A Semi_LASER 1H MRS Sequence Designed with High Bandwidth RF Pulses for Use at 4.0 T

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Introduction

The advantages of high magnetic field for *in vivo* magnetic resonance spectroscopy (MRS) include improved S/N and increased spectral dispersion, which aid in the separation and quantitation of resonances which overlap at lower magnetic field strengths. In particular, MRS at high magnetic field has the potential to better quantitate metabolites exhibiting J-coupled resonances such as glutamate (Glu), glutamine (Gln), and Myo-Inositol (mI), which are all of clinical interest. However, the increased spectral dispersion at high field also exacerbates MRS localization artifacts such as the four compartment spatial interference artifact in which J-coupled spins give rise to differing, anomalous signals from different regions of the localized voxel (1). Unless the echo time, TE, is much less than 1/J, these differing signals do not add constructively, and the resultant signal is both distorted and reduced in amplitude (1). Methods to alleviate the four compartment artifact include performing the experiment at short TE, and using high bandwidth RF pulses to reduce the volume of the regions giving rise to the anomalous signals. For example, the STEAM and SPECIAL (2) experiments can be performed at short TE. However, short echo-time *in vivo* spectra can suffer significant baseline contamination from residual water, lipid signal, and macromolecules. Moreover, the STEAM experiment suffers from acquiring only half the signal available compared to PRESS, while the SPECIAL experiment uses a subtraction scheme and is thus susceptible to motion artifacts. When the standard coils available on commercial MRI instruments are used, the bandwidth of conventional RF localization pulses is significantly limited by the available power. One exception to this is the LASER sequence (3) in which a non-selective adiabatic excitation pulse is used, along with three pairs of adiabatic inversion pulses for the localization. The primary advantage of this experiment is that the inversion pulses can be designed with relatively high bandwidth. Another advantage is that, if the intra-pulse spacing is short compared to 1/J values and 1/(chemical shift) (in Hz) of coupled resonances, the sequence performs as does a Carr-Purcell experiment to preserve the resonances of the coupled spins (4). The primary disadvantage of this experiment is the relatively high SAR generated by the six adiabatic inversion pulses. Thus, to facilitate *in vivo* MRS at high magnetic field, we recently reported on a optimization routine that enabled broad bandwidth excitation pulses for MRS to be generated at relatively low RF power (5). We also argued that dual inversion pulses would be more efficient (in terms of SAR) for generating a spin echo than a broadband spin echo pulse. For this study, we implemented a semi-LASER sequence with new, relatively high bandwidth, low power excitation and inversion pulses to minimize signal losses of J-coupled metabolites due to the four-compartment artifact at 4T.

Methods

For single-voxel MRS on human brain on 4.0T, we used our optimization routine incorporated into our MatPulse program (6) to design new broadband slice-selective excitation and inversion RF pulses analogous to our previously described pulses (5) and implemented them in a semi-LASER (7) sequence (Fig. 1). The pulses all had a maximum B_1 field of 20 uT, and bandwidth of 5.0 kHz. Both excitation and inversion pulses had duration of 4.8 ms (Fig. 2a and Fig.2b). Although the pulses were not designed with immunity to B_1 inhomogeneity, they were tested to ensure that they were not overly sensitive to a small degree (10%) of B_1 inhomogeneity. VAPOR water suppression with standard SLR pulses (8) was incorporated into the experiment, along with an option for dual inversion pulses to obtain metabolite-suppressed results to enable baseline undulations to be estimated. A Carr-Purcell (CP) pulse module was also included as an option to further recover J-coupled resonances.

The semi-LASER MRS experiments were then conducted on normal human subjects. All of the subjects gave informed consent, which was approved by the local Institutional Review Board. Data were acquired using an 8-channel birdcage excite/receive RF coil on 4.0 T Bruker MedSpec instrument with a 7 kW RF amplifier providing a maximum B_1 field of 30 μT. After scout images, T1-weighted and T2-weighted images were acquired, a 2 x 2 x 2 cm^3 voxel was positioned sequentially in the occipital lobe, parietal lobe, and frontal lobe to acquire spectroscopic data, with the following parameters: TR/TE = 3000 ms/57 ms, averages = 128. Following each spectroscopic acquisition, a non-water-suppressed spectrum was acquired (4 averages), and a metabolite-suppressed spectrum was collected (16 averages). The spectral processing was accomplished with in-house Matlab routines making use of the non-water-suppressed spectrum to implement as a reference de-convolution spectral enhancement scheme, which was also combined with a Traf filter (9) to retain optimal S/N.

