Rapid 3D-SPGR Imaging of the Liver with Multi-Echo IDEAL

S. B. Reeder[1,2], A. T. Vu[3], B. A. Hargreaves[4], A. Shimakawa[5], O. Wieben[1,2], C. A. McKenzie[6], J. A. Polzin[7], J. H. Brittain[8]

[1]Radiology, University of Wisconsin, Madison, WI, United States, [2]Medical Physics, University of Wisconsin, Madison, WI, United States, [3]MR/PSD Applications Engineering, GE Healthcare, Waukesha, WI, United States, [4]Radiology, Stanford University, Stanford, CA, United States, [5]Global Applied Science Lab, GE Healthcare, Menlo Park, CA, United States, [6]Radiology, Beth Israel Deaconess Medical Center, Boston, MA, United States, [7]MR Engineering, GE Healthcare, Waukesha, WI, United States, [8]Global Applied Science Lab, GE Healthcare, Madison, WI, United States

Introduction: Dynamic contrast enhanced imaging of the liver requires robust fat-suppression and complete volumetric liver coverage within a reasonable breath-hold interval. Few approaches have been able to achieve reasonable scans time with high quality fat-suppression. The IDEAL (Iterative Decomposition of water and fat with Echo Asymmetry and Least squares estimation) method is a three-echo, chemical shift based approach that provides uniform separation of water and fat, even in the presence of B_o and B_1 inhomogeneities [1,2,3]. However, IDEAL traditionally acquires one echo per TR increasing scan time three-fold. Previous work has demonstrated a spectroscopic imaging technique that acquires all echoes in a single TR utilizing a reconstruction similar to IDEAL [4]. In this study, we demonstrate a modified 3D-IDEAL-SPGR acquisition that gathers the three required echoes in a single TR, reducing acquisition time by a factor of three, improving the method's SNR efficiency, and enabling the use of IDEAL for breath-held abdominal imaging with robust water-fat separation.

Theory: IDEAL acquires three images at arbitrary echo times in order to decompose water from fat. Pineda *et al* demonstrated that echoes chosen with the water-fat phase of the middle echo in quadrature ($\pi/2+\pi k$, k=any integer) and the first and last echoes acquired $2\pi/3$ before and after the middle echo (ie: $-\pi/6+\pi k$, $\pi/2+\pi k$, $7\pi/6+\pi k$) provide the maximum possible SNR, with an effective signal averaging (NSA) of three [2]. This theoretical SNR performance has been verified experimentally [5].

The use of multi-echo IDEAL imaging is compelling; if SNR-optimal IDEAL echo shifts can be achieved, the acquisition of all three echoes would generate an *effective signal averaging of three within a single TR*. Although this approach requires higher bandwidths, (necessary to achieve the optimal echo spacing), the effective averaging of IDEAL offsets SNR reductions from high bandwidths. In fact, we propose the use of an "effective bandwidth", $BW_{eff} = BW/3$, as a useful measure to compare the SNR performance of multi-echo IDEAL to conventional imaging. In addition, the overall efficiency of multi-echo sequences increases, further improving SNR [6]. High SNR performance is critical if parallel imaging is also used.

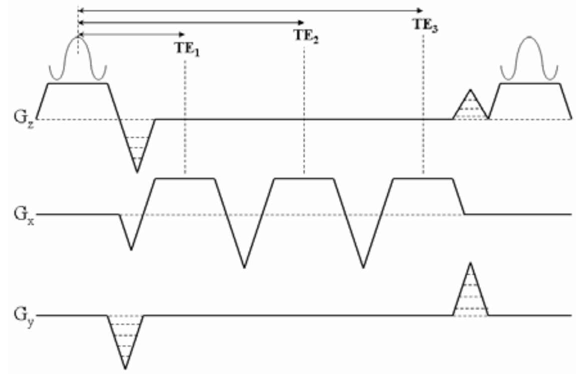

Fig 1: Schematic of the multi-echo IDEAL-SPGR pulse sequence. Three echoes are acquired using fly-back gradients. Echo times are chosen to maximize SNR performance.

