Reduced specific absorption rate (SAR) Magnetization Transfer imaging with Low Density MT pulse technique for 7 Tesla

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INTRODUCTION Magnetization Transfer (MT) imaging and MT ratio (MTR) map have been proposed as a potential biomarker for myelin concentration in the brain. (1, 2) For this reason the application of MT can be used to characterize white matter diseases in the brain, such as multiple sclerosis (MS). However, due to the much higher specific absorption rate (SAR) of tissue at ultra-high field (UHF), the acquisition time of MT imaging at UHF is much longer than at lower filed strengths. Thus, MT imaging at UHF MRI has not, heretofore been suitable for clinical scanning. In this work, we described a new MT acquisition technique within a clinically reasonable time (<6 min) which uses a sparsely applied MT pulse. This method takes advantage of the relatively long recovery time, which is approximately five times T_1 of tissue (1), particularly at UHF. With new proposed MT acquisition scheme, the scan time is reduced considerably (3.19 min in MT_{R4}) while maintaining similar MTR when compared with the case of MT pulse applied in all k-space lines (12.16 min).

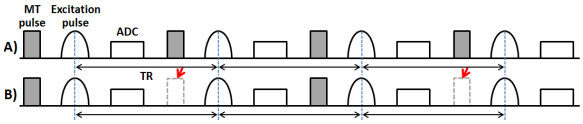

Figure 1. MT sequence diagrams of two different examples. MT pulse applied in (A) all (MT_{full}; original method) and (B) every second (MT_{R2}) k-space lines

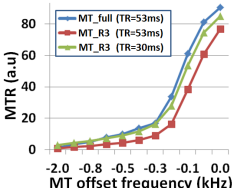

Figure 2. MTR for agar phantom. Data are plotted for three different cases.

METHODS Phantom and *in vivo* (IRB-approved) data were acquired on a 7T MRI scanner (MAGNETOM, Siemens) using a 32-channel phased array head coil (Nova Medical). ***Low density MT sequence:*** MT saturation pulses are applied every second (MT_{R2}, Fig.1B) or third (MT_{R3}) k-space lines prior to excitation RF pulses. The density level of MT applied k-space line and TR were jittered to test the effect of MT. These results were incorporated into the design of the low density MT sequence. For the sequence, MT RF pulse (flip angle: 540, duration: 7.68 ms, offset frequency 2 kHz) was used with 3D GRE readout. ***Phantom experiments:*** To verify the MTR characteristics of vdMT, BIRN phantom (3) data were acquired over different offset frequencies and TR to characterize the MTR spectrum. The scan parameters were as follows: 80 slices, resolution = 2 mm^3 iso, TR = 53 and 30 ms, TE = 2.84 ms, GRAPPA factor = 3, partial Fourier = 6/8 in k_y and k_z, and scan time = 3.0 and 1.42 min for TR of 53 and 30 ms, respectively. ***Healthy subject scan:*** Three acquisitions were performed as follows: ***Scan 1)*** MT pulses applied in all k-space lines (MT_{full}): resolution = 1.0 mm^3 iso voxel, TR = 108 ms, TE = 3.2 ms, 96 slices, GRAPPA factor = 3, partial Fourier = 6/8 in k_y and k_z, and scan time = 12.16 min. ***Scan 2)*** MT pulses applied in every fourth k-space lines (MT_{R4}): the same sequence structure and parameters as in Scan 1 except TR = 29 ms, and scan time = 3.19 min. ***Scan 3)*** MT pulses applied in every third k-space lines (MT_{R3}): the same sequence structure and parameters as in Scan 1 except TR = 36 ms, and scan time = 4.06 min. Matched non-MT 3D GRE scans were collected in all cases for MTR calculation. All data were acquired in the same session. ***MS patient scan:*** Images were acquired from clinically diagnosed MS patients to demonstrate signal characteristics of high-resolution low density MT in MS lesions. The sequence was acquired after MP2RAGE (sagittal orientation, 0.75 mm^3 iso) and FLAIR (axial orientation, 0.75x0.75x2 mm^3). The scan parameters were as follows: 128 slices, resolution = 0.75 mm^3 iso TR/TE = 24/3.2 ms, GRAPPA factor = 3, partial k-space in phase = 6/8, and scan time = 5.26 min. ***Characterization of MTR in low density MT***: To verify the MTR characteristics of MT, ROI analysis was performed (ROIs are shown in Fig. 4) through the brain.

