Quantitative Magnetization Transfer Imaging of Human Brain at 3T using Selective Inversion Recovery

R. D. Dortch[1,2], K. Li[1,2], A. A. Tamhane[3], E. B. Welch[2,4], D. F. Gochberg[1,2], J. C. Gore[1,2], and S. A. Smith[1,2]

[1]Department of Radiology and Radiological Sciences, Vanderbilt University, Nashville, TN, United States, [2]Vanderbilt University Institute of Imaging Science, Vanderbilt University, Nashville, TN, United States, [3]Department of Biomedical Engineering, Illinois Institute of Technology, Chicago, IL, United States, [4]MR Clinical Science, Philips Healthcare, Cleveland, OH, United States

Introduction: Magnetization transfer (MT) imaging provides contrast that is sensitive to the interactions between immobile macromolecular protons and free water protons. Clinically, this effect is most commonly characterized via the magnetization transfer ratio (MTR), a measure that has been shown to correlate with myelin content [1]. Unfortunately, MTR values are affected by scanner hardware [2], tissue relaxation times, and RF pulse parameters [3]. To alleviate this sensitivity to non-physiological parameters and to deliver indices that are directly related to the underlying tissue, several quantitative MT (qMT) techniques have been developed [3-6]. The pulsed, off-resonance saturation technique originally proposed by Sled and Pike [5] has received considerable attention because it allows qMT data to be collected in clinically relevant scan times; however, this technique suffers from: *i*) complicated data analysis, *ii*) the need to acquire additional data (measurement of ΔB_0, B_1, and T_1), and *iii*) sensitivity to macromolecular proton lineshape assumptions. The selective inversion recovery (SIR) approach [6] does not suffer from these shortcomings, but has not been widely implemented on clinical systems. The goal of this study was to implement the SIR approach on a clinical 3T system and to compare the resultant qMT parameters obtained in healthy brain to previously published values [7]. In order to acquire these data efficiently, a turbo spin echo readout (SIR-TSE) and reduced TR were employed [6].

Theory: Assume an inversion pulse is applied with a duration that is much longer than the T_2 of macromolecular protons (≈10 μs) and much shorter than the T_2 of free protons (10-100 ms). The effect of such a pulse will be to invert water protons while affecting macromolecular protons to lesser degree. Following inversion, the free water longitudinal magnetization can be described by a biexponential recovery

$$M_z^f(t_i) = b^+ \exp(-R_1^+ t_i) + b^- \exp(-R_1^- t_i) + M_0^f \quad (1)$$

where $R_1^- < R_1^+$, t_i is the inversion time, and the superscript *f* denotes the free water pool (*m* denotes the macromolecular pool below). Assuming the exchange rate from the macromolecular to the free pool k_{mf} is much larger than any of the other rates, $k_{mf} \approx R_1^+$. Furthermore, if the TSE readout train is sufficiently long (≈100 ms), the longitudinal magnetization of both pools will be effectively zero at the end of the TSE train. In this case, the ratio of macromolecular to free pool sizes, or pool size ratio *PSR*, can be estimated from

$$PSR \approx b^+ / \{b^+ + b^- + 1 - S_m[1 - \exp(-R_1^- t_d)]\} \quad (2)$$

where S_m is the numerically estimated macromolecular pool saturation due to the inversion pulse (S_m = 0.83 for the 1-ms block pulse used herein [6]) and t_d is the time from the center of the last spin echo in the TSE train to the next inversion pulse.

Methods: Four healthy volunteers were imaged using a 3.0T, Philips 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 single 5-mm slice parallel to the AC-PC line was selected from survey images. SIR-TSE data were then acquired in this slice using the following parameters: t_i logarithmically spaced between 10 ms and 2 s (15 values) and t_i = 10 s, t_d = 2.5 s, block inversion pulse duration = 1 ms, TSE factor = 24, echo spacing = 5.9 ms, TE = 74 ms, SENSE factor = 2, in-plane resolution = 2 × 2 mm^2, and number of signal acquisitions averages = 2. Data from each voxel were fitted to the biexponential recovery described by Eq. (1) using a subspace trust-region method [8]. The fitted exponential rate constants and amplitudes were then related to qMT parameters as described above.

