

Magnetization Transfer from Inhomogeneously Broadened Lines (ihMT): Sequence Optimization

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Target audience: MR physicists and physicians interested in novel endogenous contrast mechanisms and specific white matter imaging.

PURPOSE: Inhomogeneous magnetization transfer (ihMT) imaging has been proposed as a new method for imaging myelinated tissues of the central nervous system [1-4]. Improved specificity is obtained, presumably due to the unique architecture of the myelin sheath structure [4,5]. Restricted motion in such densely packed lipid membranes is hypothesized to give rise to significant residual dipolar coupling (i.e. un-averaged dipolar interaction), making their broad resonance line inhomogeneous. With such lines, proton magnetization exchange relatively slowly throughout the NMR spectrum, and this can be probed using a dedicated ihMT sequence (Fig1). Previous studies have been performed on humans [1-6] and small animals [7], at various magnetic field strengths (1.5T, 3T and 11.75T), and promising results have been obtained (e.g see Fig2). Various sequence parameters were used and a better understanding of the involved contrast mechanisms is now necessary to further optimize the ihMT effect. This study aims at optimizing the sequence parameters of a pulsed ihMT preparation module at 1.5T.

METHODS: *ihMT sequence design:* Experiments were performed at 1.5T (Avanto MRI, Siemens, Erlangen, Germany) on healthy volunteers. A pulsed ihMT preparation module (Fig1) was implemented in combination with a HASTE readout module for imaging. The pulsed ihMT preparation consisted of a train of Hann-shaped pulses (pw = pulse duration, Δt = interpulse repetition time, and τ = total prep. duration) with varying offset-frequency cycling schemes (Fig1a vs Fig1b)). Offsets of $\Delta f = \pm 7$ kHz were used based on previous optimization [2,4]. The ihMT contrast was calculated as $ihMT = MT^{+\Delta f} + MT^{-\Delta f} - MT^{+\Delta f-\Delta f} - MT^{-\Delta f+\Delta f}$, where $MT^{+\Delta f}$ and $MT^{-\Delta f}$ are MT images obtained with positive or negative single-frequency saturation (Fig1,a), respectively, and the other MT images correspond to a dual frequency saturation (Fig1,b). ihMT ratios were calculated as $ihMTR = ihMT/S_0$, where S_0 is the signal measured with RF saturation power set to zero. For the readout module, we used the following parameters: 22cm FOV, 192 matrix, 1cm slice, TR/TE = 3s/21ms, 789Hz/pixel BW and 120° refocusing angles. Acquisitions were performed in the axial plane, approximately mid-ventricles (Fig2). MT and S_0 datasets were averaged 20 and 3 times, respectively, for a total scan time of 4'15". *Optimization procedure:* The ihMT effect was optimized with respect to pw, Δt , and τ . For each parameter, 3 volunteers (23 y.o. mean age) underwent several acquisitions, keeping other parameters constant. The total RF energy of the MT preparation was varied by increasing the B_1 field from about 2 $\mu T^2.s$ up to the maximum allowed level corresponding to the standard SAR regulatory limitation. ROIs were selected in both hemispheres and in several brain areas, and the mean ihMT ratio and corresponding standard error were calculated over the three volunteers.

