Single-Shot $^{13}C\{^{1}H\}$ Polarization Transfer Spectroscopy with 3D Proton Localization and Double Adiabatic Spin Echoes

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INTRODUCTION

Adiabatic polarization transfer techniques have been used for improving the sensitivity of in vivo ^{13}C MRS where surface coils are necessary for optimal sensitivity and 3D ISIS, which is prone to subtraction errors and significantly increases the overall RF power deposition, has been the choice of spatial localization in adiabatic polarization transfer due to the non-selective BIR-type pulses needed. Here we propose a single shot 3D localized "mostly" adiabatic polarization transfer method. Single shot 3D spatial localization is achieved here using two 90° slice-selective non-adiabatic pulses and a pair of AFP pulses for slice-selective adiabatic refocusing. Other than the two slice-selective 90° pulses, all other pulses in the polarization transfer sequence are adiabatic.

METHOD

The experiments were performed on a Bruker 4.7T 29.5cm bore horizontal magnet capable of primate studies. A single loop, 6-cm in diameter, ^{13}C surface coil was placed inside a butterfly ^{1}H coil which is formed on the surface of a 12-cm diameter cylindrical tube (Fig. 1). A 6-cm diameter bottle containing concentrated 1-^{13}C-glucose and a 6-cm diameter bottle containing 2 mM ^{13}C -labeled glutamate were used for sequence optimization. A thin layer of corn coil was used to mimic extracerebral lipids. The pulse sequence was constructed based on the INEPT sequence (Fig. 2). Due to the inhomogeneity of the surface coils, adiabatic pulses were used for both ^{13}C and ^{1}H channels except for the two slice-selective nominal 90° pulses (500 us, sinc3). Prior to polarization transfer, an AHP pulse (1.2 ms, modified tanh/tan) on ^{13}C channel with crusher gradients was used to eliminate signals directly from ^{13}C. This pulse together with decoupling (WALTZ-4, 9.6 ms) eliminates the need for phase cycling to cancel direct ^{13}C signals. It also simplifies the outer volume suppression (OVS) which can therefore be restricted to the proton channel only. The first slice-selective 90° pulse acts as an excitation pulse for protons attached to ^{13}C. Two subsequent slice-selective AFP pulses (1.5 ms, sech, u=4, 1% truncation) on the proton channel form two spin echoes (TE=12.5 ms) and refocus chemical shift evolution. The ^{1}H-^{13}C one bond evolution was reintroduced using a ^{13}C AFP pulse (1.5 ms, sech, u=4, 1% truncation) and a nominal delay of 1/4J (β) before the second slice-selective 90° pulse on proton which acts as a de-excitation pulse and creates the ^{1}H-^{13}C longitudinal two-spin order (H_zC_z) in the localized volume only (4x3x4 cm^3, dashed box in Fig. 1). OVS using a slice-selective nominal 90° sech pulse (1.5 ms, u=5, 1% truncation) along the y direction was added after the formation of H_zC_z to further suppress lipid signals close to the ^{13}C coil. Then the longitudinal two-spin order was converted into ^{13}C signals by the second AHP pulse (1.5 ms, modified tanh/tan) on ^{13}C. The ^{13}C signals are then rephased during γ (γ=1/2J for 1-^{13}C-glucose, 1/4J for 4-^{13}C-glutamate).

RESULTS

Fig.3 shows an axial phantom image of the circular ^{1}H butterfly coil. Four magnitude spectra shown in Fig. 4 were obtained from the phantom containing concentrated 1-^{13}C-glucose. The single shot 3D proton localization in our sequence clearly eliminated the peaks from the natural abundance ^{13}C in corn oil. The non-localized spectra were obtained by setting all gradients and the RF power of the OVS pulse to zero. Fig. 5 shows the spectra obtained from the glutamate phantom (NS = 32, lb = 5 Hz) demonstrating excellent sensitivity and outer volume suppression.

