Improved Resolution of 2D and 3D [1-^{13}C] Hyperpolarized MRSI using a 3-element coil and SENSE reconstruction

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Introduction

Prior studies have demonstrated that MRSI acquisitions can detect the uptake of hyperpolarized ^{13}C-pyruvate and its metabolic conversion to ^{13}C-lactate, ^{13}C-alanine, and ^{13}C-bicarbonate *in vivo* [1,2]. Rapid ^{13}C metabolic imaging has since allowed us to gain insight to biochemical processes occurring in vivo in various animal models of cancer. The majority of these rapid ^{13}C MRSI techniques utilize a flyback echo-planar readout acquisition scheme [3] and/or compressed sensing [4] to accelerate MRSI when using small animal volume coils. In this study, a custom-built 3-element receive coil allowed for incorporation of parallel imaging into the ^{13}C MRSI acquisition. Since prior ^{1}H parallel MRSI studies in our group favored a SENSE reconstruction over GRAPPA [5], the goal of this study was to use SENSE to increase the resolution of ^{13}C MRSI in both a 2D acquisition with standard phase encoding and 3D acquisition that used phase encoding and flyback spatial trajectories.

Methods

Experimental Setup: The DNP and dissolution method [1] was used to achieve 17%-21% polarization for [1-^{13}C]-pyruvate in the solution state using a Hypersense DNP polarizer (Oxford Instruments). The polarized solution was immediately transferred to an anesthetized Sprague-Dawley rat inside a 3T GE EXCITE MR scanner equipped with multinuclear spectroscopic capabilities and a broadband amplifier. Scans were performed using custom designed coils: a ^{13}C Helmholtz pair with capacitive mesh for transmission, and a 3-element array for reception. Proton blocking of the carbon-tuned resonators allowed proton imaging with the system body coil. Rats were positioned length-wise on top of the coil with the row of receive elements oriented in the left-right direction in the magnet, perpendicular to B_0.

Data Acquisition: ^{13}C MRSI acquisitions were acquired on each rat following injection of separate 2.5ml boluses of hyperpolarized pyruvate solution (~1hour apart) through a tail vein catheter (12s injection). Data acquisition started either 25s (2D) or 35s (3D) after the start of the injection. A pulse-acquire sequence was used for the 2D data acquisition with a 10° flip angle and TR=80ms (5000Hz/256pts readout). The 1cm thick slab was spatially encoded with a 16x10 matrix while prescribing either a 16cmx10cm FOV or 8cmx10cm FOV, the latter resulting in a SENSE acquisition with reduction factor (R) of 2. The 3D ^{13}C MRSI acquisition utilized a half echo pulse sequence with a progressive flip-angle, 15 cm slab excitation pulse and concentric phase encoding with TE/TR=3/126ms. A 16x8x1 phase-encoding matrix with flyback echo-planar readout trajectory on the z-axis (16x8x16 effective matrix) was employed over a 16cm x 8cm x 16cm FOV (8cm x 8cm x 16cm FOV for SENSE) with 59 points per spectrum and a 581 Hz bandwidth for a total acquisition time of only 16 seconds. Coronal T2-FSE ^{1}H MR images were acquired and used to manually define anatomical regions of interests of the heart, kidney, and liver for subsequent analysis. At the end of the experiment, the animal was replaced with a large sealed bag filled with corn oil. A 3D ^{13}C MRSI dataset was acquired from this oil phantom to generate the coil sensitivity maps used in both the SENSE reconstruction and combination of the full FOV spectra from the different coil elements.

Data Reconstruction & Analysis: All spectra datasets were reconstructed at 2 in-plane resolutions: 5mmx5mm for SNR and CNR comparison, and 10mmx10mm for correlations. The high resolution original and SENSE datasets was zero-filled in the SI direction to obtain isotropic voxels in-plane. Spectra were reconstructed using custom designed software that included phase, frequency, and baseline correction prior to combining data from the individual coils. For the data obtained using a SENSE acquisition, the phased corrected spectra were unfolded along the RL direction of the reduced FOV datasets to regain the full FOV. SNR maps were created for each metabolite from the peak heights of the spectra and normalized by the percent polarization. Spearman rank correlation coefficients were calculated to compare peak SNR values between acquisitions.