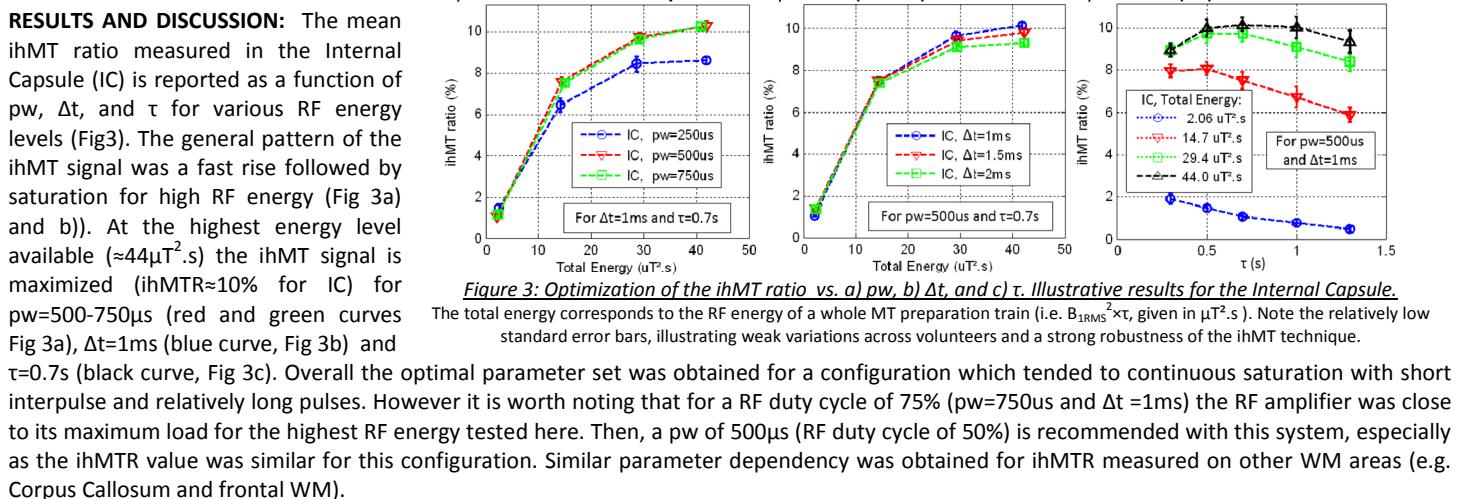


Figure 3: Optimization of the ihMT ratio vs. a) pw, b) Δt , and c) τ . Illustrative results for the Internal Capsule.
The total energy corresponds to the RF energy of a whole MT preparation train (i.e. $B_{1,\text{RMS}}^2 \times t$, given in $\mu T^2.s$). Note the relatively low standard error bars, illustrating weak variations across volunteers and a strong robustness of the ihMT technique.

RESULTS AND DISCUSSION: The mean ihMT ratio measured in the Internal Capsule (IC) is reported as a function of pw, Δt , and τ for various RF energy levels (Fig3). The general pattern of the ihMT signal was a fast rise followed by saturation for high RF energy (Fig 3a) and b)). At the highest energy level available ($\approx 44 \mu T^2.s$) the ihMT signal is maximized (ihMTR $\approx 10\%$ for IC) for pw=500-750μs (red and green curves Fig 3a), $\Delta t=1ms$ (blue curve, Fig 3b) and $\tau=0.7s$ (black curve, Fig 3c). Overall the optimal parameter set was obtained for a configuration which tended to continuous saturation with short interpulse and relatively long pulses. However it is worth noting that for a RF duty cycle of 75% (pw=750μs and $\Delta t=1ms$) the RF amplifier was close to its maximum load for the highest RF energy tested here. Then, a pw of 500μs (RF duty cycle of 50%) is recommended with this system, especially as the ihMTR value was similar for this configuration. Similar parameter dependency was obtained for ihMTR measured on other WM areas (e.g. Corpus Callosum and frontal WM).

CONCLUSION: This study focused on optimizing the ihMT effect for 3 of the main free sequence parameters of a pulsed preparation scheme. Very useful information can be derived from presented results in order to optimize ihMT signal and contrast in various experimental conditions. Here we have derived an optimal parameter set for ihMT imaging at 1.5T. Experiments at higher field strength (e.g. 3T) may not allow such high RF energy levels and other optimal parameters may be preferable to maximize the ihMT signal and/or to reduce the influence of B_1 heterogeneity.

REFERENCES: [1]. Alsop et al., Proc. ISMRM 2004; #2324 [2]. Alsop et al., Proc. ISMRM 2005; #2224 [3]. Alsop et al., Proc. ISMRM 2007; #2188 [4] Varma et al. MRM, in revision [5] Varma et al. Proc. ISMRM 2013; #2536 [6]. Girard et al., Proc. ISMRM 2013; #2506 [7]. Duhamel et al., Proc. ISMRM 2013; #2535