Diffusion correlation imaging (DCI) reveals microscopic anisotropy following traumatic brain injury

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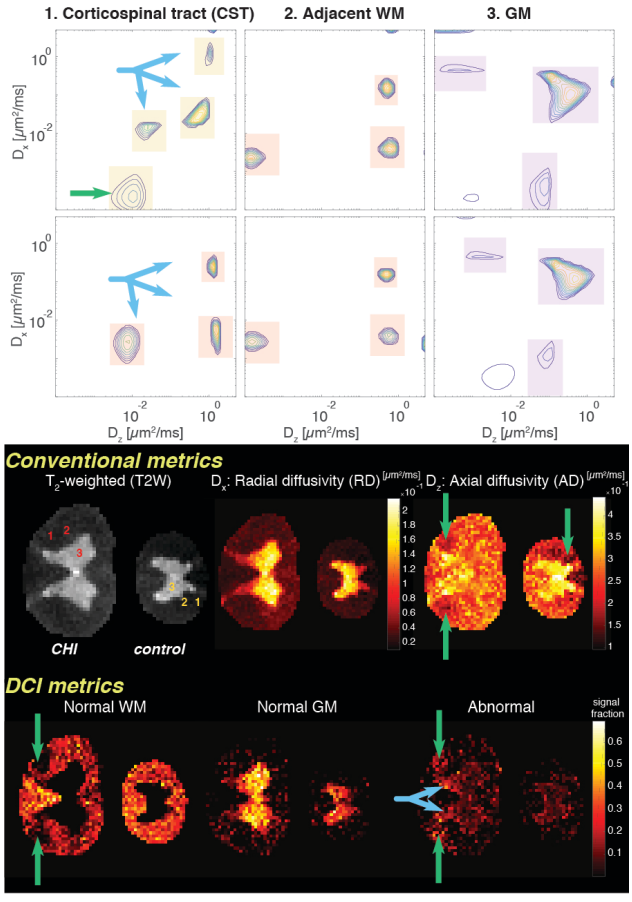
Introduction: Diffusion MRI (dMRI) can reveal nervous system pathology in the absence of other MRI signal changes by its sensitivity to the microscale tissue environment, although first-order models such as diffusion tensor imaging (DTI) [1] often cannot provide the specific origin of cellular changes. While conventional dMRI describes water mobility in tissue along different directions, Diffusion-Diffusion Correlation SpectroscopY (DDCOSY) is an MR method that provides correlations between water mobility along different directions [2]. DDCOSY can directly quantify microscopic anisotropy, making it a potentially powerful method to explore white matter (WM) injuries. Here we use the marginal distributions constrained optimization (MADCO) [3] framework to facilitate Diffusion Correlation Imaging (DCI) on healthy and injured ferret spinal cord specimens.

Methods: Two cervical cord sections were selected, one from an uninjured control and the other 1 week following closed head injury (CHI), which resulted in focal corticospinal tract (CST) hemorrhage. Wallerian degeneration was expected along the CST, but not along others. The two specimens were inserted into the same NMR tube, and data were collected using a 10mm coil with a 7T Bruker MRI. DCI data were collected using the double diffusion encoding (DDE) sequence [2]. The diffusion gradients were applied in parallel (z) and perpendicular (x) to the spinal cord axis of symmetry. The MADCO framework was used with a total of 66 acquisitions, and b_{max}=36,000 s/mm^2.



Results and Discussion: No apparent abnormalities were observed on the T_2W, radial diffusivity, or fractional anisotropy images. A reduction in axial diffusivity was observed at the lateral CST of the CHI sample, but also at regions of the control sample (green arrows). Representative diffusion correlation spectra (DCS) from the CST, adjacent WM (AWM), and gray matter (GM) are shown. Normal appearing WM tracts all had similar DCS signatures (red). GM DCS from both control and CHI samples were similar (purple). The DCS of the CHI CST region was unique (yellow); it revealed (1) decreased water mobility in both axial and radial directions (green arrow), along with a (2) shifted three-peak signature that was evident in the control sample (blue arrows). Voxelwise DCS can be used to generate images of specific diffusion components based on their mobility in the radial and axial directions. Normal WM and GM components were identified based on the above DCS signature, which was then used to generate the corresponding quantitative images. A complete absence of signal intensity in the normal WM image was observed at the lateral CST of the CHI sample (green arrows). Similarly, an abnormal component was identified and imaged, where hyperintensities of the CST were observed only in the CHI sample.

Conclusion: The ability of DCI to reveal distinct populations of axons at the site of injury, and in addition, to localize cellular alterations in the GM, suggests potential specificity for microscopic anisotropy caused by traumatic brain injury that led to axonal beading.

References: [1] Basser, Biophys. J. (1994). [2] Callaghan, J. Chem. Phys. (2004). [3] Benjamini, J. Magn. Reson. (2016).