Multi Gradient and Spin-Echo Radial Acquisition for Hyperpolarized ^{13}C MRSI

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Target Audience

Scientists and engineers interested in new acquisition methods for hyperpolarized MRSI.

Introduction

Magnetic resonance spectroscopic imaging (MRSI) of hyperpolarized (HP) ^{13}C-labeled substrates permits real-time investigation of cancer metabolism in vivo[1,2]. Due to the T_1 relaxation of HP agents and the nonrenewable signal loss from radiofrequency (RF) excitation, care should be taken to optimize HP acquisition strategies. Sequences must provide spatial, temporal, and metabolic differentiation while preserving signal to adequately probe metabolic kinetics. We have recently investigated 2D multislice radial MRSI acquisitions for cumulative and single-time point imaging of HP [1-^{13}C] pyruvate at 7 Tesla[3]. A multiband frequency encoding (MBFE) approach[4] can simultaneously provide spatial and chemical differentiation within one gradient echo. Unfortunately, SNR and spatial resolution are limited by the rapid T_2* relaxation (T_2*$_{\text{effective, in vivo}}$ ~ 12 ms at 7T) and the long readout window. In vivo spin echo imaging of HP agents is challenging, due to potential signal cancelation caused by 180° refocusing pulses in combination with flowing HP spins, but provides substantial benefits including: insensitivity to local field inhomogeneities and increased SNR due to the long T_2 of HP ^{13}C pyruvate. Long readout windows and long adiabatic inversion pulses result in lengthy minimum spin echo times that exceed the cardiac rate of mice and limit the ability to measure HP tracer volumes in the heart. Such measurement is desirable for estimating vascular input functions (VIFs), which can be used for subsequent kinetic modeling. A radial gradient-echo imaging approach was recently developed to measure the VIF of T_1-reducing contrast agents in the left ventricle for improved dynamic contrast-enhanced (DCE-) MRI analysis in mice[5]. In this work, we investigate the feasibility of a multi-echo radial MBFE sequence in which a gradient-echo is used to measure the VIF of HP pyruvate in the blood and a train of spin-echoes is used to enhance SNR for tumor measurement. The sequence was evaluated in dynamic HP phantoms and in a murine model of anaplastic thyroid cancer in vivo.

Methods

A 2D multislice radial MBFE sequence[3] was modified to alternatively acquire spin-echo and gradient-echo projections in distinct slices. To test the acquisition, a 1-mL syringe was filled with HP [1-^{13}C] pyruvate, inserted into the magnet isocenter, and was scanned using the developed sequence. Acquisition parameters included a train of four spin echoes at 65-ms increments and a train of gradient echoes at 45-ms increments. Dynamic scans were acquired over 1.5 minutes (TR=750 ms, 120 projections). A 20° excitation angle was prescribed in combination with two 8-mm slices that were placed over homogeneous regions of the dynamic phantom. Nonselective hyperbolic secant pulses (180°, 19.5 ms) were used for refocusing. Sequence parameters for in vivo imaging were identical except the gradient-echo slice was positioned over the mouse heart and the spin-echo slice was prescribed over the tumor (Figure1). Polarization of a 26-mg sample of pyruvic acid was performed with a HyperSense polarizer[6]. To avoid unwanted interaction with spins during agent injection, the sequences were initiated immediately after 200 µL of HP agent was administered into the animal. A dual-tuned ^{1}H/^{13}C volume coil was used for phantom imaging, and a 15-mm ^{13}C surface coil was used to enhance sensitivity for in vivo imaging on a 7T 30-cm Bruker BioSpec MRI system.

Results

Dynamic phantom images illustrate the advantages for spin echo imaging of HP tracers compared with the T_2*-sensitive gradient echo acquisitions. As shown in Figure 2, spin-echo images of HP [1-^{13}C] pyruvate are persistent throughout all four echoes, whereas signal is almost completely gone after the second gradient echo. Relaxation times are shorter in vivo, and spin motion in the heart contributes to a rapid loss of signal for gradient-echo images, making only the first gradient echo useable for VIF measurement. This is illustrated in Figure 3, which shows the global dynamic time courses derived from the radial MBFE sequence for each of the echoes.

Discussion

We have demonstrated a hybrid radial MRSI sequence that is useful for measuring the VIF in the heart and generating global metabolite time courses or images representing the cumulative average of metabolites over time (data not shown). Efforts are ongoing for reducing echo spacing and improving spatiotemporal resolution through constrained reconstruction.

References

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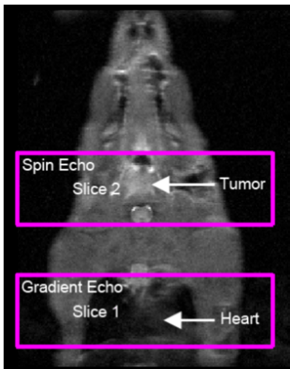

Figure 1: The spin-echo slice is placed over the tumor and the gradient echo slice over the heart.

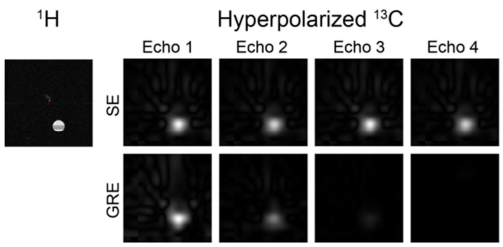

Figure 2: Radial spin- and gradient-echo pyruvate images (right) generated from each of the four echoes. Due to the T_2/T_2* ratio, spin-echo signals are much more persistent. Pyruvate images correlate well with the ^{1}H reference image (left).

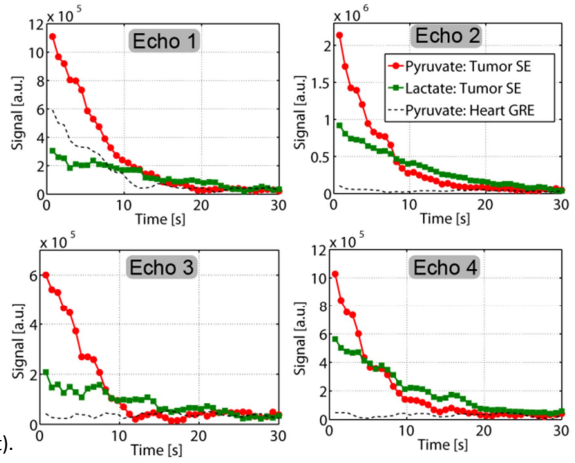

Figure 3: Dynamic global metabolite time courses derived from the hybrid MRSI imaging sequence (right).