Pool Size Ratio Mapping in the Spine from a Single Magnetization Transfer Measurement

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Purpose. To demonstrate quantitative magnetization transfer (qMT) imaging analyses in the spine can be performed by a single off-resonance measurement. While magnetization transfer (MT) imaging has been used to assess brain tissue microstructure, similar studies in the human spinal cord have been limited. This is largely due to the difficulties associated with imaging the spine, including high resolution demands, motion artifacts, and susceptibility gradients. Despite these difficulties, studies have demonstrated qMT approaches are feasible in the spine. Additionally, single-measurement studies have been performed in the past, providing a rapid and robust method for determining pool size ratio (PSR) [1]. However, these studies have only been demonstrated in the brain. We therefore demonstrate the feasibility of the single-point method in the cervical spine at 3T, and here we report data acquired in healthy subjects.

Methods. Four healthy volunteers were imaged using a 3.0T Achieva whole body MR scanner (Philips Healthcare, Best, The Netherlands). A quadrature body coil was used for excitation and a 16-channel SENSE neurovascular coil (Invivo Inc., Gainesville, FL) was used for signal reception. For each volunteer, a transverse volume between C2 and C4 was selected from survey images. Quantitative MT data were acquired in this volume using the 3D MT-prepared spoiled gradient echo sequence originally proposed by Sled and Pike [2]. For MT-preparation, a single-lobe sinc pulse with Gaussian apodization was applied with a duration = 24 ms, nominal flip angles (θ_{MT}) = 700° and 1000°, and offset frequencies (Δ) = 1, 2, 4, 8, 96 kHz, resulting in 10 images of different MT-weighting. Additional imaging parameters included: TR/TE=98/5.8 ms, excitation flip angle = 15° (Proset 1-3-3-1 pulse to suppress fat), SENSE factor = 2, FOV = 150 × 150 × 30 mm^3, acquisition resolution = 1.5 × 1.5 × 3 mm^3, reconstructed resolution = 0.47 × 0.47 × 3 mm^3, and number of acquisitions averaged = 2. B_1 was measured in the same volume using the actual flip angle imaging (AFI) method [3] with TR_1/TR_2= 100/30 ms and excitation flip angle = 60°. ΔB_0 was also measured from gradient echo phase images acquired with a ΔTE = 10 ms [4]. Total scan time to acquire qMT and field map data was ≈ 11.5 minutes.

Transverse slices were co-registered by determining the 2D affine transformation that minimized the normalized mutual information between slices [5]. Prior to this, each transverse slice was cropped to a 47 × 47 mm^2 window centered about the spinal cord and multiplied by a Gaussian kernel (σ= 23.5 mm). Once co-registered, ROIs were defined for the dorsal column (dc), lateral column (lc), and grey matter (gm) within one slice at the level of C3. Normalized (to Δ= 96 kHz data) mean ROI signal intensities were then fitted [6] to a two pool-model – macromolecular (m) and free water proton (f) pools – using all data points, using the mathematical formalism in Ref. [7], to provide a reference PSR for subsequent analyses. The PSR for a single measurement point for each off-resonance excitation and θ_{MT} was then determined, and the error was calculated using the formalism in Ref. [1]. Previously reported T_1s of white (1 s^{-1}) and grey matter (0.7 s^{-1}) structures in the brain at 3T [7] were used to constrain these fits. As recently suggested [7], it was assumed that $T_2^f R_1^f$ = 0.024 and T_2^m = 11 µs. The mean field values ($B_1$and ΔB_0) across the cord were used to correct for errors in the fits associated with field inhomogeneities.

