

# Accelerating Magnetic Resonance Spectroscopy Imaging by Compressed Sensing

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## INTRODUCTION

Conventional phase encoded MRSI is relatively inefficient and time-consuming because it involves a large number of phase encodings [1]. As a result, small number of phase encodings are commonly employed in practice, leading to low spatial resolution and intra-voxel contamination [2]. In this study, we aimed to examine the applicability of compressed sensing (CS) [3] to MRSI in order to accelerate data acquisition. We proposed that by undersampling the 2D phase encodings in a random and non-uniform manner, the proton MRSI acquisition could be significantly reduced without sacrificing the spectral quality while maintaining high spatial resolution.

## METHODS

**Random Phase Encoding:** The random undersampling procedure was first demonstrated by Lustig et.al.[4]. In our study, undersampling along two phase encoding directions was achieved by randomly selecting the phase encoding lines (readout) measured. The acquisition order was phase encoding in Kx-direction, phase encoding in Ky-direction and readout in Kf-direction (Fig. 1a). The sampling density function was quadratic with the highest value in the center of Kx-Ky plane.

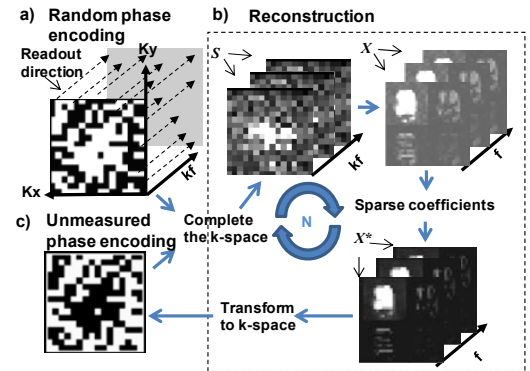
**Image Reconstruction:** As shown in Fig. 1, reconstruction was performed with the following procedures: (1) Undersampled data (Fig. 1a) was reordered into the form Kx-Ky-Kf ( $S$  in Fig. 1b) and the unmeasured phase encoding lines were filled with zero; (2) 1D Fourier transform was performed along Kf direction while 2D Inverse Fourier transform and wavelet transform were performed on Kx-Ky plane, producing  $X$ ; (3) The sparse coefficients [4] of  $X$  were calculated and used to generate  $X^*$ ; (4) unmeasured phase encoding lines in Fig. 1a were filled with the values from  $X^*$  (after transform to k-space, Fig. 1c) to form a new  $S$ ; (5) steps 2 to 4 were iterated until the data converged. The convergence criterion is  $\|X - X^*\|_2 / \|X\|_2 < 10^{-4}$ .

**Phantom MR Experiments:** All experiments were performed on a 7T Bruker scanner. Fig. 2a shows a T1-weighted (T1W) image of a cylindrical phantom containing dimethyl sulfoxide (DMSO) and distilled water separated by a plastic layer. The phantom was then scanned using a PRESS sequence with TR/TE = 1000/20ms, NEX = 1, no water suppression and scan time of 17 mins. The FOV 30×30mm<sup>2</sup> and 32×32 matrix gave a true resolution of 0.937mm/pixel. A total of 1024 phase encodings were acquired. Random undersampling was done retrospectively by randomly selecting 551 phase encodings from the full dataset (undersampling ratio = 53%).

