

## MT spectra asymmetry and NOE studies in the Brachial plexus

Zaid Bin Mahbub<sup>1</sup>, Olivier Mougín<sup>2</sup>, and Penny Gowland<sup>2</sup>

<sup>1</sup>Arts & Sciences, Ahsanullah University of Science & Technology, Dhaka, Dhaka, Bangladesh, <sup>2</sup>SPMMRC, University of Nottingham, Nottingham, Nottinghamshire, United Kingdom

**Target Audience:** Neurologists interested in characterizing the brachial plexus nerves and spinal cord; physicists interested in MT and NOE.

**Purpose:** Studies in the CNS suggest that the MT and nuclear overhauser enhancement (NOE) components of the z-spectrum contain information related to myelination which may also be useful measures in studying the peripheral nerves<sup>1,5</sup>. However tracking the peripheral nerves and nerve roots in MT scans can be difficult because of a lack of contrast with the surrounding tissues and breathing movements, but diffusion weighted whole body imaging with background suppression (DWIBS) technique provides a mean of highlighting the peripheral nerves<sup>3</sup>. Furthermore the NOE component of the MT spectrum is difficult to distinguish in areas where respiratory noise leads to broadening of the spectrum rather than a separate peak<sup>4,6</sup>, but this can be overcome by assessing the asymmetry of the spectrum resulting from NOE effects rather than the amplitude of the NOE effect directly. **Aim:** to develop a novel combined diffusion weighted and magnetization transfer sequence and asymmetry analysis method for quantitative MT imaging of the brachial plexus by highlighting nerves, roots, root ganglions, spinal cord WM and GM etc. from surrounding tissues.

**Methods:** This study had local ethics committee approval. Eight healthy subjects (25 -55 y.o.) were scanned with a 3.0T Philips Achieva MRI scanner, using the torso 16 channel phased-array coil. MT DWIBS (a pre saturated PGSE sequence with an EPI readout) was implemented with TE = 75 ms, b = 300 s/mm<sup>2</sup>, Δ = 56 ms, δ = 10 ms for surrounding tissue and IVIM signal suppression; T1 = 215 ms for fat suppression. The saturation consisted of 8 sinc pulses of amplitude P1 = 0.18 μT or P2 = 0.3 μT, acquired for 24 off-resonance frequencies in the range 0 to ±750 Hz, with the normalization scan acquired at 10 kHz off resonance. B<sub>0</sub> field inhomogeneities were corrected using water shift saturation referencing (WASSR)<sup>4</sup>, with low power presaturation (B1=0.01 μT) and off-resonance frequencies of ±120 Hz at 20Hz steps (although this cannot correct for shim variations during the spectral acquisition). Tailored segmentation software was used to select ROIs corresponding to nerves (1 pixel in sagittal view) and cord (4 pixels in transverse view). To assess asymmetry, z-spectra downfield (+) and upfield (-) sides were separately fitted to a Lorentzian centred on zero,  $L_1 = 1 - \frac{A}{1 + (\frac{x}{W})^2}$  where x and W are in Hz.

Asymmetry was assessed from the difference between the widths: W<sub>-</sub>, W<sub>+</sub> and ΔW (= W<sub>-</sub>-W<sub>+</sub>). The spectra were also fitted to a double Lorentzian  $L_2 = 1 - \frac{A_c}{1 + (\frac{x}{W_c})^2} - \frac{A_n}{1 + (\frac{x - (-448)}{W_n})^2}$  where W<sub>c</sub>, W<sub>n</sub> and A<sub>c</sub>, A<sub>n</sub> were the widths and amplitudes of the central peak and NOE dominated peaks at x<sub>c</sub> = 0, and the NOE peak x<sub>n</sub> = -3.5ppm = -448Hz respectively. The areas under both the double Lorentzian peaks were estimated as, Γ<sub>c</sub>=A<sub>c</sub>W<sub>c</sub> and Γ<sub>n</sub>=A<sub>n</sub>W<sub>n</sub>. These values were analysed both for individual and subject averaged spectra.

**Results:** Figure 1 shows example images and figure 2 shows example fitted z-spectra. In the L1 Lorentzian fit the down field side of the peak is significantly wider than the upfield side (figure 3a), and this difference (ΔW) is significantly larger at higher power. Figure 3b and c show that the areas under the 'c' and 'n' peaks in the L2 Lorentzian vary with power (all <0.05 Wilcoxon two tailed signed rank test).

