Self-navigated IDEAL Water-Fat Separation

Y. Jiang[1], and J. Tsao[1]
[1]Global Imaging Group, Novartis Institutes For BioMedical Research, Cambridge, MA, United States

Introduction: IDEAL (Iterative Decomposition of water and fat with Echo Asymmetry and Least squares estimation) has proven to be a robust method to achieve uniform water-fat separation [1]. Recently, it has been adopted in quantitative analysis of adiposity as well [2]. However, the three-point acquisition prolongs the scan time, which leads to increased susceptibility to motion. The presence of motion causes artifacts and B_0 fluctuation. Motion artifacts are manifested as signal smearing and ghosting, which change signal intensities. For water-fat separation, motion could shift the water signal onto the fat signal and vice versa, thereby negatively affecting quantification accuracy. For example, respiratory artifacts could reach a mean intensity of 3.8 ± 1.0 % in the liver images [3]. Meanwhile, the normal hepatic fat fraction is only a few percent [4], so the artifact can easily be on the same order as the true signal. This poses a stringent requirement for suppressing motion artifacts, such that they are insignificant to interfere with the quantification. In addition, B_0 fluctuation due to motion affects the reliability of the field map estimation in IDEAL.

To overcome this challenge, we propose to use navigators. The basis of navigators is to acquire a region of *k*-space (typically the center) repeatedly to monitor the signal fluctuation caused by motion. In our study, the double echo sequence [5] was used as a self-gating method. The sequence collects the navigator by rewinding the readout gradient back through the center line of *k*-space. This has the advantages that it reuses the magnetization from the imaging readout, it does not increase echo time, and it does not increase the repetition time too much with modern gradient strength. However, the original double echo sequence acquires the navigator right after the image readout, which leads to different echo times for the navigators in the IDEAL sequence. We compensated for the different echo times by inserting different delays between the imaging readout and the navigator readout. This allows the navigators to be compared among the IDEAL echo times, which are interleaved to eliminate spatial misregistration.

Methods: The double gradient echo IDEAL pulse sequence [6] is illustrated in Fig. 1. TE_1, TE_2, and TE_3 represent three shortest echo times to achieve optimized SNR performance for the water-fat separation [7]. TE_{navi} is chosen as the shortest achievable echo time for the navigator echo. The pulse sequence was repeated multiple times during the acquisition, and off-line retrospective correction was applied to reduce motion artifacts.

Retrospective motion correction was performed by calculating the real part of the unnormalized cross-correlation between each navigator and the average navigator in the spatial domain, and rejecting data lines for cross-correlation values below the mean. All remaining data lines for each IDEAL echo time were averaged to increase the signal-to-noise ratio. Motion-corrected datasets were reconstructed by hierarchical IDEAL [8]. The reconstruction and motion correction were performed using a custom program in Matlab (The Mathworks, Natick, MA) that interacted with the scanner software.

The pulse sequence was implemented on a Bruker PharmaScan 4.7T MR scanner (Bruker Biospin, Ettlingen, Germany). Data were acquired with the following parameters: TEs = 2.79, 3.27, 3.76 ms, TE_{navi} = 6.76 ms, TR = 200 ms, flip angle = 20°, matrix size = 128×96, spatial resolution = 0.35 × 0.47 mm^2, slice thickness = 1.5 mm. The fat percentage map was calculated by dividing the fat-only image by the sum of the water- and fat-only images. To evaluate the performance of motion correction, a data set with 20 repetitions was acquired, and then different subsets of data (from 3 to 12 averages with 9 different combinations for each number of averages) were extracted and compared with the corresponding reconstruction with 20 averages by determining the root-mean-square (RMS) difference of the fat percentage within a liver ROI.

