High resolution myelin water measurements in rat spinal cord

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Introduction

Quantitative analysis of T_2 decay curves acquired with a multi-echo CPMG sequence can be used to produce continuous spectra of T_2 values representing various T_2 components present in the tissue [1]. This technique has been used in CNS and PNS tissue to measure fractional amounts of water trapped between myelin sheaths – the so called myelin water fraction (MWF) [2], which has been shown to correlate well with the amount of myelin [2]. Measuring MWF in a rat model of spinal cord injury (SCI) can therefore be an important marker of the cord pathology, and can be used to measure the success of potential SCI therapies. Myelin water measurements, however, require very high SNR and spatial resolution, making it challenging to apply this technique in rat spinal cord. Here we present preliminary results of high spatial resolution MWF mapping in ex vivo and in vivo rat spinal cord.

Methods

All MRI experiments were carried out on a 7T animal scanner (Bruker, Germany). For in vivo measurements, rats were anaesthetized with isofluorane and placed in a specially designed holder in a supine position over a 3 cm i.d. circular surface coil that was used for pulse transmission and signal reception. For ex vivo measurements, a control spinal cord was excised and fixed with paraformaldehyde/glutaraldehyde solution. The excised cord was positioned in a 5mm i.d. glass tube filled with the fixation solution. A wooden splint was attached to the cord with Teflon tape to support the cord. A 2 cm i.d. 4 turn solenoid coil was used for pulse transmission and signal reception. Myelin water measurements were carried out using a single slice, multi-echo CPMG sequence [3] (256x256 matrix, TR/TE=1500/6.673ms, NA=6, 32 echoes). For in vivo experiments, a 1.5mm slice was selected through the lumbar spine and an FOV of 3cm was used resulting in in-plane resolution of 117μm. For ex vivo experiments, a 1 mm slice was selected through the cervical spine and 3 FOV values were used: 2.56cm, 2cm, and 1.56cm resulting in in-plane resolution of 100μm, 78μm, and 61μm respectively. T_2 distributions were calculated from the multi-echo data using non-negative least squares analysis [2]. MWF maps were generated by integrating the 7.75-20 ms range and divided by the total integral of the T_2 distribution in each pixel.

Results and Discussion

Figure 1 shows the first echoes of the CPMG data (top) and the reconstructed MWF maps (bottom) acquired from the excised rat spinal cord with the in-plane resolution of 100μm (left), 78μm (middle) and 61μm (right). The average MWF values in grey matter (GM) and white matter (WM) for three data sets are: 18% and 39%, 12% and 33%, and 4% and 30% respectively. The circular structure in the centre of the images (marked wood) is the wooden splint that was used to stabilize the cord. It contains water with short T_2 times, which is consistent with previous studies of wood [4]. Figure 2 shows the first echo of the CPMG data (top left) and the reconstructed MWF map (top right) acquired from the rat spinal cord in vivo. The T_2 distribution (bottom) in GM (solid line) and WM (dashed line) shows, as expected, three distinct water components. The average MWF values are 5% in GM and 24% in WM.

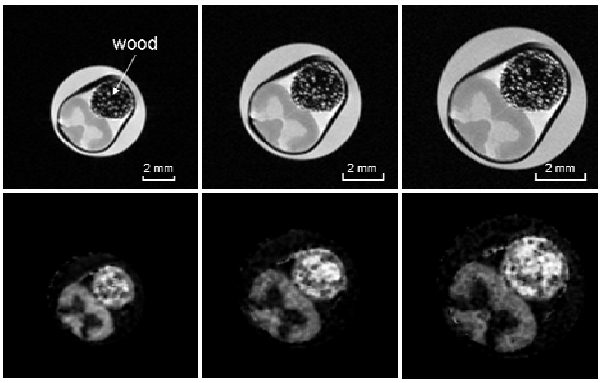

Fig. 1. First echo of the CPMG data (top) and the reconstructed MWF maps (bottom) acquired from an excised rat spinal cord. The in-plane resolution is 100μm (left), 78μm (middle) and 61μm (right).

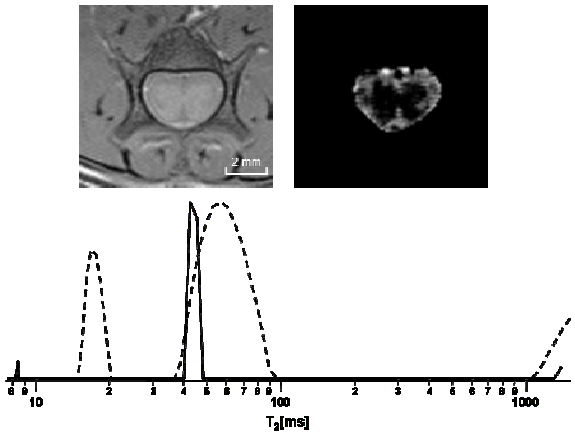

Fig. 2. First echo of the CPMG data (top left) and the reconstructed MWF map (top right) acquired from a rat spinal cord in vivo with in-plane resolution of 117μm. The bottom graph shows T_2 distribution in GM (solid line) and WM (dashed line).

The reconstructed MWF maps from the excised spinal cord show details of the cord morphology, although the maps become progressively noisier with increased resolution. It is unclear why the ROI analysis show decreasing MWF values in both GM and WM with the increased spatial resolution. The possible reason may be differences in partial volume effect or in SNR, although the "residual SNR" values defined as the signal intensity of the first echo over the standard deviation of the differences between the fitted and the experimental echo decay curves were in the range of 800-1500 for GM and 1200-1700 for WM. The MWF map reconstructed from the in vivo data also shows the morphology of the cord, albeit with lower SNR. The quality of the in vivo data can be improved by acquiring the NMR signal with an implantable RF coil system actively decoupled from a large volume RF coil used for spin excitation. We are currently working on developing such a coil system.

Conclusions

In this pilot study we have shown that high resolution myelin water mapping in rat spinal cord is feasible both ex vivo and in vivo. The MWF maps show details of the cord morphology, and the average MWF values in WM and GM correspond well with previously published results and the expected amounts of myelin within the cord.

Acknowledgments

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