1H-MR spectroscopic imaging of the human brain using adiabatic refocusing pulses at 3 and 7T

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Introduction

Proton MR spectroscopic imaging (MRSI), the preferred method of choice to detect the spatial distribution of metabolites in the human brain, is challenging on high field systems (≥ 3T). To make full use of the increased SNR and chemical shift dispersion at 3 or even 7 Tesla a number of difficulties need to be overcome. Two of these – inhomogeneity of the B1 transmit field, and the increased chemical shift displacement error – will be dealt with in this work. We present a semi-LASER spectroscopic imaging pulse sequence that uses a non-adiabatic optimized slice-selective excitation pulse in combination with two pairs of adiabatic refocusing pulses with sharp slice selection profiles to produce a localized spin echo at short echo times.

Materials and methods

Instrumental set-up. A 25-year-old female volunteer was examined on a 3T whole body MR system (Magnetom Trio with TIM, Siemens Medical Solutions, Erlangen, Germany) with the body coil for excitation and a 12-channel head coil for signal reception. A healthy, fully informed and aware collegue was examined on a 7T whole body MR system (Siemens Medical Solutions, Erlangen, Germany) with a transmit receive circularly polarized head coil.

2D proton-spectroscopic imaging of the brain. The acquisition weighted MRSI pulse sequence was constructed in the following way: an initial slice-selective Shinnar-Le-Roux optimized 90º excitation pulse was followed by two couples of slice-selective adiabatic full passage 180º refocusing pulses [1]. Pulse durations were limited by the available transmit power. The γB_1 field of 1300 Hz at 3T resulted in durations of 2.0 and 5.0 ms for excitation and refocusing pulses (TE 30 ms), and a γB_1 field of 650Hz at 7T resulted in pulse durations of 4.0 and 10.0 ms (TE 50.0 ms) for excitation and refocusing, respectively. Both excitation and refocusing pulses had bandwidths of 5 kHz at 3T, and 2.5 kHz at 7T. Crusher gradients were positioned around the final AFP pulse, with the phase-encoding gradients superimposed on the final crusher. Water signals were suppressed with a WET pulse scheme [2], and outer volume saturation slabs could be positioned on subcutaneous lipid tissues. After filtering (100% Hanning filter), zerofilling to the nearest power of two and Fourier transformation of the spatial directions the signals of the individual voxels were filtered and Fourier transformed into spectra. At 3T the semi-LASER sequence was compared with a regular 30 ms echo time PRESS sequence, and for all measurements a reference file without water suppression was also acquired. RF power deposition of the semi-LASER was about 4.5 times the RF power of the PRESS sequence, but remained well within SAR limits at 3T, whereas the TR needed to be prolonged to 1.75 s at 7T (from 1.5s at 3T) to remain within SAR limits. Parameters for the MRSI measurement were: nominal voxel volume before apodization of 10 x 10 x 10 mm at 3T and 8 x 8 x 8 mm at 7T and total acquisition time around 12 minutes (2 acquisition weighted averages of 20 x 18 matrix).

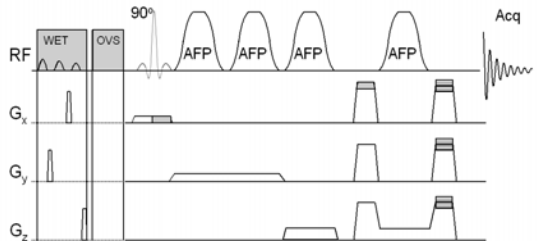
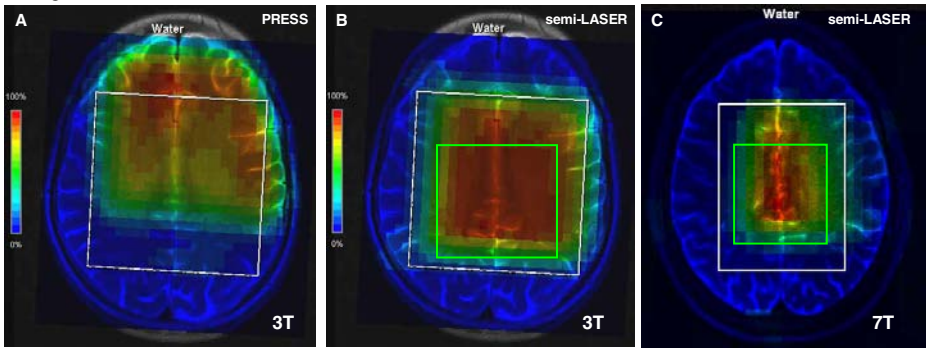


Figure 1. Diagram of the semi-LASER spectroscopic imaging pulse sequence. The water suppression (WET) and outer volume saturation (OVS) modules are not drawn to scale.



