Application of Parallel Imaging and Compressed Sensing to Metabolic Imaging of the Brain using H-1 MRSI at 7T and Using Hyperpolarized C-13 MRSI at 3T

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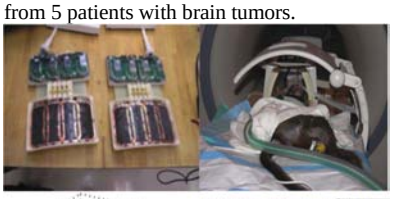
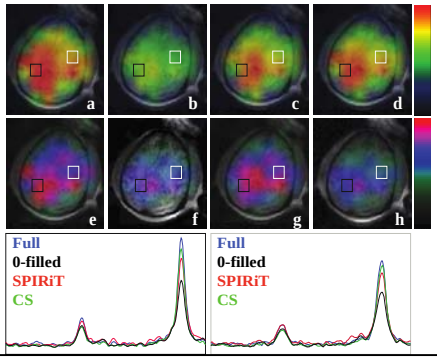
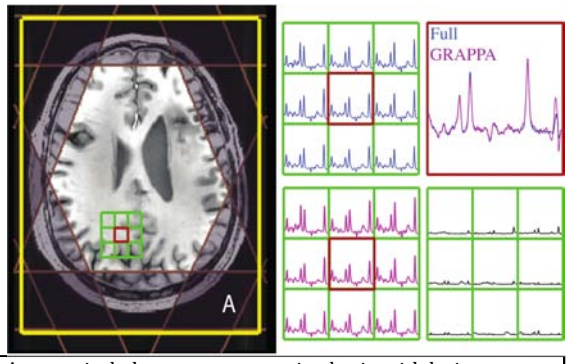
Introduction: The increasing availability of 7 Tesla MR scanners and coil arrays allow for shorter acquisition times, higher spatial resolution and larger spatial coverage for H-1 MRSI data. This is important for decreasing the total acquisition time and/or improving the spatial resolution of the data in order to facilitate patient studies. A second application where high signal-to-noise ratio (SNR) and the need to minimize the number of excitations encourages the application of parallel imaging is hyperpolarized C13 metabolic imaging. When at 3T this enables real time monitoring of enzymatic activity of the diseased tissues, requiring very rapid acquisition times due to unrecoverable T1 decay, RF excitation and metabolism. As a consequence, both of these applications require efficient, rapid k-space sampling. The purpose of this study was to develop a strategy for combining echo planar k-space sampling with self-calibrating parallel imaging (PI) and compressed sensing (CS) strategies to rapidly acquire metabolic imaging data from the brain.

Methods: Self-calibrating techniques such as GRAPPA[1], SPIRiT[2], and L_1SPIRiT[2] are particularly attractive for the proposed applications because coil sensitivity information is estimated from the data themselves. The SPIRiT algorithm is a generalized form of GRAPPA but has the ability to enforce an additional L_1 constraint in order to take advantage of compressed sensing[3] as well (L_1SPRiT). This allows the CS method to accelerate beyond what would be possible using PI alone. In this initial study, we implemented GRAPPA, SPIRiT and CS strategies that allowed the reconstruction of phase sensitive spectroscopy data and tested their performance using a combination of simulations of phantoms with representative geometries, hyperpolarized C-13 datasets from the brain of a non-human primate and 7T H-1 MRSI data from 5 patients with brain tumors.







Left: Figure 1: bi-lateral 8 channel 13C receive coil and its Simulation. Setup for C-13 primate. A numerical phantom representing brain with lesions.
Middle: Figure 2: Pyruate(a-d)and Pyruate Hydrate (e-h) map. Fully-sampled (a,e), zero-filled recon (b,f), SPRiT recon (c,g), CS recon (d,h)
Right: Figure 3: H-1 MRSI patinet A data at 7T. Fully sampled spectra is presented in blue and grappa recon is presented in pink, the difference is shown in black.

Simulation: A numerical phantom (Figure1) was generated with 2 chemical species (pyruvate and lactate) and 3 different tissue types (Normal brain, Tumor and Vasculature). The coil sensitivities for the phased array coil used for primate studies were simulated based on the Biot-Savart Law in the Matlab (The Math-Works, Natick, MA, USA). Arrays of k-space FIDS were generated for each coil at a spatial resolution of 1cm and adjusted to represent the different under sampling patterns.

