IDEAL Water-Fat Separation with Simultaneous T2* Estimation

H. Yu[1], C. A. McKenzie[2], A. Shimakawa[1], N. J. Pelc[3], J. H. Brittain[4], S. B. Reeder[5]

[1]Global Applied Science Laboratory, GE Healthcare, Menlo Park, CA, United States, [2]Department of Radiology, Beth Israel-Deaconess Medical Center and Harvard Medical School, Boston, MA, United States, [3]Departments of Radiology and Bioengineering, Stanford University, Stanford, CA, United States, [4]Global Applied Science Laboratory, GE Healthcare, Madison, WI, United States, [5]Departments of Radiology and Medical Physics, University of Wisconsin, Madison, WI, United States

Introduction Three-point chemical-shift based water-fat decomposition methods utilizes images with different water-fat phase shifts to achieve reliable water-fat separation. Historically, it has been assumed that T2* decay results in negligible signal changes between the three echoes. This assumption is valid for most applications, with the echo times typically used for gradient-echo sequences less than 10ms at 1.5 T. However, T2* may be shortened for applications such as liver imaging in patients with hemochromatosis or hemosiderosis where iron deposition may reduce T2* to as little as 2-3 ms [1]. Liver imaging is an important application where both water-fat separation (to evaluate fatty infiltration) and T2* estimation (to evaluate iron deposition) are essential for accurate diagnoses. However, rapid T2* decay may lead to incorrect water-fat decomposition using standard chemical-shift reconstruction methods, and the phase shift from the fat component may also disturb T2* relaxometry if the presence of fat is not known. In this work, we propose an algorithm to achieve water-fat separation and T2* estimation simultaneously based on the 3-pt IDEAL (**I**terative **D**ecomposition of water and fat with **E**cho **A**symmetry and **L**east-squares estimation) method [3,4]. Furthermore, the signal intensities of the decomposed water and fat images are recovered from the T2* effect. This T2*-IDEAL technique has potential applications in liver imaging for quantification of both fatty infiltration and iron deposition.

Theory In the presence of iron deposition, we assume the T2* effect is dominated by iron and as a result, water and fat will have the same T2*. The signals (S_i) for each pixel at the three echo times (t_i, $i=1, 2, 3$) can be represented as:

$$S_i = \left(W + F\cdot e^{j2\pi\Delta f\, t_i}\right)\cdot e^{j2\pi\psi t_i}\cdot e^{-R_2^* t_i} = \left(W + F\cdot e^{j2\pi\Delta f\, t_i}\right)\cdot e^{j2\pi(\psi + jR_2^*/2\pi)t_i} = \left(W + F\cdot e^{j2\pi\Delta f\, t_i}\right)\cdot e^{j2\pi\hat{\psi} t_i}$$

where W and F denote the water and the fat components in this pixel, respectively. Δf is the chemical shift of fat with respect to water. ψ represents the Bo field inhomogeneity at this pixel. We have used R2* (= 1/T2*) for convenience. As can be seen, with the "complex field map" $\hat{\psi} = \psi + jR_2^*/2\pi$, the above equation is similar to the IDEAL signal model [2], and a simple modification to the IDEAL reconstruction can be used. The R2* map is simply determined from the imaginary part of $\hat{\psi}$, which is estimated iteratively [2]. The source signals then are demodulated by $\hat{\psi}$, correcting for both B_0 field inhomogeneity and T2* decay, and final water-fat decomposition is achieved with a linear least squares inversion [2].

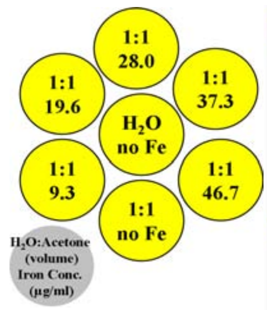

Figure 1: (above) composition of the phantom tubes

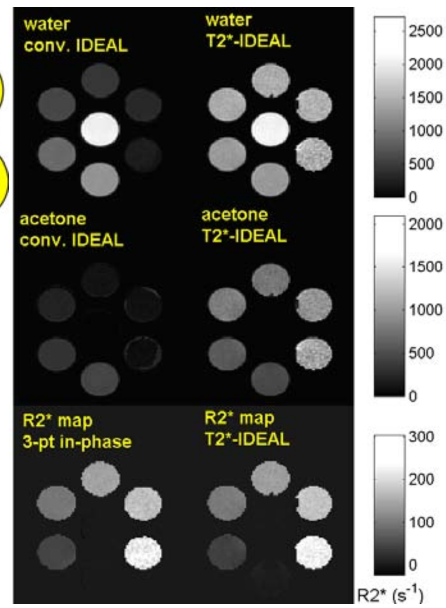

Figure 2: (right) water and acetone images reconstructed from the conventional IDEAL and T2*-IDEAL methods. R2* maps estimated from in-phase signals and T2*-IDEAL.

