Accelerated 3D-localized echo planar correlated spectroscopic imaging of calf muscle using compressed sensing

Neil E Wilson[1], Brian L Burns[1], and M Albert Thomas[1]
[1]University of California, Los Angeles, CA, United States

Target Audience: Those interested in localized correlated spectroscopy or spectroscopic imaging of skeletal muscle; those interested in nonuniform sampling (NUS) and compressed sensing (CS).

Purpose: While one dimensional (1D) spectroscopy indicates the presence of J-coupled spin multiplets by exhibiting a frequency splitting and phase modulation, there is no information about the specific coupling network as there is with 2D localized correlated spectroscopy (L-COSY) [1], which also produces much less crowded spectra. Recently, an echo planar spectroscopic imaging readout [2,3] was added to L-COSY to collect a 4D data slice in (k_x, k_y, t_2, t_1) space (EP-COSI) [4]. Showing the potential for scan time reductions, NUS was retrospectively applied on the incrementally-acquired (k_y, t_1) plane [5]. Here, we extend EP-COSI to a 3rd spatial dimension collecting data in 5D (k_x, k_y, k_z, t_2, t_1) and apply NUS prospectively on the (k_y, k_z, t_1) volume.

Methods: A human calf muscle was scanned using a CP extremity transmit/receive coil with the following parameters: TE/TR = 30/1200 ms, FOV = 16x16x12 cm^3, 1x1x1.5 cm^3 resolution, 64 t_1 increments, spectral bandwidths 1190/1250 Hz in the direct/indirect dimensions respectively, 1 average, 8x NUS for a total scan time of ~20min.

The sampling distribution followed an exponential decay from the origin of k-space. This ensures that the most influential, highest SNR data is adequately sampled [6]. While the overall envelope of a COSY signal also follows a decaying exponential, the signal envelope of the cross peaks theoretically follows a sine bell whose exponent depends on the coupling network. To enhance cross peak visibility, data was apodized by a skewed square sine curve in t_2 and a 30 degree shifted sine curve in t_1. In order to ensure the highest amplitude data after filtering was adequately sampled, the sampling distribution also followed a 30 degree shifted sine curve in t_1.

2D COSY spectra are known to be self sparse [7], so the CS reconstruction required minimization of the L1 norm of the reconstructed data subject to a data fidelity constraint.

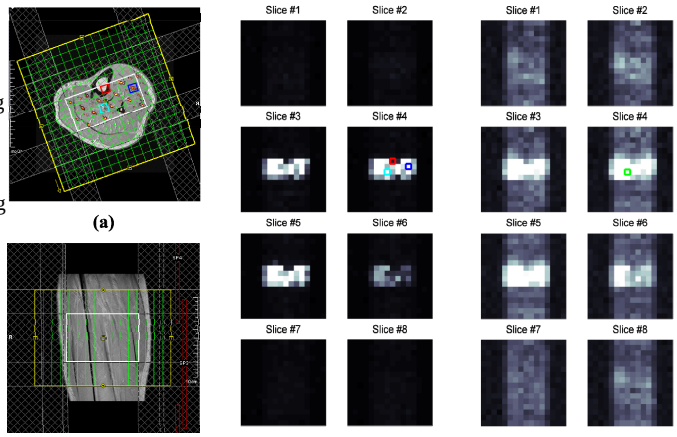

Figure 1. Human calf with 8x NUS. **(a)** Axial localization with Cr 3.9 ppm peaks overlaid, **(b)** Coronal localization, **(c)** CS-reconstructed Cr 3.9 ppm metabolite map, **(d)** raw data reconstructed Cr 3.9 ppm metabolite map.

Results: Figures 1a and 1b show the T1-weighted axial and coronal localization images. In the slice in Fig 1a, the spatial distribution of the CS-reconstructed creatine (Cr) 3.9ppm peak is overlaid on the MRI. Note the splitting in the tibialis anterior (blue) and its absence in the marrow (red). Figure 1c and 1d show the metabolite maps of Cr over each axial slice for the CS-reconstructed and raw data, respectively.

Figure 2 shows the COSY spectra from the highlighted 1.5 cm^3 voxels in the CS reconstruction soleus (a), tibialis anterior (c), and marrow (d). Figure 2b shows the highlighted voxel from the soleus of the raw data. Each spectrum also indicates the spectral region plotted for Cr at 3.9ppm.

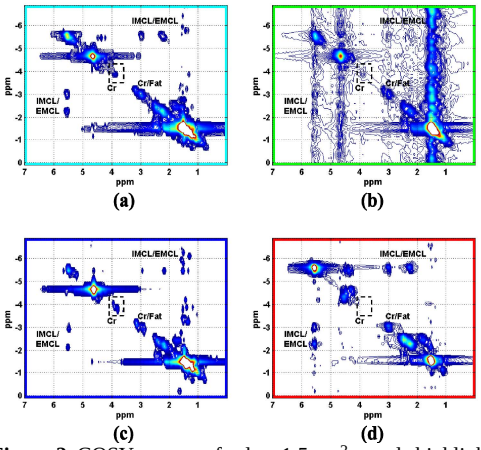

Figure 2. COSY spectra of select 1.5 cm^3 voxels highlighted in Figure 1. CS-reconstructed **(a)** soleus muscle, **(c)** tibialis anterior, and **(d)** marrow. **(b)** Raw data reconstruction of the same voxel as in (a).

Discussion: Figure 1d shows the spatial aliasing artifacts that are removed in the CS reconstruction (Fig 1c) in both the phase encode and slice dimensions. Figure 2b shows the spectral aliasing in the indirect spectral dimension that almost completely obscures the IMCL/EMCL cross peaks. The reconstruction removes this aliasing as evidenced in Fig 2a which is the same voxel location. Raw data reconstructions for the tibialias anterior and marrow show the same degree of aliasing but are not shown. Due to muscle fiber orientation in the tibialis anterior, the residual dipolar coupling of Cr does not average to zero, and the Cr peak at 3.9ppm shows a well-defined splitting [8]. This can be seen in the spatial distribution in Fig 1a and the full COSY spectrum in Fig 2c. As expected, there is no Cr visible in the bone marrow in Fig 2d. The ability to differentiate regions of the calf confirms that the CS reconstruction accurately removes spatial aliasing without significant loss of resolution.

Conclusion: NUS can be applied to the (k_y, k_z, t_1) volume of a 5D EP-COSI scan, allowing for 5D acquisition in the same amount of time it takes to fully sample a single 4D slice. CS faithfully reconstructs both diagonal and cross peaks and preserves spatial localization.

References: [1] Thomas *et al.*, MRM 2001, 46(1):58-67. [2] Mansfield, MRM 1984, 1(3):370-86. [3] Posse *et al.*, MRM 1996, 33(1):34-40. [4] Lipnick *et al.*, MRM 2010, 64(4):947-56. [5] Furuyama *et al.*, ISMRM 2012, p0008. [6] Lustig *et al.*, MRM 2007, 58(6):1182-95. [7] Holland *et al.*, AngChem 2011, 123(29):6678-81. [8] Kreis *et al.*, JMR 1996, B113(2):103-18.

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