3T C-13 MRSI data : The subject was a 9-year old female cynomolgus monkey (body weight=4.3 kg) who was imaged on multiple occasions to verify the experimental setup being developed for human brain studies. A clamshell volumetric 13C transmit coil and bi-lateral 8-channel phased array receive coil were used on a GE 3T scanner (GE, Medical Systems, Milwaukee, WI). Fully sampled 2D dynamic datasets with a symmetric EPSI[4] in RL direction providing in-plane resolution of 1cm were acquired (TE/TR=4.6,130ms) at a time resolution of 3s following an injection of 5.9 mL [1-13C]-pyruvate (250 mM) through the saphenous vein. Poisson-disc under-sampling patterns with an acceleration factor of 2 were simulated from the fully-sampled individual channel data and reconstructed using the different methods.

7T H-1 MRSI data: 5 patients with brain tumors were studied using a 32-channel receive-only array with a volume transmit head coil on a GE 7 Tesla scanner (GE Healthcare, Waukesha, WI). 3D H-1 MRSI was localized with CHESS water suppression, 8 VSS outer volume suppression, spin echo slice selection TE/TR=30/2000ms, spectra array=18x22x8 with an interleaved flyback echo-planar trajectory and spatial resolution of 1 cm was applied[5]. The total acquisition time is about 10 minutes. The 32 channels of data were combined, processed as described previously[5,6] and then quantified using LCModel. Undersampling by a factor of 2 was simulated by eliminating the appropriate k-space components and the data were reconstructed with GRAPPA.

ID	(GPC+PC)/NAA						Number of voxels with Glu CRLB<=20	
	T2		NAWM		GM			
	Full	GRAPPA	Full	GRAPPA	Full	GRAPPA	Full	GRAPPA
A	0.23 ± 0.10	0.21 ± 0.06	0.14 ± 0.03	0.14 ± 0.03	0.09 ± 0.03	0.09 ± 0.03	137	129
B	0.26 ± 0.14	0.24 ± 0.12	0.16 ± 0.04	0.16 ± 0.04	0.16 ± 0.04	0.15 ± 0.04	84	74
C	0.13 ± 0.02	0.10 ± 0	0.13 ± 0.06	0.14 ± 0.07	0.14 ± 0.06	0.15 ± 0.07	133	92
D	0.38 ± 0.15	0.36 ± 0.13	0.16 ± 0.03	0.15 ± 0.03	0.10 ± 0.03	0.09 ± 0.03	72	60
E	0.18 ± 0.07	0.18 ± 0.08	0.17 ± 0.01	0.17 ± 0.02	0.11 ± 0.01	0.11 ± 0.02	95	89

Result and Discussion: Figure 2 shows the pyruvate and pyruvate hydrate maps for the fully sampled, zero-filled data, SPIRiT and CS reconstructions ([abcd],[efgh]) of the hyperpolarized C-13 data using a calibration size of 4, kernel size of 3 and 50% undersampling. Two voxels with overlaid spectra for the different techniques are also presented. The maps are well estimated in both cases but the CS is more successful in recovering the pyruvate peak, whereas SPRiT is more successful in recovering the pyruvate hydyrate. This suggests that the combination of SPIRiT and CS (hence L_1SPIRiT) will produce an even better result. In Figure 3 there is an example of the impact of using GRAPPA for the 7T H-1 MRSI data. Table 1 summarize the results for all 5 patients. No significant difference (P>0.05) was found in (GPC+PC)/NAA between fully sampled spectra and spectra with the GRAPPA recon; and the number of voxels with quantifiable Glu are similar between the two methods. These results are very promising and when implemented experimentally would reduce the acquisition time to 5 minutes, which is ideal for patient studies. By considering higher acceleration factors in combination with SPRiT and CS we may also be able to decrease voxel size.

Conclusion: The application of PI and CS algorithms that reconstruct phase sensitive hyperpolairzed 3T C-13 and 7T H-1 MRSI data is essential for taking advantage of the improved sensitivity provided by these technologies. Further studies will consider increased acceleration factors and larger acquisition matrices in order to determine which combination of methods is most robust for patient studies.

References [1] Griswold et al., *Magn Reson Med*. 2002. [2] Lustig et al., *Magn Reson Med*. 2010. [3] Lustig et al., *Magn Reson Med*. 2007. [4] Larson et al., *Magn Reson Med*. 2010. [5] Li, Y., et al. *ISMRM* 2012. [6] Nelson, SJ. *Magn Reson Med*, 2001.

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