Magnetization Transfer (MT) Asymmetry in Human Cervical Spinal Cord

M. C. Ng[1], J. Hua[2,3], P. C. van Zijl[2,3], E. S. Yang[4], H. Hu[5], K. D. Luk[5], and E. Y. Lam[1]

[1]Electrical and Electronic Engineering, The University of Hong Kong, Pokfulam, Hong Kong, China, People's Republic of, [2]Russell H. Morgan Department of Radiology and Radiological Sciences, Division of MR Research, Johns Hopkins University, Baltimore, Maryland, United States, [3]F.M. Kirby Center for Functional Brain Imaging, Kennedy Krieger Institute, Johns Hopkins University, Baltimore, Maryland, United States, [4]ASTRI, Science Park, Shatin, Hong Kong, China, People's Republic of, [5]Department of Orthopaedics and Traumatology, The University of Hong Kong, Pokfulam, Hong Kong, China, People's Republic of

Introduction:

The solid-like macromolecules and mobile proteins in tissue can be selectively saturated by an off-resonance magnetization transfer (MT) pre-pulse. As the saturation transfer effect is tissue specific, MT can be used to increase image contrast. The z-spectrum is a curve in which the ratio of water signal intensities with and without the MT pulse is plotted as a function of frequency offset of the irradiation. The MT effect includes the interaction between bulk water and semisolid macromolecules (conventional MT) and the saturation transfer associated with exchangeable protons of some side groups e.g. –OH, –SH, and –NH (CEST)[1]. For the conventional MT effect, it has been reported in the brain that the z-spectra in tissue are slightly asymmetric around the water proton resonance frequency, with the center of the z-spectrum shifted slightly upfield (lower frequency) from the water resonance[2-4]. The discovery of the MT asymmetry (conventional MT and CEST) provides a new method for tissue characterization which reflects the chemical exchange and cross-relaxation. It has been reported that the MT asymmetry in 9L rat brain tumors is different from that in contralateral normal-appearing brain tissue[4]. In the current study, we would like to investigate both the conventional MT and the CEST effects in human cervical spinal cord at 3T MR system.

Methods:

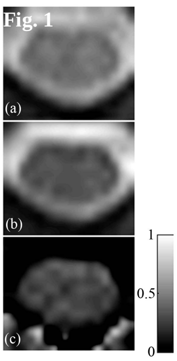
Scanning: 17 healthy male subjects, aged between 20-28 years were scanned at Philips Achieva 3T scanner with a multi-element spine coil covering the vertebral level, C3/C4-C5 (two subjects were excluded due to motion during scan, i.e. number of subjects undergoing analysis: 15). Single shot spin-echo echo-planar imaging (SE-EPI) with MT pre-pulse (pulse shape: block, saturation power: 2μT, saturation duration: 500ms) was employed with frequency offsets from -80ppm to 80ppm. The frequency step was 5ppm at frequency offsets between 10ppm and 80ppm and 0.5ppm between 0ppm and 8ppm. The pulse sequence parameters were as follows: field of view (FOV) = 80mm, rectangular FOV = 45%, number of slices = 4, voxel resolution=1*1.24*7mm^3, fat saturation and cardiac triggering = ON.

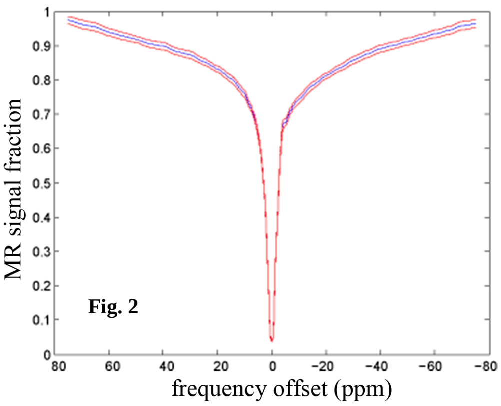
Post-processing: The data were processed by means of a 2D rigid-body registration with three degrees of freedom to reduce any effect of bulk motion. This was carried out with the Automated Image Registration software[6]. To minimize the field inhomogeneity problem, the z-spectrum was interpolated to 1-Hz resolution and curve fitting was conducted. The minimum of the fitted z-spectra was assumed to be the water frequency and was shifted to 0 Hz. This was similar to the magnetic field (B_0) homogeneity correction method described in Hua, J. et al., 2007[3]. Because of this shifting, the two outermost points in z-spectra were excluded. Two regions of interest (ROI) were drawn manually. The first one covered the gray and white matter of the spinal cord and the second one covered only the cerebrospinal fluid (CSF). To minimize the partial volume effect, the ROIs were eroded for 1 voxel.