Results: Fig. 2 shows representative coronal hepatic fat percentage maps of a diet-induced obese (DIO) mouse from different number of averages with and without motion correction. Arrows point to the regions with significant fat percentage fluctuation in images without motion correction, which are not observed in the motion-corrected data. With motion correction, different averages generated similar fat maps, with the signal-to-noise ratio improving with more averages. Without motion correction, the fat map deviated at low number of averages, and finally converged at high number of averages to that observed with motion correction. Fig. 3 shows the pixel-wise fat percentage error (RMS ± standard deviation) over the selected ROI shown in Fig. 2. It can be seen that the fat percentage errors with and without motion correction reduced with increasing number of averages. The error with motion correction was smaller and reduced faster than the one without motion correction and the standard deviation of the error was also considerably tighter. For example, the error for 3 averages with motion correction was equivalent to the error of 8 averages without motion correction, indicating the improved accuracy.

Conclusion: In this work, we developed a self-gated IDEAL method for quantifying hepatic lipid contents. The use of motion correction led to a substantial reduction of motion artifacts, thereby improving the accuracy and robustness of the quantification.

References: [1] Reeder SB, et al. *MRM*, 51: 35 – 45. 2004. [2] Liu CY, et al. *MRM*, 58: 354 – 364. 2007. [3] Cassidy PJ, et al. *JMRI*, 19: 229 – 237. 2004. [4] Kim H, et al. *MRM*, 59: 521 – 527. 2008. [5] Spraggins T. *MRI*, 8: 675 – 681. 1990. [6] Reeder SB, et al. *JMRI* 25: 644 – 652. 2007. [7] Pineda AR, et al. *MRM*, 54: 625 – 635. 2005. [8] Tsao J, et al *ISMRM 2008* Abstract 653.

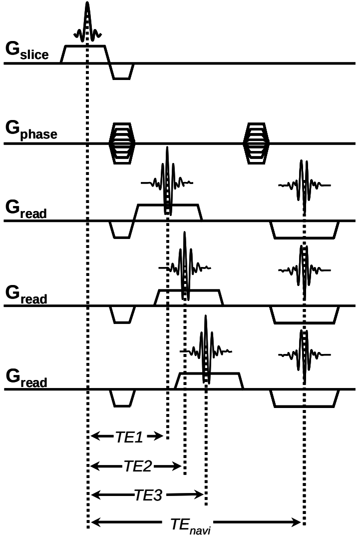

Fig. 1 A double-gradient echo navigator IDEAL pulse sequence.

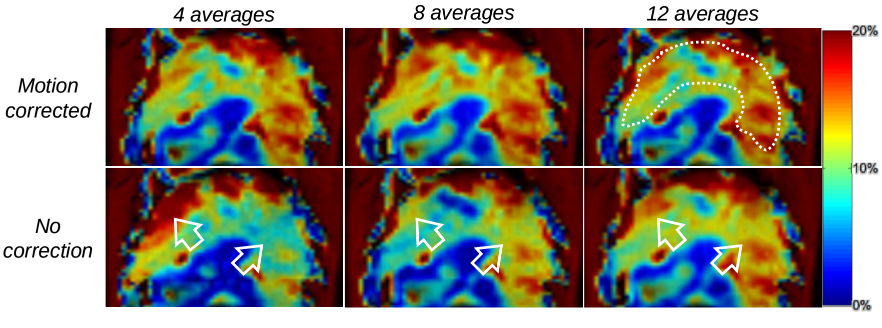

Fig. 2 Fat percentage map of a representative DIO mouse liver from 4, 8 and 12 averages with (top row) and without (bottom row) motion correction. Arrows indicate regions with significant fat percentage fluctuation without motion correction. The dotted line in the motion-corrected fat map with 12 averages indicates the ROI used to calculate the fat percentage error in Fig. 3

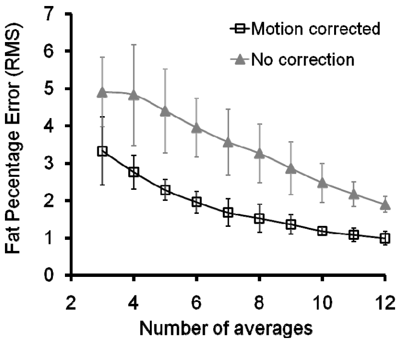

Fig.3 Fat percentage error (RMS±SD, n=9) for different number of averages with and without motion correction.