3D volumetric in vivo spiral CSI at 7T

B. A. Gagoski[1], E-M. Ratai[2,3], F. S. Eichler[3,4], G. Wiggins[2,3], S. Roell[5], G. Krueger[5], J. Lee[1], and E. Adalsteinsson[1,6]

[1]Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, United States, [2]Radiology, Massachusetts General Hospital - A.A. Martinos Center for Biomedical, Charlestown, MA, United States, [3]Harvard Medical School, Boston, MA, United States, [4]Neurology, Massachusetts General Hospital - A.A. Martinos Center for Biomedical Engineering, Boston, MA, United States, [5]Siemens Medical Solutions, Erlangen, Germany, [6]Harvard-MIT Division of Health Sciences and Technology, Massachussets Institute of Technology, Cambridge, MA, United States

Introduction: Among the challenges in chemical shift imaging (CSI) are the intrinsically low signal-to-noise ratio (SNR) of the metabolites of interest as well as main field (B_0) and RF excitation field (B_1) inhomogeneities. In addition, in phase-encoded (PE) CSI, field-of-view (FOV), spatial resolution and imaging time are not independent parameters, imposing imaging time constraints. CSI with time-varying readout gradients offers significantly improved acquisition efficiency without SNR tradeoffs, but at the cost of high-fidelity gradient hardware, high-capacity receiver pipeline, and non-trivial trajectory designs and reconstruction algorithms. With emerging 7T human scanners, SNR and chemical shift dispersion are improved over 1.5T and 3T platforms [1,2], but at the cost of more severe B_0 and B_1 inhomogeneities. For brain imaging at 7T, these inhomogeneities are very pronounced and responsible for a significant signal variation within the volume of interest (VOI) [3]. In this work we present in vivo PRESS box excitation spiral CSI results for 1) single slice excitation, and 2) 3D volumetric encoding with PRESS box excitation wholly within the brain. The feasibility of efficient spatial encoding for CSI without SNR tradeoffs is demonstrated and compared to phase encoded acquisitions.

Methods: Variable density spiral readout was appended to a conventional PRESS on the Siemens platform. The readout duration was 400 ms with 4μs sampling, and a reconstructed spectral bandwidth of 1.6 kHz. The spiral designs used gradient slew rate and amplitude of 120 mT/m/ms and 20 mT/m, respectively. The data was acquired using an 8-channel coil receive array and the reconstruction for each coil was achieved with 1X gridding using triangular kernel followed a Hanning windowing in k_x,k_y and k_z and a tapered-cosine-shaped window in k_f. For a single-slice excitation readout, we used a variable-density spiral trajectory [4] that matched the voxel size of 16x16 PE CSI over a 24cm FOV. The minimum scan time was 1.2 minutes (TR=2s), thus seven averages of the spiral CSI acquisition were collected in order to match the standard PE CSI acquisition time of 8.5 minutes. The excitation box included the entire in-plane FOV and no outer volume saturation (OVS) bands were used. The slice was axially positioned in the ventricles and was 10mm thick. The variable-density 3D spiral CSI applied phase-encoding in k_z for a voxel size of 1.1cc and a total acquisition time of 22 minutes. The PRESS box excitation volume was (x,y,z) = 70x100x50mm placed wholly within the brain. To minimize lipid contamination 8 OVS pulses were prescribed. For both scans, separate unsuppressed water data was acquired with TR = 1s to provide phasing and frequency information in reconstruction.

Results and Discussion: The single-slice spiral CSI was compared with PE CSI in a phantom study for validation. Fig. 1 shows spectra from four spatial locations in the middle of the uniform spherical phantom with physiological concentrations of the major brain metabolites acquired by 1) PE CSI (16x16 grid, TR = 2s) and 2) Spiral CSI (7 averages) with spirals matching the PE voxel size. We show that for fixed voxel size and acquisition time, the PE and spiral readouts yield equivalent results. Fig. 2 shows spectra from the single slice excitation on a healthy volunteer. As expected, peripheral lipid signals are strong, but the Hanning apodization aids in limiting the extent of contamination. Fig. 3 shows spectra from six spatial locations (located in 2 different slices) of an in vivo 7T spiral PRESS CSI scan done on a healthy volunteer. Fig. 4 shows the estimated water reference and NAA maps for the central 12 slices.