DISCUSSIONS

The phantom image demonstrated excellent B_1 field homogeneity of the circular butterfly coil, as compared with conventional planar butterfly coil. Of all the RF pulses in Fig. 3, the two 90° slice-selective pulses are therefore the least susceptible to B_1 inhomogeneity if all pulses were made non-adiabatic. These two pulses are made non-adiabatic to facilitate single-shot spatial localization. All other polarization transfer pulses in Fig. 2 are adiabatic. As a result, signal loss due to B_1 inhomogeneity is minimized. The spectra were presented here in magnitude mode for convenience. The first order phase accumulated during the γ delay can be eliminated using either linear prediction or an adiabatic refocusing BIREF-1 pulse on ^{13}C and a simultaneous AFP pulse on proton. For studies focusing on glutamate C-4 (34.2 ppm) and glutamine C-4 (31.7 ppm) turnover at 4.7 Tesla, the spectra can be easily phase- and baseline-corrected without using linear prediction or the additional pulses.

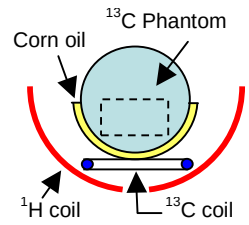

Fig.1 Coil and phantom setup.

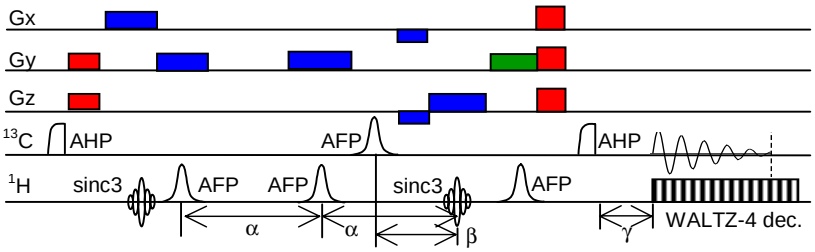

Fig. 2. Pulse sequence for the adiabatic polarization transfer ^{13}C spectroscopy.

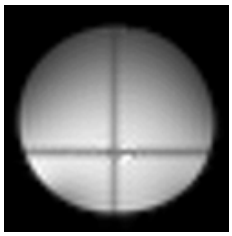

Fig. 3 Phantom image by ^{1}H coil

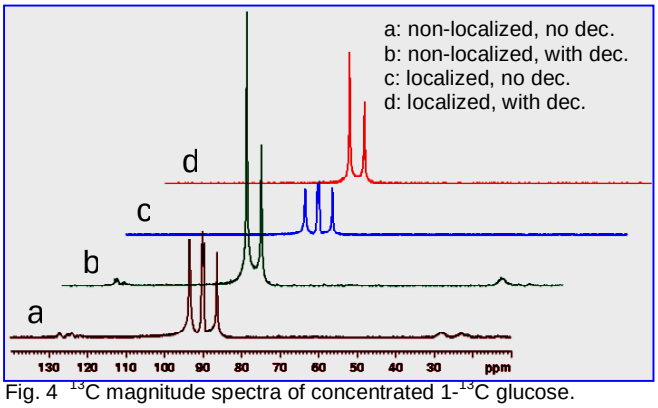

Fig. 4 ^{13}C magnitude spectra of concentrated 1-^{13}C glucose.

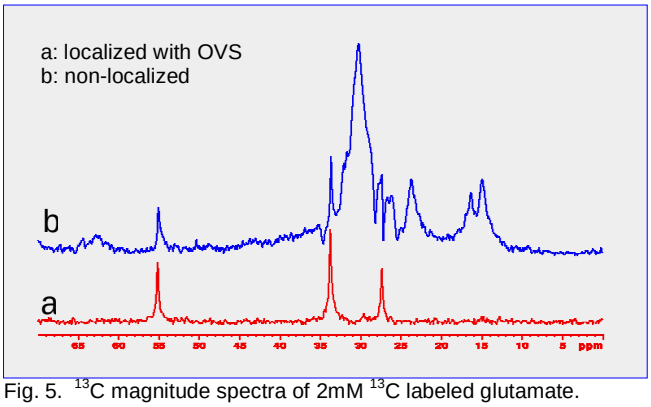

Fig. 5. ^{13}C magnitude spectra of 2mM ^{13}C labeled glutamate.