Independent Estimation of T2* for Water and Fat for Improved Accuracy of Fat Quantification

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Introduction: Quantification of fat with MRI has the potential to provide non-invasive detection and quantification of hepatic steatosis without the risk, cost and inaccuracy of biopsy. Accurate quantification of fat necessitates correction for confounding factors such as T_2^* decay[1,2], T_1 bias[2,3] and the multiple spectral peaks of fat[2,4]. Typical values of liver T_2^* range from 25-30 ms in normal livers to less than 5ms in patients with hepatic iron overload[5]. Past work on T_2^* correction has assumed a common T_2^* for water and fat[1] or a fixed difference between water and fat T_2^* values[2]. The purpose of this work is to loosen these assumptions to allow estimation of independent T_2^* decay for water and fat. Using this "dual T_2^*" correction method, we aim to achieve more accurate estimates of fat.

Theory and Methods: The signal from a voxel containing water and fat with independent T_2^* decay can be written as: $s(t) = (W\exp(-R_w t) + F\exp(-R_f t)\sum_{p=1}^{P} r_p \exp(2\pi i \Delta f_p t))\exp(2\pi i \psi t)$ [1]
where W and F are the water and fat signals, ψ is the shift (Hz) in the spectrum caused by local Bo field inhomogeneities, R_w is the R_2^* of water and R_f is the R_2^* of fat, Δf_p is the resonance frequency of the p^{th} fat peak, r_p are the relative proportions of the different fat peaks such that $\sum_{p=1}^{P} r_p = 1$.

R_2^* values of water and fat were independently estimated iteratively using the Gauss-Newton method for multiple variables. The initial guess for all the parameters was obtained from the single T_2^*–IDEAL method with accurate spectral modeling of multiple peaks of fat. An appropriate initial guess for W, F, R_w=R_f= R_2^*, and ψ is required, not only to reduce the number of iterations, but also to avoid convergence to local minima. No additional region growing, other than that used for single T_2^*-IDEAL was used[7]. The initial guess of the parameters was successively updated using Taylor's first order approximation for multiple variables, as is done in the Gauss-Newton method to reduce the error. Error was calculated by taking the difference between the measured signal and the signal estimated from the parameters in the current iteration, using Equation 1. The error was reduced by finding a constant multiplying factor that minimizes the L2 norm for the difference vector used to update the parameters. In other words, the step size obtained from the Gauss-Newton method was optimized by performing a linear search in the direction of the difference vector. The process was repeated until the mean squared error was reduced to a value smaller than a predetermined value, or if the numbers of iterations exceeded a particular count.

A phantom was constructed containing varying fat fractions (0.11, 0.21, 0.32, 0.42, 0.52) and iron concentrations (0, 10, 21, 32 µg Fe/mL), using a variation of a phantom described by Bernard et al[6], where agar was supplemented for carrageenan, in order to create a more stable emulsion (details submitted separately). Imaging was performed using the head coil of a 1.5T Signa HDx system (TwinSpeed, GE Healthcare, Waukesha, WI) using a multiecho 3D spoiled gradient echo pulse sequence. Imaging parameters included the following: TE_{min} = 1.4 ms, ΔTE= 1.6 ms, 6 echoes per TR, and TR = 42.7 ms, with flip = 5° to minimize T_1 bias[3], FOV = 35x35 cm, matrix = 256 x 256, BW = ± 100 kHz, 1 signal average, and slice thickness = 8 mm.

Results: Figure 1 shows the estimated percentage fat-fractions from three reconstruction techniques, with three different reconstructions regarding T_2^* decay for water and fat: (a) no T_2^* decay correction, (b) T_2^* correction assuming common T_2^* for water and fat (ref Yu), and c) T_2^* correction with the proposed dual T_2^* method. For iron concentrations less than 32 µg/mL, errors in estimated % fat-fractions reduce from 30% with no T_2^* correction to 25% with single T_2^* correction to less than 5% with dual T_2^* correction.

Figure 2 shows the independently estimated of R_2^* values of water and fat at different iron concentrations using the dual T_2^* method. The results for R_2^* show that the R_2^* of water is similar to the R_2^* of fat for iron concentrations below 5 µg/mL and that the R_2^* of water is significantly greater than the R_2^* of fat for iron concentrations above 5 µg/mL. Our results show that iron affects R_2^* of water more than the R_2^* of fat, for this phantom, and underscore the need for a dual T_2* correction method.

