Noise Performance of Magnitude-based Water-Fat Separation is Sensitive to the Echo Times

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Introduction

There has been increasing interest in using multi-point water-fat separation methods for quantitative fat-fraction imaging in a variety of applications such as liver, muscle and bone marrow. Accurate measurement of fat-fraction, typically in the form of percentage of fat signals relative to total signals, requires correction of confounding factors such as T2* decay [1, 2], spectral complexity of fat [2, 3] and T1 bias [4]. System non-idealities such as phase errors caused by eddy currents, are also important particularly at low fat-fractions [5]. Magnitude-signal based water-fat separation methods [2] are in general insensitive to the undesired phase modulation. However, fat-fraction can be only estimated in a 50% range without using other a priori information [2].

We have developed a fat-fraction quantitation technique [5] where six gradient echoes are collected and a magnitude-based reconstruction is performed following a complex-based T2*-IDEAL [1] water-fat separation method. The fine tuning step of the magnitude-based reconstruction removes errors from undesired phase modulation, while the complex-based reconstruction allows a full 0%~100% range fat-fraction estimation. The purpose of this work is to evaluate the noise performance of this magnitude-based approach, and show that it is sensitive to echo times. As a result, careful choice of the echo times are required to avoid poor SNR performance that may lead to inaccurate fat-fraction measurements when using magnitude-based reconstruction, either alone or as a fine-tuning of a complex-based reconstruction.

Methods

Monte Carlo simulations were performed to map the noise performance for complex-based and magnitude-based reconstructions at different echo times. Six equally spaced echo times were studied, characterized by TE_1 (first TE) and ΔTE (echo time increment). For each echo time combination, 6 echo source images were generated for a simulated pixel with 10% fat and T2* of 25ms. Gaussian distributed noise was added to the source signals. Complex-based T2* IDEAL and the magnitude-based reconstruction (followed by complex reconstruction) were performed on the source data, each generating a set of water, fat and fat-fraction estimates. This was repeated 1000 times with different random Gaussian noise for each echo time combination. The effective NSA (Number of Signal Averages) of the decomposed fat estimate was calculated for each echo time combination, defined as noise variance in fat signals normalized by the variance in the source data.

Abdominal acquisitions were performed in patients with hepatic steatosis. Informed consent and IRB approval were obtained. Patients were scanned on 1.5T systems (HDxt, GE Healthcare, Waukesha, WI) using slightly different echo times.

Results

For complex-based T2* IDEAL (NSA map not shown), in general, the shortest TEs allowed by the hardware achieve best noise performance [1]. The NSA map of the magnitude-based reconstruction for the fat signal is shown in Figure 1. The TE_1 and ΔTE are denoted in water-fat phase shift and in time at 1.5T. There are combinations of echo times that lead to very poor noise performance in the regions that appear "blue". The minimum of NSA=0 occurs when ΔTE is near 2.3ms and TE_1 is near 1.2ms and 2.4ms at 1.5T. The shortest possible TEs allowed by the hardware were evaluated for axial abdomen protocols at 1.5T (BW = ±125kHz) and 3T (BW = ±200kHz) with varying resolution in the read-out direction (2mm, 1.6mm, 1.4mm, 1.3mm, 1.1mm, 1mm). The trajectories of the TEs were plotted as magenta lines. Some of the 1.5T protocols may result in poor noise performance. For the 3T acquisitions, six echoes are collected in two TRs such that the effective ΔTE in water-fat phase shift remains the same as 1.5T for a more robust water-fat separation [6]. As a result, the 3T trajectory line has roughly the same ΔTE as 1.5T but with doubled TE_1 (in water-fat phase shift) due to the higher chemical shift. Interestingly, the 3T trajectory avoids the "deep blue" poor noise regions.

