Feasibility of ^{13}C NMR spectroscopy of the human brain at 7 Tesla using adiabatic ^{1}H decoupling

Rolf GRUETTER[1], Gregor ADRIANY[1], Peter ANDERSEN[1], Kamil UGURBIL[1]
[1]University of Minnesota, Center for MR Research, Minneapolis, MN USA;

Introduction

Optimal sensitivity of ^{13}C NMR spectroscopy requires ^{1}H decoupling, whose applicability may be limited by the FDA guidelines for SAR, especially at very high magnetic fields, where SAR requirements are increased. In the past four years, we have consistently shown that broadband decoupling of the human head was possible at 4 Tesla (1) using a dedicated RF coil design (2). Provided that the SAR for a given bandwidth increases linearly with static field, our previous results suggested that decoupling of the amino acid and neurotransmitter signals should be possible at 7 Tesla using similar methods in conjunction with adiabatic decoupling.

The purpose of the present study was to explore the feasibility of ^{1}H decoupled ^{13}C NMRin humans at 7 Tesla in conjunction with adiabatic decoupling and quadrature RF coil design.

Methods

All experiments were carried out on a 7 Tesla whole-body system with a 38 cm i.d. head gradient coil (Magnex) and a Siemens gradient amplifier interfaced with a Varian INOVA console. Shimming was performed using FAST(EST)MAP (3). The RF coil consisted of a proton quadrature coil with 11cm x 14cm loop dimensions each, in conjunction with a 10 cm carbon observe coil according to previous designs (2). The coils were capacitively coupled using a balanced output circuitry. An RF shield was incorporated into the resonant structure to reduce radiative losses.

A small sphere containing 99% enriched ^{13}C formic acid was used to calibrate RF power and decoupling RF field at the ^{13}C coil center. One-dimensional projections along the ^{13}C coil axis were used to estimate the RF inhomogeneity used for calculating local SAR.

Pulse sequence consisted of bi-level decoupling using WALTZ-16 for NOE generation and ^{1}H WALTZ-16 decoupling or adiabatic decoupling for 102 ms using a hyperbolic secant RF pulse with a low R value as the basic element according to procedures described elsewhere (4).

Excitation was achieved using a 1.5 ms rapid half-passage RF pulse applied within 500 Hz of the resonances of interest. The repetition time TR was adjusted to maintain SAR within FDA guidelines.

Five subjects were studied and power calibrations were consistent between subjects indicating reproducible coil loading.

Results

The adiabatic decoupling scheme we used resulted in a bandwidth of approximately 3 ppm at 7 Tesla (900 Hz) illustrated in Fig. 1, while cycling sidebands were assessed to be below 4% on-resonance. In phantoms, this scheme was shown to provide an ~30% increased decouplig bandwidth compared to WALTZ-16 at the same average RF power deposition.

Sensitivity of ^{13}C NMR at 7 Tesla was increased, as judged from the detection of natural abundance glycogen C1 at 100.5 ppm in human calf muscle using only 16 excitations (Fig. 2).

Improved sensitivity and spectral resolution were implied by the consistent detection of 4 resolved myo-inositol resonances in human brain, the resolved detection of glutamate (Glu) and glutamine (Gln) C2 and the detection low concentration metabolite signals such as aspartate (Asp, 53.2ppm) and taurine (Tau, 48.3 ppm) shown in Fig. 3 (480 transients, no apodization). Spectral resolution implied that possibly choline (Cho) and creatine (Cr) could be resolved at 54.7 ppm (inset of Fig. 3). When placing the ^{1}H decoupling frequency on the Cr methyl resonance at 3.0 ppm, the aspartyl C3 NAA resonance at 54.0 ppm (^{1}H resonance at 4.4 ppm) was fully decoupled in vivo.

Discussion and Conclusion

At equal average deposited RF power, the use of adiabatic pattern decoupling can increase the decoupling bandwidth and therefore reduce RF power requirements. The detection of a decoupled NAA C3 resonance at 54.0 ppm implied a bandwidth of approximately 1 kHz in vivo. Substantial gains in sensitivity were implied from the detection of glycogen using only a few number of excitations (Fig. 2) as well as the detection of low concentration (1-2 mM) metabolites, such as Asp and Tau (Fig. 3), corresponding to 16 nmol/g of ^{13}C concentration.

We conclude that ^{1}H decoupling of the human brain is feasible using surface coils and adiabatic decoupling methods at 7 Tesla and that spectral resolution in ^{13}C NMR spectra increases substantially with static field. By adjusting the repetition time TR it was possible to maintain the SAR within the FDA guidelines, while decoupling a 3 ppm bandwidth at 7 Tesla, suggesting that natural abundance brain glycogen, as well as neurotransmitter and glutamine turnover can be detected in humans at a higher spectral and spatial resolution than previously possible (5).

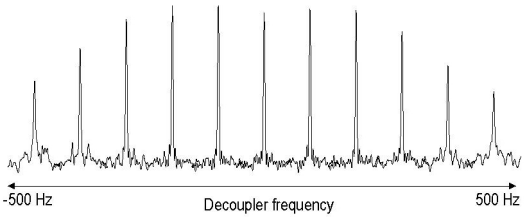

Fig. 1 Adiabatic decoupling bandwidth at 7 Tesla

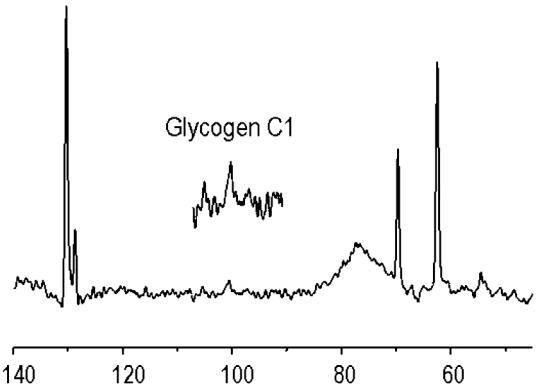

Fig. 2 Detection of glycogen in humans at 7 Tesla (LB=30Hz)

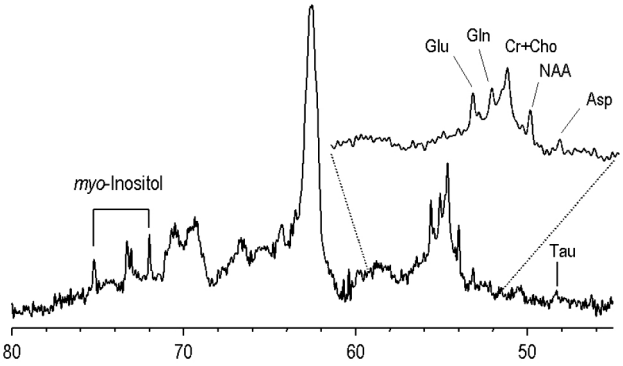

Fig. 3 Detection of natural abundance signals of low concentration metabolites in human brain

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Acknowledgments

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