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Accuracy of Fatty Acid Quantification using Bipolar Multi-Echo MRI for Varying Numbers of Echoes

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Synopsis

Multi-echo MRI data can be used to quantify the fatty acid composition of human adipose tissue. The total echo train readout length and the number of acquired echoes are important parameters affecting the overall accuracy of the fatty acid parameter maps. The purpose of this study was to quantify the expected error in fatty acid estimates depending on the used total echo train readout length, using an oil phantom at 3T. Echo train readout lengths of at least 13-14ms were required to accurately estimate the different fat components. Shorter echo train readouts led to less accurate parameter maps.

Introduction

Hepatic fatty acid composition (FAC) is a potentially useful biomarker of non-alcoholic fatty liver disease. For example, FAC was shown to correlate with histopathologically confirmed hepatocyte ballooning¹, which is a hallmark of progression from simple non-alcoholic fatty liver to non-alcoholic steatohepatitis. Since the degree of saturation of triglycerides is reflected in their spectrum, parametric maps of the triglyceride saturation state can be extracted from complex multi-echo MR data, provided that certain confounding factors have been properly taken into account²⁻⁵. The duration of a liver MR scan is typically constrained to a breath-hold, a fact that naturally leads to a trade-off between resolution and accuracy. The overall acquisition time is roughly proportional to the echo train readout length, which determines the resolution in the spectral domain. While the dependence of the error propagation for monopolar acquisitions has been described², the accuracy of MRI-based FAC quantification regarding the total echo train readout length remains unexplored. Our goal was to quantify the expected error in saturated, mono-unsaturated and poly-unsaturated fat maps as a function of the echo train length based on a vegetable oil phantom study.

Methods

FAC quantification: Bipolar multi-echo MRI data was denoised using a spectral denoising approach^{6,7} and then fitted to a complex signal model. The non-linear model incorporated 9 spectral fat peaks⁸ and spatially dependent parameters for the B0 off-resonance frequency^{9,10}, R_2^* ¹¹ and the eddy-current-induced phase discrepancy¹². The relative sizes of the fat peaks were modeled in terms of the number of double bonds (ndb), number of methylene-interrupted double bonds (nmidb), and the chain length (cl)⁸. Additionally a heuristic approximation for the cl¹³ was applied. Parameter maps for the saturated, mono-unsaturated and poly-unsaturated fat components were determined from ndb and nmidb as proposed by Peterson et al.³ using an implementation in C++.

Phantom study: Different commercially available vegetable oils and oil mixtures were filled into plastic vials (diameter = 28mm, volume = 50ml) and placed in a water bath. The phantom set-up is shown in Fig. 1. Multi-echo MR data of the phantom was acquired on a 3T MR scanner (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany) using an 18-channel body and a spine array coil and a prototypical 2D multi-slice GRE sequence (12 slices, TE1 = 1.23ms, Δ TE = 0.84ms, FA = 10°, voxel size = 1.3x1.3x5.0mm³, bipolar readout gradients, bandwidth = 1950Hz/px) and was then processed using the described method. To evaluate the effect of the echo train readout length on the estimated FAC, 13 experiments with varying numbers of echoes (ranging from 6 up to 30 echoes) were conducted. The echo train readout length, which is governed by TE1, Δ TE and the number of echoes, varied from 5.4ms to 25.6ms.

Statistical analysis: For every measured protocol, mean fatty acid values within cylindrical volumes of interest (VOIs) (comprising 6 slices and approx. 650 voxels) were calculated for the 17 oil mixtures. The accuracy of all quantification results was assessed by estimating the mean absolute error (MAE) with respect to reference values given by the oil manufacturers. Exemplary, for the 10- and 16-echo acquisitions a linear regression analysis was performed.

In-vivo measurements: Two datasets from one volunteer were acquired using the 10-echo and 16-echo protocols within a breath-hold (acquisition time = 17s), and were inspected for consistency with the phantom study.

Results and Discussion

Fig. 2 demonstrates the MAEs for all measured protocols for the phantom study. The smallest MAEs for all three components were achieved using echo train readout lengths from 13-14ms to about 19ms. Shorter echo train readout times led to reduced accuracy in the fatty acid estimates. Interestingly, the accuracy does not monotonically decrease for longer echo train lengths, which may be due to the fact that acquisitions at longer echo times are more sensitive to the spectral modeling or systematic errors in general.

Fig. 3 shows linear regression plots for the 10-echo and 16-echo acquisitions. The 10-echo protocol overestimated the saturated fat component (intercept = -14.85% with 95% confidence intervals of [-20.6%, -9.1%]) and at the same time underestimated the mono-unsaturated component (intercept = 11.71% with 95% confidence intervals of [6.4%, 17.0%]).

