Oscillating Gradient Spin-Echo (OGSE) Diffusion Tensor Imaging of the Human Brain

Corey Allan Baron[1] and Christian Beaulieu[1]
[1]*Biomedical Engineering, University of Alberta, Edmonton, Alberta, Canada*

Purpose. In the brain, water diffusion is restricted by the presence of cellular membranes and other components. Accordingly, apparent diffusion coefficients (ADCs) depend on the time allowed for the molecules to probe the local environment; namely, the "diffusion time" (t_D). DTI is typically performed using pulsed gradient spin-echo (PGSE) diffusion encoding, which has an inherently large t_D (Fig 1). The oscillating gradient spin-echo (OGSE) method enables greatly reduced t_D (Fig 1), which grants a greater sensitivity to diffusion restriction/hindrance over smaller length scales [1]. A dependence of ADCs on t_D has been shown in mouse brain, with larger ADC (both parallel and perpendicular) and smaller FA observed for smaller t_D [2]. There is only one human study utilizing OGSE [3], where perpendicular ADC determined using a tetrahedral scheme (b = 150 s/mm^2) increased with decreasing t_D (10-4 ms) in the white matter of 2 subjects. The purpose of this work was to investigate the t_D dependence (5-40 ms) of the full diffusion tensor in white matter of healthy subjects by comparing OGSE and PGSE DTI (b = 300 s/mm^2).

Methods. Four DTI protocols were acquired in 5 human subjects on a Varian Unity Inova 4.7 T MRI using t_D = 5 ms (OGSE 50 Hz), 10 ms (OGSE 25 Hz), 20 ms (PGSE), and 40 ms (PGSE). Each protocol used: TR = 12.5 s; TE = 110 ms; FOV = 24 cm; 2 mm x 2 mm acquired in-plane resolution; 40 slices, thickness 2.5 mm; 6 averages; R=2 GRAPPA; 60 mT/m gradients; b = 300 s/mm^2; scan time 10 min each. ExploreDTI was used for tractography using an FA threshold of 0.3 and angle threshold of 30°. The splenium (~2 cm central portion) and corticospinal tracts (from brainstem to internal capsule) were analyzed. The data from the 4 scans were motion corrected relative to each other using in-house software, and voxels for analysis were chosen using the tract mask obtained from the t_D = 40 ms scan. The scans were also performed on four different occasions for a water phantom. Statistical significance of overall t_D-dependence was evaluated using a repeated measures ANOVA, and changes with respect to the t_D = 40 ms scans were evaluated using paired t-tests.

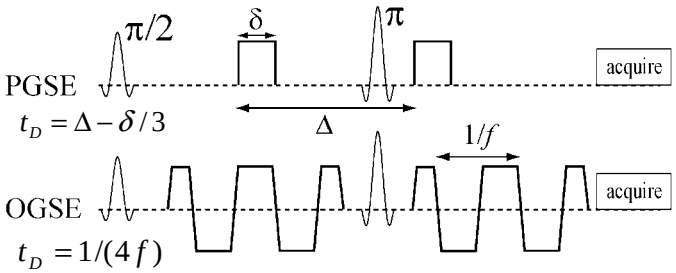

FIG 1: Diffusion gradient timing for PGSE and OGSE that results in much shorter diffusion times (t_D) for OGSE.

Results and Discussion. Even with a low b value of 300 s/mm^2 (and high SNR of 39 in splenium on b0 images), DTI images and tracts were of good quality (Fig 2) and qualitatively similar for all diffusion times for either OGSE or PGSE. Quantitative analysis over the tracts showed statistically significant variations of DTI eigenvalues (both parallel, $\lambda_{\parallel}$, and perpendicular, $\lambda_{\perp}$) and FA, where ADC increased and FA decreased as t_D decreased in both the corticospinal tract ($\lambda_{\parallel}$: +10%, $\lambda_{\perp}$: +24%, FA: -6%) and splenium ($\lambda_{\parallel}$: +9%, $\lambda_{\perp}$: +14%, FA: -3%) (Fig. 3). A notable greater % increase of $\lambda_{\perp}$ is observed compared to $\lambda_{\parallel}$, and these changes mirror results observed in animal models [2]. As expected, no significant variation with respect to t_D (i.e. $p_{ANOVA} > 0.05$) was observed in the water phantom (Fig. 3).

Conclusion. OGSE has demonstrated diffusion time dependencies of the diffusion tensor for the first time in humans. The ability to target different length scales via the diffusion time may improve sensitivity to changes in tissue microstructure.

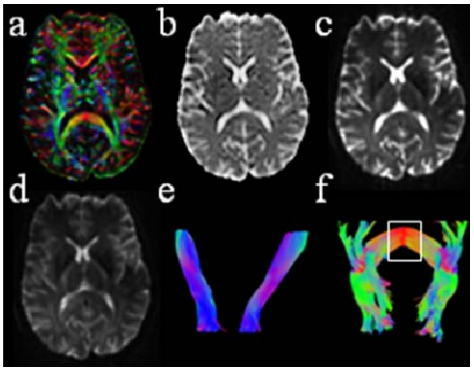

FIG 2: Examples for OGSE t_D = 5 ms: (a) FA, (b) MD, (c) b = 0 s/mm^2, (d) b = 300 s/mm^2 for one direction, and tractography of the (e) corticospinal tract and (f) splenium. FA and tracts are color coded with principle eigenvector direction. The box in (f) indicates the central portion used for analysis.

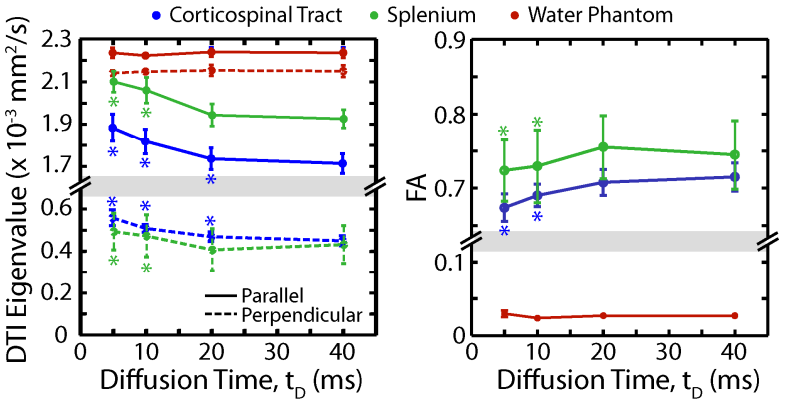

FIG 3: Mean DTI eigenvalues and FA measured in 5 subjects using tractography. Larger eigenvalues and smaller FA are observed at shorter diffusion times. All measures in white matter had $p_{ANOVA} < 0.001$, while all measures in the phantom had $p_{ANOVA} > 0.05$. Significant differences (paired t-test with $p < 0.05$) with respect to the t_D = 40 ms scans are denoted by *.

References. [1] Does MD et al. MRM 49:206 (2003). [2] Aggarwal et al. MRM 67:98 (2012). [3] Van et al. ISMRM 2012, #354