Results and Discussion: Representative data and fits are shown in Fig. 1, demonstrating the biexponential nature of SIR data. Based upon these fits, parametric maps—k_{mf}, *PSR*, and R_1^-—were generated (Fig. 2). For *PSR*, note the contrast between white and grey matter as well as the heterogeneity within white matter. These regional differences are thought to mainly reflect differences in myelin content in these tissues. Mean ROI values were tabulated for a number of tissues (Table I). The measured *PSR* and R_1^- values obtained herein were in good agreement with previously published values [7]. However, the measured exchange rates were found to be systematically slower (≈25%) [7], which may be due to the different acquisition strategies and/or model assumptions made by each approach.

Results were found to be in reasonable agreement with previously published values, especially for *PSR*. Future work includes: *i*) extending SIR-TSE to a 3D sequence to allow for whole brain coverage, *ii*) using optimized t_i and t_d values, which may allow for quantification of qMT parameters from as few as five images (instead of the 16 used herein) [9], and *iii*) applying this approach to patients with multiple sclerosis.

References: [1] Odrobina. NMR Biomed 2005(18):923. [2] Berry. JMRI 1999(9):441. [3] Henkelman. MRM 1993(29):759. [4] Wolff. MRM 1989(10):135. [5] Sled. MRM 2001(46):923. [6] Gochberg. MRM 2007(57):437. [7] Underhill. NeuroImage 2009(47):1568. [8] Coleman Siam J Optim 1996(6):418. [9] Li. ISMRM 2009:4500.

Acknowledgments: We thank NIH/NBIB K01 EB009120 and NIH T32 EB001628 for funding.

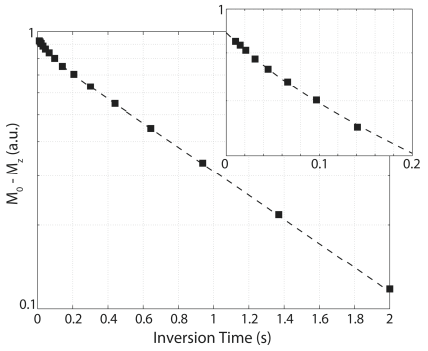

FIG. 1. Sample data (ROI C in Fig. 2) and model fit. Data were subtracted from thermal equilibrium and plotted on a semi-logarithmic plot to demonstrate the biexponential recovery, which is especially evident at shorter t_is.

TABLE I. Mean ± SD qMT parameters across volunteers for the ROIs defined in Fig. 2 (plus contralateral ROIs).

ROI	*PSR* (%)	k_{mf} (s^{-1})	R_1^- (s^{-1})
A	5.6 ± 1.3	15.1 ± 5.2	0.57 ± 0.06
B	10.9 ± 0.7	13.9 ± 1.5	1.07 ± 0.07
C	10.0 ± 1.3	14.1 ± 2.2	1.03 ± 0.06
D	10.4 ± 1.0	13.0 ± 1.6	1.04 ± 0.04
E	10.1 ± 1.6	12.2 ± 2.3	1.01 ± 0.10

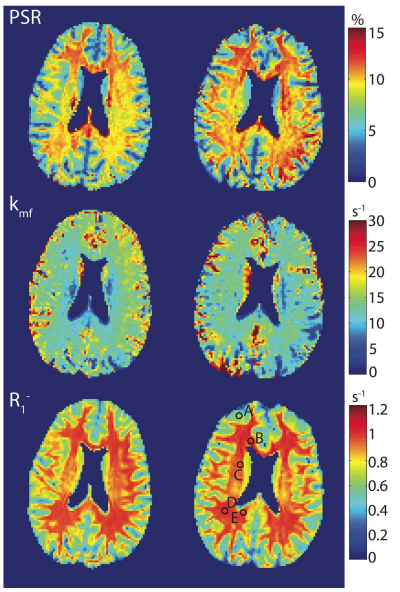

FIG. 2. *PSR* (top), k_{mf} (middle), and R_1^- maps (bottom) from two volunteers (left and right). Sample ROIs are given for: A–frontal grey matter, B–corpus callosum (genu), C–corona radiata, D–corpus callosum (splenium), and E–occipital white matter.