EPSI Sampling Strategies for Spectroscopic Imaging of Sparse Spectra: Applications for Hyperpolarized 13C imaging

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Introduction

Echo Planar Spectroscopic Imaging[1,2] (EPSI) is a popular sampling technique for fast 3D spectroscopic imaging. Here we report EPSI sampling strategies in gradient echo sequences that improve signal to noise ratio (SNR) for metabolic imaging using hyperpolarized ^{13}C-pyruvate[3,4]. The ^{13}C spectrum consists of pyruvate and its metabolic products, lactate and alanine, as well as pyruvate-hydrate (in dynamic equilibrium with pyruvate but not metabolically active) over 500 Hz at 3T[5]. We applied variable flip angles (VFA) and centric phase encoding (PE) techniques to fully utilize the unrecoverable magnetization while optimizing the overall image quality. The EPSI waveform design is subject to a trade-off between spectral bandwidth (BW) and spatial resolution. We explored the following strategies: 1) EPSI-flyback with 500Hz BW, 2) EPSI-flyback with strategically reduced BW, and 3) EPSI-symmetric waveform with 500Hz BW.

Method

VFA and Centric PE: The combination of VFA and sequential PE improved SNR and image quality in hyperpolarized ^{129}Xe imaging[6]. In this work, since the *in vivo* T1 is unknown and metabolites undergo different dynamics[5], we designed the VFA by assuming T1 is infinite. Following the injection of hyperpolarized ^{13}C-pyruvate, scan started after a time delay in order to image on the plateau of lactate dynamic curve[5] while the pyruvate signal decayed due to both the T1 relaxation and metabolic exchange. Centric PE allows us to sample the relatively high signal from the origin of k-space and yet obtain balanced signal in the outer k-space. This strategy (EPSI+) was evaluated in simulation using the *in vivo* dynamic curves and also validated in rat experiments.

EPSI Designs: EPSI-flyback is very efficient for proton imaging because of its relatively small gyromagnetic ratio. For ^{13}C imaging of 5-mm resolution, the efficiency of EPSI-flyback is only 47% with 500Hz BW. By allowing a smaller bandwidth, the efficiency can be improved but the spectrum needs to be unfolded in reconstruction[7]. With 265Hz BW, the efficiency is 75% and the folded metabolic peaks are almost equally spaced. Because the ^{13}C spectrum is sparse, the spatial distribution of each metabolite resolves without spectral leakage. Finally, we explored the EPSI-symmetric waveform and used all data sampled (on ramps and plateaus) for analysis[8]. The efficiency was 85% after correcting for sampling density.

Animal Studies: Sprague-Dawley rats were used in the studies. Their blood oxygen saturation and heart rate were monitored during scans. A typical dose consists of pyruvic acid/EPA mixture dissolved in TRIS/EDTA solution, yielding a 79mM concentration. 3mL was injected in 12 seconds. All animal experiments were approved by UCSF Institutional Animal Care and Use Committee.

Results

Metabolic spectra, ^{13}C (color) and proton (gray) images of rat kidney are shown in Figure 1. In the spectrum of 265Hz BW (middle), lactate (L), pyruvate (P), and pyruvate-hydrate (P-H) peaks are wrapped around, and pyruvate and pyruvate-hydrate peaks overlap. Bicarbonate peak, which is ~700Hz off resonance, is visible, located in between alanine (A) and pyruvate. For symmetric EPSI, spectra (right) of odd (blue) and even (red) echoes have similar signal to noise, although there is a small shift between the two, possibly due to eddy current distortion of the EPSI waveform. All ^{13}C images show strong signal in kidney.

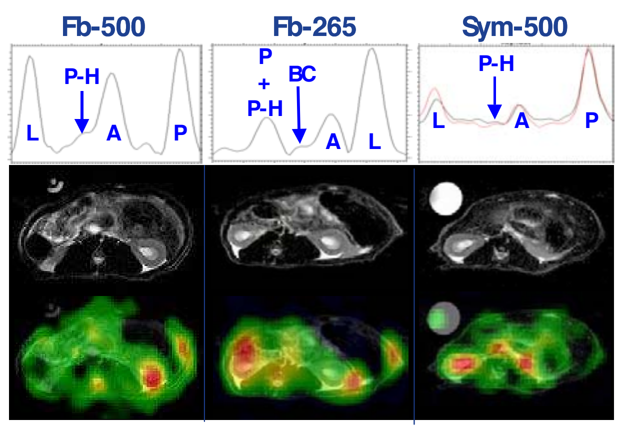

Figure 1: Metabolic spectra and images of rat kidney using EPSI-flyback 500Hz BW (left), EPSI-flyback 265Hz (middle) and symmetric EPSI 500Hz BW (right). The Sym-500Hz spectra show a small shift between the odd (blue) and even (red) echoes.

Table 1: Signal to noise (SNR) comparisons. The *in vivo* lactate SNR was the maximum SNR within rat kidney. The reference lactate SNR was measured from the syringe. The expected ratio was derived from simulations for *in vivo* lactate SNR.

	in vivo Lac SNR	Ref Lac SNR	Expected
EPSI : EPSI+	1 : 2.44	1 : 1.33	1 : 2.0
Fb 500: Fb 265	1 : 1.19	1 : 1.40	1 : 1.28
Fb 500: Sym 500	1 : 1.85	1 : 1.32	1 : 1.41

SNR comparisons (Table 1) show enhanced *in vivo* lactate SNR by a factor of 2.44 comparing the baseline EPSI (constant flip angles and sequential PE) and EPSI+ (VFA and centric PE). Both the 265Hz bandwidth and symmetric waveform result in SNR improvement.

Conclusion:

These strategies combined can lead to a 3-4 fold SNR improvement in 3D spectroscopic imaging using hyperpolarized ^{13}C-pyruvate.

Reference:

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