Magnetization Transfer from Inhomogeneously Broadened Lines (ihMT): Field Strength Dependency

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

PURPOSE: Myelin MR imaging is a fast expanding research area because of high clinical relevance of myelin-associated diseases such as multiple sclerosis. Advanced techniques such as Myelin Water Fraction (MWF), quantitative Magnetization Transfer (MT) and Diffusion Tensor imaging (DTI) have allowed deriving quantitative metrics related to the WM fiber integrity, but there is still a high demand for improved specificity. Our attention has been focused on a promising alternative: a new kind of MT that specifically addresses the inhomogeneously broadened lines of the NMR spectrum (hence so-called ihMT imaging [1-3]). Inhomogeneous broadening of a resonance line may occur in semi-solids whose proton magnetization do not exchange rapidly throughout the molecule (e.g. because of restricted motion), as can be the case in highly structured lipid membranes such as those encountered in myelin [3-4]. IhMT has been shown to be highly specific to myelinated tissue as almost no signal was observed in other tissues (scalp, muscle, Fig1). Previous studies have been performed at 3T and 1.5T by two different groups [1-7], using different MR systems, and high similarities were observed. In this work the ihMT contrast is quantified at both field strengths using the same acquisition protocol and volunteers to further address the potential field dependency of the ihMT effect.

Left: T2 weighted turbo spin echo axial image acquired approximately mid-ventricles. Middle: corresponding ihMT ratio image. Right: Sagittal ihMT ratio image demonstrating unique specificity toward WM (almost no signal is observed in fatty tissue, muscle, nor vertebrae)

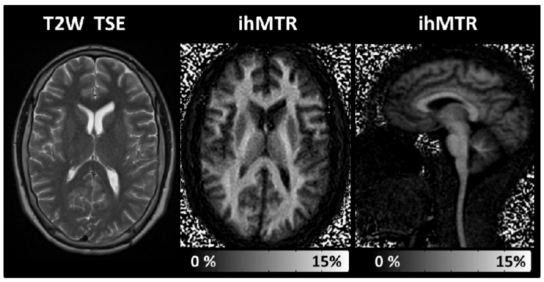


Figure 1: Representative ihMT ratio images

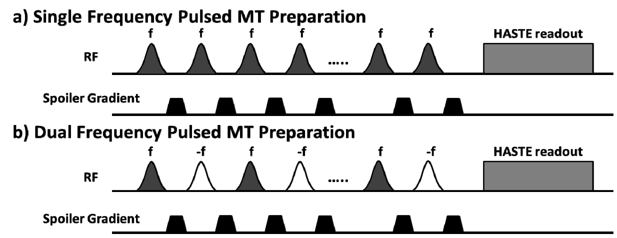
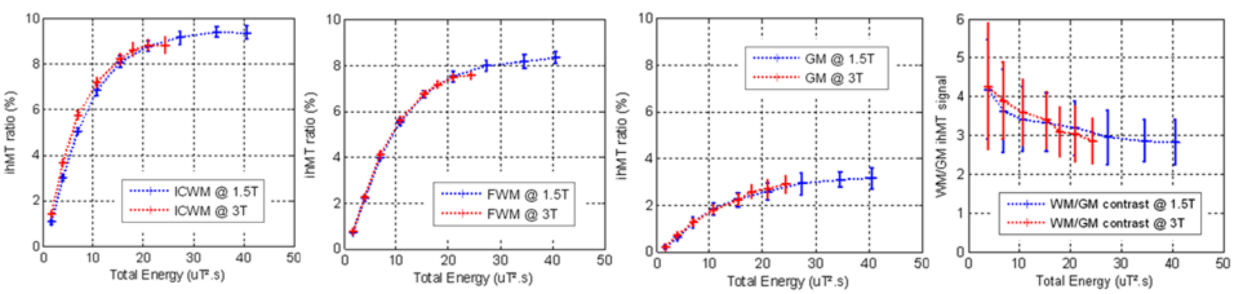


