Combining DWI with MT - Towards Compartment-Specific Diffusion Measurements

I. Ronen[1], K. Ugurbil[1], D-S. Kim[2]

[1]Dept. of Radiology, CMRR/University of Minnesota, Minneapolis, MN, United States, [2]Dept. of Anatomy and Neurobiology, Boston University, Boston, MA, United States

Introduction

In this study, water diffusion in the cat brain was investigated using an approach that combines multidirectional diffusion-weighted images (DWI) using multiple b-values, together with magnetization transfer contrast (MTC)[1]. The MTC allows attenuate signal originating from water molecules that rapidly exchange with binding sites on large macromolecular structures, and in brain white matter it is assumed that a significant portion of the MTC is due to the interaction of water with the extra-axonal myelin sheath[2]. Henceforth, multiexponential analysis of diffusion curves with and without MTC may shed light on the contribution of the extra-axonal water to the diffusion signal, and on the relationship between *diffusion components* and *tissue compartments* in the brain, particularly in white matter. When a biexponential model was applied to the data, the volume fractions of the two diffusion components change significantly in white matter with the application of the MTC, resulting in a significant decrease in the fraction of the fast diffusion component, while in gray matter the change is much less significant. More experimental data is being gathered at different MT pulse lengths in order to investigate the contribution of exchange between the various tissue compartments.

Materials and Methods

Experiments were performed on a 9.4T/31cm spectrometer (Varian, CA). Animals: Four cats (800g-1.1kg) were first anesthetized with a ketamine/xyalzine cocktail, then orally intubated and ventilated with 1% isoflurane and 3:7 O_2:N_2O throughout the experiment. Body temperature was controlled via a rectal probe and kept stable around 38.5° by means of a feedback water loop. Pulse sequence: double spin-echo echo-planar-imaging sequence (SE-EPI) with diffusion gradients, where the π-pulses were slice-selective adiabatic full passages (AFP) and the $\pi/2$ excitation pulse was an adiabatic half passage (AHP). The MTC was achieved using an MT pulse of variable duration (0s-3s) prior to the excitation pulse and at $\Delta\omega$ = 20khz form the water resonance frequency. The B_1 field generated by the MT pulse was set to about 0.54 gauss. An additional delay prior to the MTC pulse resulted in TR=5s per image segment. Typical MRI parameters: data matrix 256x256 with four center-out segments, FOV 5x5x0.2cm^3 (nominal resolution 195×195µm^2 denoised with a hanning filter), TE/TR = 34ms/5s, diffusion: δ=8.5ms, Δ=11.5ms. b-values: 40 gradient strength values were used between g = 0.75g/cm and g = 30g/cm, spanning a b-value range between 5 and ~9300 s/mm^2 for a combination of two gradients. Diffusion weighting was achieved using the six gradient combinations according to the commonly used scheme for DTI (X,Y,0), (X,0,Z), (0,Y,Z), (X,-Y,0), (0,Y,-Z), (-X,0,Z).

Results and Discussion

After a pixel-by-pixel fitting of the data to a biexponential model, the slow and fast diffusion coefficients, $ADC_{slow/fast}$ and the corresponding volumetric fractions, $f_{slow/fast}$ were averaged on ROIs representing gray matter and white matter. Fig.1 shows the changes in diffusivity as well as in volume fractions of the two components at the longest MT pulse of 3 seconds. It is seen that the major changes in diffusivity are associated with ADC_{fast}, whether the ADC_{slow} is almost constant under application of the MT pulse. The most dramatic change is in the volumetric fractions,

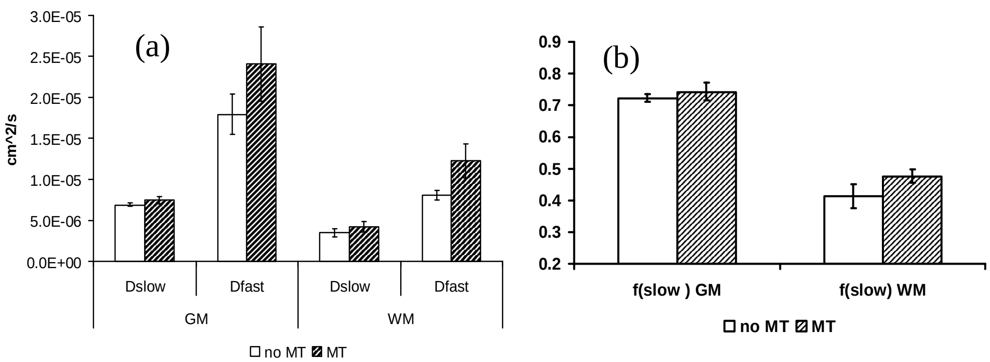

Fig. 1: (a) $ADC_{slow/fast}$ in white and gray matter, as measured with and without MT. The increase in diffusivity is significant mostly for D_{fast}. (b) f_{slow} in WM/GM as measured with and without MT. The significant changes are in white matter.

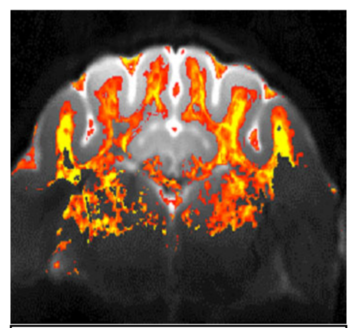

Fig. 2: map of the increase in f_{slow}, thresholded at 10%. The area with the largest increase corresponds with white

expressed in an increase of f_{slow} and thus a complementary decrease in f_{fast}. This may indicate that f_{fast}, associated with the non-restricted diffusion of water, may have a significant extracellular contribution in white matter, where the MT is expected to derive from the extracellular interaction with the myelin sheath. In Fig. 2 is shown a map based on the increase in f_{slow} (or decrease in f_{fast}) and it is seen that the areas where the increase is most significant correspond with white matter areas. Further investigation of the MTC effect on the diffusion attenuation curve as modeled by a biexponential has to take into consideration exchange between extra- and intracellular water, and thus additional measurements with varying MT pulse lengths were performed and will be presented. In *conclusion*, the combination of DWI and MTC is a promising tool for the investigation of the dynamics of water in tissue and the correlation between tissue compartments and diffusion components present in the multiexponential model for the multiple b-value diffusion attenuation curves.

Acknowledgements:

This work was supported by NIH grant P41 RR08079, by the Keck foundation grant and by Human Frontiers Science Program.

References:

1. Wolff SD, Balaban RS, Magn Reson Med 1989;10(1):135-44.
2. Koenig SH, Magn Reson Med 1991;20(2):285-91.