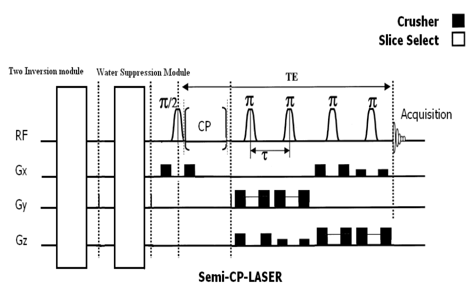

Fig. 1. Semi-LASER sequence diagram

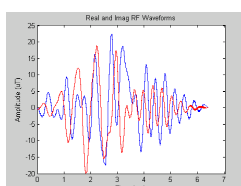

Fig. 2a. Excitation pulse

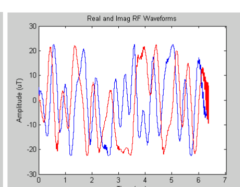

Fig. 2b. Inversion pulse

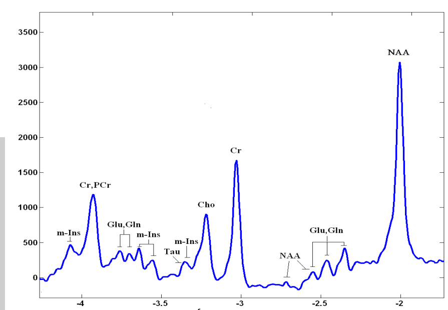

Fig. 3. Spectrum from an occipital voxel ($2x2x2cm^3$).

Results and Discussion

A representative spectrum from the occipital region is shown in Fig. 3. The spectrum shows that, although the TE time is relatively long (57 ms), the coupled resonances of Glu, Gln, and mI are relatively well preserved, and even coupled patterns from NAA and Taurine are visible. Also, at this TE the baseline contamination from residual water, lipids, and macromolecules does not pose a major problem for quantitation. The relatively good S/N of the coupled resonances is in part due to the suppression of the four compartment artifact by the relatively high bandwidth localization pulses. For example, for resonances separated by 1 ppm at 4T (170 Hz), the relative voxel shift is 170Hz/5000Hz (5000Hz is the RF pulse bandwidth), so that the total anomalous signal would arise from only approximately 10% of the voxel. Thus, the four-compartment artifact can be essentially ignored for J-coupled resonances separated by less than 1 ppm.

Conclusion

A single voxel semi-LASER localization scheme suitable for use on commercial MRI instruments was implemented at 4T at a relatively long echo time (57 ms) with high bandwidth RF pulses, designed with MatPulse. The higher bandwidth RF pulses combined with the semi-LASER localization scheme helped to suppress the four-compartment artifact, and also enabled J-coupled resonances to be acquired with relatively high S/N, even at the relatively long TE time of 57 ms. The MatPulse program is available at: www.cind.research.va.gov. This work was supported by NIH grants 5R01EB000766 and 1P41RR023953.

References: [1] Kaiser LG,et al. J Magn Reson 2008; 195: 67-75. [2] Mekle R et al. MRM 2009; 61: 1279-1285. [3] Michaeli S et al. MRM 2002; 47: 629-633. [4] Hennig J et al. Magn Reson Med 1997; 37: 816-820. [5] Matson GB, et al. J Magn Reson 2009; 199: 30-40. [6] Matson GB. MRI 1994;12: 1205-1225. [7] Scheenen TW et al. MRM 2008; 59: 1-6. [8] Pauly J et al. IEEE Trans Med Imaging 1991; 10: 53-65. [9] Traficante DD et al. Concepts Magn Reson 2000; 12: 83-101..