Figure 2: ihMT sequence design

METHODS: Experiments were performed at both 1.5T and 3T (Avanto and Verio MRI systems, Siemens, Erlangen, Germany) on two healthy volunteers (2 males, mean age 36 yo), using the same in-house developed sequence. A pulsed ihMT preparation module (Fig2) was implemented in combination with a product HASTE readout module for imaging. The ihMT contrast was generated from 4 sets of MT images acquired with varying offset-frequency scheme. The ihMT contrast was calculated as $ihMT = MT^{+f} + MT^{-f} – MT^{+f-f} – MT^{-f+f}$, where MT^{+f} and MT^{-f} were obtained with single frequency saturation (Fig2a) whereas the other images corresponded to dual frequency saturation (Fig2b). Measurement of the S_0 signal (i.e. with RF saturation power set to zero) was incorporated in the sequence to enable calculation of the ihMT ratio $ihMTR = ihMT/S_0$. For the pulsed MT preparation, Hann-shaped pulses (500µs duration each, repeated every 1.5ms during 500ms) and ± 7 kHz frequency offsets were used, based on previous work [1,3] The B_1 saturation field was varied from 1.85µT RMS (or 1.7 µT².s in terms of RF energy per MT preparation train) up to the maximum allowed level corresponding to the SAR regulatory limitation. For the readout module, we used 120° refocusing angles to reduce power deposition (FOV=22cm, Mtx=192 at 1.5T and 128 at 3T, 1cm slice, $TR/TE/BW_{/pixel}$ of 3s/21ms/789Hz at 1.5T and 4s/32ms/420Hz at 3T). Data were averaged over 132 NEX (4x S_0, and 32x for each of the four offset frequency conditions). ROIs were drawn on frontal WM (FWM), internal capsule (IC) and frontal GM. For each anatomical location, the mean ihMT ratio and corresponding standard error were calculated over both volunteers and brain hemisphere (to reduce potential error due to B1 inhomogeneities).



IhMT effects have similar intensity at 1.5T and 3T as shown by quantitative ihMT ratio measurements. Higher RF energy levels could be investigated at 1.5T, due to lower energy deposition.

Figure 3: ihMT ratio vs. RF energy measured at 1.5 and 3T

RESULTS AND DISCUSSION: The averaged ihMT ratio is reported as a function of the total RF energy (Fig3) for the three investigated brain locations. The ihMT signal rises quickly at low energy, and then tends to saturate. IhMTR values reached about 10% in the IC for the highest energy level tested (only attained at 1.5T here). A very good agreement between 1.5 and 3T datasets was obtained, showing only minor deviation during the rising part of the curves for IC, and perhaps a slightly different saturation behavior in WM at high RF energy levels. Note that such deviations may be due to RF inhomogeneities, which are anticipated at 3T, as well as user-dependent imaging slice adjustment and ROI location. Overall, the good agreement between both datasets strongly supports the dipolar origin of the inhomogeneous broadened line evidenced with the ihMT technique (as opposed to chemical- or susceptibility induced shift), as the residual dipolar coupling is typically independent of B_0. Moreover, the average WM to GM ihMT contrast ratio slightly decreased with RF energy and stayed around 3 whereas it was only around 1.4 for conventional MT, further acknowledging the unique specificity of the ihMT contrast toward WM.

CONCLUSION: This study was designed to evaluate the ihMT contrast dependency with regard to magnetic field strength. ihMT datasets obtained at 1.5T and 3T are very consistent and show no obvious field dependency. The ihMT technique is very robust, as demonstrated by low standard errors, and experiments may be performed at various field strengths with similar contrast properties.

REFERENCES: [1]. Alsop et al., Proc. ISMRM 2005; #2224 [2]. Alsop et al., Proc. ISMRM 2007; #2188 [3] Varma et al. MRM, in revision [4] Varma et al. Proc. ISMRM 2013; #2536 #2535 [5]. Girard et al., Proc. ISMRM 2013; #2506; [6] Varma et al. Proc. ISMRM 2013; #4224 [7] Rangwala et al. Proc. ISMRM 2013; #350