^{13}C Echo Planar Spectroscopic Imaging with Spectral Spatial Excitation in a Clinical System

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Abstract: Echo planar spectroscopic imaging sequence with spectral spatial selective pulses for hyperpolarized ^{13}C in clinical system is presented. The spectral spatial selectivity was achieved using binomial pulse module to produce different flip angles across the spectral domain. The sequence was tested on a clinical 3 T whole body Siemens scanner using dedicated ^{13}C coils. The sequence allows fast imaging with more efficient use of the non-recoverable magnetization in hyperpolarized magnetic resonance imaging.

Zusammenfassung: Hier wird eine Echo-Planar-Spektroskopische Bildgebungssequenz (engl.: EPSI) mit räumlich und spektral selektiven Pulsen vorgestellt. Die duale Selektivität wurde mithilfe einer binomialen Pulsfunktion erreicht, womit verschieden starke Anregungen in voneinander getrennten Frequenzbereichen erreicht werden können. Die Methode wurde *in vitro* an einem klinischen 3T Ganzkörperscanner (Siemens), ausgerüstet mit einer ^{1}H-^{13}C-Spule (Rapid), getestet. Die neue Sequenz erlaubt eine schnelle Bildgebung mit gleichzeitig hoher spektroskopischen Auflösung bei effizienter Nutzung der nicht wiederherstellbaren hyperpolarisierten Magnetisierung.

Motivation

Since the introduction of dissolution Dynamic Nuclear Polarization technique (dDNP) [1], Magnetic Resonance Spectroscopy (MRS) of hyperpolarized ^{13}C has emerged as a powerful modality to image metabolic turnover *in vivo* [2]–[4]. The enhanced magnetization obtained from hyperpolarization is, however, short-lived, and the magnetization spent on excitations is non-recoverable. This dictates the use of specialized MR sequences that can better utilize the decaying magnetization. Many fast sequences, that were originally designed for ^{1}H MRS [5]–[7], have now been tailored for use with hyperpolarized ^{13}C MRS. However, the availability of most of these acquisition methods in many clinical platforms is still limited. This hinders the transition of hyperpolarized ^{13}C MRS from preclinical to human studies.

The objective of this work is to implement fast ^{13}C echo-planar spectroscopic imaging (EPSI) pulse sequence in a Siemens system with binomial excitation modules, which make better use of the non-recoverable magnetization from hyperpolarization.

Material und Methoden

The implementation of the EPSI sequence and the spectral-spatial selective pulses (SSSP) were done in a Trio scanner (Siemens Healthcare, Germany), with a maximum gradient strength and slew rates of 38 mT/m and 170 mT/m.s, respectively. The sequence was design starting from a Siemens CSI-FID product sequence by incorporating a binomial pulse module in the excitation, with a maximum of 10 sub-pulses, and by modifying the phase encoded readout to echo planar spectroscopic readout.

The binomial pulse used in this experiment consists of two sub-pulses with duration of 800 us each and 5.4 ms time interval between the sub-pulses, resulting in an interval of 93 Hz between the stopband and passband in the frequency domain of the pulse. The echo planar readout was designed with train of bipolar gradients with echo spacing of 1 ms, yielding a maximum resolution of 5 mm in the

Fig. 1: The sequence diagram of 2D SSSP-EPSI with three sub-pulses in the excitation and echo planar readout in one of the two spatial directions.

readout direction. Figure 1 shows the sequence diagram of SSSP-EPSI.

The ^{13}C images were acquired using a ^{13}C mm diameter birdcage ^{13}C coil (RAPID Biomedical, Germany). 7 mL vial phantoms of urea was used in the experiments.

Results

Figure 2 shows the sinusoidal spectral response for the excitation module obtained from the experiment, with the ^{13}C-urea phantom.

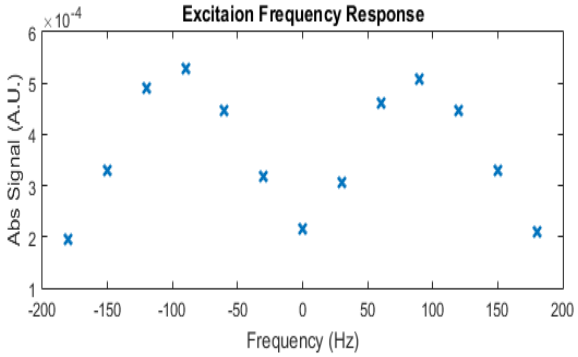

Fig. 2: The absolute signal from the urea phantom obtained with a binomial model of 2 sub-pulses, which had 180^{o} phase difference resulting in cutoff for on resonance substrate.

Discussion

The binomial spectral-spatial selective pulses utilized in this work provide tunable flip angles for different frequency offsets. These pulses can be used to excite the injected hyperpolarized substrates less, while exciting metabolic products more. Binomial pulse are relatively shorter compared to other types of spectral spatial selective pulse [8] and they are more robust toward inhomogeneity in B1 field. These pulses are also easy to design.

The EPSI sequence used here allows short imaging duration which is crucial for hyperpolarized applications.

Conclusion

An implementation of ^{13}C EPSI sequence with binomial spectral spatial selective excitation in a clinical system was presented. The sequence allows fast imaging with controllable flip angle in the spectral domain which makes it very well suited for hyperpolarized imaging.

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