Signal Enhancement in Low-Dose Hyperpolarized ^{13}C Imaging using Multi-Slice FSEPSI Sequence

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Introduction

Last year, we reported [1] *in vivo* ^{13}C metabolic imaging of dog prostate using 1.4mL/kg of hyperpolarized ^{13}C-pyruvate. In this dog study, we explored the application of an FSEPSI sequence to enhance signal to noise ratio (SNR) for low-dose, hyperpolarized ^{13}C imaging applications. The sequence utilized a 90° slice-selective excitation pulse followed by a train of slice-selective 125° refocusing pulses to maintain the transverse magnetization of the selected slice under CPMG condition. The magnetization outside of the imaging slice was remained undisturbed by the long T1 relaxation time of ^{13}C-labeled metabolites. Spectroscopic imaging data were acquired by employing a symmetric EPSI waveform [2] at spin echo. Multiple slices were imaged, each with a single-shot FSEPSI acquisition. The performance of FSEPSI was evaluated by the SNR and image quality comparisons to single-slice fastCSI [3] of the same doses.

Method

***Animal and Experimental Setup*:** Healthy adult male beagles were used in the study. The animal preparation procedure followed a protocol approved by the UCSF Institutional Animal Care and Use Committee. The experimental setup is similar to that in the previous dog study [1]. Modifications have been made to improve the receptivity of the dual-tuned ^{1}H/^{13}C endorectal coil [4]. The clamshell ^{13}C transmit coil was reconstructed to work with a 16kW power amplifier to deliver 0.63 uT of B1. All experiments were performed on a 3T GE Signa system. ^{13}C-pyruvate was polarized by dynamic nuclear polarization technique and dissolved in TRIS/EDTA NaOH solution [5], yielding a 250mM concentration. Polarization ranged from 16% to 22%. Each dog was injected three times at 2-hour intervals. An amount of 0.36mL/kg or 0.18mL/kg was injected each time, which was 1/4 or 1/8 of the dose used previously [1].

***Pulse Sequence*:** Multiple slices were imaged sequentially. The 90° excitation and 125° refocusing pulses were designed [6] to have matched profile and bandwidth (1750 Hz and 1650 Hz for the 90° and 125° pulses, respectively). Given the chemical shift of ~450 Hz between lactate and pyruvate peaks at 3T, the excited slice location between the two was offset by 27% of the slice thickness. Therefore, a slice thickness of 7 mm with a 3 mm gap was prescribed in order to avoid disturbing the magnetization of adjacent slices. The symmetric EPSI waveform was used to optimize sampling efficiency [2]. Spectral bandwidth of 500Hz was sampled in 16 time points. FOV was 9cm X 8cm and in-plane resolution was 5mm. Six slices were imaged to cover the prostate in 6 seconds. The fastCSI parameters used in dog prostate imaging were reported in Ref. 1.

Data Analysis: All FSEPSI data including ramp samples were used in the analysis. Both kx and ky domains were zero-filled to 32. A 20Hz Gaussian spectral apodization and 100/50 Fermi k-space filter were applied before Fourier transform to spectral and spatial domains. Odd and even EPSI echoes were added in magnitude. The fastCSI data analysis followed the method described in Ref. 1 and 3. The SNR reported here is the maximum SNR in prostate, normalized to 7mm slice and 18% polarization.

Results

Profiles of the 90° excitation and 125° refocusing RF pulses match well (Fig. 1). The ripples outside of the profiles are very small and thus, allow the longitudinal magnetization outside the imaging slice undisturbed. The signal intensity of metabolites are presented in colors, overlay on proton images for 0.36mL/kg (Fig. 2) and 0.18mL/kg (Fig. 3) doses. The color scale is normalized to the maximum signal of each metabolite and therefore, cannot be used for cross comparison. Strong pyruvate signal is found in urethra. Lactate signal is more evenly distributed in prostates. The round object in the middle of the endorectal coil is an internal reference made of 1.7M ^{13}C-lactate. It shows that the proton and ^{13}C-lactate images are registered well. FSEPSI yields 38:1 and 31:1 lactate SNR, and 53:1 and 34:1 pyruvate SNR at 0.36mL/kg and 0.18mL/kg doses, respectively. Compared to fastCSI (not shown) of the same doses, the FSEPSI lactate signal is 26% and 16% larger and the FSEPSI pyruvate signal is 82% and 21% larger than the fastCSI signals at 0.36mL/kg and 0.18mL/kg dose levels, respectively.

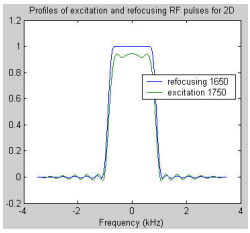

Figure 1: Profiles of 90° (blue) and 125° (green) RF pulses.

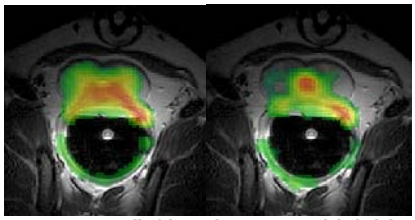

Figure 2: Lactate (left) and pyruvate (right) images overlay on proton images of dog prostate. The injection dose was 0.36mL/kg of 250mM concentration.

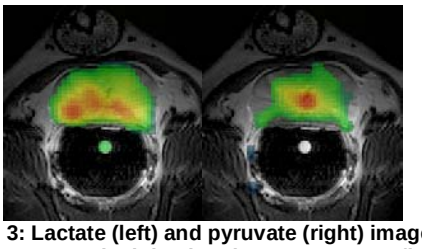

Figure 3: Lactate (left) and pyruvate (right) images of dog prostate. The injection dose was 0.18mL/kg of 250mM concentration.

Discussion and Conclusion

FSEPSI yields good SNR at low dose levels and demonstrates advantages in SNR and imaging volume coverage over fastCSI. The sequence is extendable to 3D acquisition. If T2 relaxation time of ^{13}C-metabolites is long enough, the FSEPSI sequence can be applied to 3D imaging to obtain isotropic spatial resolution and continuous coverage of the prostate.

Reference:

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