Diffusion Tensor Spectroscopy of NAA and Water in the Corpus Callosum of the Human Brain at 7 Tesla

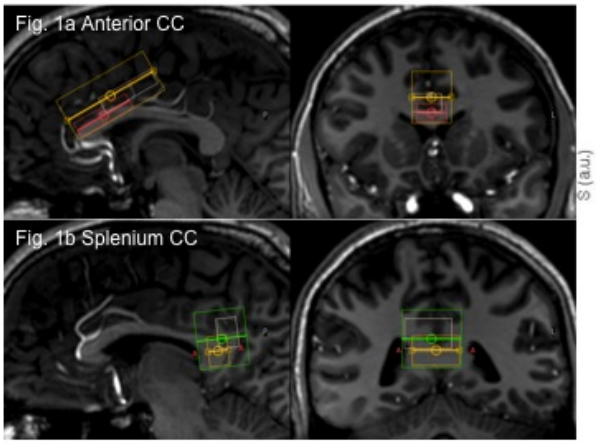
E. T. Wood[1,2], D. S. Reich[2,3], J. A. Farrell[3,4], J. S. Gillen[4], P. B. Barker[3], and I. Ronen[5]

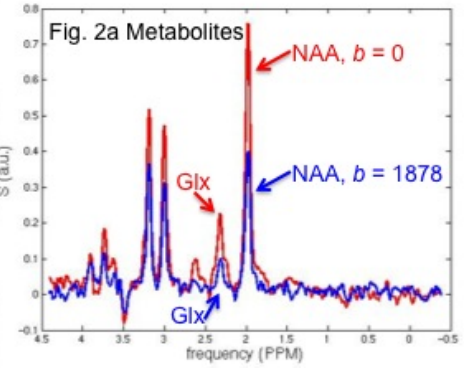
[1]Neuroscience, Johns Hopkins University School of Medicine, Baltimore, MD, United States, [2]NeuroImmunology Branch (NINDS), National Institutes of Health, Bethesda, MD, United States, [3]Department of Radiology, Johns Hopkins University School of Medicine, Baltimore, MD, United States, [4]F.M. Kirby Research Center for Functional Brain Imaging, Kennedy Krieger Institute, Baltimore, MD, United States, [5]Leiden University Medical Center, Leiden, Netherlands

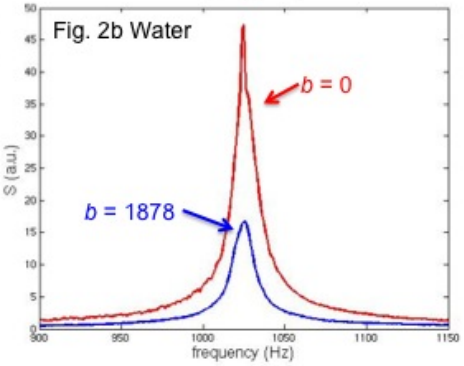
Introduction: Diffusion tensor imaging (DTI) provides information about microscopic structural features of anisotropic tissues such as white matter tracts. However, the pathological sensitivity of DTI is limited because the measured signal is derived form water protons, which are found in all tissue types (including inflammatory cells, myelin, and neurons). In contrast, magnetic resonance spectroscopy (MRS) is neurochemically specific and can therefore provide more detailed information about a measured tissue, but it is very limited in providing structural information pertaining to the measured neurochemicals. Diffusion tensor spectroscopy (DTS) [1,2] combines features of both DTI and MRS, allowing measurement of the diffusion properties of intracellular metabolites. As such, it may be sensitive to disruption of tissue microstructure within neurons and might consequently serve as a useful marker of axonal degeneration in white matter diseases. It has been shown at 3T that the fractional anisotropy (FA) of N-acetyl-aspartate (NAA) is more sensitive than FA of water to small variations in axonal geometry across two distinct segments of the corpus callosum (CC). [3,4] That result offers some support for the notion that DTS of NAA is a more specific probe of intra-axonal physiology than DTI of water and can therefore add additional information. The CC is a good structure in which to apply DTS because it is relatively homogeneous, contains fiber bundles that are predominantly oriented in the same direction, and is large enough to harbor a voxel of the size needed to perform a DTS experiment. The CC is also frequently involved in neurological disorders such as multiple sclerosis. Acquisition at 7T makes it possible to achieve adequate signal-to-noise ratio (SNR) with fewer averages and to measure diffusion properties of metabolites other than NAA, in particular glutamate and glutamine (Glx). In this study, we compare the diffusion properties of NAA and water at two locations in the CC at 7T.

