Noise weighted T_2*-IDEAL Reconstruction for Non-uniformly Under-Sampled *k*-space Acquisitions

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Introduction: Non-invasive quantification of hepatic steatosis would be advantageous for early detection and grading of non-alcoholic fatty liver disease (NAFLD). T2* corrected Iterative Decomposition of water and fat with Echo Asymmetry and Least-squares estimation (T_2*-IDEAL) with spoiled gradient echo (SPGR) imaging provides accurate liver fat fraction quantification using MRS as a reference standard [1-3]. Achieving full liver coverage with T_2*-IDEAL in a single breath hold (~20s) requires the use of self-calibrated parallel MRI.

Prior work has shown that the *k*-space undersampling pattern and/or the acceleration factors of each IDEAL echo image can differ and that the coil sensitivity calibration can be determined from only one of those images [4]. Using different undersampling patterns for the non-calibration and calibration echoes has been shown to improve SNR by up to 40% [5]. The different acceleration factors and *k*-space undersampling patterns result in different noise enhancement (as described by the g-factor) in the non-calibration and calibration echoes. Previously, the T_2*-IDEAL reconstruction assumed that each echo had identical noise enhancement. Since this assumption is no longer valid, T_2*-IDEAL reconstructions of images with varying noise will have sub-optimal SNR performance. In this work we modify T_2*-IDEAL reconstructions to include noise weighting and demonstrate that SNR improves with the modified reconstruction.

Theory: After T_2* correction, the noise in each echo image is no longer equal. Thus, T_2*-IDEAL uses a T_2*-weighted least-squares fit [3]. An additional weighting factor of $1/(g_i(\mathbf{r})R_i^{1/2})$ (where **r** is the spatial position and *R* is the acceleration factor for the i^{th} echo) was added to the T_2*-weighting to correct for the echo dependent noise amplification caused by sampling the non-calibration and calibration echoes differently.

Methods: A fully encoded dataset was acquired from phantoms [5] of varying concentrations of fat and iron (0-100% fat, 0-50µg/mL iron) using an investigational version of the IDEAL-SPGR sequence and a 32 element abdominal array at 3T (MR 750, GE Healthcare, Waukesha, WI). Imaging parameters were: TR=5.8 ms, 3 shots of 2 echoes/TR for 6 echoes with TE=[1.02, 1.56, 2.11, 2.65, 3.20, 3.74] ms, 224x120x54, slice thickness=7mm, FOV=42x36cm, and BW=143Hz.

The fully encoded dataset was sub-sampled in both phase encode directions using the sampling pattern proposed by Kisch et al [6]. The non-calibration echoes were undersampled with a uniform acceleration of 4 in both directions (R=15.4) and the calibration echo was undersampled at an acceleration of 4 in both directions plus fully sampling the center 24x24 phase encode lines (net R=6.8). The net acceleration for the entire IDEAL acquisition was 14.2. The images were reconstructed using a generalized encoding matrix (GEM) reconstruction [7]. SNR and noise maps of the fully-sampled and under-sampled datasets were estimated using the pseudo multiple replica method [8]. The noise maps were spatially smoothed using an averaging filter and then used in the noise weighted T_2*-IDEAL reconstruction. Water-only and fat-only images were produced with and without noise weighting and SNR maps of the resulting images were generated using method proposed by Kisch et al [8].

The sensitivity of the noise weighted IDEAL reconstructions to incorrect noise weighting was investigated. During iterations of the pseudo multiple replica method of a fully sampled image, the standard deviation of the noise was doubled for non-calibration echoes, thereby simulating a known noise difference. Water and fat images were reconstructed using incorrect noise estimates in the noise weighted T_2*-IDEAL reconstruction. SNR maps were generated using the method proposed by Kisch et al [6].

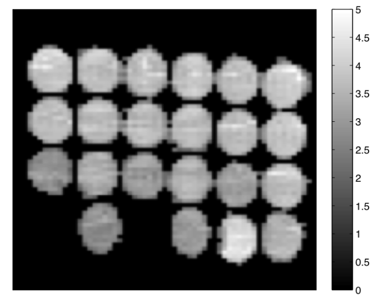

Figure 1: Logarithm of Water SNR map of noise weighted IDEAL reconstructions for an net acceleration of 14.2.

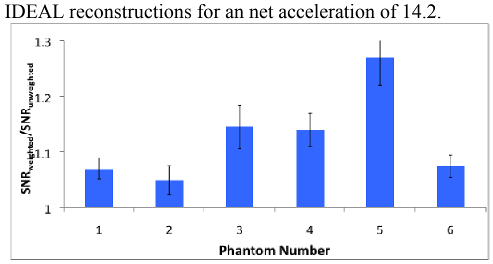

Figure 2: Relative water SNR of noise weighted and non-weighted IDEAL reconstructions of phantoms in third row of Figure 1.

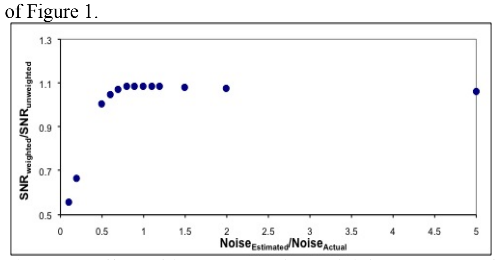

Figure 3: Effect of inaccurate noise weighting on SNR of noise weighted IDEAL reconstruction.

Results: Both non-weighted and noise weighted T_2*-IDEAL reconstructions gave the same fat fraction (fat/(water+fat)) measurements. SNR of water-only and fat-only images were calculated for both noise weighted and non-weighted IDEAL reconstruction at various acceleration factors. These results showed small increases in SNR due to noise weighting which increased as the acceleration factor increased. Figure 1 shows the logarithm of the water SNR of the noise weighted T_2*-IDEAL for a net acceleration of 14.2. Figure 2 shows the relative SNR of noise weighted over non-weighted IDEAL reconstructions of the third row of phantoms for the 14.2-fold accelerated data. A 11.9% increase in mean SNR for all phantoms and a maximum 27% increase in SNR over a single phantom. Similar increases in SNR were seen in the fat-only images. Figure 3 shows effect of inaccurate noise weighting on SNR by plotting the SNR gain due to weighting as a function of the factor by which the noise in the non-calibration was incorrectly estimated. Noise weighted IDEAL reconstructions are insensitive to overestimation of the ratio of the noise in the calibration echo to the noise in the non-calibration echoes. However, underestimation to the extent where the wrong echo is thought to be noise dominant will result in a SNR loss.

Discussion: The SNR gain from noise weighting increases with acceleration factor because the difference in g-factor between calibration and non-calibration echoes also increases. The SNR gains demonstrated here are modest, but come at no additional cost in terms of acquisition or reconstruction time and are in addition to the 40% increase in SNR obtained from using the sampling pattern proposed by Kisch et al [7]. Large SNR gains are located in the center of the image where the g-factor is large and the object of interest lies.

Conclusion: Including g-factor weighting in T_2*-IDEAL significantly improves SNR for self calibrated parallel MRI accelerated acquisitions.

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