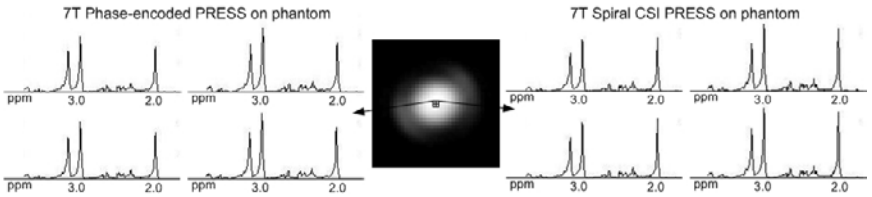

Fig. 1: ^{1}H Comparison of data acquired with phase encoded (left) and spiral readout (right) on a metabolite phantom at 7T. For fixed voxel size and acquisition time, the two are identical.

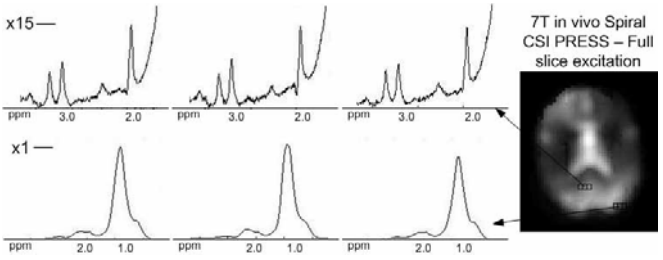

Fig. 2*:* 7T in vivo spiral CSI with full FOV excitation including subcutaneous fat.

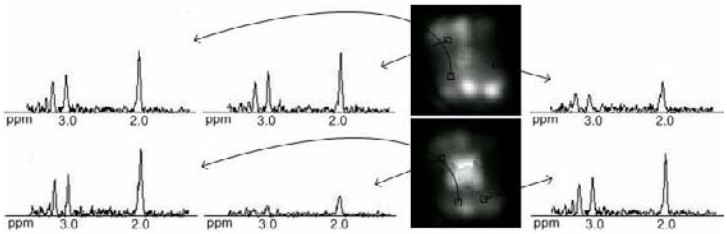

Fig. 3*:* 3D volumetric 7T in vivo spiral CSI using PRESS excitation with outer-volume spatial saturation (OVS) bands for lipid suppression. Spectra from 2 different slices show significant variation in the signal intensity across given slice.

Non-uniform B_1, inherent to brain imaging at 7T, is a dominant problem for large-volume CSI. Means of correcting for this non-uniformity [5,6] need to be pursued for robust and reliable volumetric CSI at high field.

Conclusion: In this work we have demonstrated in vivo 7T 3D spiral CSI acquisition with variable-density sampling. As is the case for conventional imaging, means of providing uniform excitation flip angle across the volume of interest are critical to the success of large-volume CSI at 7T, and future work will combine the efficient encoding presented with adiabatic or parallel RF excitation schemes for uniform excitation.

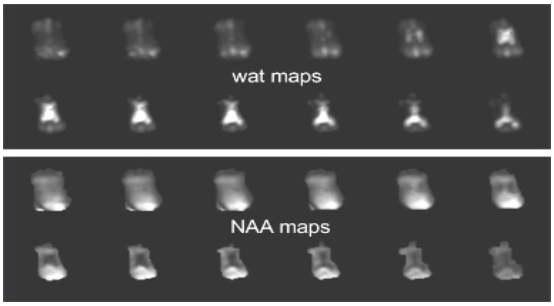

Fig. 4*:* Estimated NAA and water reference maps of the middle 12 slices for in vivo Spiral CSI with 32 slices

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