" (range 1.25-3.75 ms). All echoes were evenly spaced based on a given separation. Each location in the matrix was simulated with 5,000 independent samples of equation 1 with two ΔT settings, 0°C and 6°C. The temperature and field values at 0°C were subtracted from the values at 6°C (to mimic referenced temperature imaging) and the mean calculated. Similar simulations were performed using a three-peak lipid IDEAL fat-water separation algorithm, except a 72x41 matrix for the same ranges was used

Results and Discussion

Maps of the mean temperature and mean field differences for IDEAL and the nonlinear fit methods are shown in Figures 1 and 2. Matrices have been interpolated for display. Temperature and field values measured with the IDEAL algorithm are biased in certain regions, varying from the respective true values of 6°C and 0 Hz. However, there are regions where the values are unbiased, but they are limited in range. No bias in either value is seen when there is no temperature change. Thus, we hypothesize that the bias seen in the IDEAL algorithm is due to the linearity of the signal model used and exclusion of a temperature term from that model. However, from our simulations it seems that there is always an unbiased region for measuring temperature for all A_w/A_f values. Unfortunately, the same cannot be said for the IDEAL field measurement, which has no unbiased regions at many other A_w/A_f values. Future work will focus on the effects of various parameters on the bias of both algorithms (such as changes in the fat-water frequency difference) as well as the performance of the nonlinear algorithm during phantom experiments with heat.

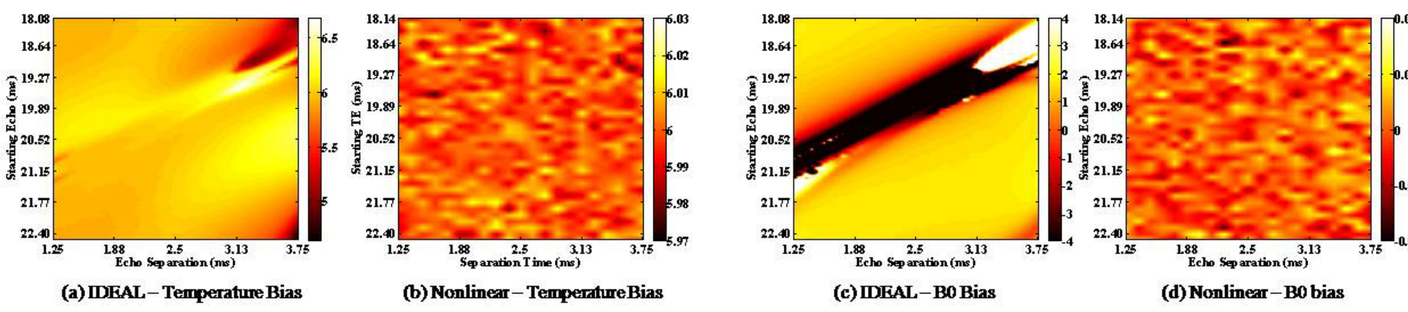

Figure 1: Bias of IDEAL and Nonlinear algorithms. Note the side colorbars have different scale ranges.

References

[1] Reeder, SB., et al. MRM. 51: 35-45 (2004) [2] Soher, BJ., et al. 16th ISMRM , Toronto, p3018 (2008)