Development of a Novel 2DRF Pulse Sequence to Achieve Improved Localization in Hyperpolarized ^{13}C Imaging

Shuyu Tang[1], Hsin-Yu Chen[1], Robert A. Bok[1], Daniel B. Vigneron[1], and Peder Larson[1]
[1]*Department of Radiology and Biomedical Imaging, UCSF, San Francisco, California, United States*

Purpose: Hyperpolarization of metabolically active compounds labeled with ^{13}C is an emerging approach for imaging metabolic processes *in vivo* [1]. Here, we designed a new two-dimensional spatially-selective radiofrequency (2DRF) pulse for bolus tracking in hyperpolarized ^{13}C imaging. Bolus tracking with 2DRF is advantageous in hyperpolarized ^{13}C imaging because it reduces polarization loss and shortens acquisition time. Due to the use of a spiral excitation trajectory, our design allows for minimal perturbation of off-resonance metabolites. Since our 2DRF pulse was developed for a clinical 3T scanner with conventional gradient performances, rapid translation of our design to human studies is possible.

Methods: Our 2DRF pulse design (Fig. 1) was based on the *k*-space analysis for small-tip angles [2]. We chose constant-slew-rate inward spiral as the *k*-space trajectory [3] and a modulated Hamming-windowed jinc function as the weighting function, which generates an ellipsoid excitation profile. Off-resonance profiles and spatial selectivity of our design were tested in proton (Fig 2.) and ^{13}C phantoms, respectively. We tested our 2DRF pulse on the major vessels and kidneys of rats in *in vivo* hyperpolarized ^{13}C imaging experiments, which were performed on a GE 3T MR scanner with a custom, dual-tuned ^{13}C-^{1}H rat coil by injecting into a rat 2 mL of 100 mM [1-^{13}C]pyruvate pre-polarized in a HyperSense polarizer (Oxford Instruments). For experiments on the major vessels, our 2DRF pulse (5° flip, 5 mm-diameter cylinder) was targeted on the inferior vena cava and normal to the axial plane (Fig. 3a). Image data was read out using an echo-planar spectral imaging (EPSI) sequence [4] with TR = 1000 ms localizing to 5 × 5 × 5 mm^3 voxels along the 2DRF excitation cylinder (Fig. 3b). The bolus injection was followed by saline flush at the end. For experiments on kidneys our 2DRF pulse (30° flip) was targeted on the left kidney and normal to the coronal plane (Fig. 4b). The same EPSI readout sequence was performed for 24 s, which was followed by a 5 × 5 × 10 mm^3 2D chemical-shift imaging in the axial plane at 30 s after bolus injection (Fig. 4a). 1DRF pulse comparison studies were performed in both major-vessels and kidney experiments with all other parameters kept the same.

Results and Discussion:

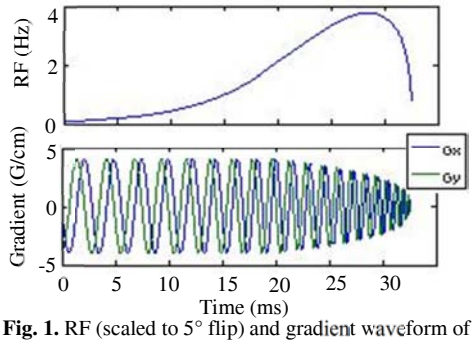

Fig. 1. RF (scaled to 5° flip) and gradient waveform of our design

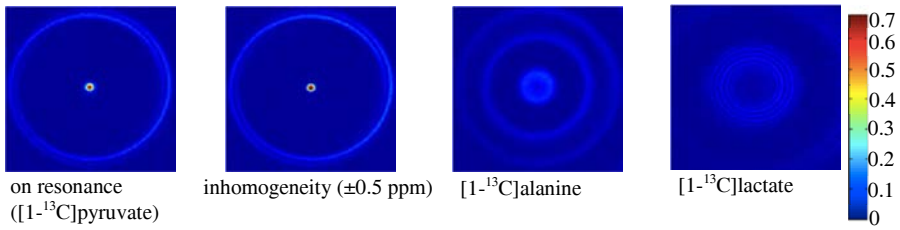

Fig. 2. Experimental excitation profiles at 3T. It can be seen that B0 inhomogeneity does not induce dramatic change in the pattern and amplitude of the profile, in contrast, frequency offsets corresponding to alanine and lactate at 3T significantly blur and reduce the peak excitation, which is attributed to the use of a spiral trajectory. The above results also indicate that when our designed RF is applied at the pyruvate frequency it will minimally perturb the metabolic products while being immune to ±0.5 ppm magnetic field inhomogeneity at 3T.

