Effect of k-space Sampling Pattern on SNR in Parallel MRI Accelerated IDEAL Sequences.

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Introduction: Liver steatosis is an early indicator of several increasingly common liver diseases, including non-alcoholic fatty liver disease (NAFLD). In order to quantify fat non-invasively, the MRI signal from liver tissue water and fat must be separated using a technique like Iterative Decomposition of water and fat with Echo Asymmetry and Least-squares estimation (IDEAL) [1]. Like all abdominal imaging acquisitions that are breath-hold limited, the use of parallel imaging with IDEAL is advantageous to improve spatial resolution and/or regions of coverage within a 20s breath-hold. Parallel MRI in the abdomen is generally done with self-calibrated approaches to avoid error from motion induced sensitivity mis-calibration. It has been previously shown that the sensitivity data may be acquired from only one of the IDEAL images [2] and that the level of parallel MRI acceleration may vary between each of the IDEAL source images. Early detection of disease requires measurement of small hepatic fat fractions, so it is crucial to minimize the signal-to-noise ratio (SNR) penalty of parallel MRI. Noise amplification due to g-factor is thought to increase as the k-space sampling becomes less uniform; therefore, we hypothesized that if the total acceleration is held constant, the final water and fat SNR images will be maximized when there is the least difference in k-space sampling between the IDEAL echoes. We also considered the possibility that the SNR of the IDEAL reconstruction may vary depending on which of the three echoes was used for self calibration and thus had higher SNR since previous work [3] had shown that the echo with water and fat in quadrature was particularly important to the SNR of the final IDEAL reconstruction.

Methods: Fully gradient encoded datasets were collected from phantoms containing various fat-water mixtures (0%-100% fat) using a 3D T1 weighted IDEAL spoiled gradient echo sequence [4], (TR = 7.4 ms, TE = 2.0/3.6/5.2 ms, one echo/TR, FOV=20cm, 4mm thick slice, 256x 256x12, acquisition time 69s) using an 8 coil head array on 1.5T Signa MRI (GE Healthcare, Waukesha, WI). The datasets were sub-sampled so that the overall acceleration factor was held constant at two (or 384 phase encode lines) and one of the IDEAL echoes contained the fully sampled 32 central lines of k-space necessary for sensitivity calibration. The datasets were sub-sampled to simulate acceleration factors of 2, 3 and 4 in the non-calibration echoes, while the calibration echo external acceleration factors (C_{AF}) of 2.33, 1.25 and 1 (fully sampled) were used respectively to maintain an overall acceleration factor of 2. Images were reconstructed using a generalized parallel MRI reconstruction [5] followed by an investigational version of the IDEAL reconstruction to produce water-only and fat-only images. Per-voxel SNR maps of the images were determined with a pseudo multiple replica technique [6]. This process was repeated for each of the above patterns and with calibration data added to each of the three echoes, for a total of nine experiments.

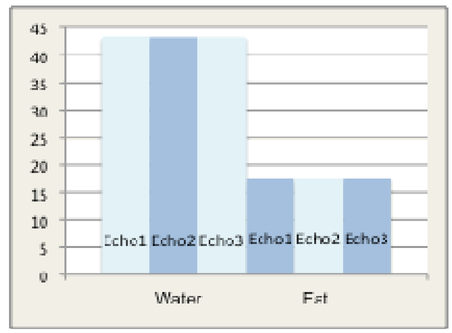

Figure 1: Mean Water and Fat SNR of ROI's in phantoms with varying Water/Fat mixtures with calibration phase encode lines in Echo 1 (TE = 2.0 ms), Echo 2 (TE = 3.6 ms) and Echo 3 (TE = 5.2 ms).

Results: Figure 1 shows the mean water and fat SNR for Regions of Interest (ROIs) in various fat-water phantoms when the phase encode calibration lines are added to each echo for C_{AF}=1. Clearly there is no SNR dependency on echo calibration selection. Equivalent results were found for C_{AF}=1.25 and 2.33. Figure 2 compares the SNR maps of phantom water and fat images from the three different k-space sampling patterns with an overall acceleration factor of two (echo 1 was always the calibration echo). It can be seen that there is considerable SNR variation and the k-space sampling pattern with a non-calibration echo acceleration factor of 2 and a calibration echo external acceleration factor of 2.33 shows the highest SNR of the patterns tested with a mean SNR of 76.0. This is roughly 40% greater than the SNR from the most non-uniform k-space sampling (C_{AF}=1). This suggests that a near-uniform k-space sampling will result in higher SNR. Equivalent results were obtained from the fat images.

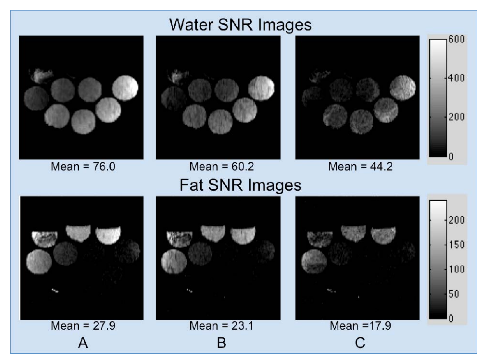

Figure 2: Phantom comparison of SNR:
A) C_{AF} = 2.33, Water/Fat mean SNR = 76.0/27.9
B) C_{AF} = 1.25, Water/Fat mean SNR = 60.2/23.1
C) C_{AF} = 1.00. Water/Fat mean SNR = 44.2/17.9

Discussion: These results demonstrate that the variation in SNR due to calibration echo selection is negligible, implying that the calibration echo can be chosen freely without concern about SNR degradation. This may result in an important degree of freedom in sequence design, allowing the calibration echo to be chosen to account for other issues like eddy currents.

However, the large variation in SNR due to different choices in k-space trajectory design suggests that care must be taken to select the most SNR efficient k-space sampling pattern. It is interesting to note that the sampling pattern with the highest SNR in the calibration echo actually yielded the worst final SNR, while the sampling with the most even distribution of k-space lines between echoes gave the best final SNR. These effects are expected to be even more pronounced when using arrays with large numbers of elements (32+) and the large multidimensional acceleration factors such arrays make possible.

Memory limitations in the SNR calculation software forced the use of smaller numbers of 3D slices than would typically be used in vivo, making it infeasible to investigate the effects of parallel MRI acceleration in two dimensions. More efficient versions of the SNR calculation software are being developed so that larger data sets can be used to investigate the effects of higher acceleration factors and two dimensional accelerations. Future investigations will use truly accelerated data which will allow imaging of the liver. These tests will look at determining the k-space sampling pattern that will maximize the SNR of the image while still allowing self-calibration.

Conclusion: These results demonstrate that there is no variation in SNR due to calibration echo selection, but that the choice of k-space sampling can cause as much as 40% variations in SNR even when the total acceleration is unchanged.

References: 1. Reeder et al. MRM 2004 51:35-45. 2. McKenzie et al, Proc ISMRM 2004 p917. 3. Yu et al, MRM 2006 55: 413-422. 4. Reeder et al. JMRI 2007 25:644-652. 5. Sodickson et al. Med. Phys. 2002 28 (8): 1629-43. 6. Robson et al. MRM 2008 60:895-907.

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