3D Dynamic MRSI for Hyperpolarized $^{13}$C with Compressed Sensing and Multiband Excitation Pulses

P. E. Larson¹, S. Hu¹, M. Lustig², A. B. Kerr², S. J. Nelson¹, J. Kurhanewicz¹, J. M. Pauly², and D. B. Vigneron¹

¹Radiology and Biomedical Imaging, University of California - San Francisco, San Francisco, CA, United States, ²Electrical Engineering, Stanford University, Stanford, CA, United States

Introduction: Rapid, repetitive metabolic imaging using injected hyperpolarized [1-$^{13}$C]-pyruvate can provide valuable in vivo kinetic information. We have combined a multiband excitation approach [1] with a compressed sensing acquisition and reconstruction scheme [2] for dynamic $^{13}$C MRSI to allow time-resolved 3D MRSI of cellular uptake and metabolism of hyperpolarized substrates.

Methods: The spectrally selective multiband excitation pulse [1] applies a smaller flip angle to [1-$^{13}$C]-pyruvate, the injected substrate, because it has a much higher concentration and signal intensity (Fig. 2). The metabolic products, lactate and alanine, are excited by larger flip angles so they can be more easily observed. This allows for efficient use and preservation of the hyperpolarized magnetization that is crucial for dynamic imaging. Pyruvate-hydrate is not excited, which increases the spectral sparsity and improves the reconstruction. Random phase encode blips [2] were applied in both the x and y directions during a flyback EPSI readout gradient, resulting in a random sampling pattern in $k_x$-$k_y$-$k_z$ space, and the central region of k-space was fully sampled, as shown in Fig. 3. The missing encodes have an incoherent aliasing pattern because of this randomness, making the acquisition suitable for compressed sensing [2]. The random blips and phase encode ordering were varied for each temporal acquisition, introducing further randomness in the time domain for dynamic imaging. The missing data was filled in iteratively using a non-linear conjugate gradient implementation [3]. This included a total variation (TV) penalty and used a wavelet transform as the sparsifying transform in order to exploit both the spectral sparsity as well as the smoothly varying signal in time. Animal imaging was performed on a GE 3T system using a double spin-echo sequence with TE = 160ms, TR = 250ms, and 5x5x5.4 mm resolution (0.135 cc) similarly to [1,2].

Results: Figure 4 shows in vivo imaging results in a Transgenic Adenocarcinoma of Mouse Prostate (TRAMP) mouse with a time resolution of 5 s, a 12x12x16 matrix size and a factor of 7.2 acceleration using the sampling pattern shown in Fig. 3. The injected pyruvate was initially seen near the great vessels and then it increased in other tissues. Alanine was primarily observed in the liver, while the kidneys demonstrated high lactate and pyruvate. The lactate signal was highest in the tumor where it had the longest duration. In the kidneys, the lactate was also quite high but peaked earlier than in the tumor. Both the pyruvate uptake and lactate also varied spatially within the tumor.

Conclusion: This technique provides full 3D dynamic imaging through an accelerated compressed sensing acquisition and efficient magnetization usage with multiband excitation pulses, providing dynamic information resolved over a large volume.