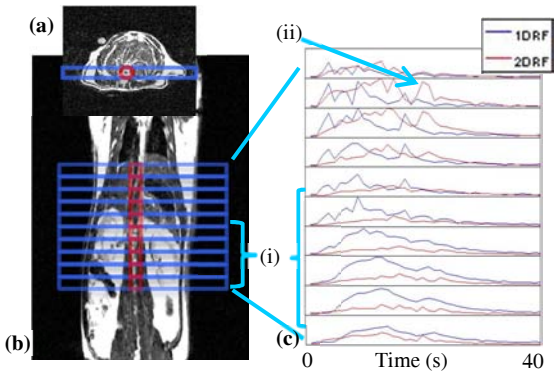

Fig. 3. Excitation (a), acquisition (b) and hyperpolarized ^{13}C-labeled pyruvate signals (c) with 1DRF (blue) and 2DRF (red) pulses applied on the major vessels. The pyruvate signal demonstrates that our designed 2DRF was able to monitor dynamic signals of injected bolus. A slower signal arrival with 2DRF was due to a slower manual injection. The second peak (ii) in time results from the saline flush of residual pyruvate in the catheter. The pyruvate signals of 2DRF decay from superior to inferior corresponding to where the pulse prolife intersects the major vessels while pyruvate signals of 1DRF are increased at the kidney level (i), probably due to pyruvate arriving in the kidneys, demonstrating the importance of spatial selectivity of 2DRF.

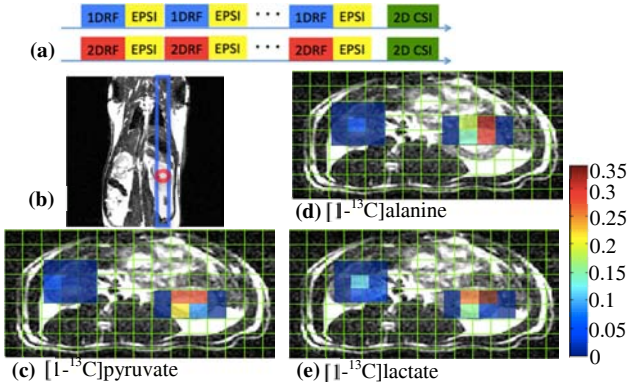

Fig. 4. "Bolus tracking" sequence schematic diagram (a), excitation scheme (b), and 2D CSI comparison results (c-e) of a hyperpolarized ^{13}C experiment with 1DRF and 2DRF on the left kidney. The maps are the percentage differences (PD) ((S(2D)-S(1D))/S(2D)) between the CSI acquired after 2DRF and 1DRF bolus tracking pulse sequences. (Normalized by the maximum signal in the right kidney.) High PD of all the three metabolites in left kidney is due to increased saturation of hyperpolarized magnetization with 1DRF compared to the more spatially selective 2DRF. Therefore, 2DRF is advantageous for bolus tracking and results in a greater SNR in subsequent imaging.

Conclusion: We have successfully designed a 2DRF pulse to improve localization in hyperpolarized ^{13}C imaging and applied it to track the hyperpolarized ^{13}C-labeled pyruvate bolus *in vivo,* while minimally perturbing the metabolic products of lactate and alanine. The parameters of our design are based on clinical scanner limits, which allows for rapid translation to human studies.

References: [1]Kurhanewicz J, et al. Neoplasia 2011;13:81-97.[2] Pauly J, et al. JMR 1989;81:43-56.[3] Hardy CJ, Cline HE. J Appl Phys 1989;66:1513-1516.[4] Mansfield P. MRM 1984;1:370-386.