Gradient-Delay-Compensated Radial MRI for Fat Content and Fatty Acid Composition Quantification

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Target audience: MR researchers and physicists interested in fat content and fatty acid composition quantification or gradient imperfection compensation strategies for radial trajectories.

Purpose: Extracting fat content and fatty acid composition (FAC) from multi-echo MRI data shows great potential, but also requires careful consideration of phase-influencing effects. Gradient errors due to gradient imperfections and eddy-current-induced delays lead to first- and higher-order phase variations in multi-echo MRI data. Complex, bipolar, multi-echo MRI methods for fat content and FAC estimation based on Cartesian trajectories model these deficiencies either using a linear phase ramp (for first-order variations) or a spatially variable phase discrepancy (for higher-order variations) between even and odd echoes. Radial sampling trajectories are in general more sensitive to gradient errors, and accounting for these deficiencies in the image domain is not feasible, since the radial spokes are acquired in different readout directions. Instead, an adaptive gradient calibration (GC) procedure that jointly compensates phase errors for all echoes and receiver channels can be applied for first-order phase error compensation in radial MRI methods[1]. A similar calibration method that compensates gradient delays separately for each echo and channel has the potential to also address non-linear phase errors[2]. However, its effect on FAC parameter estimates has not yet been evaluated. The main aim of this work was hence to evaluate the effect of two variants of such an adaptive gradient calibration procedure on radial, complex fat and fatty acid quantification.

Methods: Two adaptive gradient calibration methods were developed and integrated into the scanner reconstruction pipeline of a prototypical, bipolar, free-breathing 3-D stack-of-radial sequence. Along with the actual image data, the methods acquired calibration spokes for all measured partitions to separately estimate gradient delays in x- and y-direction for every echo and receiver channel. The calculated gradient delays were used to estimate angle-dependent shifts in k-space and to compensate for phase errors by shifting respective k-space image data along the readout direction. The first method (termed "GC") averaged calibration spokes from all measured partitions and applied the same delays for all partitions. In comparison, the second method (termed "GC SLC-DEP") decoupled individual slices by performing a FT in the partition direction on calibration spokes as well as image data. Slice-dependent, effective gradient delays were then estimated and compensated for in the k_x-k_y-z domain. In-vivo abdominal measurements were performed in two volunteers (1 female, 1 male) using an 18-channel body and a spine array coil and a 3T MR scanner (MAGNETOM Skyra, Siemens Healthcare, Erlangen, Germany). The following protocol parameters were used: 12 echoes, 400 radial spokes, TE1 = 1.27 ms, ΔTE = 1.21 ms, TR = 17 ms, 24 slices, voxel size = 1.98x1.98x5 mm^3, FA = 4°, bandwidth = 1185 Hz/px, total measurement time = 4min 12s. For one of the volunteers, an additional dataset in the lower abdomen using the same protocol parameters was obtained to assess the fat depots inferiorly. For PDFF and FAC quantification, a technique that jointly estimates the confounding factors field map and R_2^*, as well as maps for the fat fraction and saturated, mono-unsaturated and poly-unsaturated fat components was applied. PDFF and FAC estimation was performed three times for every acquired dataset: once without GC and once using each of the two adaptive calibration procedures. Additionally, reference parameter estimates were calculated for both volunteers using a Cartesian PDFF magnitude-fitting method[3] (based on a 6-point, prototypical 3-D VIBE sequence) and a Cartesian FAC quantification technique[4] (based on a 16-point, prototypical 2-D multi-slice GRE sequence). Circular ROIs were drawn on all calculated parameter maps in the subcutaneous adipose tissue (SAT) and the visceral adipose tissue (VAT). On the PDFF maps, additional ROIs were drawn in the liver and muscle tissue. The accuracy of the estimated parameter maps was evaluated by calculating mean absolute errors (MAEs) in the ROIs with respect to the Cartesian reference methods.

Results and Discussion: Fig. 1 depicts exemplary PDFF and saturated fat maps for all analyzed methods. Both adaptive GC methods improved the visual PDFF map impression and reduced artifacts in the muscle, VAT and SAT (arrows). Similarly, the PDFF ROI analysis demonstrated lower MAEs for the methods "GC" and "GC SLC-DEP" (3.1% and 2.8%, respectively) compared to the radial method without GC (8.4%).

The radial method without GC failed to reliably estimate fatty acid maps (MAEs of 35.9%, 37.5% and 28.5% for the saturated, mono-unsaturated and poly-unsaturated fat components, respectively), especially in the SAT. Adaptive gradient calibration improved the fatty acid map appearance and the estimated MAEs with respect to the Cartesian reference method were 4.9%, 7.3% and 5.4% (for the method "GC"), as well as 4.8%, 6.6% and 5.9% (for the method "GC SLC-DEP") for the saturated, mono-unsaturated and poly-unsaturated fat components, respectively.

Conclusion: The analyzed slice-invariant and slice-dependent GC methods improved both visual appearance and accuracy of PDFF and FAC parameter estimates.

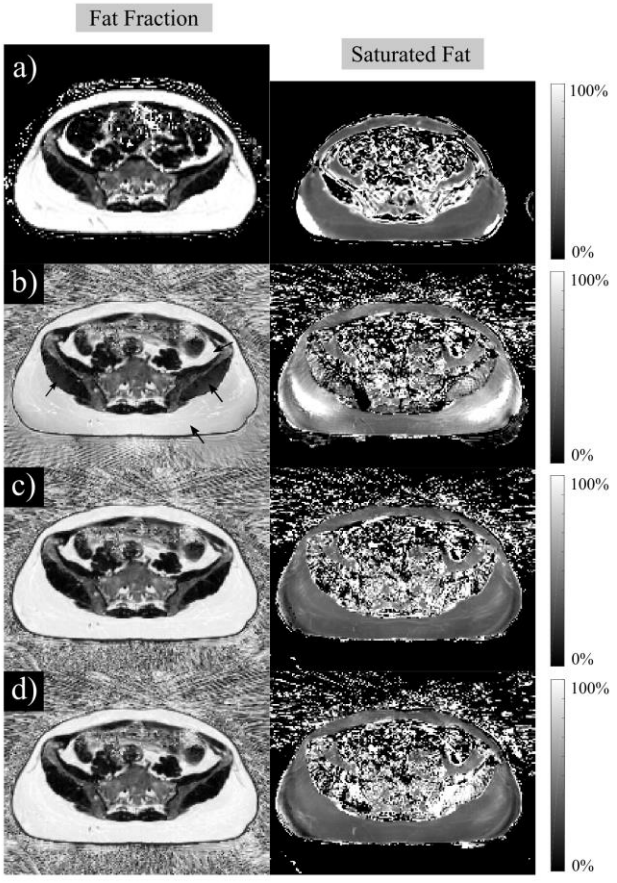

Fig. 1: Fat fraction and saturated fat parameter maps for the Cartesian reference methods **(a)**, as well as the radial methods without GC **(b)**, with GC **(c)**, and with slice-dependent GC **(d)**.

References:

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