Results

For the 2D dataset, SNRs of lactate and pyruvate for the SENSE acquisition were 37-61% greater than expected based on the coil geometry and acquisition in all regions (see Table 1). Spectra from two slices of the 3D acquisition, corresponding to the kidney and liver regions are shown in Figure 1 for both the original and SENSE reconstructed datasets. The original spectra shown here were zero-filled to the same resolution as the SENSE dataset for comparison. Geometry factors (g) were slightly higher in all regions for the 3D acquisition, resulting in slightly elevated SNR ratios. CNR ratios were all less than 2 except for pyruvate in the kidney, suggesting that despite the expected decrease in SNR, the actual contrast between tissues improved with the heightened resolution. The peak heights for the metabolites obtained from the SENSE data were highly correlated (with all R>.5, median R=.83; P<.02) with the full FOV dataset in all regions for all metabolites (Figure 1, *bottom*) for the 3D acquisition.

Table 1: Metabolite SNRs in different regions

Metabolite	Region	SNR_{orig}	SNR_{SENSE}	SNR_{ratio}	g*R
Pyruvate (2D)	*heart*	17.85	14.48	1.23	2.22
	liver	16.74	15.6	1.07	2.36
	kidney	17.50	13.09	1.34	2.32
Lactate	*heart*	3.46	4.03	0.86	2.22
	liver	7.60	7.33	1.04	2.36
	kidney	5.53	4.19	1.32	2.32
Alanine	*liver*	2.48	3.07	0.81	2.36
Pyruvate (3D)	*heart*	14.20	27.15	0.52	2.40
	liver	16.49	13.71	1.20	2.88
	kidney	19.54	10.60	1.84	2.38
Lactate	*heart*	6.16	8.17	0.75	2.40
	liver	8.09	5.20	1.56	2.88
	kidney	7.47	2.10	3.55	2.38
Alanine	*liver*	7.71	5.32	1.45	2.88

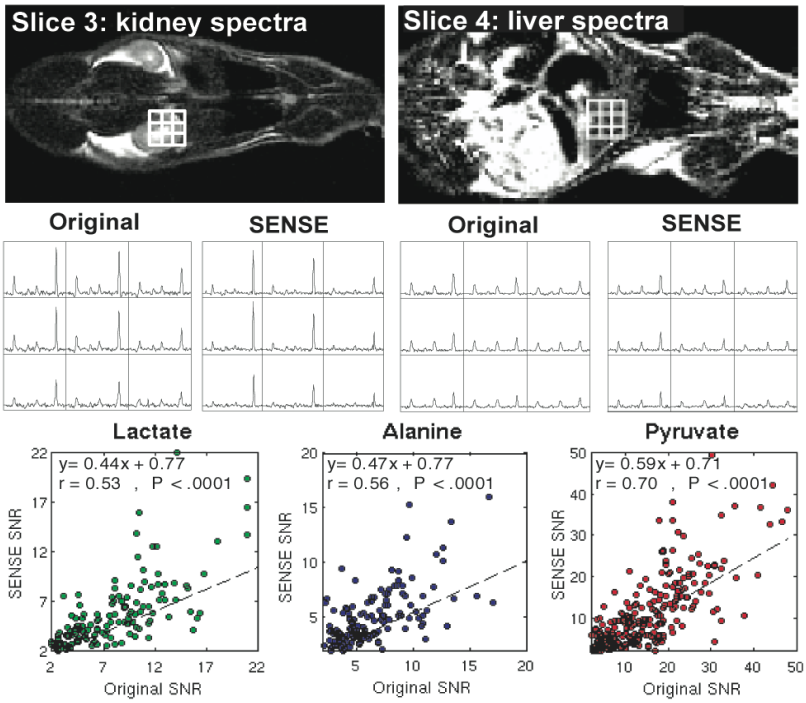

Figure 1: Original 3D ^{13}C MRSI with flyback and the addition of SENSE (*top*) and plots of SENSE SNR vs original SNR for all voxels within the rat body (*bottom*)

Conclusions

This study demonstrated the feasibility of using parallel imaging with SENSE to increase the resolution of ^{13}C MRSI. By incorporating SENSE and flyback in different directions of a 3D acquisition, we were able to acquire 4096 voxels with a 0.5cc spatial resolution in 16s without significantly compromising the overall quality of the spectra. Implementation of SENSE to accelerate acquisition time rather than increase the resolution would help recover some of the lost SNR due to SENSE.

References: [1]Golman K et al, PNAS, 2006;103(30) [2]Kohler SJ et al, MRM, 2007;58(1) [3]Cunningham CH et al, MRM, 2005;54(5) [4] Hu S et al, JMR, 2008;192(2) [5] Ozturk E et al. IEEE EMBS, 2006;1.

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