Effects of RF excitation scheme on signal-to-noise-ratio and apparent rate constant estimation in dynamic volumetric imaging of hyperpolarized [1-13C]-pyruvate

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Introduction

Recent studies have demonstrated dynamic metabolic imaging of hyperpolarized pyruvate (Pyr) and its metabolic products for a wide variety of applications [1]. While 3D techniques permit the largest volumetric coverage, they require a large number of RF excitations, which can have a substantial impact on the shape of the dynamic response, the calculation of apparent rate constants, and signal to noise ratio (SNR) averaged over the response. Multiband spectral-spatial RF pulses provide an efficient use of hyperpolarized magnetization for dynamic imaging by using a low excitation flip angle for the injected substrate to preserve its magnetization for subsequent conversion and a higher flip angle for the metabolic products to increase their SNR [2]. However, due to different tissue perfusion, i.e., in- and outflow rates, and metabolic activities, the optimal excitation scheme might depend on the specific organ. This work investigates the performance of different flip angle schemes in multiple organs.

Methods

All measurements were performed on a GE 3T MR scanner with custom-built dual-tuned ($^1H/^{13}C$) transmit-receive quadrature coils (body coil: dia=8cm, length=9cm; or brain coil: dia=5cm, length=6cm). Healthy male Wistar rats (n=5, 183-365g) were injected in a tail vein with 2.25-3 ml of 80-mM solution of [1-^{13}C]-pyruvate that was hyperpolarized via DNP. The time from dissolution to start of injection was 20-21s. Imaging was started at 5 s after the start of injection.

A multiband spectral-spatial RF excitation pulse was designed as described in [3], with a 5º flip angle for Pyr and 20º for lactate (Lac) and alanine (Ala) while suppressing Pyr-hydrate, with peak B1=0.21G, duration=15.2ms and 4cm slab excitation. The 5º/20º Pyr/Lac RF pulse amplitude was also scaled down to achieve a 2º/8º or 1º/4º flip angle pairing. Dynamic 3D ^{13}C data were acquired for kidney and liver using the 1º/4º, 2º/8º, 5º/20º multiband or 5º/5º flip angle schemes, and for brain using the 2º/8º and 5º/20º schemes. A 2D undersampled spiral spectroscopic imaging sequence [3] was extended for volumetric coverage. Imaging parameters were:

Body coil (kidney/liver): clinical gradients, FOV=80×80×60mm^3, 5×5×5mm^3 nominal resolution, 36 excitations/volume, TR=4.91s.

Brain coil: insert gradients, FOV=43.5×43.5×64.8mm^3, 2.7×2.7×5.4mm^3 nominal resolution, 12 excitations/volume, TR=1.64s. TR/excitation=136.5ms, TE=9ms, spectral width=280Hz were used in both cases. Note that a given flip/excitation leads to a much higher flip/TR as multiple excitations are needed to image the volume.

The data were reconstructed similarly to the 2D case described in [3] with an additional Fourier transform step in the slice direction. Metabolic maps for Pyr, and Lac were calculated by integrating the signal around each peak in absorption mode. Regions of interest (ROIs) were manually drawn for each organ to calculate the time-courses of Pyr and Lac signals. A weighted average image was also computed for each organ by using the respective normalized time-resolved signal intensities as weights to average the data from all time-points. Lac SNR was calculated from the weighted average images. Apparent Pyr-to-Lac rate constant fits were also obtained for the data after correcting for the differing RF excitation schemes used.

Results and Discussion

Figure 1 shows representative time-courses of Pyr and Lac signals from liver and brain ROIs as well as the weighted average Lac images. Each of the flip angle schemes allows the measurement of signal dynamics and estimation of apparent exchange rates, with different SNR depending on Pyr inflow/refresh rate of the targeted organs.

The 2º flip provided adequate Pyr SNR for dynamic measurements while preserving more Pyr for metabolic conversion vs. the 5º flip. Comparing the Lac SNR from the weighted average images, the average ratio of SNR of 2º/8º to SNR of 5º/20º was: brain=1.44±0.08; kidney=1.27±0.24; liver=1.11±0.07. The relative SNR ratios of 1º/4º:2º/8º:5º/20º were 0.74:1:0.84 in kidney and 0.74:1:0.9 in liver (in 1 animal). The SNR of 2º/8º relative to 5º/5º was 1.13 in kidney and 1.26 in liver (in 1 animal).

The 2º/8º provides significantly higher Lac SNR in the brain as Pyr crosses the blood brain barrier during the bolus peak with little inflow afterwards and the cumulative effect of a 20º flip over 12 excitations quickly saturates the stationary Lac. In comparison, there was no significant difference in Lac SNR of the 5/20º and 2/8º schemes for kidney and liver. The higher inflow rates in kidney and liver provide fresh Pyr spins available for conversion every TR, however the highly saturated sampling with 20º flip over 36 excitations provides no SNR gain over the 8º per excitation. The 8º flip angle also gave better fit quality for apparent exchange rate estimation than the more heavily saturated 20º case, by allowing a more accurate compensation for the effect of RF sampling (Table 1).

In conclusion, the 2º/8º excitation scheme for dynamic 3D imaging provides good SNR for a wide range of transport kinetics and metabolic activity allowing estimation of tissue specific apparent rate constants.

	2º/8º		5º/20º	
	Apparent K_{pl} (s^{-1})	$\chi 2$	Apparent K_{pl} (s^{-1})	$\chi 2$
Brain	0.023 ± 0.004	0.007-0.01	0.026± 0.004	0.23-0.33
Kidney	0.012± 0.001	0.01-0.05	0.015± 0.002	0.09-0.19
Liver	0.040± 0.005	0.005-0.009	0.039± 0.005	0.01-0.03

Table1: Similar apparent Pyr-to-Lac (K_{pl}) rate constants were obtained with both 2º/8º and 5º/20º schemes, but the fit quality ($\chi 2$) was better with 2º/8º due to a more accurate RF correction

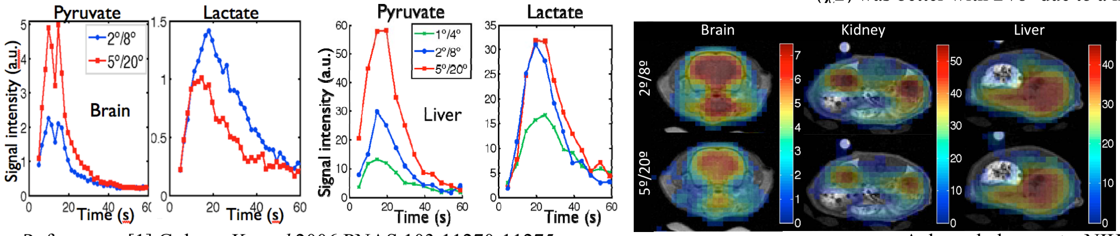

Figure1: Representative time courses from brain and liver, and weighted average Lac images. The 2º/8º flip angle scheme provided higher Lac SNR in brain and equal SNR in kidney/liver vs. the 5º/20º

References: [1] Golman K *et al* 2006 PNAS 103:11270-11275
[2] Larson P *et al* 2008 JMR 194:121-127 [3] Mayer D *et al* 2009 MRM 62:557:564

Acknowledgements: NIH RR09784, AA05965, AA018681, AA13521-INIA, EB009070 and EB007588