Methods Phantom studies were performed to demonstrate the T2*-IDEAL algorithm. Acetone was used as an alternative for fat as it mixes well with water. The chemical shift of acetone was measured by spectroscopy and determined to be -155 Hz at 1.5 Tesla. Water and acetone were mixed in six 50ml tubes, which were then doped with varying concentrations of Feridex IV®(Berlex Laboratories, Wayne, NJ USA), a ferumoxide contrast agent that shortens T2*. The composition of the phantom tubes is illustrated in Fig. 1. A 2D SPGR IDEAL sequence was used, with echo times t_i = [3.8 8.2 12.5] ms, corresponding to phase differences between acetone and water of [5π/2 - 4π/3, 5π/2, 5π/2 + 4π/3] selected to achieve optimal IDEAL SNR performance [3]. The acquired data were processed with both the T2*-IDEAL algorithm and the conventional IDEAL method. The phantom was also imaged at three echo times such that water and acetone were in-phase (i.e. [2π, 4π, 6π], t_i = [6.5 13.1, 19.6] ms) in order to measure R2* independently, achieved by fitting the signal intensities to a single exponential. Comparison between the R2* maps obtained from the two approaches was made. R2* was not calculated for the background pixels, as determined by thresholding.

Results Figure 2 shows the separated water and acetone images from the conventional IDEAL and the proposed T2*-IDEAL reconstructions. At higher iron concentrations with shorter T2*, the signal decay was incorrectly propagated into the decomposed water and acetone images in the conventional IDEAL reconstruction In contrast, the original signal intensities (at echo time 0) were recovered by the T2*-IDEAL reconstruction. Furthermore, the T2*-IDEAL method provided accurate estimates of the R2* map, which were in close agreement the in-phase R2* measurements. Figure 3 plots R2* calculated from the T2*-IDEAL method and the in-phase signals against the iron concentration. Mean values from each tube were used (error bars indicate standard deviation). A linear relation is evident, in close agreement with previous measurements of R2* [1,4]. Close agreement between the two approaches suggests high confidence of the R2* estimated using the T2*-IDEAL method. In a separate experiment performed on a water-only phantom doped with Feridex (T2*~10ms), approximately 20% of the signal intensity occurred in the acetone image when reconstructed by the conventional IDEAL method. However, the phantom was correctly identified as water-only by the T2*-IDEAL reconstruction.

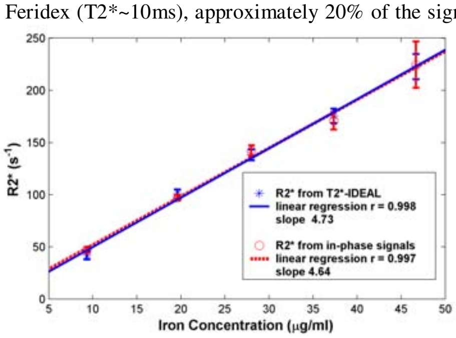

Figure 3: Plots of R2* estimated from T2*-IDEAL and the 3-pt in-phase signals against iron concentration. Error bars represent standard deviation.

Discussion and Conclusion Using conventional methods, it can be difficult to accurately separate water and fat in the presence of shortened T2* or to estimate T2* in the presence of multiple chemical species due to their interference with one another. The T2*-IDEAL method is capable of decoupling and estimating different parameters simultaneously. Our studies successfully estimated T2* values from approximately 4.5ms to 24ms using echo times ranging from 3.8ms to 12.5ms. Intuitively, echo times should be comparable to the T2* value for the best estimation of T2*. Our experience shows that even though the calculated T2* may be noisy at large values (T2* ~ 1000ms), water and fat can still be separated correctly. In the short T2* regime (e.g. T2* < 1ms), decomposition may be difficult due to the low SNR at the IDEAL echo times. The noise performance of the new algorithm requires further study. In conclusion, we have proposed an algorithm that can achieve chemical species separation and T2* quantification simultaneously, extending the scope of applications for water-fat separation methods such as IDEAL. Particularly, it is a promising technique for quantitative assessment of patients with conditions such as hemochromatosis and fatty infiltration of the liver.

Acknowledgement NIH grants RR09784, EB00198, the Lucas Foundation, Dr. Yi-Fen Yen, Dr. Dirk Mayer

References
[1]. St Pierre et al, NMR Biomed, 2004;17:446-458 [2]. Reeder et al, MRM. 2004;51:35-45.
[3]. Reeder et al, MRM. 2005; 54:636-44. [4]. Dahnke et al, MRM. 2005; 53:1202-1206.