Results and Discussion. The error between the reference PSR measurement and the one-point measurement as a function of the off-resonance frequency are shown in Fig. 1, 2, and 3, for dc, lc, and gm, respectively. As can be seen in the figures, the error stays below 10% from 1-4 kHz, and then grows exponentially. This suggests that the optimal scan frequency is around 2-3 kHz. Additionally, a saturation flip angle of 1000° provides more accurate values than a flip angle of 700°. Therefore, the optimal measurement parameters should be around 2-3 kHz at a saturation angle of ~1000°. In each material, these parameters yield errors of approximately 3.35 ± 5.06%, 7.44 ± 2.05%, and 2.68 ± 1.81% in the dc, lc, and gm, respectively. However, these large variations may be due to the ROI analysis, and a more accurate measurement may be provided by a voxelwise analysis.

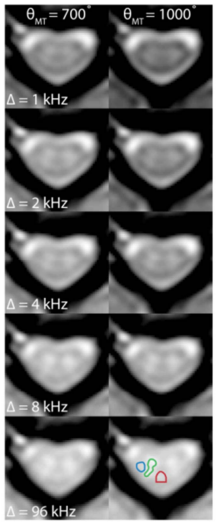

Figure 1: Sample MT-weighted data. ROIs: dc – red, lc – blue, gm – green.

These results suggest that the PSR can be robustly quantified in healthy cervical spinal cord at 3T using only a single off-resonance measurement. This is the fastest approach to qMT imaging to date, if complementary T_1, B_0, and B_1 maps are available. This is promising, because this will reduce motion artifacts due to the reduced measurements needed, as well as provide extra time to boost SNR and resolution.

References: [1] Yarnykh. MRM 2012(68):166. [2] Sled. MRM 2001(46):923. [3] Yarnykh. MRM 2007(57): 192. [4] Skinner. MRM 1997(37):628. [5] Studholme. Pat Recog 1994 (31):633. [6] Coleman Siam J Optim 1996(6):418. [7] Underhill. NeuroImage 2009(47):1568.

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Table 1: PSR values for the full and 1 point fits for each measurement. The top and bottom rows for each ROI represent 1000° and 700°, respectively

ROI	PSR_{ref}	1000 Hz	2000 Hz	4000 Hz	8000 Hz
dc	17.7±4.6%	18.2±4.9%	18.3±4.8%	18.3±3.8%	18.6±7.2%
		15.9±4.2%	17.0±5.2%	17.7±4.5%	19.6±5.5%
lc	16.8±3.8%	16.7±4.2%	17.5±4.7%	17.0±3.8%	16.1±5.1%
		15.6±2.9%	16.7±5.6%	16.7±3.6%	20.0±6.3%
gm	9.7±2.1%	9.83±2.2%	9.84±2.2%	9.45±1.6%	10.44±5.1%
		9.69±2.7%	9.29±2.9%	9.36±2.3%	9.85±2.1%

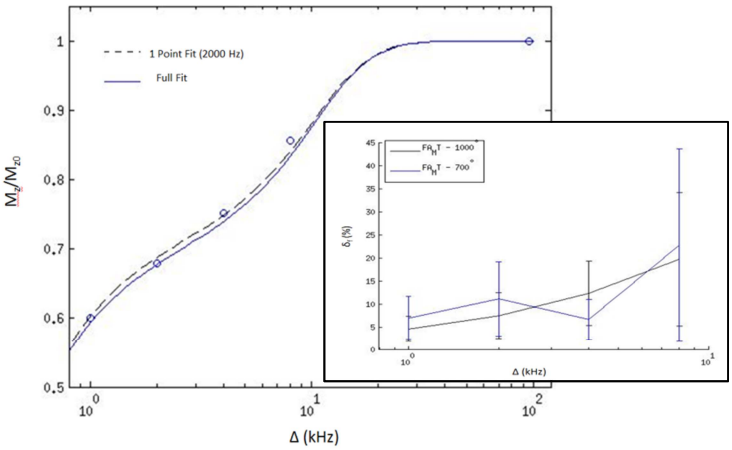

Figure 2: Sample z-spectra for the lc for the reference measurement and the one point fit at 2000 Hz.

Inset: The percent error at each off-resonance measurement for the lc. Error bars represent the SD of the error over all subjects.