Inversion preparation in magnetization transfer imaging reduces irradiation requirements in human brain at 3 T

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Introduction

Magnetization transfer (MT) properties correlate with myelin content in brain tissue, and are known to be important parameters affected by disease. Steady-state (SS) MT ratio (MTR) maps from data acquired with off-resonance irradiation of sufficient duration to saturate immobile protons in macromolecules are the most sensitive to inherent MT properties. However, achieving SS without exceeding specific absorption rate (SAR) limitations can be difficult — and even impossible — on clinical scanners, especially at high magnetic field. It is therefore important to obtain high-quality MTR maps with minimal RF power deposition. It has been shown that a simple inversion recovery imaging sequence with an on-resonance (at water frequency) inversion pulse whose duration is within specific limits is capable of quantifying MT properties without need of any off-resonance MT irradiation (1). Alternatively, estimates of MT parameters while avoiding the SAR problem have been made based on the approach to SS, where consecutive measurements are acquired with or without an on-resonance inversion prepulse to change the initial magnetization orientation prior to off-resonance MT irradiation (2). We compare the effect of various strategies utilizing on-resonance inversion prepulses and demonstrate that similar quality MTR maps can be obtained at significantly reduced irradiation times (i.e., much lower RF power deposition), as compared with maps acquired without the inversion prepulse at SS.

Methods

Three male subjects were studied on a 3-T Siemens scanner using a volume head coil. When the inversion prepulse was included it consisted of adiabatic fast passage of 16 ms duration applied at water proton resonance frequency. When off-resonance MT irradiation was applied, it was at 4 kHz relative to water proton resonance frequency, consisting of a train of pulses because continuous-wave RF irradiation was not an option; each segment was 65-ms duration, with a spoiler gradient was applied during the 5-ms delays between segments to suppress residual transverse magnetization (3). Off-resonance MT power levels were $\omega_1/2\pi$ = 100 or 177 Hz with 20 different pulse train durations (0 to 7 s). Images were acquired with single-shot spin-echo, echo planar imaging with slice thickness = 5 mm, matrix size = 64×64 and FOV = 24×24 cm^2, TR = 10 s and TE = 40 ms. Pixel values for MT images were calculated as MTR = $(M_0-M_s)/M_0 \times 100$ (4), where M_0 is the signal intensity without MT irradiation, and M_s is the signal intensity with MT irradiation. Gray and white matter regions were assigned with Statistical Parametric Mapping based on segmentation probability > 0.8.

Results and Discussion

Fig. 1 shows MT saturation curves (averages of brain pixel values) for MT strategies utilizing different combinations of on-resonance inversion prepulses and/or off-resonance irradiation. Figs. 2 and 3 show individual MT images, with the pixel-by-pixel comparisons appearing in Fig. 4. When $\omega_1/2\pi$ = 100 Hz (blue circles in Fig. 1), the MT images with both on-resonance inversion prepulse and off-resonance for the irradiation time of 0.18 s (Fig. 2D) are similar to maps without the on-resonance inversion prepulse, but with a much longer off-resonance irradiation of 7 s (Fig. 2A). When $\omega_1/2\pi$ = 177 Hz (red squares in Fig. 1), it was impossible to achieve SS due to SAR limitations, but we consider the longest achievable off-resonance irradiation duration of 2.1 s to approximate SS since it is > 3 times the MT saturation constant (T_{1sat} = 0.65^{-1}. Under this condition of $\omega_1/2\pi$ = 177 Hz, the maps with both on-resonance inversion prepulse and off-resonance irradiation time of 0.25 s (Fig. 3B) are similar to maps without the on-resonance inversion prepulse, but with a much longer off-resonance irradiation of 2.1 s (Fig A). For these two different off-resonance RF power levels employed, pixel-by-pixel comparisons are well matched between strategies utilizing no on-resonance inversion prepulse vs. those with on-resonance prepulse (Fig. 4). This work demonstrates that incorporation of on-resonance inversion prepulses yields MT images of similar quality as compared to maps acquired without the inversion prepulse at SS, but at significantly reduced off-resonance irradiation times (well within SAR limits). Future analysis is required to investigate the differences between MT perturbations of the macromolecular pool and/or the free water pool.

