1H MRS in the human spinal cord at 7T using a combined RF shimming and travelling wave transmit approach

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Introduction

Magnetic resonance spectroscopy (MRS) of the human central nervous system (CNS) is a valuable tool for in vivo investigation of biochemical processes and differential diagnostics of various CNS pathologies. Its non-invasive nature is of specific benefit in the spinal cord where performing biopsies is perilous. Spinal cord ^{1}H MRS is impaired by strong susceptibility changes around the cord, pulsatile flow of the cerebrospinal fluid, B_0 fluctuations due to respiratory and patient motion and its finite diameter, all of which limit the attainable signal to noise ratio (SNR) and distort the spectral lineshape. Recently several methodological developments with regard to shimming, localization, lipid suppression and flow and motion correction largely improved the applicability of ^{1}H MRS in the human spinal cord in the clinical environment [1-2]. A state of the art 3T ^{1}H MRS protocol comprises inner volume saturated PRESS localization, ECG-triggered 2nd order FASTERMAP shimming, F0 determination and spectral acquisition, and metabolite cycled non-water suppressed spectral acquisition for single shot frequency alignments [5]. However the finite size and deep location of the human spinal cord still limit the obtainable SNR, which in turn also limits the number of quantifiable metabolites at field strengths $\leq$ 3T. **Therefore, in this work**, ^{1}H MRS of the human spinal cord at 7T is introduced for the first time to tackle the intrinsic SNR problem and exploit the improved spectral separation to increase the number of quantifiable metabolites. To that a B_1^+ shimming and travelling wave transmit approach was combined with adiabatic inner volume saturated (IVS) localization, 3rd order FASTERMAP shimming and a 30-channel receive array.

Materials and Methods

All measurements were performed on a 7T whole body system (Philips Healthcare, Cleveland, USA). Five volunteers were involved in the optimization of the measurement protocol and three volunteers in reproducibility measurements. All volunteers gave informed consent in line with local ethics regulations. A custom built RF coil setup was used (Figure 1). The transmit coil consists of two radiative antennas attached to a neck pillow filled with D_2O that forms a dielectric waveguide [3]. This approach exploits the travelling wave effects inside the neck pillow and avoids local SAR hotspots in close proximity to the coil elements. A dual transmit setup allowing for B_1^+ shimming delivered a maximum of 2 kW to each transmit coil element. After phase shimming a B_1^+ of 15 µT was achieved in the cervical spinal cord. A custom built 30-channel array was used for reception (Figure 1). T1W gradient echo and T2W spin echo localizer images were acquired. Spectroscopy localization was achieved by semi-LASER [4] based on a frequency modulated excitation pulse and trapezoidal adiabatic refocusing pulses (Figure 2) (TR = 3500ms; TE = 42ms; 512 avg; BW 4000 Hz; 8192 sample points; 2000 ms acquisition time). Excellent water suppression was achieved using a numerically and experimentally optimized 8-pulse VAPOR pre-saturation sequence. VAPOR was interleaved with 6 broadband spatial saturation bands for reduction of the chemical shift displacement artifact as well as flow compensation and lipid suppression (Figure 2). Automatic volume based third order FASTERMAP shimming and manual F_0 adjustment were performed prior each measurement. Spectra were DC offset, phase and eddy current corrected, SVD channel combined and down sampled to 4192 sample points. For displaying 2Hz exponential and 2Hz Gaussian smoothing and HLSVD water filtering was applied. A basis set containing 18 metabolites was simulated using GAMMA for a field strength of 7T. ^{1}H MR spectra were then quantified using LC-Model.