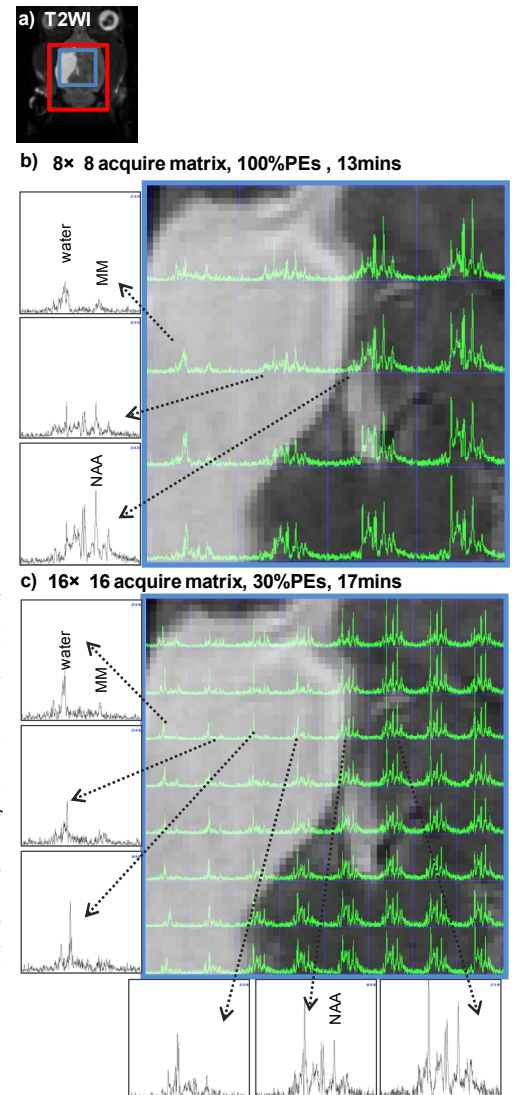
**In vivo Rat Brain MR Experiment:** A semi-LASER sequence (TR/TE = 800/40ms) with 4 steps phase cycling was applied to adult Sprague Dawley rat brain with severe neonatal hypoxic-ischemic injured (see Fig. 3a). We compared the low resolution MRSI (8×8 acquisition matrix, 13 mins, NEX = 16) with the proposed method (30% undersampling ratio, 16×16 acquisition matrix, 17 mins, NEX = 16). The two spectroscopic measurements were acquired at approximately 30 minutes apart and the undersampling was achieved by embedding the random phase encoding table into the Semi-LASER sequence.

**RESULTS:** With 53% undersampling ratio, the random phase encoding method preserved the boundaries between water and DMSO (Fig. 2b), with minimal ringing artifact (Fig. 2c). With 30% undersampling ratio Fig. 3c and 3d showed that the proposed undersampling led to a 2 fold increase in resolution for delineation of the lesion boundary with only 31% increase in scan time. With the same number of averages and ¼ the voxel volume, the proposed undersampling approach still yielded spectral SNR comparable with the control.

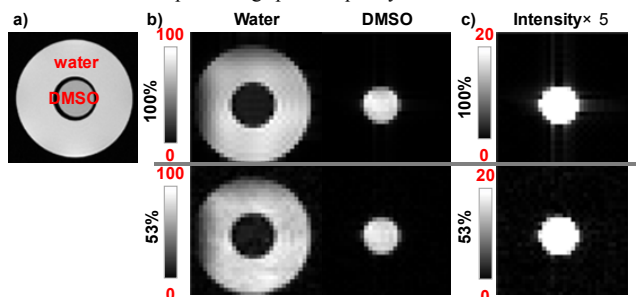
**CONCLUSION:** These experimental results demonstrated that the proposed CS method can be applied to 2D MRSI, yielding a large undersampling and acceleration factor. Such approach can improve spatial resolution without compromising spectral quality.



**Fig.1:** Random phase encoding and reconstruction procedures. (a) Random phase encoding strategy and the under sampling pattern. (b) Reconstruction scheme. (c) Unmeasured phase encoding in k-space. White voxel in (a) and (c) indicates data is collected.



**Fig.3:** Spectra obtained by using low resolution standard MRSI and the proposed high resolution CS method. (a) T2W image of a rat brain with severe hypoxic-ischemia injury and showing MRSI encoding field of view by red box. (b) Mosaic view of spectra in blue box in (a) from low resolution 100% phase encodings (PEs). (c) Corresponding spectra reconstructed from high resolution random phase encodings.



**Fig.2:** (a) T1W image of cylindrical phantom. (b) Water peak maps and DMSO peak maps of fully phase encoded and 53% random phase encoded. (c) Intensity multiplied by 5.

**REFERENCES:** 1. Barker, Prog. in Magn. Reson. Spec. 49: 99-128 (2006); 2. Vikhoff-Baaz, Magn. Reson. Med. 19:1227-1234(2001); 3. Donoho, IEEE Trans. Inform. Theory 52:1289-1306(2006); 4. M. Lustig, Magn. Reson. Med. 58:1182-1195(2007).