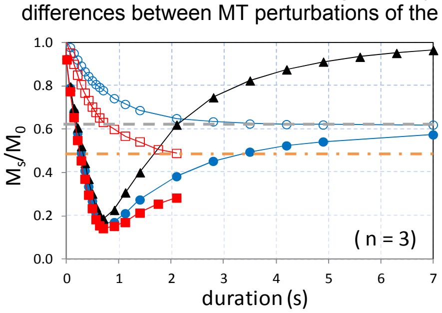

Fig. 1. MT saturation curves. Absolute values of M_s/M_0 (average of brain pixels within the slice) are plotted as a function of either off-resonance irradiation duration or inversion recovery time (when there is no off-resonance irradiation), where data were acquired without (open symbols) or with (closed symbols) on-resonance inversion preparation followed by off-resonance MT irradiation, or with only on-resonance inversion preparation (black triangles). Off-resonance MT irradiation was at two different power levels, with $\omega_1/2\pi$ = 100 Hz (blue circles) or = 177 Hz (red squares). The gray dotted line shows steady-state M_s/M_0 when $\omega_1/2\pi$ = 100 Hz, while the orange dotted line approximates steady-state M_s/M_0 when $\omega_1/2\pi$ = 177 Hz.

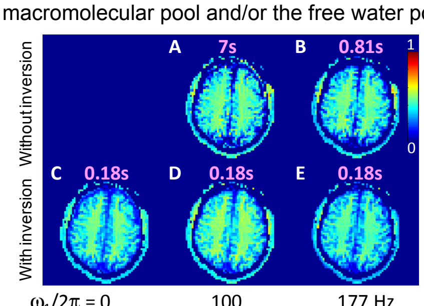

Fig. 2. MT images generated from measurements made at the time points intersecting the gray dotted line in Fig. 1. Data were acquired under conditions of either (A-B) no on-resonance inversion prepulse with off-resonance MT irradiation, or (C-E) with on-resonance inversion prepulse and either (C) no off-resonance MT irradiation, or (D-E) with off-resonance MT irradiation. Pink values indicate off-resonance irradiation duration or inversion recovery time, while $\omega_1/2\pi$ indicates off-resonance power levels.

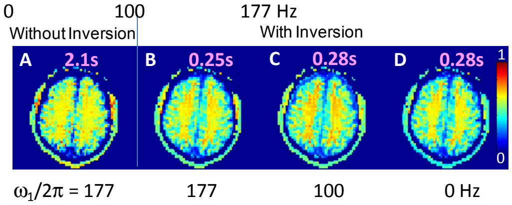

Fig. 3. MT images generated from measurements made at the time points intersecting the orange dotted line in Fig. 1. Data were acquired under conditions of either (A) no on-resonance inversion prepulse with off-resonance MT irradiation, or (B-D) with on-resonance inversion prepulse and either (B-C) with off-resonance MT irradiation or (D) no off-resonance MT irradiation. Pink values indicate off-resonance irradiation duration or inversion recovery time, while $\omega_1/2\pi$ indicates off-resonance power levels.

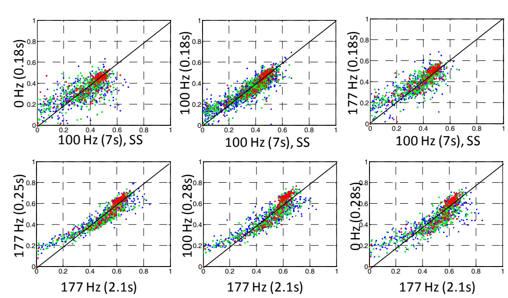

Fig. 4. Pixel by pixel comparisons of MT images from data acquired under conditions of Fig. 2 (upper row) and Fig. 3 (lower row), where the horizontal axis is data without an inversion prepulse at a steady-state (or near steady-state) condition, while the vertical axis is data with an inversion prepulse. Green dots: gray matter, red dots: white matter, blue dots: remaining pixels (e.g., cerebrospinal fluid and muscle). Lines of identity are shown.

References: 1. Gochberg and Gore, MRM (2003) **2.** Mangia et al., MRI (2011), **3.** Mougin et al., Neuroimage (2010), **4.**Henkelman et al., MRM (1993)**Acknowledgments:** NIH grants (EB003375, EB003324, NS44589, EB012140)