**Discussion:** A combined DWIBS and MT sequence has been developed for brachial plexus imaging and shown the effects of MT asymmetry in the peripheral nervous system for the first time. Although there are no clear peaks on the wings of the spectra of the cord and nerves, probably due to the variable effects of respiration during the spectral acquisition, when the spectra were fitted to the single Lorentzian equation (L<sub>1</sub>) for lowfield and upfield sides separately, the widths (W) of each side, and difference in widths between sides (ΔW) indicated an asymmetry, possibly due to NOE contribution on the negative frequency offset side of the spectrum. The double Lorentzian fit to the spectrum found significant 2<sup>nd</sup> peaks at negative frequency offsets for both individual and subject averaged z-spectra for nerves and cord, which further suggests NOE effects. Areas Γ<sub>c</sub> were higher at high power than at low power for individual MT spectra cord and nerves, as expected for MT and direct saturation effects; whereas areas Γ<sub>n</sub> were lower at high power compared to low power as expected for NOE. L<sub>1</sub> fitting provides a simple method of assessing MT asymmetry but L<sub>2</sub> fitting potentially provides a method of separating MT and NOE effects more quantitatively.

**Conclusion:** MT asymmetry consistent with NOE effects can be detected in the peripheral nerves and cord and could provide a new tool for quantifying myelin content, demyelination and remyelination in brachial plexus.

**References:** 1.Jones, Neuroimag. 77:114-124, 2013; 2.Xu, NMR Biomed. 27(4): 406-416; 3. Takahara, Radiol. 2004; 4. Kim, MRM 61(6): 1441-1450; 5. Mougín, NMR Biomed. 26(11): 1508-1517, 2013; 6. Liu, MRM 70(4):1070-1081, 2013.

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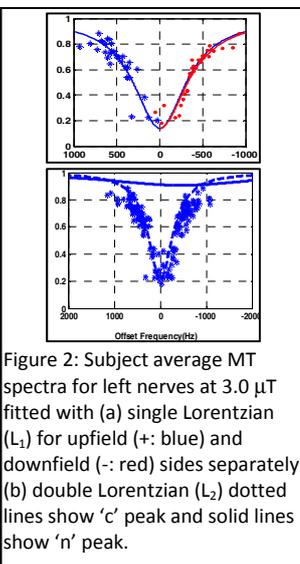


Figure 2: Subject average MT spectra for left nerves at 3.0 μT fitted with (a) single Lorentzian (L<sub>1</sub>) for upfield (+: blue) and downfield (-: red) sides separately (b) double Lorentzian (L<sub>2</sub>) dotted lines show 'c' peak and solid lines show 'n' peak.

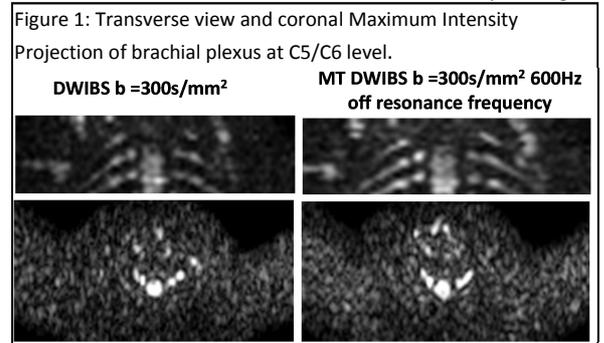


Figure 1: Transverse view and coronal Maximum Intensity Projection of brachial plexus at C5/C6 level.

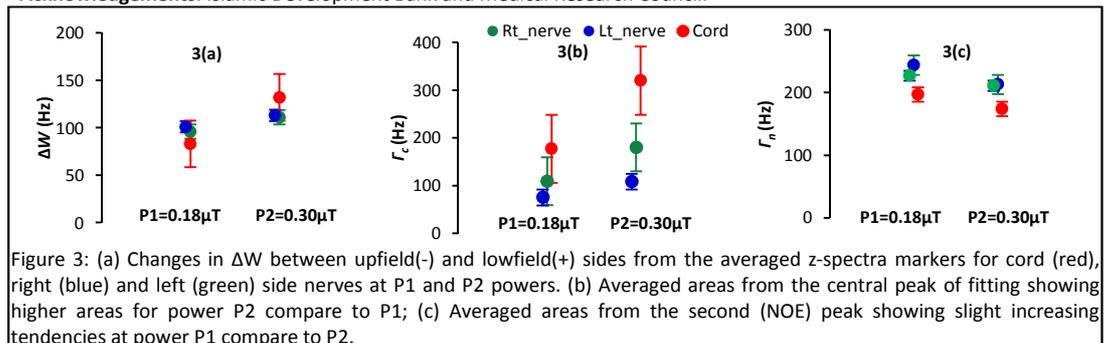


Figure 3: (a) Changes in ΔW between upfield(-) and lowfield(+) sides from the averaged z-spectra markers for cord (red), right (blue) and left (green) side nerves at P1 and P2 powers. (b) Averaged areas from the central peak of fitting showing higher areas for power P2 compare to P1; (c) Averaged areas from the second (NOE) peak showing slight increasing tendencies at power P1 compare to P2.