Simultaneous Imaging of ^{13}C Metabolism and ^{1}H Structure for Improved Co-Registration and Off-Resonance Correction

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INTRODUCTION: Simultaneously acquired ^{1}H information can provide constraining or calibration data, aiding in the reconstruction of non-proton nuclei [1, 2]. For instance with an accurate estimate of field inhomogeneity, acquisition times could potentially be lengthened to increase SNR. To demonstrate the utility of simltaneously acquired ^{1}H data, Cartesian and spiral pulse sequences were modified for simultaneous imaging of hyperpolarized (HP) [1-^{13}C]pyruvate metabolism and ^{1}H nuclei using spectral-spatial (SPSP) and conventional slice-selective excitation schemes. The simultaneously acquired ^{1}H data provides complementary information that was used to localize and aid in the reconstruction of ^{13}C metabolites, while requiring little to no lengthening of the scan time.

METHODS: Two experiments demonstrated utility of the simultaneous approach. One used a Cartesian acquisition to simultaneously acquire a fat/water anatomical reference for registration to the ^{13}C metabolic images. A second used a sprial multi-echo acquisition to obtain a real-time field map for improved inhomogeneity correction.

Cartesian Imaging: For the Cartesian acquisition, a 15ms SPSP RF pulse was designed for independent excitation of ^{13}C metabolites (TR/TE = 21.7/10.9ms, independent metabolite flip-angles θ_{Pyr} = 15°, θ_{Lac} = 30°). Multinuclear image sets of pyruvate and water were simultaneously acquired with a gradient echo (GRE) sequence, followed immediately by lactate and fat. In order to further preserve the ^{13}C polarization and maintain the same FOV (in the phase encoding direction), every 4th phase encode was acquired on the ^{13}C channel.

Spiral Imaging: For the spiral accquisition, ^{13}C data were reconstructed using a least-squares model [3]. Five echoes were acquired (TR/TE/ΔTE = 50/0.6/1.19ms, 26.8ms readout duration, and independent flip-angles θ_{13C} = 15°, θ_{1H} = 30°). The field map for each timeframe was estimated from the simultaneously acquired spiral ^{1}H data using an image-space IDEAL algorithm [4]. Performance of the reconstruction using the real-time field map estimation was compared to a single reference field map acquired prior to simultaneous imaging with a Cartesian multi-echo GRE sequence (TR/TE/ΔTE = 16/4.2/0.4ms and 8 acquired echoes).

All experiments were performed on a 4.7T small animal scanner (Agilent, Palo Alto, CA) using a commercial dual-tuned ^{1}H/^{13}C volume coil (Doty Scientific, Columbia, South Carolina). The transmission and demodulation frequencies were independently set for ^{1}H and ^{13}C, and reception was performed with two separate amplifiers, each demodulated by the appropriate frequency (**Fig. 1**). ^{1}H data were acquired with 0.5mm^2 resolution and a 2.5mm thick slice, resulting in 2mm^2 in-plane resolution and a slice thickness of 10mm for ^{13}C. A five second delay was inserted between timeframes to allow for metabolism to occur.

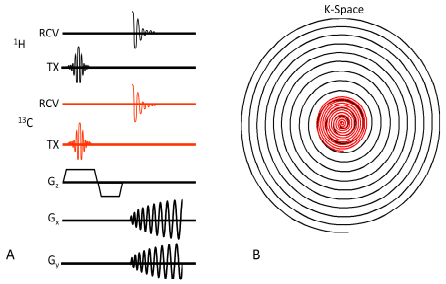

Figure 1. The simultaneous pulse sequence (A) illustrates the spiral acquisition used in this work. The ^{13}C k-space trajectory (B) is modulated by $\gamma(^{13}C)$, leading to a factor of 4 increase in FOV and voxel size relative to ^{1}H.

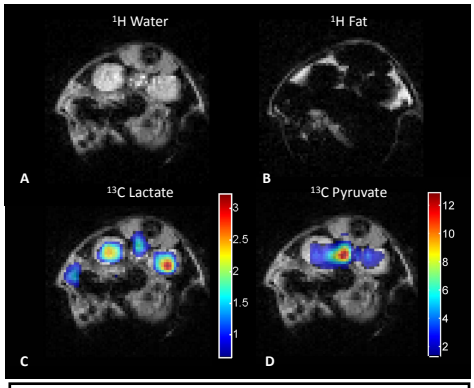

Figure 2. Simultaneous images of renal metabolism acquired with a SPSP excitation. ^{1}H images show excellent separation of water (A) and fat (B). Metabolite images (C, D) agree well with the underlying anatomy.

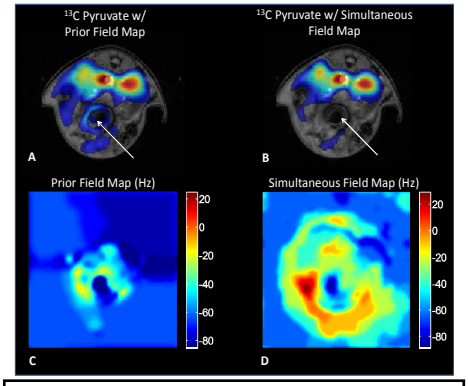

Figure 3. Single time point pyruvate images (A, B) and field maps obtained from ^{1}H data (C, D). The mis-estimation of field inhomogeneity manifests as spurious signal in the ^{13}C dataset reconstructed with the prior Cartesian field map.

RESULTS: Fat and water images (**Fig. 2A, B**) show excellent separation of the renal cortex from surrounding adipose tissue. Metabolite maps of lactate and pyruvate (**Fig. 2C, D)** agree well with the anatomy. Reconstruction with the a priori field map leads to phase related errors in the metabolite images (**Fig. 3A**) not seen when using the simultaneously acquired field map (**Fig. 3B**). The errors correspond to artifacts likely from pulsatility and abdominal motion visible in the a priori Cartesian field map (**Fig. 3C**) absent in the real-time spiral field map (**Fig. 3D**).

DISCUSSION: The simultaneous imaging method proposed here allows estimatation of the real-time field inhomogeneity from dyanamic ^{1}H images rather than prior to ^{13}C imaging. While motion artifacts present in the Cartesian field map could be mitigated with flow-suppressing gradients, motion between scans cannot be accounted for. Overall, the data from both nuclei results in images that are inherently registered both spatially and temporally, mitigating artifacts related to inter-scan motion that change the estimate of local field inhomogeneities, and in turn can lead to incorrect measures of metabolism. Moreover, simultaneous SPSP pulses enable tailored excitation for each chemical species on both channels in a time efficient manner. This is advantageous for HP ^{13}C experiments, as the concentration of the injected substrate is typically an order of magnitude greater than its product metabolites.

REFERENCES: [1] Peterson et al., ISMRM 2010; p. 1020. [2] Smith et al., Transactions on IEEE, 2011; 99: 45-49. [3] Gordon et al., ISMRM 2012; p. 4299. [4] Hernando et al., MRM 2010; 63(1): 79-90.

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