High resolution Magnetization Transfer Imaging at 7T

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Purpose: Magnetization transfer (MT) and technically related effects such as Chemical Exchange are important sources of contrast in MRI, especially when looking at (de)myelination of tissues as in Multiple Sclerosis (MS). MT has not previously been studied in the brain at 7T due to SAR constraints. In particular standard MT imaging sequences (interleaving single MT pulses with single imaging pulses in a TFE readout) must be run with a long TR at 7T to maintain a reasonable SAR, but severely limiting sensitivity to MT. We overcame this problem by using a pulsed saturation train followed by a turbo-field echo readout (similar in concept to the IR prepared MP-RAGE sequence [1], hence named MT-RAGE) to provide high spatial resolution MT images. We have used these to study MS lesions at 7T and compare the sensitivity of MT at 7 and 3T.

Method: Scanning was carried out using Philips Achieva scanners at 3 and 7T. The high resolution MT-RAGE sequence (figure 1) required the acquisition of two images. The first (MTon) applied a train of 20 off-resonance pulses (13.5 µT Gaussian-windowed, sinc pulses with a bandwidth of 300 Hz and off-resonance by 1.1 kHz, with 50 ms between each pulse), followed by a Turbo-Field echo (TFE) readout (TR/TE=10/5.4ms, flip angle= 8°, 1x1x1mm^{3}at 3T and 0.86x0.86x1mm^3 at 7T) with a shot to shot interval (SSi) of 10 s. The actual FOV is 220x220x45mm for a total imaging time of 4min40s for the MS study. Pulsed saturation [2] is less efficient and broader bandwidth than CW saturation but is readily implemented on standard scanner hardware. The TFE readout sampled k-space centre-out to maximize the MT contrast in the image. The second (MT_{off}) image was a reference image acquired as the TFE sequence, with no off-resonance saturation pulses applied. High resolution MT ratio images were calculated by computing $(MT_{off}-MT_{on})/MT_{off}$ on a pixel by pixel basis. A number of normal volunteers (N=5) and MS patients (N=3) have been scanned with this sequence in accordance with approval from the local ethics committee.

Results: Figure 2 shows that high resolution and high contrast MTR images can be acquired in a reasonable imaging time at both 7T and 3T but shows better contrast to noise ratio (CNR) at 7T. This improved CNR allows variations in MT between WM regions to be distinguished at 7T, as previously shown at lower fields [3], but with lower resolution. Figure 3 shows that high CNR and high resolution can be achieved with MT-RAGE at 7T with the use of two averages for a resolution of 0.7x0.7x1.5mm^3. Table 1 quantifies MTR at 7T and 3T. Figure 4 shows that high sensitivity to MS lesions is achieved with MT-RAGE at 7T; the mean and standard deviation of the MTR values for a relapsing stage MS lesion were close to the GM ones (0.15±0.07 for the lesion vs 0.14±0.08 for GM).

	MTR at 3T (±S.D)	MTR at 7T (±S.D)
White Matter	0.50±0.05	0.35±0.03
Grey Matter	0.35±0.10	0.14±0.08
Corpus Callosum	0.66±0.05	0.52±0.04
CNR WM/GM	0.15±15	0.21±11

Table 1: MTR values with Standard Deviation (SD) computed from a healthy subject in White Matter, Grey Matter and Corpus Callosum regions at 3T and 7T (NSA=1). Contrast to Noise Ratio is also given.

Discussion: It is possible to acquire high resolution MT images at 7T in a reasonable imaging time in the brain without breaching the SAR limit. As far as we are aware these are the highest resolution MTR images of the brain recorded so far, and the first MTR images reported in the brain at 7T. Although the base MT_{on} images are sensitive to B_1 and B_0 inhomogeneities, which are a particular problem at 7T, these do not have much impact on the contrast in the final MTR images, because some effects cancel in the calculation of the MT ratio. However further work will investigate methods of correcting residual effects of field inhomogeneities. At 7T a longer SSi is required to allow for the increased longitudinal relaxation time, but this effect is counteracted by the increased SNR and hence reduced need to average.

MTR is known to be a sensitive marker of MS since the MT effect depends on tissue myelination, and WM lesions are known to be the site of destruction of myelin sheath. High resolution imaging in a short scan time would allow smaller white matter lesions to be studied. High spatial resolution will be particularly important when studying MT effects in normal appearing white matter. This sequence forms part of a protocol used in an ongoing study of MS patients at 7T, and the appearance of normal appearing white matter on high resolution MTR scans from these patients is now being investigated.

