Comparison of magnitude and complex data fitting for quantitative water/fat imaging

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INTRODUCTION

Magnitude fitting has been proposed as an alternative to complex data fitting for quantitative chemical shift-encoded water/fat imaging. Advantages of magnitude fitting include the removal of sensitivity to phase errors in the signal (e.g., caused by eddy currents) [1] and suppression of B0 field inhomogeneity effects (i.e., removal of one nonlinear parameter from the signal model) [2]. However, the noise performance of magnitude fitting, relative to complex fitting, has not been established. In this work, we perform a quantitative comparison of both methods, based on the bias and standard deviation of their estimates. The comparison uses theoretical Cramer-Rao Lower Bound (CRLB) results, simulation results and phantom data.

METHODS

Phantom construction: A water fat phantom was constructed by mixing water and oil in separate vials, with fat fractions (%): 0, 10, 20,30,40,50,60,70,100 [3,4].

Data acquisition: Phantom data were acquired using a spoiled GRE sequence with monopolar readout (flip angle==25^o, TR=2000ms), 8 TEs with initial TE=1.43ms and TE spacing=2.23ms (the same TEs used for CRLB and simulations). The acquisition was repeated 128 times to obtain "Monte-Carlo" phantom measurements. Simulations and CRLB used true R2* values of 42s^{-1} and 54s^{-1} for water and fat, respectively (means of R2*s measured in the phantom).

Processing: Data were fitted by nonlinear least-squares, both in magnitude [2] and complex methods. Magnitude fitting was performed using single-peak and multi-peak models, and complex fitting was performed with a multi-peak model. All models were implemented both with one-R2* and with two-R2* (independent for water and fat) decay models. Magnitude fitting was initialized with the estimates from complex fitting (as proposed in [1]), to avoid the ambiguities for fat fractions above 50%. Phantom multi-peak fat calibration was performed from an additional 32-point acquisition.

RESULTS

Figure 1 shows square-root NSA results (using CRLB and simulation) for fat amplitude estimation. Magnitude fitting shows higher noise sensitivity when fat amplitude is low (particularly for the two-R2* models), even when the signal model is exactly known.

Figure 2 shows standard deviation and RMSE results for the phantom data.

Figure 3 shows fat fraction estimation results for phantom data, and simulations including residual mismatch in the multi-peak model. Magnitude fitting appears to be more sensitive to model mismatch.

Note that, in the presence of significant phase errors (e.g., due to eddy currents), magnitude fitting or a mixed approach may be preferable [1,5].

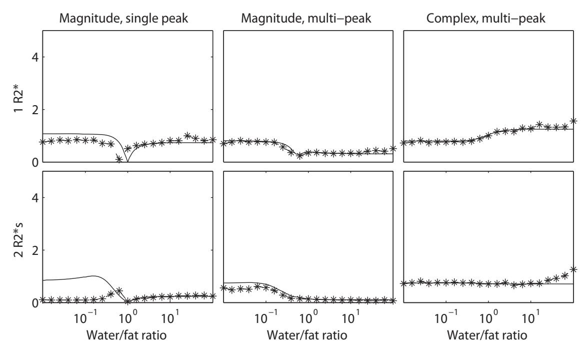

Figure 1. Square-root of NSA (number of signal averages, =1/variance) for fat amplitude estimation, both in theory (using CRLB, solid line) as by simulation (stars). CRLB plots do not account for model mismatch. Simulation plots do not include bias.

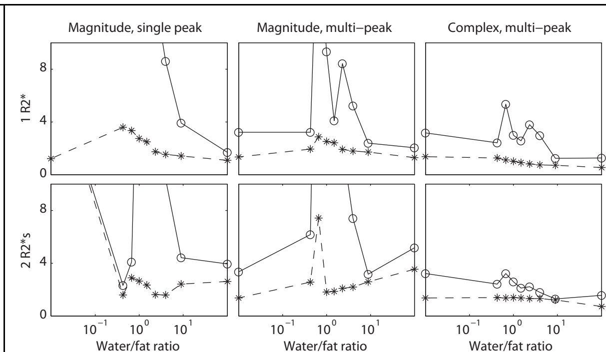

Figure 2. Standard deviation (stars) and RMSE (circles) for fat amplitude estimation. Complex fitting produces lower RMSE for most water/fat ratios, although multi-peak magnitude modeling performs well for very low water/fat ratios (high fat fractions).

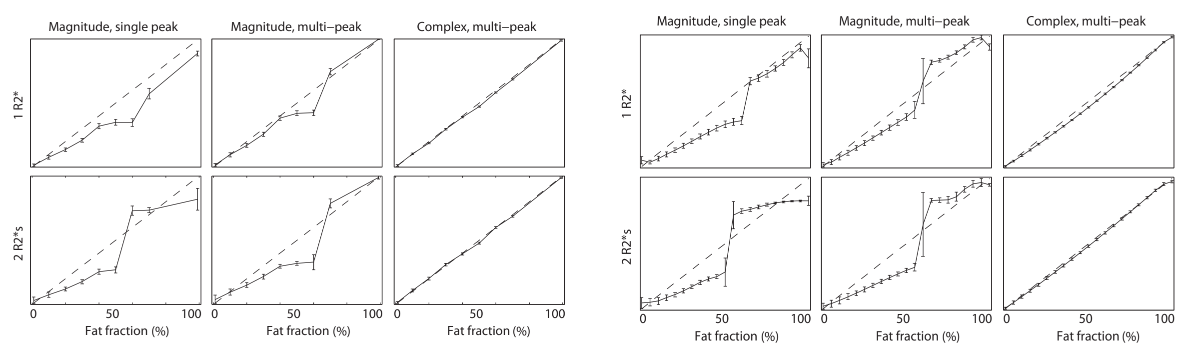

Figure 3. Fat fraction estimates (means and standard deviation bars), as a function of true fat fraction. (Left) Phantom results. Complex fitting is superior (in terms of bias and standard deviation) for most fat fractions. Complex fitting results are in good agreement with simulations where the exact multi-peak model is assumed (not shown). However, magnitude fitting results contain significant bias even when using a multi-peak model. (Right) Simulation results including slight mismatch in multi-peak model (data were fitted with 6-peak model, but generated with 8-peak model where two of the minor peaks at -117 Hz and -160 Hz were subdivided into two peaks of the same amplitude 10 Hz apart). These simulations including residual model mismatch are in good agreement with the phantom results, which suggests that magnitude fitting is more sensitive to model mismatch than complex fitting.

CONCLUSION:

Complex fitting is preferable to magnitude fitting for fat quantification, both in theory and in practice.

REFERENCES: [1] Yu H et al., ISMRM 2009, p. 461. [2] Bydder M et al., Magn Reson Imaging, 26:347-359, 2008. [3] Bernard CP et al., J Magn Reson Imaging, 27:192-197, 2008. [4] Hines CD et al., Magn Reson Med, 30:1215-1222, 2009. [5] Hernando D et al, ISMRM 2009, p. 2064.