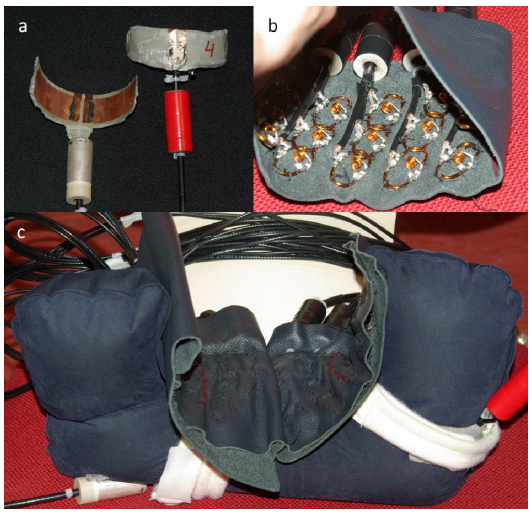

Figure 1: *Coil setup: two radiative transmit antennas(a) were attached to the outside of a neck pillow filled with D_2O (c); a 30-channel receive coil (b)was placed close to the neck on the inside (c) of the neck pillow.*

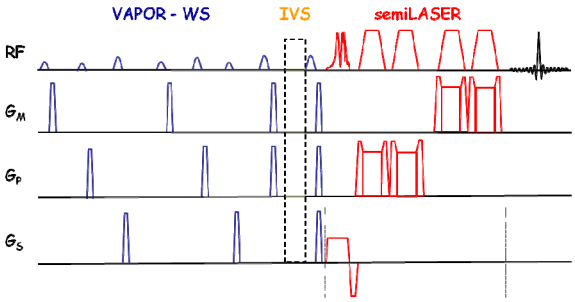

Figure 2: *Schematic VAPOR water suppressed, inner-volume saturated (IVS) semi-LASER ^{1}H MRS sequence.*

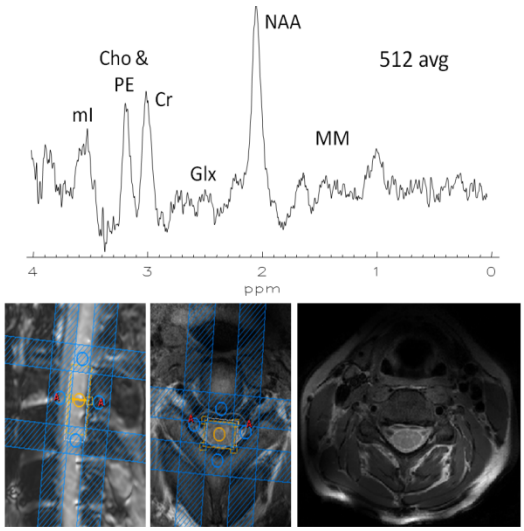

Figure 3: *Representative spectral quality obtained by ^{1}H MRS in the human cervical spinal cord at 7T (top). Voxel and IVS positioning and T2W spin echo image quality indicating high B_1^+ homogeneity (bottom).*

Results and Discussion

Spectra free from major artifacts such as lipid contamination, ghosting, baseline or phase distortions were obtained from the cervical spinal cord (C2/3) in all three healthy volunteers at 7T (Figure 3). The mean line width of unsuppressed water at FWHM was 27.5$\pm$3.2 Hz. The resulting spectral resolution and SNR allowed quantification of N-acetyl-aspartate (NAA), total choline containing compounds (tCho), total creatine (Cr) and myo-inositol (mI) in all volunteers. Quantification results for these metabolites are as follows: NAA / Cr = 1.45 $\pm$ 0.28; tCho / Cr = 0.22$\pm$ 0.04; mI / Cr = 4.28$\pm$1.14. In addition, glutamate plus glutamine (Glx), scyllo-inositol (sI) and phosphoryl-ethalonamine (PE) were detected (CRLB < 20) in two out of the three volunteers (Glx/Cr ≈ 0.8; scyllol / Cr ≈ 0.3 ; PE / Cr ≈ 1.6). In conclusion, the relatively strong and homogeneous B_1 fields (Figure 3) that can be obtained in the neck with the described RF shimming and travelling wave transmit approach allows for accurate adiabatic localization performance. Combined with sensitivity optimized receivers, inner volume saturation, VAPOR water suppression and 3rd order FASTERMAP shimming, ^{1}H MRS in the cervical spinal cord at 7T is a promising tool to study related CNS pathologies.

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