Single-Shot Spiral Chemical Shift Imaging in the Rat *In Vivo* with Hyperpolarized [1-^{13}C]-Pyruvate

D. Mayer[1,2], Y-F. Yen[3], A. Takahashi[3], J. Tropp[3], B. K. Rutt[2], R. E. Hurd[3], D. M. Spielman[2], and A. Pfefferbaum[1,4]
[1]Neuroscience Program, SRI International, Menlo Park, CA, United States, [2]Radiology, Stanford University, Stanford, CA, United States, [3]GE Healthcare, Menlo Park, CA, [4]Psychiatry and Behavioral Sciences, Stanford University, Stanford, CA, United States

Introduction

Hyperpolarization of metabolically active substrates such as [1-^{13}C]-pyruvate permits new approaches to the investigation of *in vivo* metabolism using MRS and chemical shift imaging (CSI) [1,2]. However, the transient nature of the signal amplification necessitates fast data sampling techniques. Spiral chemical shift imaging simultaneously encodes 1D spectral and 2D spatial information, but the achievable spectral bandwidth (SW) is limited by gradient strength and slew rate. This is particularly a problem in hyperpolarized ^{13}C imaging as the lower gyromagnetic ratio corresponds to a four-fold decrease in gradient performance when compared to proton CSI. The aim of this work was to achieve single-shot metabolic imaging in the rat *in vivo* by using undersampled ^{13}C spiral CSI (spCSI) [3] in combination with a high-performance gradient insert.

Materials and Methods

All measurements were performed on a clinical 3T MR scanner (GE Healthcare, Waukesha, WI) with a high-performance insert gradient coil (500 mT/m, 1865 mT/m/ms, 160-mm inner diameter) [4]. A custom-built dual-tuned (^{1}H/^{13}C) quadrature coil (∅ = 80 mm) was used for both RF excitation and signal reception. Healthy male Wistar rats (400 - 446 g) were anesthetized with 1-3% isoflurane in oxygen (~1.5 L/min). The rats were injected in a tail vein with ~3 mL of an 80-mM solution of [1-^{13}C]-pyruvate that was hyperpolarized via dynamic nuclear polarization (~20% liquid state polarization) using a HyperSense polarizer (Oxford Instruments Molecular Biotools, Oxford, UK).

Single-shot spCSI (FOV = 72×72 mm^2, 18×18 matrix, SW = 310 Hz, T_{acq} = 125 ms) was compared to conventional phase-encoded pulse-acquire CSI (FIDCSI) using the same spatial parameters and T_{acq} = 24 s. A variable-flip-angle scheme was applied in FIDCSI to maximize the use of longitudinal magnetization [2]. CSI started 35 s after the bolus injection of hyperpolarized pyruvate. In a second experiment, single-shot multi-slice spCSI (FOV=80×80 mm^2, 16×16 matrix, SW = 280 Hz, α_{exc} = 15º) was used to acquire time-resolved metabolic data (TR = 3 s) from slices through the kidneys and the heart of a rat.

After apodization of the undersampled spCSI data, "spectral tomosynthesis" reconstruction as described in [3] was performed. The data were gridded using the measured *k*-space trajectory [5] followed by 2D-FFT. Metabolic images of pyruvate (Pyr), lactate (Lac), and alanine (Ala) were calculated by integrating the signal around each peak in absorption mode.

Results and Discussion

Metabolic images of Pyr, Lac, and Ala acquired with spCSI and FIDCSI from a 10-mm axial slice through the kidneys of a rat are shown in Fig. 1. The metabolic images are superimposed onto a high-resolution ^{1}H fast spin-echo image (2-mm thickness) from the same slice. The images acquired with spCSI (Fig. 1a) exhibit a similar metabolite distribution and image quality as the FIDCSI data (Fig. 1b) despite the almost 200-fold reduction in acquisition time. There is no intrinsic SNR disadvantage of the faster spCSI method in the case of hyperpolarized MRI, as the longitudinal magnetization does not recover.

Figure 2 shows the time courses of the different metabolites from region of interest (ROIs) in the left kidney and the heart of a rat. With a slice thickness of 5 mm, the ROI in the kidney was 1 cm^3 and the 0.5 cm^3 in the heart.

Conclusion

The presented data demonstrate the feasibility of single-shot hyperpolarized ^{13}C metabolic imaging *in vivo* using spCSI with an acquisition time of 125 ms. This method can be applied to obtained dynamic measurements of the spatial distributions of the metabolites with high temporal resolution. The spatially-resolved time courses for each metabolite may be used to estimate tissue and organ specific reaction kinetics and rate constants. The extension to volumetric imaging is also straightforward.

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References

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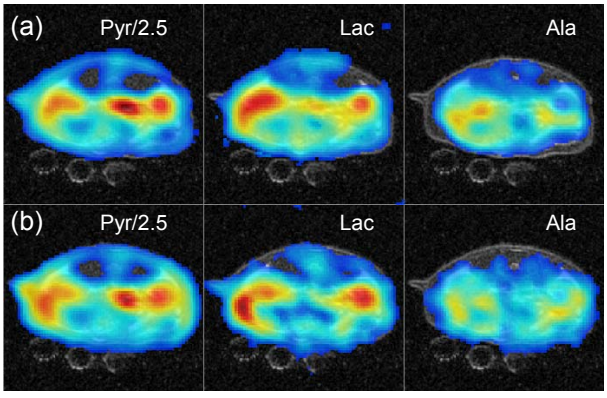

Fig. 1: (a) Metabolic images of Pyr, Lac, and Ala acquired with single-shot spCSI in 125 ms. Color scale is the same for all images (with Pyr scaled down by 2.5), threshold at 15% of maximum. (b) Same as (a), but acquired with FIDCSI (T_{acq} = 24 s).

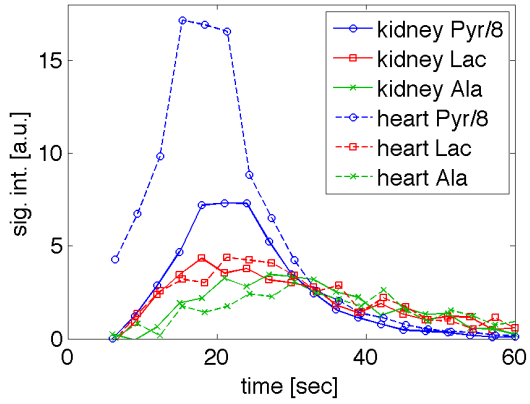

Fig. 2: Time courses of the average signal intensity from ROIs in the left kidney (solid) and heart (dashed) for Pyr (blue circle), Lac (red square), and Ala (green cross). The time courses for Pyr are scaled down by a factor of 8.