Correction for fat improves robustness of R2* mapping without SNR penalty

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Introduction: R2* mapping using multi-echo gradient-echo sequences has multiple applications in MRI, such as the assessment of tissue iron overload. However, measurement of R2* is complicated by several confounding factors, including the presence of fat [1]. Fat introduces additional modulations in the acquired signal and results in large errors in R2* quantification if not corrected. This is particularly relevant in organs that often contain fat (e.g., liver, pancreas). The presence of fat can be partially addressed by using in-phase echoes, where the water and main methylene signals are in-phase or the echo spacing is one full cycle (~4.6 ms at 1.5T), or by suppressing the fat signal using chemical shift-based or T1-based (inversion-recovery) techniques. Alternatively, the presence of fat can be addressed by including fat-water separation in the R2* estimation (i.e., by acquiring chemical shift-encoded data without fat suppression, and performing fat-water separation and R2* measurement by postprocessing). This approach introduces fewer constraints in the acquisition parameters (eg. more favorable echo times), allows for modeling of the multi-peak fat signal, and provides water-only and fat-only images, which also have diagnostic value. However, it is unknown whether including the additional parameter (fat signal amplitude) in the R2* measurement compromises the SNR performance of R2* mapping due to the need to estimate more unknown variables from the same data. In this work, we evaluate the properties (robustness and noise) of fat-water corrected R2* mapping.

Methods: In order to demonstrate the need for fat correction in liver R2* mapping, chemical shift-encoded imaging 3.0T data (acquired in accordance with the local Institutional Review Board) from a subject with high liver fat (30% fat fraction) was retrospectively reconstructed, using both fat-uncorrected (single exponential model) and fat-corrected (using a multi-peak fat model with a common R2* for the water and fat components) R2* mapping methods. Data were acquired using a single breath-hold 3D multi-echo SPGR sequence with 6 echoes and two different protocols (see Figure 1). To characterize the SNR performance of R2* measurement (both fat-uncorrected and fat-corrected), the Cramer-Rao bound (CRB, the theoretical lower bound on the variance of any unbiased estimator) [2] for R2* measurement was calculated for typical echo times at 1.5T (6 echoes, TE1=1.2ms, ΔTE=2.0ms) and increasing values of R2* between 0 and 700 s^{-1}. Additionally, an iron phantom was constructed according to Ref. [3], using SPIO (Feridex, Bayer Inc., Wayne, NJ) concentrations of 0, 25, 50, 75 and 100 mg/l. The phantom was scanned at 1.5T using a 3D multi-echo SPGR sequence with 6 echoes (TE1=1.3ms, ΔTE=2.1ms). The phantom acquisition was repeated 16 times in order to measure noise behavior on a pixel-by-pixel basis, and R2* maps were calculated for each acquisition using both fat-uncorrected and fat-corrected methods.

Results: Figure 1 shows liver R2* results. Fat-uncorrected R2* measurements are protocol-dependent, whereas fat-corrected measurements provide very similar measures with different protocols, i.e., are more robust. Phantom R2* measurements (Figure 2, top) for the 6 vials were: (fat-uncorrected) 11.0±1.5, 146.1±3.8, 285.9±8.3, 430.4±18.0, 588.1±36.5 s^{-1}, (fat-corrected) 10.8±1.6, 146.2±3.8, 287.0±8.4, 433.4±17.9, 586.6±37.1. Figure 2 (bottom) plots the measured phantom and theoretical (CRB) standard deviations for fat-uncorrected and fat-corrected R2* mapping. There is effectively no SNR penalty for including fat in the measurement, for R2*<600s^{-1}. This is analogous to the ability to obtain effective number of signal averages N when performing fat-water separation from N (properly chosen) echo times [4]. For higher R2* values, there is a small increase in standard deviation for fat-corrected R2* (e.g., for R2*=1000s-1, fat-corrected measurements would result in 25% higher standard deviation).

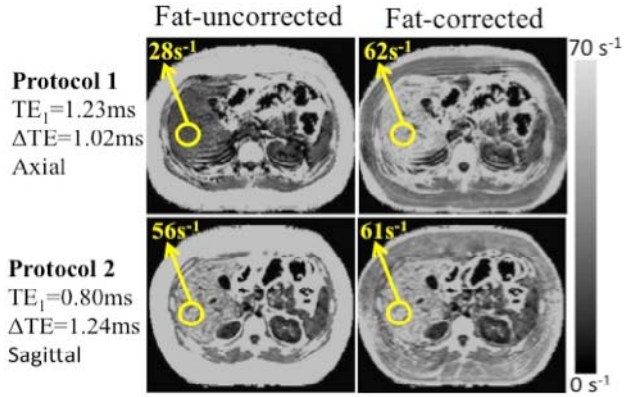

Figure 1. Correcting for the presence of fat is necessary for robust liver R2* mapping, as liver fat is very common (e.g., 33% of US population) and the presence of fat introduces additional modulations in the MR signal. The figure shows R2* measurements from two different protocols in a subject with high liver fat (30% fat fraction). Fat-uncorrected R2* measurements are heavily dependent on the echo time combination. Fat-corrected R2* provides similar measurements using different acquisition parameters.

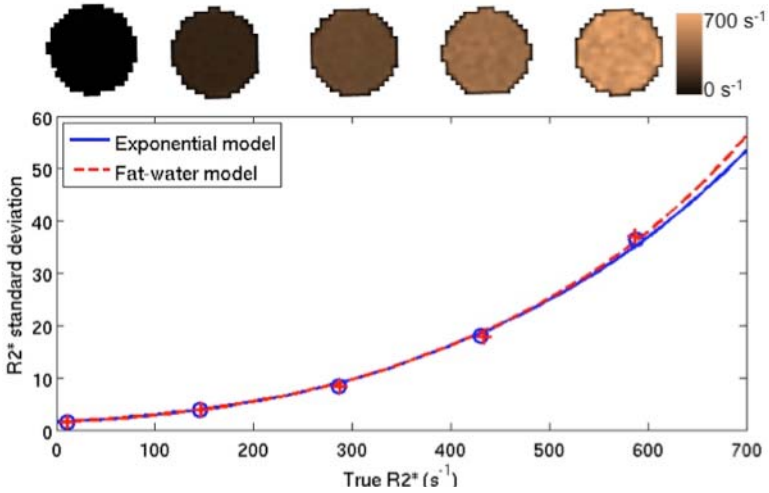

Figure 2. Including the presence of fat in R2* measurements does not result an SNR penalty over a large range of acquisition parameters and R2* values. (Top) Phantom R2* maps (fat-corrected) show increasing R2* with increasing iron concentration. (Bottom) Theoretical (CRB) and experimental (phantom) standard deviation in R2* measurements for increasing R2* (fat-uncorrected: O, fat-corrected: +) show good agreement.

Conclusion: Fat-water corrected R2* mapping improves robustness of R2* estimates without SNR penalty over a wide range of R2* values and acquisition parameters. This is particularly necessary for liver R2* mapping, where fat may be present in up to 30% of patients (ref), and has important implications for liver iron measurement using R2*-MRI.

References: [1] Reeder SB et al, MRICNA 2010. [2] Scharf LL et al, Signal Proc 1993. [3] Hines CDG et al, ISMRM 2009, p2707. [4] Pineda AR, et al, MRM 2005.

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