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[1]: Deichmann, R., et al., Neuroimage, 2000; 12: 112-127. **[2]:** Graham, S., et al., JMRI, 1997, 903-912. **[3]:** Yarnykh, V., et al., NeuroImage, 2004, 23: 409-424.

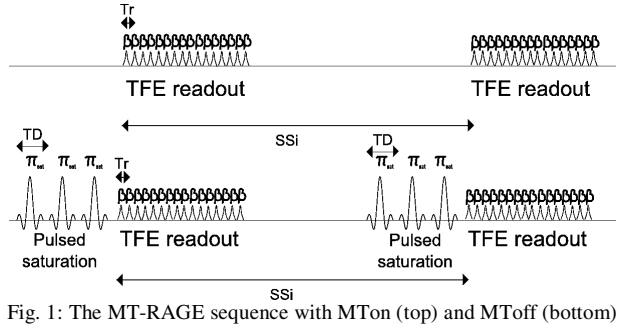

Fig. 1: The MT-RAGE sequence with MTon (top) and MToff (bottom) versions. The Shot-to-shot interval was kept at 10seconds to allow the longitudinal magnetization to fully recover before the next pulse train.

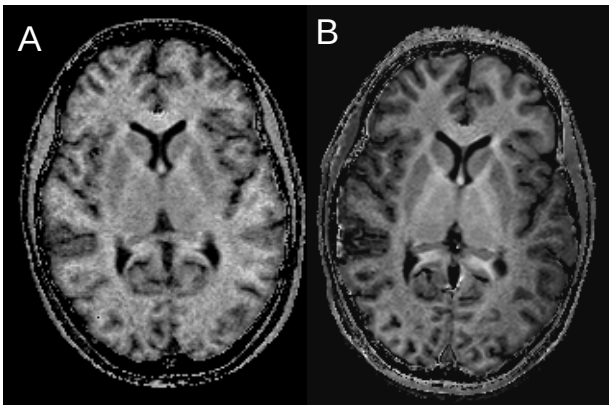

Fig. 2: MTR image at A: 3T and B: 7T acquired using MT-RAGE at resolution of 1x1x1mm^3 (3T) and 0.86x0.86x1mm^3 (7T) in 6 min 35 s.

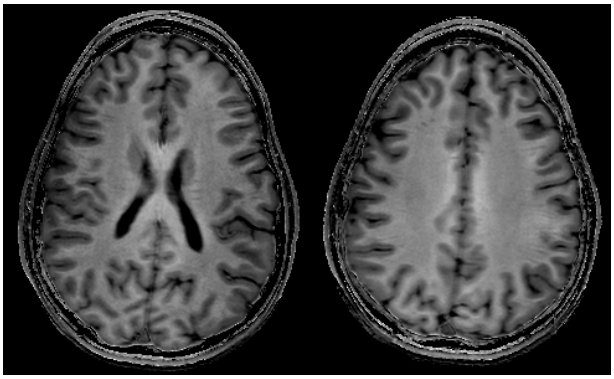

Fig. 3: MTR-RAGE at 7T on a healthy subject, 2 averages (NSA=2).

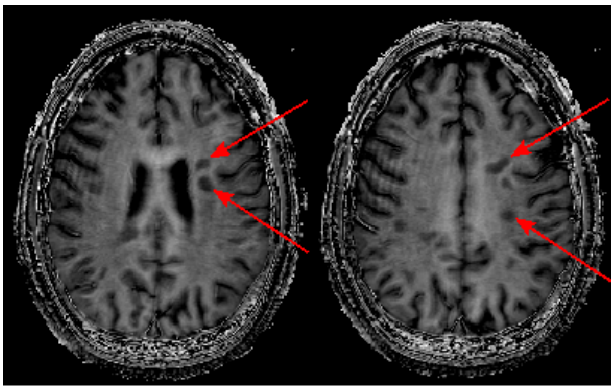

Fig. 4: MTR-RAGE at 7T on a MS patient. Arrows indicates MS lesions that were also found T2-weighted images and T1 maps. The slice thickness was 1.5mm to allow a whole brain acquisition.