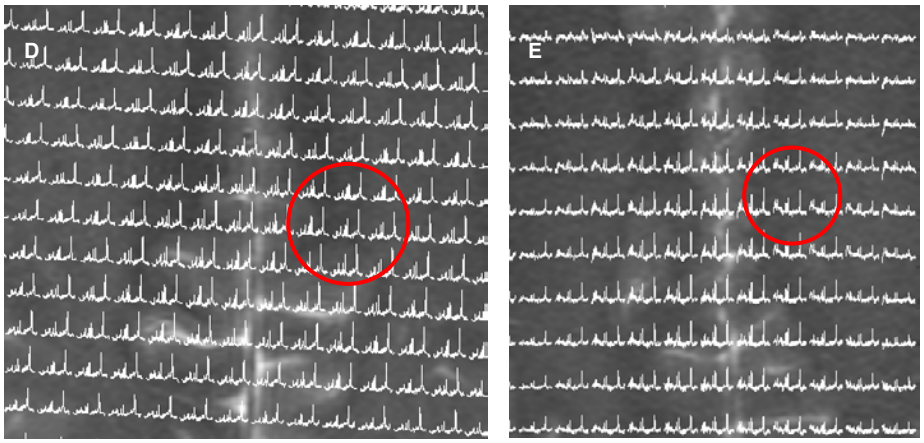


Figure 2. 2D MRSI of healthy volunteers at 3 and 7T. The chemical shift displacement error of conventional PRESS compared to the semi-LASER pulse sequence is illustrated in A and B for 3T. In C this is shown for the semi-LASER at 7T. Transverse T_2-weighted TSE images of the brain are overlaid with color-coded images of the integral of the unsuppressed water signal of the MRSI experiment (A-C). The carrier frequency is positioned at 2.2 ppm. The white box indicates the volume of interest. The green box is enlarged in D and E, with the spectra from 1.5 to 4.3 ppm of the individual voxels at 3T (D) and at 7T (E). The red circles indicate the true size of the voxel of the spectrum in the center.

Results

The high bandwidths of the semi-LASER resulted in chemical shift displacement errors over a range of 4 ppm of +/- 5% at 3T and +/- 24% at 7T, when the carrier frequency is set in the center of this range (Fig. 2B and C). The true resolution of the 2D MRSI voxels (incorporating filtering) can best be approximated by a slice-thick cylinder with a diameter of 17 mm at 3T and 14 mm at 7T. At 3T the spectra from almost the entire VOI have a high quality (Fig. 2D), at 7T excellent spectra are obtained from the center of the brain, but a drop in SNR can be observed towards the edges of the VOI (Fig. 2C and E). Hardly any lipid signals are observed within the VOI of both measurements. Outside the VOI, voxels from subcutaneous lipids showed very small lipid residuals, with amplitudes below NAA amplitudes inside the VOI.

Discussion and conclusions

In this study we present a VOI selection sequence that overcomes the chemical shift displacement error that occurs with common PRESS sequences. Efficient prevention of this error is achieved at 3 and even 7T. With an MRSI version of this sequence excellent spectra could be obtained at an echo time of 30 ms over large regions of the brain at 3T, making it an attractive new tool to map brain metabolism. We demonstrate that even at 7T MRSI with the semi-LASER produces very useful data opening the possibility for detailed spatial metabolic exploration of the human brain at this field strength. Currently at 7T, differences in SNR exist over the VOI due to non-adiabatic excitation with an inhomogeneous B1 field, and the available RF power dictates longer pulse durations and thereby a minimal echo time of 50 ms. However, we expect that these limitations at 7T can be overcome with an increase in RF power and excitation with a multi-channel transmit receive head coil.

References:

1. Garwood M, J Magn Reson 2001;153(2):155-177.
2. Ogg RJ *et al.* J Magn Reson B 1994;104(1):1-10.