Multi-Echo IDEAL/T2*-IDEAL Liver Imaging: Simultaneous Assessment of Fatty Infiltration and Iron Overload in a Single Breath-hold

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Introduction MRI is becoming increasingly important in the characterization of chronic liver diseases. Hepatic steatosis, or fatty infiltration of the liver, is typically evaluated using in-phase and out-of-phase imaging [1]. T2* weighted sequences have excellent sensitivity to the presence of hepatic iron overload [2], as the excessive concentration of iron significantly reduces T2* in the liver. It is not uncommon that both fat and iron are present in the livers of patients with steatosis. One study has found 31% of patients with steatosis have the HFE hemochromatosis mutation [3]. To remove their confounding effects, conventional methods require careful design of imaging parameters, often leading to limitations in sequence flexibility or multiple breath-holds. We have recently introduced a novel reconstruction algorithm, referred to as T2*-IDEAL, that achieves simultaneous estimation of water, fat and T2* [4], based on the IDEAL water-fat decomposition technique ("classic" IDEAL) [5]. The technique de-couples the effects of chemical shift differences and T2*, thereby allowing accurate estimation of both fat content and T2* value. This work proposes a combined classic IDEAL/T2*-IDEAL reconstruction approach to generate high SNR water and fat images as well as quantitatively accurate R2* and fat-signal fraction images from one dataset. An optimized acquisition strategy is proposed based on noise performance studies and other practical considerations and are designed to create a liver imaging technique that can assess both fatty infiltration and iron overload in a single breath-hold.

Theory During T2*-IDEAL reconstruction, an R2* (=1/T2*) map, together with a field inhomogeneity map, are estimated iteratively similar to classic IDEAL [4]. The water and fat images are then calculated from the source images after correction for R2* and field inhomogeneities. Acquiring more than three echoes improves the R2* estimation. We found that acquiring 6 echoes achieves a good balance between short scan time and improved R2* estimation. The noise performance of a decomposition method can be quantified by NSA (Number of Signal Averages), defined as the noise variance in the source images divided by the noise variance in the decomposed images, and calculated using the Cramer-Rao bound (CRB) theory [6]. The theoretical NSA values of the water image for six equally spaced echoes are shown in Figure 1. For classic IDEAL (Fig. 1a), all echo times within the marked box achieve the optimal or near optimal NSA values (~6). Therefore, unlike 3-pt Dixon and IDEAL methods, echo times for 6-pt classic IDEAL are flexible and can be selected based on considerations other than NSA. The NSA values of the T2*-IDEAL model shown in Fig. 1b are lower than classic IDEAL due to the additional degree of freedom (T2*) and the correction for T2* decay, which exponentially magnifies the noise in the source images. It can be seen that a short TE_1 is favored to improve the noise performance and NSA is less sensitive to the change of ΔTE when water-fat phase shift is between 0.4π and 1.6π. Within these limits, the minimum echo times (minimum TE_1 and ΔTE) can be used. Acquired data can be reconstructed with both classic IDEAL and T2*-IDEAL algorithms. Classic IDEAL provides high SNR water and fat images, while T2*-IDEAL offers R2* images and more quantitatively accurate water and fat results. Furthermore, to account for differing noise variance in the T2* corrected source images, weighted least squares inversion is used when decomposing water and fat. Monte Carlo simulations demonstrate that the CRB bound for the water and fat estimates is achieved with the weighted least squares inversion, and therefore T2*-IDEAL is maximally SNR efficient.

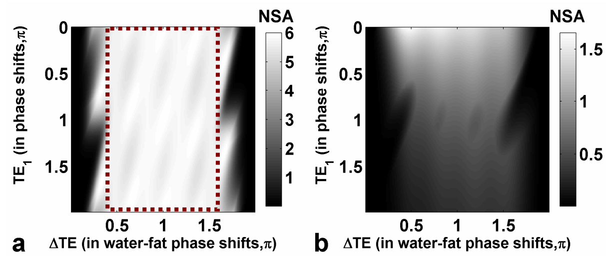

Figure 1: Water NSA maps for 6-echo classic IDEAL (a) and T2*-IDEAL (b). TE_1 and ΔTE are in the format of the water-fat phase shift (i.e. $2\pi \bullet TE \bullet \Delta f$, Δf is the chemical shift). Six-echo classic IDEAL achieves NSA close to 6 with all echo times in the marked box. A true T2* of 20ms is used for T2*-IDEAL.

