High Resolution Quantitative Magnetization Transfer Imaging of Squirrel Monkey Spinal Cord at 9.4T

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Introduction

Quantitative Magnetization Transfer (qMT) imaging yields relaxation rates and pool size ratios of macromolecular and free water proton pools, and has been widely implemented in studies of human brain. However, qMT studies of spinal cord have been more limited because of its small size (~1.5 cm diameter in human), field inhomogeneity effects, and motion artifacts. QMT is even more challenging in non-human primates (NHPs) such as squirrel monkeys because of the need for even higher spatial resolution (cord size ~0.5 cm diameter). Therefore, to date, simpler metrics such as the Magnetization Transfer Ratio (MTR) has been used based on acquisitions of only two images. However, MTR is sensitive to several non-physiological factors, such as saturation pulse power and excitation flip angle, and does not reflect explicit intrinsic properties of tissue. Extracting parameters from qMT methods may improve the reproducibility of measurements across studies, reduce the influence of sequence variables, and be more specific for characterizing pathological changes. NHPs represent especially valuable models of human disorders, so we have implemented a pulsed-MT protocol for *in vivo* studies of the spinal cord of squirrel monkeys at high field. The values of qMT parameters (pool size ratio F and exchange rate RM_{0a}) for gray matter (GM) and white matter (WM) are in agreement with those of human studies [1].

Methods

Two squirrel monkeys have been studied to date. They were anesthetized (isoflurane 0.5-0.8%) and mechanically ventilated, with heads stabilized in a MR compatible frame. Vital signs were monitored and maintained throughout the imaging session. MR images were acquired with a 9.4T Varian magnet using a saddle-shaped surface transmit-receive coil positioned around the cervical spine region. Gradient echo structural images (TR/TE 28/4.6 ms, 256X256 matrix; 156x156x500 μm^3 resolution) were acquired to identify GM and WM. R_{1obs} map was obtained with steady state gradient echo sequence with variable flip angle approach. B_1 map was obtained using gradient echo sequence with excitation flip angles of 15° and 30°, while B_0 map was calculated from two gradient echo images (TE at 6 and 8 ms). Two MT data sets were collected with 18 different frequency offsets (TR 24 ms, flip angle =7, 48 acquisitions), using 2 Gaussian-shaped saturation pulses (flip angles = 220° and 820°, pulse width = 12 ms). Frequency offsets ranged between 100 Hz and 100 kHz with a constant logrithmic interval. The datasets were processed with MATLAB, and Ramani's model was employed in the data analysis [2].

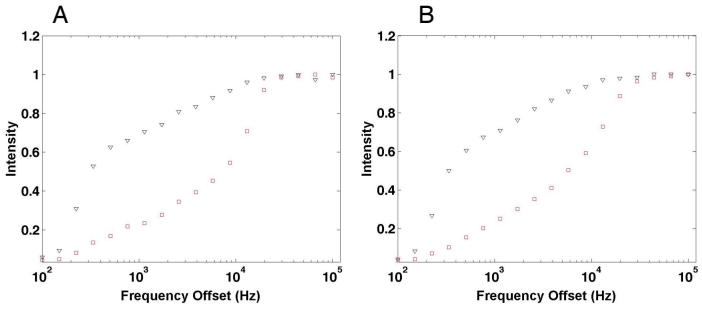

Figure 1. Magnetization transfer in-vivo data for (A) WM and (B) GM in spinal cord. Flip angles θ_{sat} are 820° (□) and 220° (∇).

Results

Figure 1 shows variations of signals from WM and GM for different powers and offsets**.** All data were normalized to the maximum intensity. The corresponding maps of RM_{0a} and F overlaid on a high-resolution structural image are shown in **Figure 2**. In the F and RM_{0a} maps, white matter showed larger pool size ratio and lower exchange rates, as expected. The averaged F values are 0.129±0.042 and 0.086±0.020, and RM_{0a} values are 12.13±1.16 and 13.93±1.31 for white matter and gray matter respectively. These results are in agreement with human spinal cord studies [1].

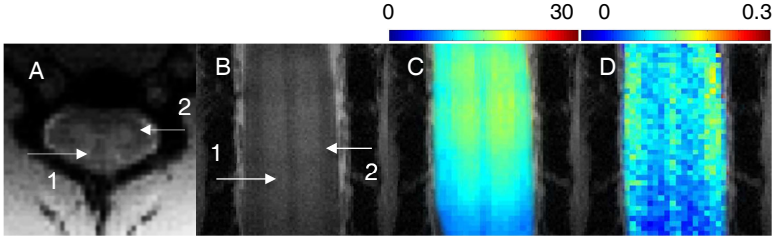

Figure 2. *In-vivo* coronal image used to position axial slice (A), high-resolution axial image (B), RM_{0a} map (C), and F map (D). 1-GM, 2-WM.

Discussion

To our knowledge, this is the first *in vivo* implementation of quantitative magnetization transfer in spinal cord of non-human primates. The results demonstrate the feasibility of obtaining high resolution, quantitative measurements of spinal cord tissues reliably in reasonable time in a realistic model of NHP spinal cord. Even though it has been suggested that the low offset frequencies (< 1kHz) should be avoided when using Ramani's equation, we did not observe significant differences in the averaged F values with or without the first 5 data points. However, the results were closer to those of human studies and less noisy when the low offset frequencies were excluded. More data in healthy monkeys will be acquired with further optimization of the imaging protocol. This method can then be applied to study the progression of spinal cord damage in NHPs.

References

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2. Ramani A, Dalton C, Miller DH, Tofts PS, Barker GJ: **Precise estimate of fundamental in-vivo MT parameters in human brain in clinically feasible times**. *Magn Reson Imaging* 2002, **20**(10):721-731.