Methods: 2 healthy volunteers were scanned on a 7T Philips Achieva scanner using quadrature volume transmit and 32-channel receive head coils (Nova Medical). For each volunteer, one full-brain T_1-weighted structural image and DTS spectra from 3.6 cm^3 volumes of interest (VOI) in the anterior CC (VOI = 3.0 x 1.5 x 0.8 cm^3) and splenium (VOI = 1.0 x 2.4 x 1.5 cm^3) were collected. VOIs were positioned and angled on axial, coronal, and sagittal T_1-weighted images to minimize partial volume effects of cerebrospinal fluid and adjacent non-callosal brain tissue. Metabolite and water diffusion measurements were obtained by incorporating bipolar diffusion gradients within a point-resolved spectroscopic (PRESS) sequence (minimum TR = 3000 ms, TE = 124 ms).[3] Diffusion measurements were cardiac gated and made using b=1878 s/mm^2, g=1.6 G/cm, and diffusion weighting in 6 non-collinear directions. 32 and 4 spectra were averaged for NAA and water diffusion characterization, respectively. Water suppression using VAPOR was performed during NAA diffusion characterization, allowing sufficient residual water peak that was used for phase correction of the NAA spectra. DC offset correction, exponential filtering, zero filling, zeroth order phase correction of individual spectra, summation of the phased spectra, and final phase correction of summed spectra were performed using in-house software written in the MATLAB 7.0 environment (MathWorks, Natick, MA). Baseline offset adjustments, and peak analysis for quantification of the metabolites for each diffusion direction/b-value was performed to yield the respective diffusion tensors. From the resulting tensors, the mean diffusivity (MD), perpendicular diffusivity ($\lambda_\perp=(\lambda_2+\lambda_3)/2$) and parallel diffusivity ($\lambda_\parallel=\lambda_1$) were calculated for NAA and water.

Results: Figure 1 illustrates acquisition voxel placement in the anterior CC (top) and splenium (bottom) for subject 2. The outer box represents the shimming volume. The white box demonstrates the large chemical shift displacement of water at 7T, which necessitated a separate acquisition of the water spectrum. Figure 2 shows spectra at b=0 (red) and b=1878 s/mm^2 (blue) for NAA (a) and water (b) and demonstrates that other metabolites, including glutamate/glutamine (Glx), could be quantified with this technique. The table presents FA and diffusivity values for both subjects. FA and MD values for both NAA and water are consistent with previous reports at 3T [3,4] and similar in the two subjects. Variability in FA, $\lambda_\parallel$, and $\lambda_\perp$ probably reflects partial volume averaging with adjacent tissue, including ventricular CSF.







	Subject	Location	FA	MD (μm^2/ms)	$\lambda_\parallel$ (μm^2/ms)	$\lambda_\perp$ (μm^2/ms)
Water	1	AntCC	0.63	0.71	1.31	0.41
	1	Splenium	0.58	0.74	1.29	0.46
	2	AntCC	0.40	0.79	1.18	0.60
	2	Splenium	0.38	0.93	1.36	0.72
NAA	1	AntCC	0.77	0.20	0.42	0.09
	1	Splenium	0.54	0.24	0.40	0.16
	2	AntCC	0.55	0.24	0.40	0.15
	2	Splenium	0.65	0.21	0.39	0.12

Discussion: DTS of the human corpus callosum is feasible at 7T and can be used to quantify a range of metabolites. The use of a high field strength and 32-channel head coil has the potential to increase spatial resolution compared to prior studies at lower field strengths. Further work will focus on technical refinement and application to disease.

Acknowledgment: Aranee Techawiboonwong

References: [1]Ellegood J et al. MRM. 2006; 55:1-8. [2]Ellegood J et al. MRM. 2005: 53:1025-32. [3]Upadhyay J et al. Neuroimage. 2008; 39:1-9. [4]Upadhyay J et al. MRM. 2007; 58:1045-53.