Methods Abdominal imaging was performed on 1.5T General Electric Signa® scanners (GE Healthcare, Waukesha, WI) on 10 healthy volunteers and 6 patients with chronic liver disease. All scanning was IRB approved and informed consent was obtained. Six echoes were acquired with a multi-echo SPGR sequence (all echoes acquired in one TR). The following imaging parameter ranges were used: TE_1=1.6ms to 2.8ms, ΔTE=1.8ms to 3.2ms, imaging matrices=224x128 (patient scans) and 384x256 (volunteer scans), bandwidths=±100kHz to ±167kHz. An efficient auto-calibrating parallel imaging technique [7] with reduction factor of 2 was used for high resolution volunteer scans. These imaging parameters lead to a single breath-hold between 22 and 33 seconds. Data were reconstructed using both classic IDEAL and T2*-IDEAL. Fat-signal fraction (fat/(water+fat)) images were calculated from the T2*-IDEAL method.

Results Representative results are presented in Figure 2, including those from a genetic hemochromatosis patient with iron overload (first column), a patient with fatty infiltration (second column) and an asymptomatic volunteer (third column). The R2* map (first row) and the fat-signal fraction images (second row), obtained from T2*-IDEAL reconstruction, may be useful for quantification studies. The mean T2* values in the indicated ROIs are 6ms, 25ms and 23ms respectively. The iron overload liver clearly shows an elevated R2* level, suggesting the presence of high iron concentration. The fat-signal fraction calculated in the ROI for the fatty liver patient is 30%, and is 3% for the other two studies, a non-zero value caused by noise bias in the magnitude fat images. The high quality, high SNR water images were generated using the classic IDEAL reconstruction (3rd row). As expected, the iron liver has low signal intensity because of the rapid T2* decay.

Discussion and Conclusion Fast and multidimensional tissue characterization can be achieved from the combined classic IDEAL/T2*-IDEAL processing. T2*-IDEAL produces the fat-signal fraction image and R2* map for quantitative assessment. Classic IDEAL provides high SNR water and fat images. Six echoes can be acquired with the minimum echo times, minimizing scan time while also maximizing NSA and T2* accuracy. Using more than six echoes achieves similar NSA behavior at the cost of lengthened scan time. Although the accuracy of the T2*-IDEAL technique requires further clinical validation, our initial results show that the combined classic IDEAL/T2*-IDEAL technique is promising for a comprehensive and quantitative assessment of liver for fatty infiltration and iron overload in a single breath-hold.

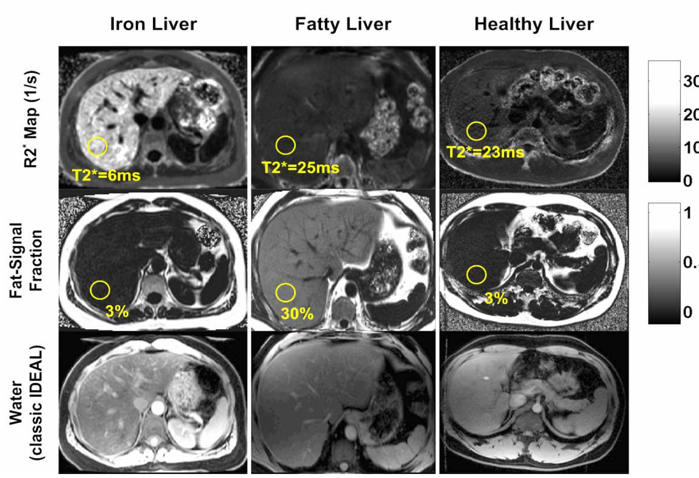

Figure 2: Representative images from a patient with hemochromatosis (first column), a patient with fatty liver (second column) and an asymptomatic volunteer (third column). The R2* maps (first row) and the fat-signal fraction images (second row) are obtained from T2*-IDEAL reconstruction, which demonstrate shortened T2* for the iron liver patient and 30% fat-signal fraction for the fatty liver patient. High SNR water images can be obtained from classic IDEAL reconstruction (third row).

References

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