Discussion: The maximum error in estimation of fat-fraction increases at higher fat-fraction and with increases in iron concentration. As the relative amount of fat increases, the relative differences in R_2^* between fat and water become increasingly important, leading to errors in fat quantification, due to an averaging effect. For our phantom, relative differences in R_2^* between fat and water increase at higher iron concentration, possibly due to a preferential effect of the iron on water. It is unknown whether iron overload *in vivo* will have the same effect.

Currently, our proposed dual T_2^* method becomes ill-conditioned at low (high) fat fractions when there is very little signal from fat (water). This occurs because very low fat signal observed at the sample times could occur either from the absence of fat or from extremely short T_2^* values of fat. In these cases, the single T_2^* model may be a better signal model. Future work will focus on regularization methods for smooth transition between the two models at low (high) fat-fractions. Adding an additional degree of freedom increases the signal model complexity, and is expected to degrade noise performance, and may introduce instabilities into the estimation. Future work will optimize the noise performance and investigate the performance of this method for *in vivo* applications.

References: [1] Yu et al, JMRI 2007;26(4):1153-1161. [2] Bydder et al, MRI 2008;26(3):347-359. [3] Liu et al, MRM 2007;58(2):354-364. [4] Yu et al, MRM 2008;60(5):1122-1134. [5] Wood et al, Blood, 2005 106(4):1460- 65. [6] Bernard et al, JMRI 2008;27(1):192-197. [7] Yu et al, MRM 2005;54:1032–1039.

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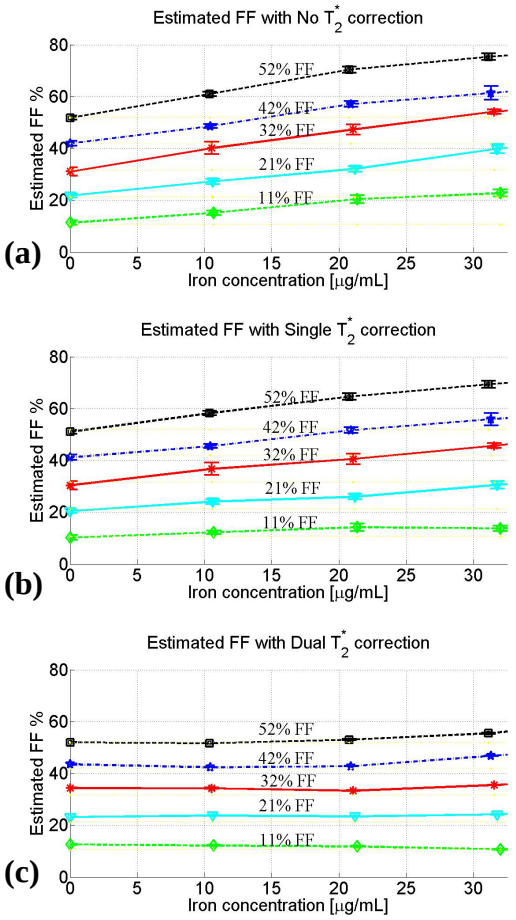

Figure 1: *Estimated fat-fractions at different true fat-fractions and at different iron concentrations. Progressive improvement in estimation is observed when using models with no T_2* correction (a), to single T_2* correction (b) and with dual T_2* correction (c). More accurate estimation of fat-fraction, particularly at higher iron concentrations is achieved using dual T_2* correction method.*

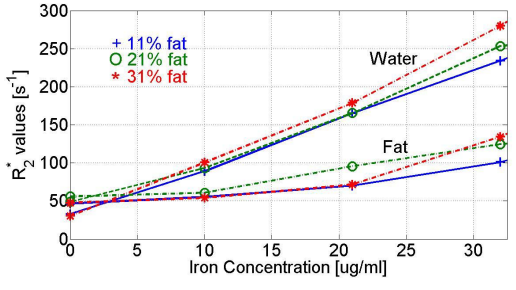

Figure 2: *R_2^* values of water and fat at different iron concentrations and at different true fat-fractions. It can be observed that R_2^* values of water and fat are significantly different at higher iron concentrations for this phantom. Differences in the $R_2^*$of water and fat explains the better performance of dual T_2^* method at high iron concentrations.*