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Hansen, Rie Beck; Hanson, Lars G. ; Ardenkjær-Larsen, Jan Henrik

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Non-Cartesian Parallel Imaging Reconstruction of Undersampled IDEAL Spiral ^{13}C CSI Data

Rie B Hansen[1], Lars G Hanson[1], Jan H Ardenkjær-Larsen[1,2]

[1]Department of Electrical Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark, [2]GE Healthcare, Denmark

Introduction: The short-lived nature of hyperpolarization places high demands on signal acquisition. To acquire large FOVs with high spatial resolution, and to fully capture substrate uptake and metabolic conversion, fast data acquisition is crucial. Parallel imaging uses multi-channel coils to achieve reduced scan times based on spatial information inherent to each coil element. In this work, we explored the combination of non-cartesian parallel imaging reconstruction and spatially undersampled IDEAL spiral CSI[1] acquisition for efficient encoding of multiple chemical shifts within a large FOV with high spatial resolution.

Methods: All data were acquired using a 3T GE HDx MR scanner (GE Healthcare, Milwaukee, WI, USA) with a ^{13}C clamshell coil for RF excitation and an 8-channel coil comprised of two 4-element paddles for reception (GE Healthcare, Milwaukee, WI, USA). A cylindrical phantom (Ø250 mm) with an outer compartment containing ethylene glycol and three inner compartments with 1.0 M solutions of urea-^{13}C, sodium acetate-1-^{13}C, and sodium bicarbonate-^{13}C, respectively, was used as test object. To enable emulation of a large, but partially sparse object ^{13}C-enriched solution vials were attached on the phantom surface (two 4.0 M and one 1.0 M). Data for sensitivity encoding were acquired using a high SNR, low-resolution CSI-FID sequence with the frequency centered at the ethylene glycol center peak resonance. For IDEAL spiral CSI acquisition three different schemes were applied: 1) a full-FOV 300x300 mm^2 75x75 matrix (4.0 mm in-plane nominal resolution), 2) an undersampled 150x150mm^2 60x60 matrix (2.5 mm resolution), and an undersampled 100x100mm^2 50x50 matrix (2.0 mm resolution). These schemes were repeated twice; first with the frequency centered between bicarbonate and acetate resonances, and second with the frequency centered at the ethylene glycol center peak to emulate both a sparse object and a larger object covering the full FOV. Spiral durations (including rewinder) were 45.9 ms, 50.6 ms, and 51.0 ms, respectively. To separate the three resonances in the "sparse object" and the peaks of the ethylene glycol triplet (J = 145 Hz), 7 echoes were acquired with a 1.12 ms echo spacing.

By means of the CSI-FID data, coil sensitivities were extracted as the main eigenvector of a reconstruction operator computed from the null space, based on ESPIRiT theory.[2] The IDEAL spiral CSI data were then reconstructed in two steps: first by least squares chemical shift (CS) modeling to achieve multi-channel k-space datasets for each metabolite, and second by means of non-cartesian parallel imaging reconstruction using an efficient quadratic-penalized, regularized least squares algorithm via conjugate gradients (CG).[3] The regularization parameter was chosen based on the FWHM of an FFT-approximated PSF and the CG algorithm was initialized with an all zero image.[4]

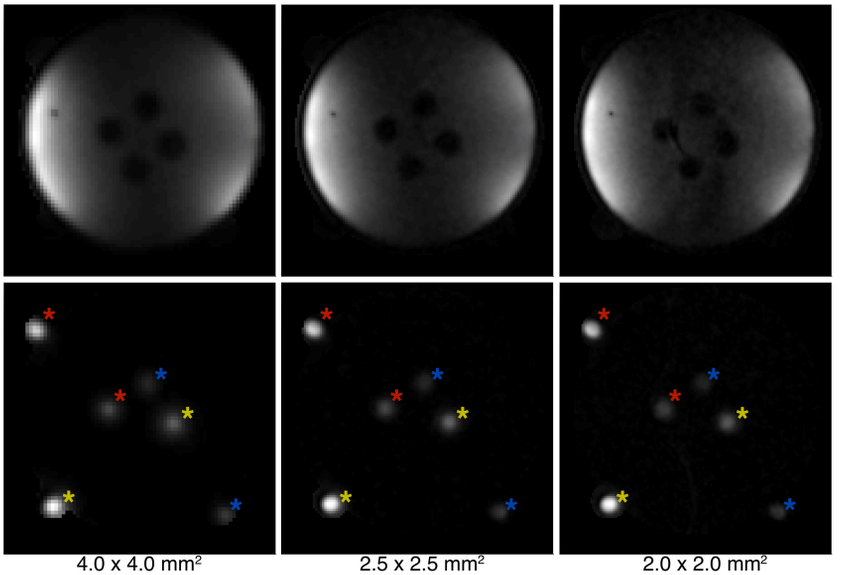

Figure 1. Reconstructions of the three IDEAL spiral CSI schemes. Top: the "large object phantom", bottom the "sparse phantom" with red asterisks indicating acetate, blue bicarbonate and yellow urea.

Results and Discussion: Figure 1 shows the reconstruction results. For R=3, the geometry factor affected the reconstruction results visibly, while not for the R=2 reconstructions. For both R=2 and R=3 the reconstructions showed significantly less signal blurring due to the higher resolution and improved PSF. Overall, the estimated SNR loss for performing parallel imaging was within the theoretically expected limits. The next development steps for this acquisition scheme include intensity profile correction, exploiting coils with better coverage and more elements, and transforming the reconstruction pipeline to a one-step procedure (CS modeling integrated in the CG algorithm). Subsequently, in vivo hyperpolarized imaging with sub-second dynamic resolution will be tested.

Conclusion: Parallel imaging in combination with IDEAL reconstruction can achieve large FOV scans with high spatial resolution for sparse as well as large objects, without sacrificing dynamic resolution. Furthermore, the SNR loss occurring when accelerating measurements in a thermal phantom experiment is theoretically non-existing in a hyperpolarized experiment within the limits of a well-behaved geometry factor.

References: [1] Wiesinger, F. et al. *MRM* **68,** 8–16 (2012). [2] Uecker, M. et al. *MRM* **71,** 990–1001 (2014). [3] Fessler, J. A. (2004). Available at: http://web.eecs.umich.edu/~fessler. [4] Fessler, J. A. & Noll, D. C. in *ISMRM Workshop on Non-Cartesian MRI* (2007).

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