Maximum Entropy Based Reconstruction of Echo-Planar Correlated Spectroscopic Imaging of Human Breast In Vivo

Brian Burns[1,2], Jon K Furuyama[3], Neil Wilson[4], Nicki DeBruhl[4], and M. Albert Thomas[4]

[1]*Department of Radiological Sciences, UCLA, Los Angeles, CA, United States,* [2]*Medical Imaging Informatics (MII), UCLA,* [3]*Radiological Sciences, UCLA,* [4]*Department of Radiological Sciences, UCLA*

Introduction – 2D Localized Correlated Spectroscopy (L-COSY) has been shown to be a powerful tool in the detection of breast cancer but is limited to a single voxel [1]. The recently introduced Echo-Planar based Correlated Spectroscopic Imaging (EPCOSI) sequence allows for the simultaneous acquisition of two spatial (k_y, k_x) and two spectral (t_2, t_1) dimensions in a single experiment [2]. The 4D EPCOSI sequence interleaves the acquisition of the k_x and t_2 dimensions along the EPI read-out, while k_y and t_1 lines are incrementally acquired as indirect dimensions, requiring 20 minutes for a typical scan. To reduce scan times using standard Fast Fourier Transform (FFT) based reconstruction techniques would require the reduction of either the k_y spatial or t_1 spectral dimensions, and a corresponding reduction in resolution. Maximum entropy (MaxEnt) image reconstruction techniques have been used in Nuclear Magnetic Resonance (NMR) to non-uniformly under-sample (NUS) indirect spectral dimensions and in imaging to NUS spatial dimensions then reconstruct the fully-sampled multi-dimensional spectra or image [3,4,5]. This technique can be used to accelerate the collection of 4D EPCOSI data *in vivo* by selectively under-sampling along k_y and t_1. We show that under-sampling the indirect dimensions by ~25% and reconstructing the spatially localized EPCOSI spectra using MaxEnt preserves the spatial distribution of the metabolite diagonal peaks found in healthy breast tissue and reduces the scan time to 5 minutes.

Methods – An EPCOSI scan of healthy breast was performed on a 3T Siemens Trio scanner with the following parameters: 1x1x2cm^3 voxel size, TR/TE=1.5s/30ms, 50 t_1 increments, 16x16cm^2 FOV, 1 average with water suppression and 2 averages without water suppression. The scan was retrospectively under-sampled to ~25% of the k_y-t_1 plane, using the map in Fig. 1. The NUS spatial and spectral dimensions were simultaneously reconstructed using MaxEnt. The MaxEnt algorithm uses a variant of the conjugate gradient method to iteratively solve the constrained convex optimization problem [5]:

$$maximize\ S_{1/2}(f)\ s.t.\ ||F^{-1}Kf - D||_2 <= \sigma \qquad (1)$$

where f is the estimated fully-sampled spatially distributed spectra at each iteration, F^{-1} is the inverse Fourier transform, K is the NUS matrix, D is the time-domain measured data, σ is the noise standard deviation, and $S_{1/2}(f)$ is the spin-½ entropy of the estimated spectra [3]. The spatially distributed spectra with the highest entropy are those which conform to the uniform distribution and have a flat baseline. Therefore, by maximizing the spin-½ entropy in (1), MaxEnt enforces sparsity of the estimated spectra in the frequency and k-space domains and reduces incoherent aliasing artifacts in the spectra caused by NUS. The fidelity constraint ensures that peaks in the estimated spectra and their spatial distribution must come from the sampled data to within a tolerance of the noise. The reconstruction is performed over all dimensions simultaneously as opposed to a series of 1D reconstructions as implemented elsewhere [5].

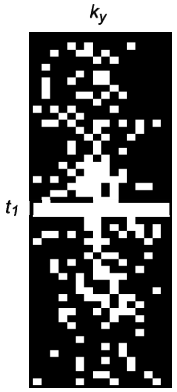

Figure 1: 4x under-sampling mask for k_y and t_1 dimensions. White points are sampled.

