High resolution 3D myelin water imaging in excised rat spinal cord

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Introduction

Myelin water imaging has been successfully used to assess myelin content in human and animal CNS tissue [1,2]. It has been shown that fractional amounts of water trapped between myelin sheaths – the so called myelin water fraction (MWF) [3] correlates well with the amount of myelin in a rat model of spinal cord injury (SCI) [2] and can therefore be an important marker of the cord pathology. One of the limitations of the current CPMG based myelin water imaging technique is that it is a single slice technique. It has been shown that a 3D version of this technique can be achieved by applying a second phase encoding gradient to provide localization along the slice direction [4]. In this pilot study we applied the 3D CPMG sequence to acquire very high spatial resolution 3D MWF maps from excised rat spinal cord. The 3D technique produced high quality data that compared favourably with the 2D measurements.

Methods

All MRI experiments were carried out on a 7T animal scanner (Bruker, Germany). A control spinal cord was excised and fixed with paraformaldehyde/glutaraldehyde solution. A 14 mm segment of the excised spinal cord, centered on C6 level, was positioned in a 4.5 mm inner-diameter plastic tube filled with the fixation solution. A small plastic rod was positioned alongside the cord to prevent it from bending. A four-turn, 13 mm inner-diameter and 20 mm long solenoid coil was used for pulse transmission and signal reception. Myelin water measurements were carried out using a 3D multi-echo CPMG sequence [4]. A 50 μs hard pulse was used to excite signal from the entire sample and hard composite 90_x-180_y-90_x pulses (200 μs total duration) were used to refocus transverse magnetization. The sequence parameters were as follows: 128x128x16 matrix, FOV=1x1x1.6 cm, TR/TE=1500/5.184 ms, NA=1 and 32 echoes. The total acquisition time was 51 minutes. T_2 distributions were calculated from the multi-echo data using non-negative least squares analysis [3]. MWF maps were generated by integrating the 6.26-20 ms range and divided by the total integral of the T_2 distribution in each pixel.

Results and Discussion

The left image of the Figure 1 shows the sagittal cross-section through the excised rat spinal cord. The red box shows the extent of the 3D volume selected for the CPMG sequence. The images on the right side of the Figure 1 show calculated MWF maps from slices 6 (top left) through 16 (bottom right) of the 3D CPMG data. Slice 16 corresponds to the top of the cord on the sagittal image. Table 1 shows the average MWF values in white and grey matter in the individual slices. The average of all slices is 0.35 ± 0.05 for the white matter and 0.08 ± 0.02 for the grey matter. These values compare favourably to the average MWF values obtained from a group of 6 normal excised rat spinal cords using a single slice CPMG sequence with the slice positioned on C6 level, i.e. 0.33 ± 0.03 for the white matter and 0.07 ± 0.02 for the grey matter [5].

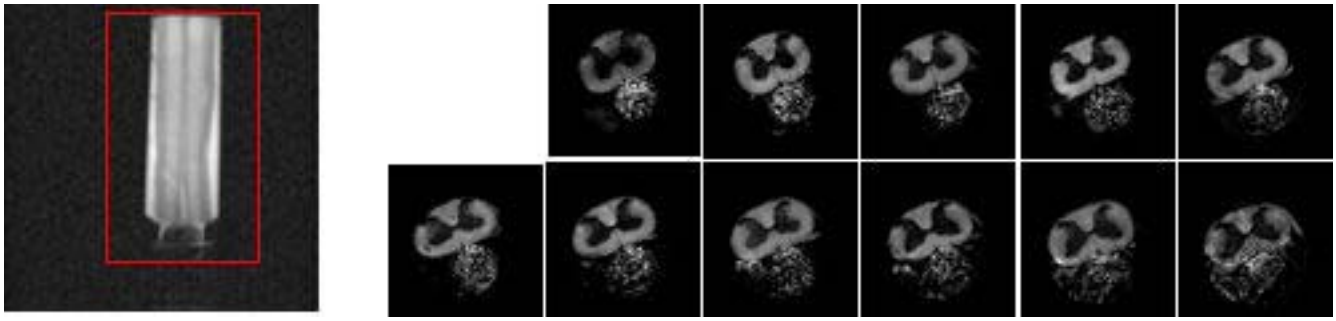

Fig. 1. Left: sagital cross-section through an excised rat spinal cord; red box depicts the extent of the 3D volume covered by the 3D CPMG sequence. Right: MWF maps calculated from slices 6 (top left) through 16 (bottom right) of the 3D CPMG data; slice 16 corresponds to the top of the cord on the sagital image.

Table 1. Average MWF values calculated from ROIs positioned in white and grey matter in the individual slices.

	slice 6	slice 7	slice 8	slice 9	slice 10	slice 11	slice 12	slice 13	slice 14	slice 15	slice 16
WM	0.25	0.39	0.34	0.39	0.35	0.36	0.35	0.42	0.33	0.39	0.30
GM	0.04	0.07	0.09	0.07	0.08	0.10	0.07	0.13	0.06	0.11	0.07

The 3D CPMG sequence generated excellent data from almost all slices across the cord. The application of the short hard 90° pulse for spin excitation allowed shortening the echo time to 5.2 ms (compared to 6.7 ms for the 2D CPMG sequence). As a result the accuracy of the NNLS fitting of the short T2 component is improved. The limitation of this approach is that the FOV in the slice direction has to be larger than the sample size to avoid aliasing of the signal from outside the FOV. However, stringent SNR requirements of this technique often necessitate the use of a small surface or implanted coil for the rat spinal cord applications. Such a small coil can then limit the extent of the acquired signal along the cord to approximately 15 mm, which should minimize the potential signal wrap.

Conclusions

In this pilot study we have shown that high resolution 3D myelin water mapping in rat spinal cord ex vivo is feasible. The MWF maps show excellent details of the cord morphology, and the average MWF values in WM and GM correspond well with previously published results obtained with the single slice CMPG sequence.

Acknowledgments

The authors are grateful to Mr. Jie Liu for preparing the excised spinal cord. This study has been supported by the Canadian Institutes of Health Research.

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