MULTI-RESONANCE 3D SPIN-ECHO EPI WITH CHEMICAL SEPARATION FOR FAST HYPERPOLARIZED ^{13}C MRI

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Target Audience Hyperpolarized (HP) ^{13}C MRI researchers.

Purpose In hyperpolarized ^{13}C experiments, the data acquisition window is fundamentally limited by rapid metabolism and T_1 relaxation of the prepolarized spins. This constraint necessitates the adoption of fast imaging schemes such as echo planar imaging (EPI) [1]. However, the application of EPI to HP ^{13}C experiments results in images with chemical shift artifacts originating from the ^{13}C resonances from the substrate and its metabolic products. Hence, proper reconstruction approaches are needed to separate the acquired data into multiple images each containing only single chemical species. In this project, we developed and tested a fast 3D EPI sequence for rapid ^{13}C data acquisition with an accompanying multi-channel chemical separation method based on joint estimation of coil sensitivities and images of different species [2]. **Method** In this preliminary work, we focused on separating images of pyruvate and urea co-polarized and injected *in vivo*. We suppressed signal contributions of lactate, alanine, and pyruvate-hydrate with a tailored RF pulse scheme exciting only pyruvate and urea resonances [3]. *Animal Experiment Setup*: A Sprague-Dawley rat was placed between 8-channel paddle receive coils (Figure 1, left). The coils were positioned in a way such that the sensitivities vary in R/L and A/P direction. A dedicated clam shell transmitter was used together with a body loader to properly load the coil. Co-polarization of pyruvate (35uL) and urea (70uL) was done using a Hypersense. The hyperpolarized sample was injected over 12s and imaging started with 5s delay to ensure sample delivery to the entire animal. *Imaging Sequence*: A custom 3D spin-echo ^{13}C EPI sequence (TE=75ms, TR=125ms) was used to collect data (Figure 1, right). A multi-band, spectro-spatial RF pulse was designed to 1) only excite pyruvate and urea resonant frequencies without perturbing other metabolites, 2) progressively increase flip angles in each TR for optimal magnetization utilization, 3) introduce phase modulation (RF chopping) on only the urea signal (Figure 2). The RF chopping shifts urea images in phase-encoding direction (A/P) in addition to the blipped direction (R/L) of the EPI gradient. This ensures better conditioning of the inverse problem to be solved compared to shifting the images only in one direction. A 32-lobe flyback EPI readout was designed to shift urea images half the field-of-view (FOV). The final imaging matrix was 32 x 16 x 24 with 0.216 cc voxel size over a FOV of 21.6 x 9.6 x 14.4 (cm) in R/L-A/P-S/I. Total imaging time = 2s. *Chemical Separation Reconstruction*: An iterative non-linear inversion scheme was used to solve the following problem: $y=FCM_{pyr} + \Phi FCM_{urea}$. Here, y is the collected data, F is the Fourier transform, C is the coil sensitivities, M are the images of different chemical species and Φ denotes the phase modulation (RF chopping and chemical shift) done on the urea signal. Given y and Φ, we jointly estimated C and Ms. Depending on how we design the Φ matrix, we can better condition the inverse problem that results in lower *g*-factor. **Results** Figure 3 shows an axial anatomical image (a) and the acquired ^{13}C image with chemical shift (b). Note that we can observe urea image being shifted in both directions. The chemical separation reconstruction properly separates pyruvate and urea into two images (Figure 3, (c) and (d)). Note that structural details of two kidneys can be seen just from the ^{13}C images. **Discussion** In this project a new fast imaging approach was developed to enable simultaneous multi-resonance MRI using the data from multiple receiver channels to separate out the HP MR images for each molecular species. This fast 3D EPI sequence provided entire volumetric coverage in two seconds, negating T_1 relaxation effects of the hyperpolarized signals. The resulting ^{13}C images demonstrated high SNR and high spatial resolution for *in vivo* carbon-13 hyperpolarized MRI. **References** [1] Reed et al., JMR 2012;217:41-47 [2] Uecker et al., Proc. 20th ISMRM 2012, 2490 [3] Larson et al., JMR 2008;194:121-127 **Acknowledgement** This work has been supported by NIBIB P41-EB013598.

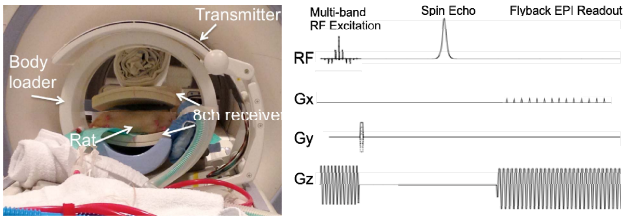

Figure 1. left) Animal experiment setup. right) 3D spin-echo EPI pulse sequence

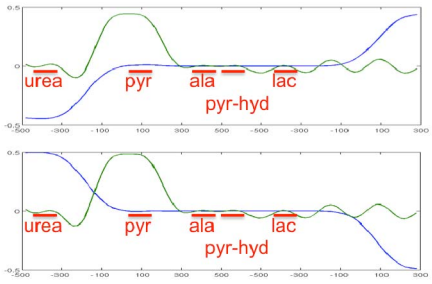

Figure 2. Excitation profiles of two multi-band RF pulses at phase encoding step of 15 (top) and 16 (bottom). Note the increase in magnitude of the magnetization and phase modulation at urea frequency.

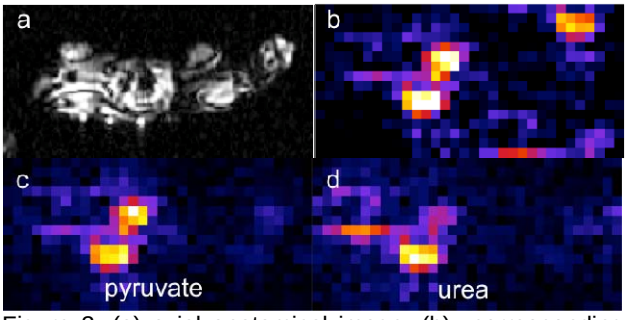

Figure 3. (a) axial anatomical image, (b) corresponding ^{13}C image, (c) seperated pyruvate and (d) urea image.