Materials and Methods: A 3D-SPGR sequence using a multi-echo readout with "fly-back" rewinder gradients was implemented on a 1.5T GE Signa MR TwinSpeed scanner. Echo spacing was adjusted to match optimal echo combinations for IDEAL, and reconstruction was performed with an on-line algorithm. Fly-back gradients were used to ensure that echoes were sampled in the same direction in k-space to avoid alternation in the direction of chemical shift artifact in images acquired with different echo times, and to avoid problems with gradient timing delays.

Further scan time reduction was achieved with elliptical sampling in the k_y-k_z plane, to avoid sampling the "corners" of k-space, reducing scan time by 30% [7]. This sequence is also compatible with a SENSE-based parallel acceleration method (ASSET), which facilitates ≥50% or greater scan time reduction.

After obtaining approval from our IRB and obtaining informed consent, imaging was performed with the following parameters: FOV=35x26cm, Δz=6mm, 256x160x32 matrix, TR=9.6ms, TE=2.0/3.6/5.2ms, BW=±167kHz (BW_{eff}=±55.7kHz), total scan time=25s. Scan time was 12s with an ASSET acceleration of two. The on-line reconstruction provides separate water and fat images, and recombined "in-phase" and "out of phase" images.

Results: Uniform separation of water and fat was seen throughout the liver for all slices in all volunteers, and images had excellent image quality with high SNR. Figure 1 shows example images.

Discussion: Multi-echo IDEAL-SPGR imaging provides robust water-fat separation with volumetric coverage of the liver. The combination of multi-echo acquisition, elliptic sampling and modest parallel imaging acceleration factors permitted full coverage of the liver within a short breath-hold period. An increased bandwidth was required to sample three echoes at the optimal echo shifts. Although this decreases SNR, the effective averaging that occurs with IDEAL and the improved sequence efficiency more than compensates for the loss of SNR.

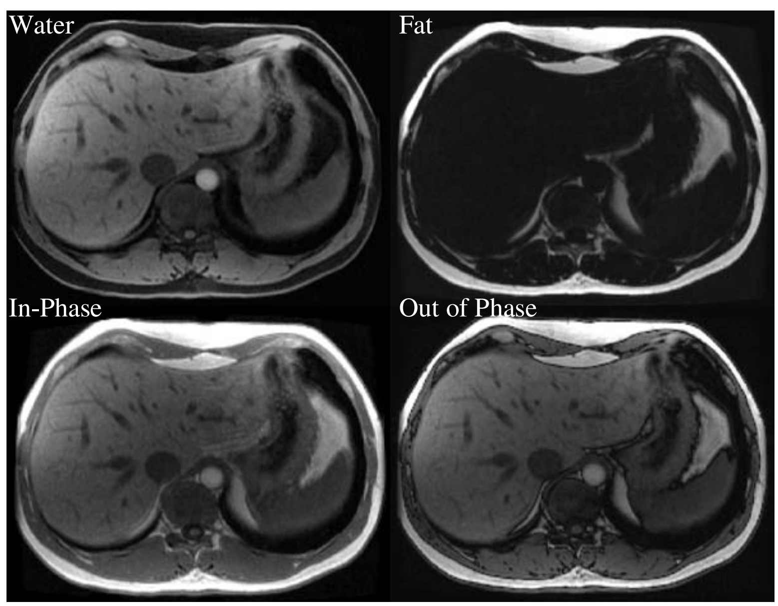

Figure 2: Multi-echo IDEAL-SPGR water, fat, and recombined in-phase and out of phase images. Excellent separation of water and fat was seen through all images, which covered the entire liver in a 25s breath-hold with no parallel acceleration.

Conclusions: Multi-Echo IDEAL-SPGR easily enables volumetric liver imaging with robust water-fat separation in a breath-hold.

References:

1. Reeder et al, MRM 2004 51(1):123-30, **2.** Pineda et al, MRM, 2005 54(3):625-35, **3.** Reeder et al, MRM 2005 54(3):636-44, **4.** Wieben et al, ISMRM 2005, p. 2386, **5.** Reeder et al, ISMRM 2005, p. 105, **6.** Parker et al, Med Phys 1990 17(2):250-7, **7.** Bernstein et al JMRI 2001 14(3):270-80