Accelerated Proton Echo-Planar Spectroscopic Imaging Using Parallel Imaging and Compressed Sensing

R. Otazo[1], D. K. Sodickson[1], A. Yoshimoto[2], and S. Posse[2,3]

[1]Center for Biomedical Imaging, NYU School of Medicine, New York, NY, United States, [2]Electrical and Computer Engineering Department, University of New Mexico, Albuquerque, NM, United States, [3]Department of Neurology, University of New Mexico, Albuquerque, NM, United States

INTRODUCTION: Proton Echo-Planar Spectroscopic Imaging (PEPSI) provides fast spatial-spectral encoding and has been demonstrated to map a variety of metabolites in the human brain [1,2]. Further acceleration in PEPSI can be accomplished by using parallel imaging along the phase-encoding dimension(s) [3,4]. However, the acceleration is limited by the relatively low SNR of the metabolites and g-factor related noise amplification. Compressed sensing was recently introduced as a powerful method to accelerate the MRI encoding process by exploiting the sparsity of the images in a known transform domain (e.g. wavelets) to reconstruct randomly undersampled k-space data [5]. Two-fold accelerated echo-planar spectroscopic imaging has been demonstrated with a compressed sensing technique using wavelets along the spectral dimension to sparsify the image and k-t random undersampling [6]. In this work, a joint reconstruction approach, named Parallel-Sparse PEPSI, is developed to combine compressed sensing and parallel imaging to further accelerate PEPSI encoding.

METHODS: Fully-sampled PEPSI data were acquired on a healthy volunteer using a 3 Tesla MR scanner (Tim Trio, Siemens Medical Solutions, Erlangen, Germany) equipped with a 12-channel array coil. The relevant imaging parameters include: FOV = 256 x 256 mm, image matrix = 32 x 32, slice thickness = 15 mm, spectral width = 1087 Hz, number of spectral points after even/odd echo separation = 1024, TE = 15ms, TR = 2 sec. Data acquisition included water-suppressed (WS) and non-water-suppressed (NWS) scans. The NWS scan was used as a reference to estimate the coil sensitivity maps, and perform spectral phase correction. Compressed sensing requires incoherent artifacts in the sparse domain which is accomplished by random undersampling. 4-fold acceleration was simulated by decimating the NWS and WS k-space data along the k_y-t plane where a different k_y random undersampling pattern with the same reduction factor (R = 4) was employed for each time point to distribute the incoherence along k_y and t. This type of trajectory can be implemented for PEPSI using phase-encoding blips as described in [6]. Parallel-Sparse PEPSI reconstruction was performed by adding the coil sensitivities explicitly into the compressed sensing approach for a single coil proposed in [5] and by enforcing sparsity on the single combined image rather than on each coil image. The acquisition model for each coil is given by $\mathbf{m}_i = \mathbf{F}\mathbf{S}_i\mathbf{d}$, where $\mathbf{m}_i$ is the undersampled PEPSI image in x-f space (x: image domain, f: spectral domain), $\mathbf{F}$ is the undersampled Fourier transform, $\mathbf{S}_i$ is the coil sensitivity and $\mathbf{d}$ is the PEPSI image to be reconstructed. The complete acquisition model is formulated by concatenating the individual models into $\mathbf{m} = \mathbf{E}\mathbf{d}$. The reconstructed image is given by the $\mathbf{d}$ that minimizes $\|\mathbf{E}\mathbf{d}-\mathbf{m}\|_2^2 + \lambda\|\mathbf{W}\mathbf{d}\|_1$, where $\mathbf{W}$ is the spectral wavelet transform (Daubechies), $\|\mathbf{x}\|_2 = \left(\sum |x_i|^2\right)^{1/2}$ is the L_2-norm, $\|\mathbf{x}\|_1 = \sum |x_i|$ is the L_1-norm and λ is a regularization parameter that controls the tradeoff between parallel imaging data consistency (left term) and sparsity in the spectral wavelet domain (right term). The reconstruction was implemented with a non-linear conjugate gradient approach [5]. For comparison purposes a NWS data with regular undersampling acceleration was reconstructed using SENSE as described in [3].

RESULTS: The spectral water image reconstructed with Parallel-Sparse exhibited less noise amplification and less residual aliasing artifacts than the one with SENSE for the same acceleration factor (Fig. 1). Fig. 2 shows representative Parallel-Sparse water-suppressed spectra with 4-fold acceleration compared to the fully-sampled reconstructed spectra. The Parallel-Sparse reconstruction presented moderate residual incoherent artifacts (pseudo-noise) which are mainly associated with small wavelet components that are deeply submerged in the interference created by the random undersampling pattern. However, the proposed method does not present g-factor related noise amplification which is a major limitation in standard parallel imaging.

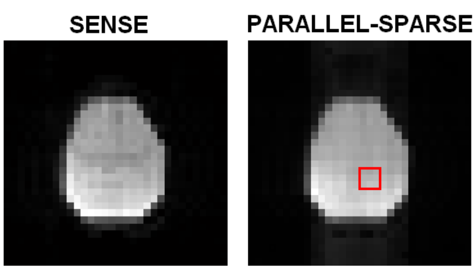

Fig. 1: Spectral water images with 4-fold acceleration.

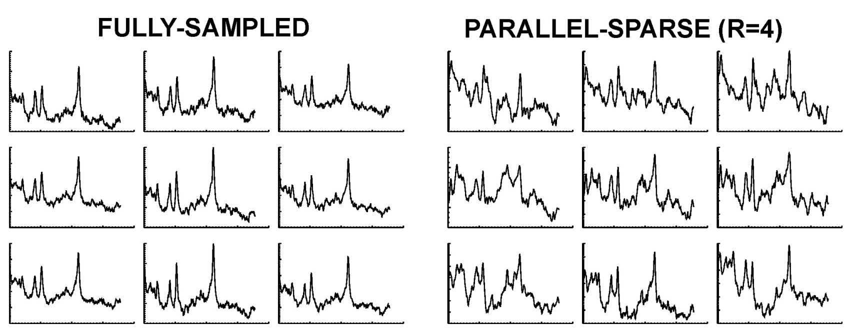

Fig. 2: Spectral arrays for the reconstructed WS data in the region indicated in Fig. 1.

DISCUSSION: The maximum acceleration available in the proposed Parallel-Sparse method is limited by the sparsity of the spectroscopic image and the number of elements in the array coil. The method could benefit from tailored sparsifying transforms which jointly weight spatial and spectral dimensions, the use of larger numbers of coil array elements and three-dimensional acquisitions that allow for k_y-k_x-t acceleration. Future work includes the implementation of the k_y-t random sub-sampling trajectory for single-shot PEPSI [8] using a 32-channel array.

GRANT SPONSOR: NIH R01-EB000447.

REFERENCES: [1] Posse S et al. Magn Reson Med 1995; 33: 34-40. [2] Posse S et al. Magn Reson Med. 2007; 58:236-44. [3] Lin FH et al. Magn Reson Med. 2007; 57:249-57. [4] Otazo R et al Magn Reson Med 2007; 58:1107-16. [5] Lustig M et al. Magn Reson Med. 2007; 58:1182-95. [6] Hu S et al. J Magn Reson. 2008; 192:258-64. [7] Posse et al. Magn Reson Med. 2008, in press.