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 T2* decay5,6, T1 bias7, and the multiple spectral peaks of fat8,9. Typical values of liver T2* range from 25-30 ms in normal livers to less than 5 ms in patients with hepatic iron overload10. Past work on T2* correction has assumed a common T2* for water and fat or a fixed difference between water and fat T2* values2. The purpose of this work is to loosen these assumptions to allow estimation of independent T2* decay for water and fat. Using this “dual T2*” 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 T2* decay can be written as: S(t) = (W exp(- R_w t) + F exp(- R_f t)) / (R_w + R_f) [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 R2 of water and R_f is the R2 of fat, ω0 is the resonance frequency of the p^9 fat peak, r_j are the relative proportions of the different fat peaks such that ∑ r_j = 1.

R2 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 T2*–IDEAL method with accurate spectral modeling of multiple peaks of fat. An appropriate initial guess for W, F, R_w, R_f, 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 T2*–IDEAL was used. 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 al12, where agar was supplemented for carageenan, 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: TR = 1.4 ms, TE= 1.6 ms, 6 echoes per TR, and TR = 42.7 ms, with flip = 5° to minimize T1 bias13. 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 T2* decay for water and fat: (a) no T2* decay correction, (b) T2* correction assuming common T2* for water and fat (ref Yu), and (c) T2* correction with the proposed dual T2* method. For iron concentrations less than 32 µg/mL, errors in estimated % fat-fractions reduce from 30% with no T2* correction to 25% with single T2* correction to less than 5% with dual T2* correction.

Figure 2 shows the independently estimated R2 values of water and fat at different iron concentrations using the dual T2* method. The results for R2* show that the R2* of water is similar to the R2* of fat for iron concentrations below 5 µg/mL and that the R2* of water is significantly greater than the R2* of fat for iron concentrations above 5 µg/mL. Our results show that iron affects R2 of water more than the R2* of fat, for this phantom, and underscore the need for a dual T2* 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 R2 between fat and water become increasingly important, leading to errors in fat quantification, due to an averaging effect. For our phantom, relative differences in R2 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 T2* 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 time farthest from the absence of fat or from extremely short T2* values of fat. In these cases, the single T2* 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.


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