Statistical analysis: To demonstrate the MT asymmetry effect in the cervical spinal cord, the homogeneity corrected z-spectral intensities (interpolated and shifted raw data) at corresponding positive and negative offsets (around the water proton resonant frequency) were compared on a voxel-by-voxel basis. The Student's t-test was performed by using the software SPSS Rel. 13.0 (SPSS, Chicago, IL, USA) on the mean asymmetry value (z-spectrum value at negative frequency offset – positive offset) among subjects at frequency offsets 10ppm-75ppm and 0ppm-8ppm to detect the conventional MT asymmetry and CEST effect respectively in the gray/white matter and CSF.

Results:

Figure 1a,b show representative SE-EPI images with and without the MT pre-pulse while figure 1c shows the magnetic transfer ratio (MTR) image. Figure 2 and 3 shows the z-spectrum and the MT asymmetry spectrum in the gray/white matter averaged over 15 subjects respectively. The statistical analysis showed that the z-spectrum was asymmetrical about the water resonance frequency with larger saturation effect on the negative offset side between 10ppm and 75ppm (minimum: -1.9% at 17.9ppm) and on the positive offset side between 0ppm and 8ppm (maximum: 7.3% at 3.8ppm) in gray/white matter ($P < 0.001$). There was no significant difference in CSF ($P > 0.05$).





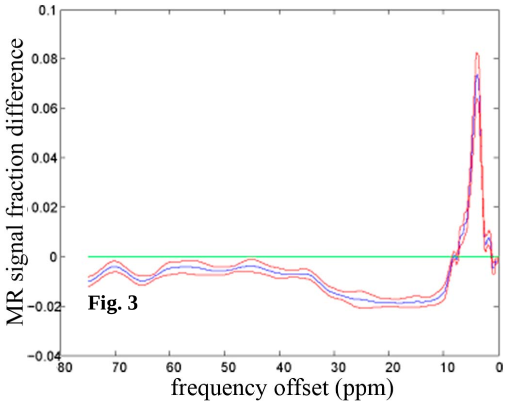


Fig. 1: (a) SE-EPI image without MT pre-pulse (b) SE-EPI with MT prepulse (frequency offset: +10ppm) (c) MTR with color bar (display range: 0 - 1)

Fig. 2: mean z-spectrum (blue line) with standard error of the mean (SEM; red line) of gray/white matter from C3/C4 - C5 (n=15).

Fig. 3: mean MT asymmetry (z-spectrum value at negative offset – positive offset; blue line) with SEM (red line).

Discussion and Conclusions:

Our results showed that the z-spectrum in gray/white matter was asymmetrical about the water resonance frequency with more saturation effect at lower frequencies (negative frequency offset) far from water and at higher frequencies (positive frequency offset) close to water. Our results were consistent with previous studies in the brain[3, 4]. The larger saturation effect at the negative offset frequencies was suggested to be attributed to a center frequency shift contribution from the semisolid pool with respect to water in conventional MT[3]. On the other hand, the larger saturation effect at the positive offset frequencies close to water can be attributed mainly to the CEST effect for example the amide proton transfer (APT) at +3.5ppm[5]. The CSF did not have any significant difference as CSF mainly consists of water which does not have any MT or CEST effect. Our results have demonstrated MT asymmetry in the gray/white matter of human cervical spinal cord due to both conventional MT and CEST effects.

References:

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