Parallel Imaging using a Concentric Rings Trajectory and Application to Hyperpolarized ^{13}C MR Spectroscopic Imaging

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Target audience: Hyperpolarized ^{13}C MRI, spectroscopic imaging scientists and engineers, reconstruction scientists

Purpose: The powerful feature of hyperpolarized ^{13}C MRSI [1] is that it reflects the altered metabolism in cancer. However, the short-lived effect of hyperpolarization requires rapid and robust imaging techniques. Parallel imaging is favorable for hyperpolarized ^{13}C imaging [2] because the shorter scan time reduces SNR losses due to T1 decay and metabolism during the acquisition, especially in larger, human-sized FOV 2D MRSI or 3D MRSI applications that require large numbers of encoding steps. Concentric rings k-space trajectory (CRT) [3,4] provides a powerful alternative for accelerating MRSI. It has the advantages of 1) acquisition time saving compared with echo-planar spectroscopic imaging (EPSI); 2) robustness to system delays and first-order eddy currents; 3) it is insusceptible to pulsatile flow artifacts. In addition, the isotropic property of CRT is advantageous for performing isotropic undersampling in parallel imaging compared to Cartesian counterparts. In this work we analyzed theoretical noise amplification (g-factor) of CRT and demonstrated feasibility of using CRT for hyperpolarized ^{13}C MRSI parallel imaging.

Methods: A Monte-Carlo technique was used to calculate g-factor maps of an 8-channel phased-array coil and 4-fold undersampling for both CRT and symmetric EPSI. For experiments, a CRT was designed for 2.5×2.5 mm^2 spatial resolution, 8×8 cm^2 FOV and 420 Hz spectral bandwidth (SBW), 10 Hz spectral resolution. Prospective 1.45 times undersampling was used as indicated by the dashed lines in Fig.1. The following acquisition parameters were used: TE/TR=3.4 ms/320 ms, 11 phase-encoded excitations with a progressive flip angle scheme, resulting in a total scan time of 3.52 s. The readout gradients were implemented in gradient echo sequence on a GE Signa 3T scanner. We used min-max NUFFT [5] for direct reconstruction, and non-Cartesian ESPIRiT [6] for parallel imaging reconstruction. We performed normal rat experiments at 35 seconds after an injection of 2.2 mL of 100 mM hyperpolarized [1-^{13}C] pyruvate (using an Oxford Instruments HyperSense polarizer) and an 8-channel ^{13}C phased-array rat coil was constructed for the study.

Results: As confirmed by the g-factor map (Fig.2), the CRT utilizes the sensitivity maps in all directions, which lowers the maximal g-factor noise amplification and also makes it more uniformly distributed. In the *in vivo* hyperpolarized ^{13}C MRSI study, we evaluated the feasibility of CRT for parallel imaging (Fig.3). The direct reconstruction of the undersampled data resulted in circular aliasing artifacts (yellow arrows) in the spatial domain for each coil images. With our parallel imaging reconstruction, the undersampling aliasing was eliminated and good image quality was achieved. The bottom right plot shows the spectrum of a selected kidney voxel, clearly showing pyruvate and its conversion to lactate.

Conclusion: The isotropic concentric rings trajectory is a good fit for parallel imaging. Our *in vivo* studies and simulation demonstrate the feasibility of using CRT in hyperpolarized ^{13}C MRSI parallel imaging. And this concentric rings undersampling scheme can be easily extended into general concentric rings imaging or ^{1}H MRSI.

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References:

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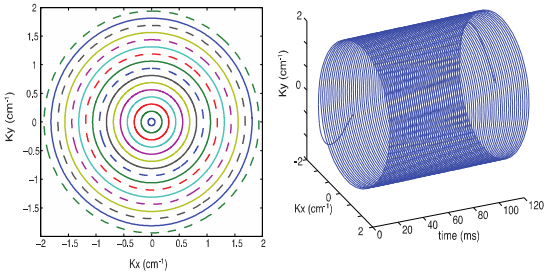

Fig. 1. (left) Spatial k-space coverage of all rings: solid lines are actual encoding rings while dashed lines are the skipped rings for undersampling; (right) A single ring retraced over time for MRSI.

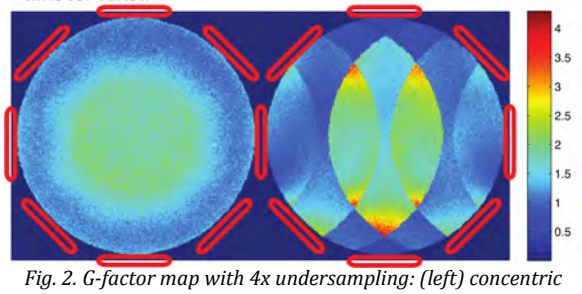

Fig. 2. G-factor map with 4x undersampling: (left) concentric rings; (right) Cartesian counterpart for an 8-channel array.

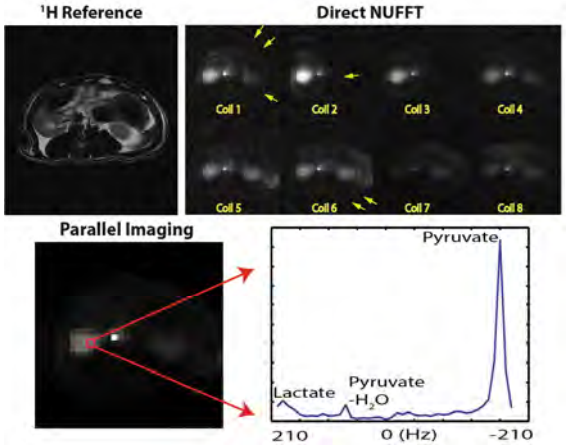

Fig. 3. Hyperpolarized carbon-13 parallel imaging in vivo results in an axial kidney slice using concentric rings with an 8-channel ^{13}C phased-array rat coil: All the images are generated by projection along the spectral domain and with a spatial resolution of 2.5x2.5 mm^2, 8x8 cm^2 FOV and 420 Hz SBW. The top row shows individual coil images of the undersampled CRT using a direct NUFFT reconstruction. The bottom row shows the parallel imaging reconstruction result. A spectrum from a selected kidney voxel was displayed to show the metabolic conversion.