Results and Discussion – Figures 2A and 2B show the fully sampled and 25% MaxEnt reconstruction of the selected 2D COSY spectra from a voxel of healthy fatty breast tissue. As can be seen, the spectral characteristics of the NUS data with MaxEnt reconstruction are equivalent to the fully sampled data; the same diagonal and cross peaks are present in both spectra without a significant increase in noise. Figures 3A and 3B show the spatial distribution of the olefinic cross peak selected in Figure 2 for the fully sampled and 25% MaxEnt reconstructed 4D EPCOSI of healthy fatty breast tissue. The spatial distributions between the fully sampled and MaxEnt reconstruction show very good agreement, with the exception of some spatial bleeding on the outer edges of the distribution.

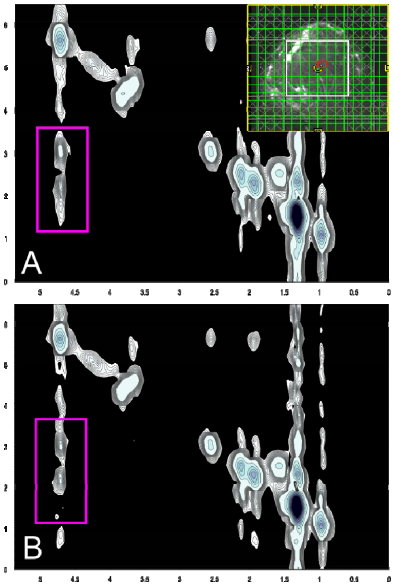

Figure 2: Selected 2D COSY spectra of healthy fatty breast tissue highlighted in red for A) fully sampled and B) 4x under-sampled with MaxEnt reconstruction.

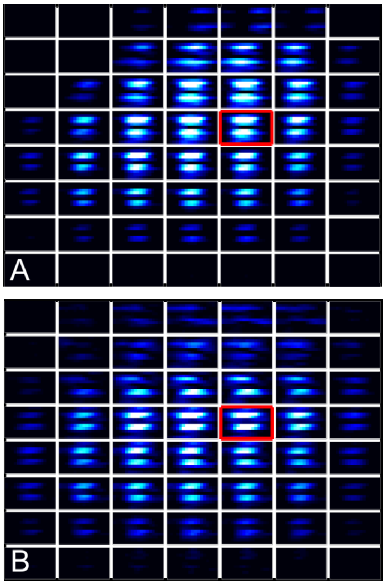

Figure 3: Spatial distribution of Olefinic cross-peaks highlighted in purple in Fig. 2 for A) fully sampled and B) 4x under-sampled with MaxEnt reconstruction.

Conclusions – We have shown that it is possible to under-sample both the spectral and spatial dimensions of an *in vivo* EPCOSI sequence by up to 25% and reconstruct the spectra with similar spatial distributions and spectral characteristics to the fully sampled data. This acceleration translates into a 5 minute EPCOSI scan time and increases the potential use of 4D MRS in the clinic. Compressed Sensing (CS)-based reconstruction can be use alternatively for processing the NUS EPCOSI data. Further research regarding the merits and demerits of the two reconstruction methods is in progress.

References – **[1]** Lipnick, et al., NMR Biomed. 2010; 23: 922-930 **[2]** Lipnick *et al,* Magn. Reson. Med. 2010; 64: 947-956 **[3]** Skilling & Bryan, Mon. Not. Roy. Astr. Soc. 1984; 211: 111-124 **[4]** Daniell & Hore Mag. Res. 1989; 84: 515-536 **[5]** Hoch & Stern, 1996, Wiley-Liss, New York **[6]** Donoho, IEEE Trans Info Theory. 2006; 52: 1289-1306 **[7]** Lustig *et al,* Magn. Reson. Med. 2007; 58:1182-1195

Acknowledgements – DoD Idea Expansion grant for Breast Cancer Research #W81XWH-10-1-0743 and NIH training grant #5T15 LM07356