Fig. 4 depicts in-vivo fatty acid estimates. A slight right-to-left intensity gradient can be seen visually for the saturated and poly-unsaturated fat components of the 10-point FAC maps. This effect is reduced in the 16-echo parameter maps.

Conclusion

An echo train readout length of at least 13-14ms was required for accurate fatty acid estimation in phantoms. Increasing the sampling further theoretically improves the signal-to-noise ratio in the parameter maps, but may introduce increasing systematic errors.

Acknowledgements

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Figures

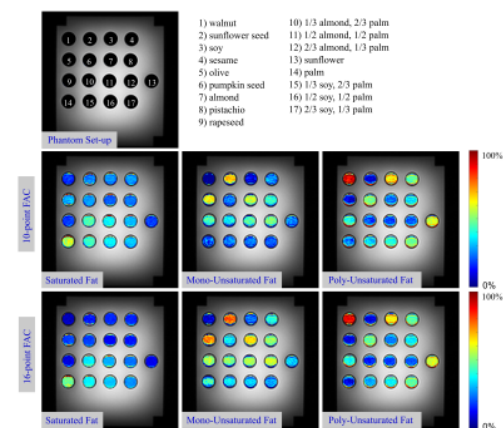


Fig. 1: Phantom set-up as well as saturated, mono-unsaturated and poly-unsaturated fatty acid maps in % for the 10-echo and 16-echo datasets. The fatty acid maps are plotted as colored overlays on the first-echo image.

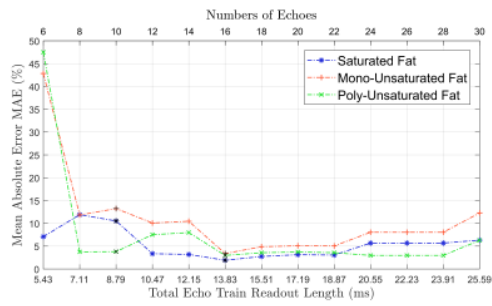


Fig. 2: Mean absolute error (MAE) in % with regard to echo numbers ranging from 6 to 30 (i.e. total echo train readout lengths ranging from 5.43ms to 25.59ms) for the saturated, mono-unsaturated and poly-unsaturated fat component of the phantom images. The MAE is calculated by comparing mean fatty acid values (within cylindrical VOIs in each oil) with the respective manufacturer-reported fatty acid values.

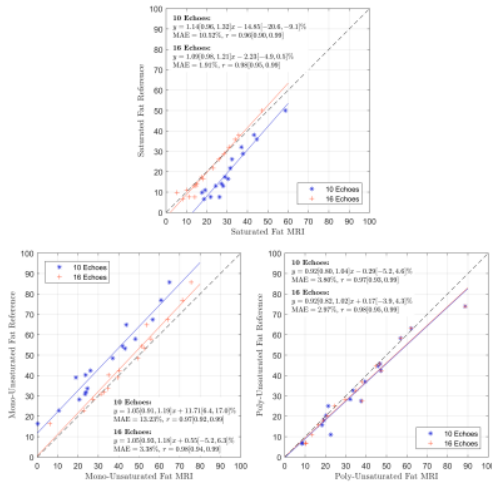


Fig. 3: Linear regression analysis for the 10-echo and the 16-echo phantom acquisitions. Every point in the plots correlates the mean fatty acid estimate within one oil with the respective reference value. The dashed line indicates the identity line between MRI measurements and the manufacturer reference values.

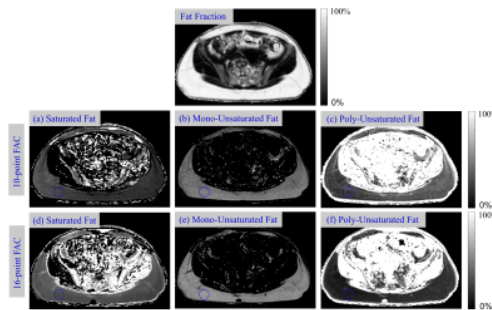


Fig. 4: In-vivo comparison of the fatty acid maps for the 10-echo and 16-echo protocol. (a) Saturated (mean \pm standard deviation in the ROI: $27.1\% \pm 2.4\%$); (b) Mono-Unsaturated (ROI: $47.3\% \pm 3.6\%$); (c) Poly-Unsaturated (ROI: $25.5\% \pm 5.0\%$); (d) Saturated (ROI: $31.8\% \pm 3.1\%$); (e) Mono-Unsaturated (ROI: $56.5\% \pm 3.9\%$); (f) Poly-Unsaturated (ROI: $11.7\% \pm 1.8\%$)