Quantification of Noise Efficiency with T_1 corrected IDEAL Spoiled Gradient Echo Imaging

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Introduction:

Non-invasive quantification of hepatic steatosis would be advantageous for early detection and quantitative grading of non-alcoholic fatty liver diseases (NAFLD). Iterative Decomposition of water and fat with Echo Asymmetry and Least-squares estimation (IDEAL) with spoiled gradient echo (SPGR) imaging provides a robust method of separating fat and water which is insensitive to B_o and B_1 inhomogeneities. IDEAL-SPGR has been shown to accurately quantify the fat mass fraction in an image pixel if T_1 bias has been corrected [1]. The difference in T_1 between fat and water causes the fat signal fraction estimated from IDEAL-SPGR to deviate from the actual fat fraction. Two methods were demonstrated by Liu et al [1] to reduce this T_1 bias. The small flip angle method uses a small, single flip angle to minimize (but not eliminate) T_1 bias by minimizing T_1 weighting, at the expense of reduced SNR due to the small flip angle. The dual-flip angle method uses two consecutive acquisitions with different flip angles, to calculate proton density images that are corrected for T_1. This method yields more accurate results at the cost of increased scan time.

In this work the dual-flip angle method was generalized to a multi-flip angle method where 2, 3, 4 or 5 flip angles are used. Applications involving measurement of liver fat fraction maps require imaging to be completed within one breath-hold, so if additional flip angles are to be collected the scan time for each must be reduced through a technique like parallel imaging. While the use of additional flip angles in the multi-flip angle method increases SNR, the necessary reduction in acquisition time decreases SNR. In this case, the parameter of interest is the noise efficiency (noise/unit time) of the reconstructed fat fraction map. In this work the noise efficiency of fat fraction measurements using the multi-flip angle method is examined and compared to the single flip method.

Methods:

Experiments were performed on six fat-water phantoms of varying concentrations of peanut oil (0%, 5.0%, 7.5%, 10%, 25%, 50%). The water solution also contained 0.2mM manganese(II) chloride tetrahydrate, 2% w/v agarose, and 43mM sodium dodecyl sulfate (surfactant). Mixing was achieved using a sonicator. Phantoms were imaged at 1.5T (Signa HDx TwinSpeed, GE Healthcare, Waukesha, WI) with an investigational version of the IDEAL-SPGR sequence at various flip angles. Flip angles sets were chosen to minimize the noise in a T_1 measurement of fat assuming T_{1fat}=343ms [2,3]. A flip angle of 5° was used for the single small flip angle method. Flip angle sets for the multiple flip angle approach were: [5°,29°]; [5°, 12°, 29°]; [5°, 10°, 16°, 29°]; and [5°, 8°, 12°, 18°, 29°]. Imaging parameters were: TR=8.0ms, TE=[2.0, 3.6, 5.2]ms, N_x=256, N_y=256, FOV=24cm, and slice thickness=6mm. Fat and water images were reconstructed using an online research implementation of the IDEAL algorithm [4]. Using DESPOT on the separated fat and water images at the N flip angles produced proton density and T_1 maps for both fat and water. A fat-fraction image was calculated from the corrected water and fat images. The fat-fraction mean and standard deviation (noise) of each phantom was calculated from a circular ROI (area in pixels) drawn within each phantom on the fat-fraction map. This noise was normalized for acquisition time by multiplying the noise by the square root of the number of flip angles used.

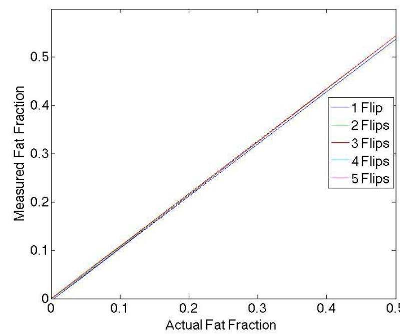

Figure 1: Correlation between measured and actual fat fraction of fat-water phantoms.

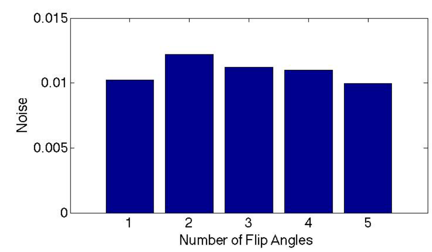

Figure 2: Mean noise of fat-water phantoms for single and multi-flip angle methods.

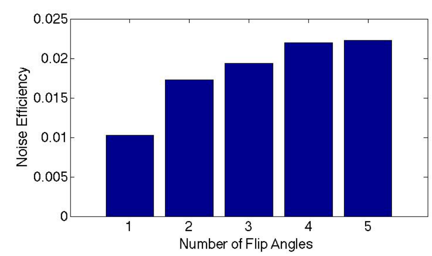

Figure 3: Mean noise normalized by acquisition time of fat-water phantoms for single and multi-flip angle methods

Results:

Figure 1 shows the measured and actual fat-fractions using either the single (1 flip) or multi (2,3,4 or 5 flips) flip methods. Figure 2 shows the fat fraction noise for the single flip angle and multi-flip angle methods. Noise increased when increasing from 1 to 2 flips and decreases as the number of flip angles used increases. Figure 3 plots the noise per unit time using either the single or multi-flip methods. T_1 measurements of fat and water yielded T_{1f}=371±6ms and T_{1w}=663±19ms, respectively. The maximum noise bias in the single flip method is 3%.

Discussion:

Both the single and multi-flip angle methods gave equally accurate estimates of the fat fraction (Figure 1). Experimental measurements of the noise performance normalized to account for acquisition time showed that the single flip angle technique is the most efficient when acquisition time is considered (Figure 3). In practice, it would be necessary to use parallel imaging acceleration to keep scan time within a single breath hold when adding additional flip angle acquisitions. In addition, the acquisition time normalization does not account for g-factor effects (ie. g-factor is assumed to be one), providing a best-case scenario of the noise observed after acceleration using parallel imaging. In practice, the noise seen in the multi-flip methods would be even higher after acceleration of acquisition time using parallel imaging particularly in cases when high numbers of flip angles, and therefore high parallel imaging acceleration factors, are used.

The lower SNR performance of the multi-flip angle method is due in part to the noise amplification that results from using DESPOT to fit values for T_1 and proton density to the data. This explains the increase in noise in figure 2 when going from one flip angle (no DESPOT fit) to two (DESPOT fit required). As more flip angles are added to the fit, the noise in the estimate of proton density is reduced but not enough to offset the loss in noise efficiency.

Conclusion:

The single flip angle method provides the best noise efficiency (i.e. the lowest noise per unit scan time) making it the best option for fat fraction measurement, particularly when there are significant restraints on acquisition time.

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