Quantitative Magnetization Transfer Imaging of Human Brain at 7 Tesla

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Introduction: Quantitative MT (qMT) imaging yields indices describing the interactions between free water protons and immobile macromolecular protons, including the macromolecular to free pool size ratio (*PSR*) and the rate of magnetization transfer (MT) from the macromolecular (*m*) to the free (*f*) pool (k_{mf}). Previous work at 1.5 [1–3] and 3T [4,5] has indicated that the *PSR* may be sensitive to myelin content in human white matter. Such studies would presumably benefit from the increased SNR available at 7T; however, they are currently hampered by the significant magnetic (ΔB_0) and RF transmit field (B_1^+) inhomogeneities as well as the SAR limitations encountered at 7T. The selective inversion recovery (SIR) qMT imaging technique [5–7], which is based upon the biexponential recovery of the free water pool after an on-resonance inversion, has previously [5] been suggested to be less sensitive to these issues than pulsed saturation techniques [1–4]. Therefore, we have developed a SIR protocol for qMT imaging of the human brain at 7T and here we report data acquired in healthy subjects.

Methods: Pulse Sequence: The 7T SIR pulse sequence (Fig. 1) employs *i*) a composite inversion pulse (Fig. 2) designed [8] to uniformly invert the free pool magnetization over the range of expected ΔB_0 and B_1^+ values, *ii*) a variable duration inversion recovery (IR) period to sample the transient biexponential recovery, *iii*) a center-out, single-shot turbo field echo (TFE) readout for reduced scan times, and *iv*) a constant predelay (PD) period to allow for longitudinal magnetization recovery after the TFE train.

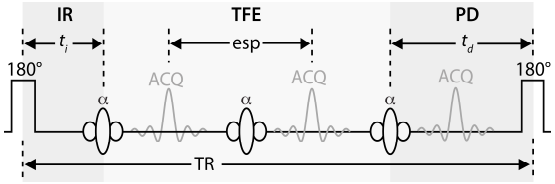

Fig. 1. SIR pulse sequence with a composite inversion pulse (see Fig. 2) and a low flip angle (α) TFE readout (first three echoes shown). Legend: t_i = inversion time, t_d = predelay, esp = echo spacing, ACQ = acquisition.

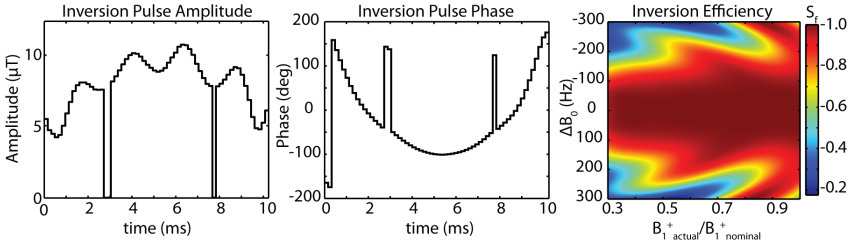

Fig. 2. Composite inversion pulse amplitude (left), phase (middle), and predicted inversion efficiency, S_f (right). $S_f = -1$ denotes complete inversion.

Data Acquisition: Three healthy volunteers (age range = 27–32 y.o.) were imaged using a 7T Philips MR scanner. A quadrature head coil was used for signal excitation and a 32-channel head coil was used for signal reception. Single-shot SIR-TFE data were acquired in a 5-mm axial slice parallel to AC–PC line using the following parameters: t_i logarithmically spaced between 10 ms and 2 s (15 values) and t_i = 10 s, TE = 2.4 ms, TFE echo spacing (esp) = 3.7 ms, SENSE factor = 2, acquired resolution = 2 × 2 mm^2, field-of-view = 212 × 212 mm^2, and two acquisitions. Unlike our 3T SIR protocol [5], which employed a TSE readout, both pools may not be fully saturated at the end of the TFE train. Therefore, we acquired SIR-TFE data over a range of predelay (t_d = 1.25–10 s) values in one volunteer to determine the minimum t_d value that did not bias our qMT parameters. This value (t_d = 5 s) was used for the subsequent scans, resulting in a scan time of four minutes per slice. B_1^+ was also measured using the actual flip angle method [9] with TR_1/TR_2 = 125/25 ms and excitation flip angle = 60°.

Data Analysis: Data from each voxel were fit to a biexponential IR model and the resulting exponential rate constants and amplitudes were related to qMT parameters as described in [10]. The inversion efficiency (S_f) of the free water pool was included as a free parameter in our model fit, while the macromolecular pool saturation fraction (S_m) was numerically estimated for the composite pulse in Fig. 2 using the measured B_1^+ map, assuming a Gaussian lineshape and T_{2m} = 13 μs [7].

Results and Discussion: Parametric maps are shown in Fig. 3. S_f was uniform over most of the slice, indicating a robust inversion. Note that this uniformity was found in the presence of significant B_1^+ errors as indicated by the spatial variation in S_m. For the qMT parameters, consistent results were observed across subjects, although it should be noted that k_{mf} was *i*) noisy in and around areas with CSF and *ii*) biased toward lower values in areas with large ΔB_0 and/or B_1^+ errors. Mean ± SD *PSR* (and k_{mf}) values across subjects were 17.6 ± 0.8% (15 ± 1 s^{-1}) and 10.5 ± 0.4% (31 ± 3 s^{-1}) in white and gray matter, respectively. These values are within the range of previously reported values at 1.5 and 3T [1–5], suggesting that qMT imaging can be robustly performed at 7T via SIR-TFE. Future work includes *i*) extending SIR-TFE to a 3D sequence and *ii*) adding composite excitation pulses to the TFE readout to minimize its sensitivity to B_1^+ errors.

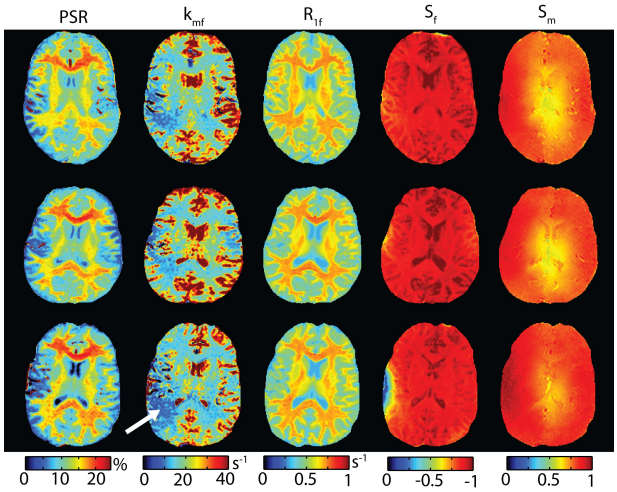

Fig. 3. Parameter maps for each subject. The white arrow denotes biased k_{mf} values due to ΔB_0 and/or B_1^+ errors.

References: [1] Sled. *MRM* 2001(46):923. [2] Yarnykh. *Neuroimage* 2004(23):409. [3] Garcia. *Neuroimage* 2010(52):532. [4] Underhill. *Neuroimage* 2009(47):1568. [5] Dortch. *ISMRM* 2010:335. [6] Edzes. *Nature* 1977(254):521. [7] Gochberg. *MRM* 2007(57):437. [8] Moore. *JMR* 2010(205):50. [9] Yarnykh. *MRM* 2007(57):192. [10] Li. *MRM* 2010(64):491.

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