A New Method for Proton Detected Carbon Edited Spectroscopy Using LASER

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Introduction

Recent studies have shown that ^{13}C MR can provide information about tissue energetics including the rate of the neurotransmission as mediated by the most abundant neurotransmitter, glutamate. One of the approaches used for monitoring ^{13}C is indirect detection through ^{1}H due to the gains in sensitivity. Indirect detection is most often performed by inverting the carbon-coupled proton magnetization on alternate scans and using difference editing. Recently, further improvements have been implemented; ACED-STEAM[1] used a 3D-localization in single scan, and adiabatic POCE used a fully adiabatic pulse sequence[2]. Also a fully adiabatic single scan 3D-localization method, LASER[3], has been introduced. Here we propose a new method, a modified LASER sequence, for the purpose of performing indirect detection of ^{13}C.

Methods

Previously published LASER sequence[3] was modified for the purpose of performing adiabatic carbon editing and decoupling (Fig. 1). Following water suppression with VAPOR, ^{1}H resonances were excited using adiabatic half passage (AHP) (4 ms). A broadband ^{13}C inversion pulse (inversion bandwidth = 12 kHz, length = 5 ms) which is turned on and off during alternating scans was implemented during the first of the six stretched hyperbolic-secant-inversion (HS8) (1.5 ms) pulses used for 3D-localization. The ^{13}C AFP and first ^{1}H AFP were centered relative to each other and to the center of evolution under J_{CH} (160 Hz). Adiabatic decoupling (HS8 pulses with a five-step phase cycle combined with MLEV-4) on carbon channel was applied during the entire acquisition time.

In vivo ^{1}H detected spectra with carbon editing using modified LASER were recorded at 9.4 T (31 cm horizontal bore) magnet from a 215 μL volume of rat's brain.

Following an overnight fast, five male Sprague-Dawley rats were intubated and both femoral veins and arteries were cannulated for glucose infusion and blood sampling. Blood gases and glycemia were measured every 15 minutes to ensure stable physiological conditions. Plasma glucose C1 isotopic enrichment was rapidly raised from 1.1% to 70% and maintained at this level using [1-^{13}C]glucose.

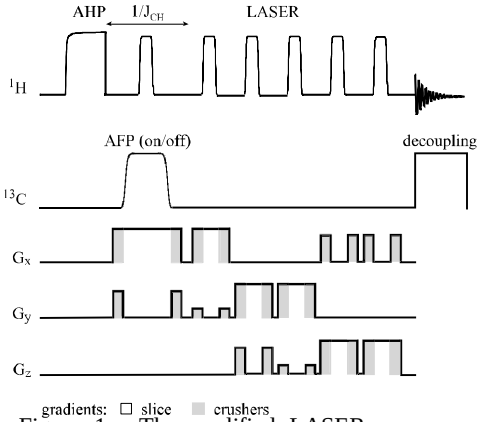

Figure 1. The modified LASER sequence. The sequence is preceded by water suppression with VAPOR.

Results and Discussion

Fig. 2a and 2b show non-edited and edited ^{1}H-{^{13}C} NMR spectra using the new method and 2c shows the edited spectrum using ACED-STEAM[1]. The non-edited ^{1}H spectrum is equivalent to standard ^{1}H spectrum acquired in the absence of ^{13}C label. In edited spectra, only protons bound to ^{13}C in different metabolites were observed after subtracting spectra obtained with and without AFP pulse applied on ^{13}C channel.

The conversion of the LASER sequence to new pulse sequence is easily accomplished by inserting appropriate delays and AFP on ^{13}C channel. The edited spectrum with the modified LASER sequence demonstrates excellent sensitivity and spectral resolution. The signal to noise ratio as measured on C4 glutamate resonance was 24 obtained during 8 min acquisition from 215 μL volume. Considerably less intense resonances such as C4 glutamine, C3 and C2 aspartate, and lactate were also observed. The quality of this spectrum was compared to the spectrum obtained with ACED-STEAM during the same study, using the identical volume of interest. Each sequence was independently optimized. The gain in signal to noise compared to ACED-STEAM varied between 30 to 70% among the resonances. The less than 100% recovery of the signal using LASER can in part be explained by proton-proton J-evolution in LASER. In experiments where homogeneous excitation is possible without the use of AHP (i.e. using separate transmit and receive coils), the gains in LASER based editing can be improved by employing a slice selective excitation and four AFP instead of six for only within slice localization.

In conclusion, the proposed LASER-based editing sequence retains the single-shot localization of ACED-STEAM while combining it with the advantage of the full sensitivity of a fully adiabatic editing sequence. Such sensitivity gains are expected to be useful in measuring neurotransmitter metabolism in small, functionally specialized areas of the brain.

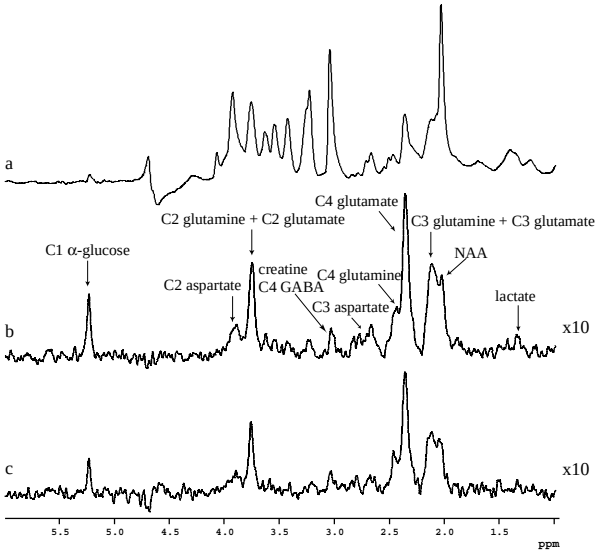

Figure 2. ^{1}H spectra obtained with (a) ^{13}C broadband decoupling with modified LASER (TE=28 ms, TR=4 s, 64 scans), (b) ^{13}C editing and broadband decoupling with modified LASER (TE=28 ms, TR=4 s, 128 scans), and (c) ^{13}C editing and broadband decoupling with ACED-STEAM (TE=6.3 ms, TR=5 s, 128 scans) from 215 μL volume in vivo during infusion of [1-^{13}C]glucose. All spectra were processed with 3 Hz Lorentzian to Gaussian line broadening and no baseline correction was applied. The vertical scale in (b) and (c) are 10-fold expanded as compared to (a).

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