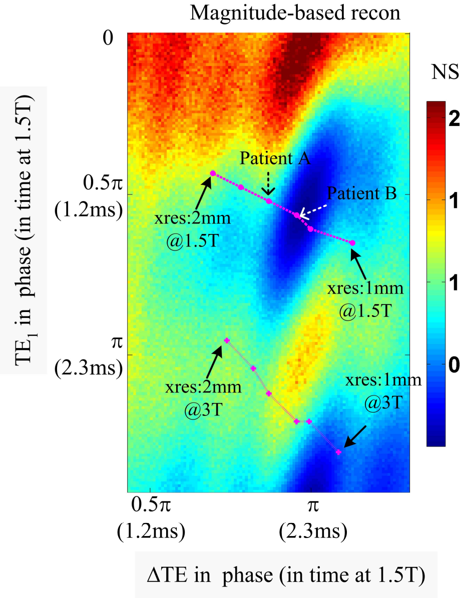

Figure 1: The NSA map for magnitude-based rreconstruction plotted against TE_1 (first TE) and ΔTE. The magenta lines indicate the trajectory of minimum TEs when the read-out resolution of clinically relevant abdomen protocols ranges from 2mm to 1mm.

Figure 2 shows results from two abdomen scans with slightly different echo times at 1.5T, as marked in the NSA maps (Figure 1: Patient A/B). Echo times of patient B fall in a region of poor noise performance, resulting noisy fat and fat-fraction images, whereas the echo times of patient A are outside the "blue holes", allowing artifact free water-fat separation. The difference in noise performance can be also seen from substantially higher standard deviation of the ROI measurement from patient B.

Discussion and Conclusion

Magnitude-based reconstruction is insensitive to phase errors, however, it also has inferior noise performance that is sensitive to the echo time choices. We have shown that clinically relevant protocols at 1.5T may be associated with very poor noise performance, affecting the precision of the fat-fraction measurements. We have used simulations to map the noise performance. The NSA maps are in agreement with theoretical calculations reported in earlier studies for complex-based [1] and magnitude-based [7] signal models, suggesting that our estimation method achieves the Cramer-Rao Bound and is efficient. The magnitude-based reconstruction can be used to remove general phase modulations. Mixed modeling of complex and magnitude signals is possible when the phase error is well modeled. Finally, the NSA plots explicitly demonstrate the benefit of using a very short TE_1 when using ultra-short TE acquisitions [8]. In conclusion, the noise performance of magnitude based water-fat separation is sensitive to the echo times. Careful design of the acquisition is needed to avoid poor noise performance that may affect the accuracy and precision of the fat quantification.

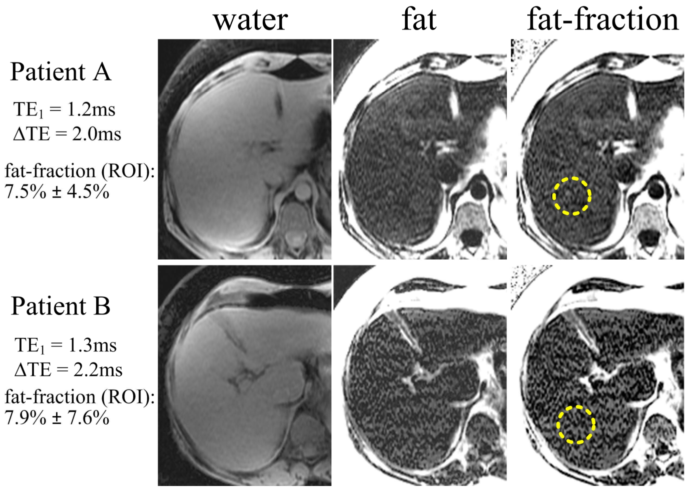

Figure 2: Water, fat and fat-fraction images from magnitude-based reconstruction in two patient scans at 1.5T. Patient A was acquired with slightly shorter TEs. The TEs from the patient B scan falls in the region with poor noise performance (Figure 1), leading to noisy and patchy artifact seen in both fat and fat-fraction images. The ROI measurements suggest similar mean fat-fraction in both patients. However, patient B is associated with substantially higher standard deviation.

References

[1]. Yu et al, JMRI 2007;26(4):1153-1161.
[2]. Bydder et al, MRM 2008;26(3):347-359.
[3]. Yu et al, MRM 2008: 60(5):1122-1134
[4]. Liu et al, MRM 2007:58(2):354-64.
[5]. Yu et al, ISMRM 2009:461
[6]. Yu et al, ISMRM 2007:3353
[7]. Hernando et al, MRM 2010;64(3):811-22.
[8]. Wang et al, JMRI 2010 31(4):1027-34.