Spinal cord MRS in and beyond the cervical spine

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Introduction
MRS non-invasively gives insight into the metabolism of neuronal tissue and can provide valuable information regarding the differential diagnosis of space-occupying lesions. While MRS is therefore increasingly applied in the human brain, spinal cord MRS has been rarely used. It has been mainly restricted to the brain-stem and the upper part of the cervical spine [1, 2]. Furthermore, the quality of spectra has not been sufficiently reproducible and consistent to do patient measurements for clinical diagnostics. In this work, first MRS patient data from the thoracic spinal cord are shown. Moreover, the spectral quality as well as the consistency of MRS in the cervical spine was improved combining outer-volume suppression bands with a very sharp excitation profile, based on quadratic-phase (QPP) and higher-order-phase (HOPP) saturation pulses, and localized higher-order shimming, based on high-resolution cardiac-triggered static magnetic field B₀-mapping. The examples of a glioblastoma metastasis in the thoracic spinal cord as well as a multiple sclerosis plaque in the cervical spinal cord underline the diagnostic value of spinal cord MRS.

Materials and Methods
All MRI and MRS experiments were performed on a Philips 3T scanner (Philips Medical Systems, Best, The Netherlands). In MRS the effective voxel size was 6 x 7 x 27 mm, TE was either 42 ms or 144 ms, and 512 averages were acquired over a bandwidth of 2000 Hz. Slightly over-prescribed PRESS (-1.5 mm) was combined with outer volume suppression based on HOPP or QPP saturation pulses [2], which were applied prior to the PRESS excitation. Pulse duration and flip angle of each suppression band were separately adjustable. Using Bloch simulation flip angles and number of suppression cycles have been optimized to simultaneously suppress fat and CSF. To saturate signal coming from the pulsatile flow of the CSF additional suppression slabs superior and inferior to the voxel have been applied and ECG triggering (300ms delay) was performed during the MRS acquisition. Localized second order shimming based on high-resolution (128 x 128) ECG-triggered B₀-mapping was applied prior to the MRS measurement.

Results and Discussion
Spinal cord single voxel spectra were acquired in the cervical, the thoracic as well as the lumbar spinal cord. The extremely sharp excitation profile of the QPP and HOPP saturation pulses (Figure 1) allowed the use of slightly over-prescribed PRESS and therefore the avoidance of signal loss and CSF flow artifacts due to chemical shift displacement. A localized higher order shim routine based on ECG-triggered B₀-mapping improved the shim significantly (Figure 2) and ensured a reproducible water line width of 7 Hz in the cervical spinal cord. ECG-triggering was essential during the acquisition of the B₀-map as well as of the MR spectrum to achieve spectra with narrow, distinguished lines and hence sufficient SNR in the cervical spine. Figure 3 shows cervical spinal cord MR spectra at the level of C2 / C3 in two different healthy volunteers. Equally high spectral quality was consistently achieved over all five measured healthy volunteers as well as in a patient with a lesion at the level C1 / C2 (Figure 4). The patient spectrum shows increased Choline, Alanine, Lactate and myo-Inositol along with decreased NAA and therefore indicates an active demyelination due to multiple sclerosis.

Figure 1 Excitation profile of a higher order phase saturation pulse

Figure 2 Improved shim a) 1st order shim; 2nd order shim b) w/o; c) with ECG triggering; d) B₀-map

Figure 3 Consistently high spectral quality acquired in the healthy cervical spine (C2/3) with TE = 42 ms. Blue bars around prescribed voxel show the position of saturation slabs.

Figure 4 Active demyelination in the cervical spine in a patient with multiple sclerosis (red arrows): TE = 42 ms

Figure 5 High grade glioma in the thoracic spinal cord (red arrows): TE = 144ms

References