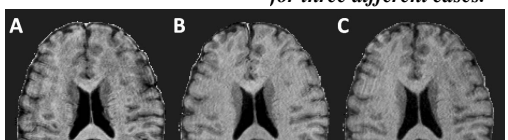

Figure 3. MTR for healthy subject. (A) MT_{full}, (B) MT_{R4} and (C) MT_{R3}(1mm^3 iso-voxel)

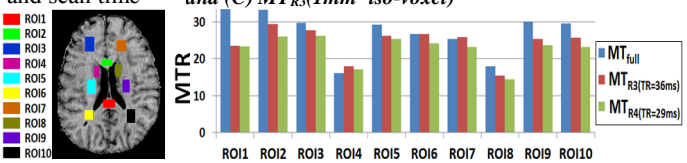

Figure 4. ROI analysis for MTR characterization

RESULTS When the MTR spectra were investigated using phantom (Fig. 2), all results show similar trend over offset frequencies. MT_{R3} scan with the same TR (=53ms; red line) of MT_{full} provides lower MTR in each frequency offset than MT_{full} (blue line) scan, as shown in Fig. 2. However, MT_{R3} with short TR (=30ms; green line) generates the comparable (slightly lower) MTR value with a conventional MT (MT_{full}) with TR of 53ms. Figure 3 visualizes MTR images from conventional MT (A) and two different low density MT scans (Figs. 3B and C). Note that low density MT with small TRs illustrate similar image quality and compatible MTR contrast, to be compared to full MT with long TR. Additionally, short scan time with low density MT tends to be less sensitive to head motion artifacts, as shown in Fig. 3. The measured MTR distributions in each ROI are shown in Figure 4. Compared to the MTR distribution from the MTR_{full} (blue bar in Fig.4), the MT_{R3} (Red) and MT_{R4} (Green) are shown 15% (mean value) reduced MTR value over ROIs. These results are similar with phantom data which shown in Fig. 2. Figure 5 shows FLAIR, MP2RAGE, and MTR using MT_{R4} images from a MS patient. The MS lesion (arrows) did not show signal enhancement in the post-contrast T_1w image (separately acquired in clinical MRI scanner, not shown here) suggesting it is, so-called, T_1 black holes with demyelination and axonal loss. In this lesion, the MTR is significantly reduced, clearly delineating the lesion (Fig. 5C). MTR (Fig. 5C) values vary across the lesion (more dark in the lesion core than lesion periphery).

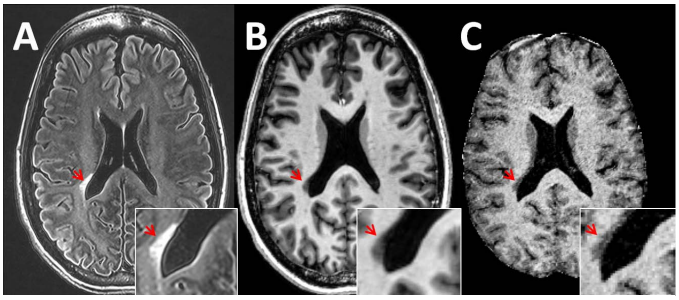

Figure 5. FLAIR (A), MP2RAGE (B), and MTR using low density MT (C) images from an MS patient. Chronic lesions (arrows) show significant signal reduction in MTR map. 0.75 mm^3 isotropic voxel.

DISCUSSION and CONCLUSION The new proposed low density MT sequence can cover a whole brain volume (FOV = 192×192×96 mm^3; resolution = 0.75 mm^3 iso) in clinically reasonable time (5.26 min) and provide similar quality MTR map with original MT imaging. This method takes advantage of the relatively long recovery time (1). Based on this, we can maintain a certain level of MT effect over several repetition times if TR is short. Compared to conventional MT, vdMT shows a smaller MTR values due to lower density of MT applied k-space lines particularly in the center of the k-space. However, the short acquisition time of new proposed MT method could minimize head motion artifact. In addition, the method appears to be useful as a clinical scan to identify MS lesions. A new MT acquisition approach, in conjunction with conventional acquisition scheme (MT_{full}) in the center of the k-space and proposed low density MT acquisition in high frequency area, may provide improved result for MTR.

References: [1] Balaban and Ceckler, 1992 [2] Gass et al., 1994 [3] Friedman, 2006, JMRI, 23:827