Accelerating Echo-Planar J-Resolved Spectroscopy of the Prostate using Compressed Sensing in a Clinical Setting

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Introduction – Four-dimensional (4D) spectroscopic imaging (SI) techniques (2 spatial, 2 spectral) can be accelerated by making use of an echo-planar spectroscopic imaging (EPSI) readout to interleave the collection of one spatial and one spectral dimension within a single TR [1]. The two remaining dimensions must be incrementally collected, requiring scan times on the order of 20+ minutes, which is well above what is clinically acceptable. We show that the application of Compressed Sensing (CS) techniques can be implemented successfully in a clinical setting to accelerate the collection of the remaining two dimensions. As illustrated in Fig. 1, two different acceleration techniques are combined to reduce the scan time of multi-dimensional spectroscopic imaging of human prostate *in vivo*, bringing it closer to a clinical reality.

Methods – The standard echo-planar *J*-resolved spectroscopic imaging (EPJPRESS) sequence was modified to non-uniformly under-sample 25% of the fully sampled data in the $k_y t_1$ plane according to the sampling density shown in Fig. 2a. The CS-modified sequence was tested in the prostate of a healthy 34 year old male volunteer, and employed on a Siemens 3T Trio-TIM scanner. A 16x16cm^2 FOV was localized onto a 16x16 grid with a 2cm slice thickness for a nominal voxel size of 2cm^3. With TR/TE = 1500/30ms, the collection of 64 t_1 points in the indirect spectral dimension and 2 averages required 12 minutes 48 seconds with 25% of the data collected. The under-sampled data was reconstructed using a modified Split Bregman algorithm [3] which solves the unconstrained optimization problem

$$\min_m \|\nabla m\|_1 + \lambda \|F_u m - y\|_2 \qquad (1)$$

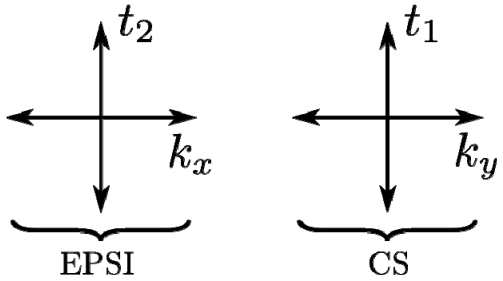

Figure 1 - Schematic showing the dimensions coupled by each acceleration strategy

where ∇ is the gradient operator, m is the reconstructed data, $||x||_n$ is the l_n norm, λ is a regularization parameter, F_u is the under-sampled Fourier transform, and y is the under-sampled data. Equation 1 removes the incoherent artifacts due to the non-uniform under-sampling by minimizing the total variation (TV) while maintaining consistency with the sampled measurements.

Results and Discussion – Figure 2b shows a spatial distribution of the *J*-resolved citrate multiplet at 2.6ppm overlaid on top of the T_1-weighted axial MRI. The citrate peaks are well localized and do not exhibit aliasing in the *y* direction that would result from under-sampling the data. The same can be seen in the indirect spectral dimension (F_1), which was also under-sampled and would be expected to exhibit aliasing. A select spectrum from the center of the prostate is shown in Fig. 2c to show the quality of the reconstruction with no visible aliasing after the reconstruction. All major metabolites, myo-Inositol (mI), creatine (Cr), choline (Cho), spermine (Spm) and citrate (Cit) are visible, and the Cit multiplet reflecting the strong coupling AB pattern is nicely *J*-resolved [4].

Conclusion – We have shown that non-uniform under-sampling techniques can successfully be implemented on a clinical 3T MRI scanner, allowing for significantly reduced spectroscopic imaging scan times. The optimization of the sampling density as well as reconstruction algorithms is expected to allow for an even greater reduction in the minimum amount of data required for reconstruction, warranting further investigation into the application of CS in multi-dimensional spectroscopic imaging.

References – [1] Lipnick *et al.* Magn. Reson. Med. **64**, 947-956 (2010). [2] Donoho. IEEE Trans Info Theory. **52**, 1289-1306 (2006). [3] Goldstein *et al.* SIAM J. Imaging Sci. **2**, 323-343 (2009). [4] Wilman et al. J Magn Reson B. 107, 25-33 (1995).

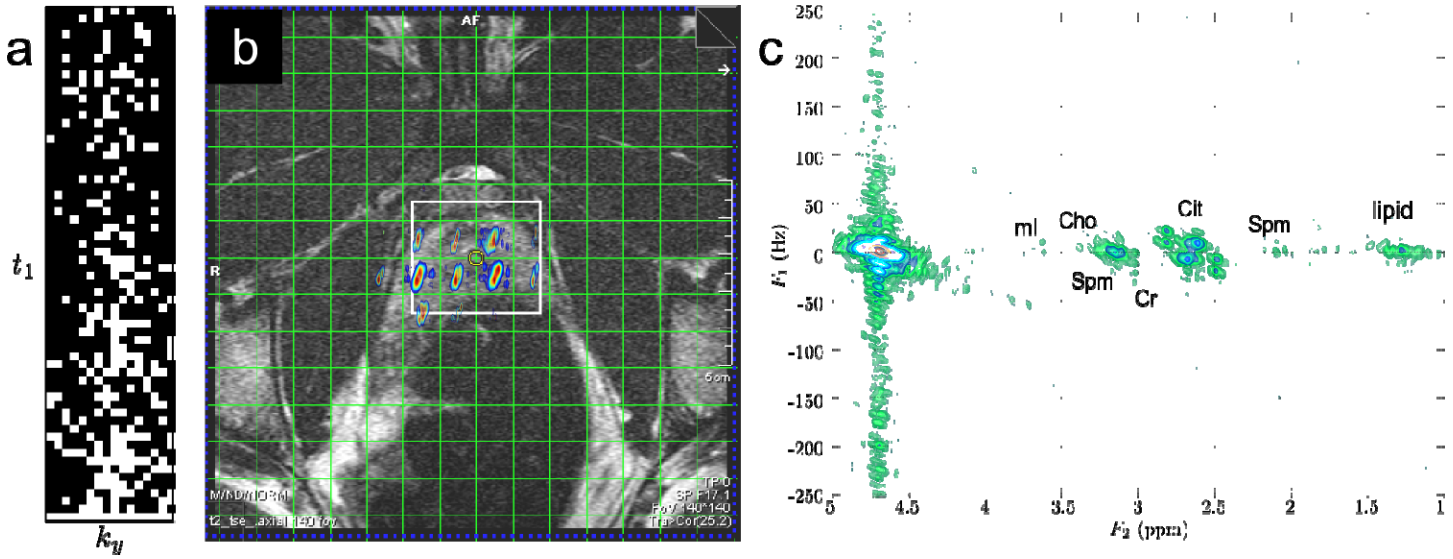

Figure 2 - a) sampling mask used to under-sample the $k_y t_1$ plane. b) T_1-weighted localization with a spatial overlay of the *J*-resolved Cit multiplet at 2.6ppm. c) select *J*-resolved spectrum taken from the center of the prostate.