Human Brain Magnetization Transfer (MT) Asymmetry Dependence on RF Saturation Power

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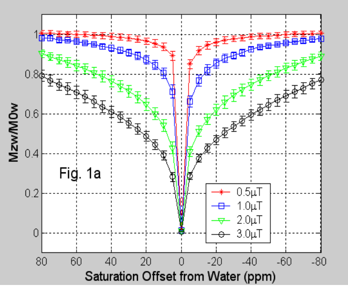
Introduction: MT in biological tissues provides a unique method of tissue characterization reflecting interaction between the solid-like macromolecular lattice and cellular water. The magnitude of MT is usually described by the so-called MT ratio (MTR), in which (1-MTR) is equal to the ratio of signal intensities with and without off-resonance irradiation. It has been shown previously that (1-3) MT is slightly asymmetric about the water proton resonance frequency, with a center frequency in the upfield range. This intrinsic asymmetry has been attributed to the chemical shift center mismatch between bulk water and macromolecules in tissue (1,2) and causes a negative background signal for the chemical exchange saturation transfer (4) and amide proton transfer (3) effects around the water resonance, where MT asymmetry analysis is used. In this study, we quantify the MT asymmetry in the human brain at 3 Tesla and study on its power and frequency offset dependence.

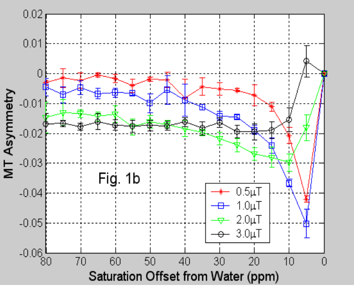
Materials and Methods: Healthy human volunteers (n = 4) were scanned on a 3T Philips MRI system. A head coil was used for RF transmission and signal reception. Continuous RF saturation scheme with power levels of 0.5, 1, 2, and 3 µT was used in this study. Frequency offsets were from –80 to 80ppm, with a step of 5ppm. TR was 6 sec.

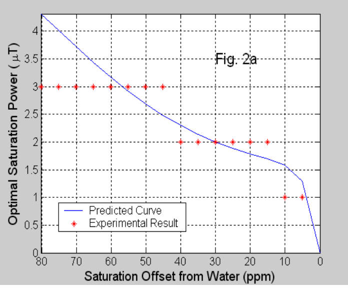
Results and Discussion: Fig. 1a shows Z-spectra (saturated signal intensities normalized with respect to unsaturated) of white matter from normal human brain (averaged over 4 subjects). This data set clearly shows the Z-spectrum is asymmetric about water resonant frequency, with a lower negative offset side ($P < 0.001$). To accounts for the chemical shift difference between water pool (w) and solid-like macromolecule pool (m), we add a new intrinsic model parameter Δ_{shift} to Henkelman's two-pool MT theory (5). The fitted Δ_{shift} value was larger in white matter (3.07 ± 0.06ppm) than in gray matter (2.33 ± 0.06ppm). We define the MTR asymmetry as the Z-spectra of negative offset (right) minus the Z-spectra of corresponding positive offset (left) with respect to water, namely $MTR_{asym} = MTR(+\text{offset}) - MTR(-\text{offset}) = \text{Z}(-\text{offset}) - \text{Z}(+\text{offset})$. Fig. 1b shows MTR_{asym} spectra of the same data set as Fig. 1a. The amplitude of the MT asymmetry is 1-2% for the offset region far from water and 3-5% for the region close to water (0-10ppm). As the applied RF saturation power increases, the dip of MT asymmetry moves toward higher offset region and its amplitude increases and then decreases after it approaches a maximum (Fig. 1b). There exists a characteristic RF saturation power for the maximal MT asymmetry ($\omega_{1,\max}$), which is different for the different offsets (Fig. 2a). According to the modified Henkelman's model, the analytical expression of $\omega_{1,\max}$ as a function of offset can be derived to be:

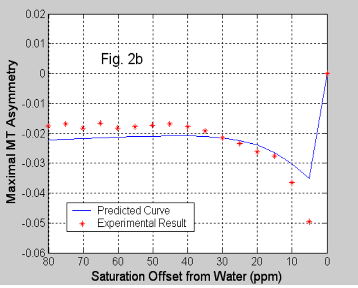
$$\omega_{1,\max} = \sqrt[4]{\frac{A^2}{C_1 C_2}}\text{, in which } A = R_m\left(\frac{RM_0^m}{R_w}\right) + R_m + R \text{ and } C_{1,2} = \left(1 + \frac{RM_0^m}{R_w}\right)\pi g_m(\mu 2\pi(\Delta + \Delta_{shift})) + (R_m + R)\left(\frac{1}{R_w T_{2w}}\right)\left(\frac{1}{2\pi\Delta}\right)^2.$$

The solid line in Fig. 2a shows the predicted maximal saturation powers as a function of frequency offset, which is well consistent with the experimental results. For each ω_1 applied, we see a range of offset frequencies that could have maximal MT asymmetry. However, the middle point of each offset range is located around the predicted curve. Fig. 2b shows the predicted results and experimental results of the maximal MTR asymmetry for each offset frequency, which are consistent especially in the frequency region far away from water. There are a lot of mobile proteins, peptides, lipids, and metabolites (3) co-existing with semi-solid macromolecules in tissue in the frequency region close to water (less than 5ppm), and a complicated multi-pool model is necessary to more accurately describe the MT effects in this region.









Conclusions: MT asymmetry in the brain depends on RF saturation power applied and the frequency offset with respect to water. For each different frequency offset, the magnitude of MT asymmetry can be maximized by a different characteristic saturation power. The MT asymmetry may provide a method to characterize both the solid-like and mobile macromolecular component in biological tissue.

References: (1) Pekar J, et al. MRM 1996;35:70. (2) Swanson SD & Pang Y. ISMRM 2003;11:660. (3) Zhou J, et al. Nat. Med. 2003;9:1085. (4) Ward KM, et al. JMR 2000;143:79. (5) Henkelman RM, et al. MRM 1993;29:759.