DSI Motion Correction and Thalamo-Cortical Fiber Pathway Alteration after Stroke

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Introduction: Fiber tracking has become an increasingly important tool for the determination of the structural basis of brain connectivities. While diffusion spectrum imaging (DSI) was shown in individual cases to provide a superior resolution, particularly the discrimination of crossing fibers [1, 2], application of this experimental setup remained limited because of its demands on scan time and signal to noise. Especially, eddy current artifacts become more severe and conventional intensity-based registration is challenging at higher b-value (2000 – 12000 s/mm^2). We present motion correction scheme for in vivo DSI experiment and investigate connectivity alteration between fore limb area of primary somatosensory cortex (S1) and ventral posterolateral (VPL) nucleus of thalamus after stroke.

Materials and Methods: In vivo MR Imaging : Male Wistar rats (n=13) were subjected to transient occlusion of the middle cerebral artery for 60 minutes (stroke on right hemisphere). Four healthy rats were studied additionally for stability and reproducibility of fiber tracking. All MRI experiments were conducted at a horizontal 11.7T system with a 16 cm diameter bore magnet and a rat head quadrature surface coil (30 × 30 mm^2). DSI-203 acquisitions were performed three time points, before, one and four weeks after stroke.

Diffusion Spectrum Imaging (DSI) protocol : To correct head motion and image shift due to eddy current effect from high gradient duty, we constructed 203-DSI protocol by inserting additional non-diffusion scans between diffusion encoded subsets with 12 different b-value. The b-values/number of diffusion directions (s/mm^2/ # of directions) for q-space encoding for the twelve subsets were as follows: 154/6, 308/12, 462/8, 615/6, 769/24, 923/24, 1231/12, 1384/30, 1538/24, 1692/24, 1846/8, 2000/24. The pulse sequence was a 4-segmented diffusion-weighted spin-echo echo-planar imaging (EPI) with the following parameters: TE/TE=300/37.9ms, resolution = 0.2x0.2x0.5 mm^3, 20 consecutive (no gap) slices, Δ/δ=25/5ms. We applied the same imaging protocol to Polyethylene glycol (PEG) phantom to evaluate motion pattern affected by eddy current at high b-value scan.

Image postprocessing : We investigated motion pattern of the DSI-203 experiment with the PEG phantom data, it could be separated with image drift and fluctuation in phase encoding axis (normally y) to construct the correction method for in vivo data having low SNR at high b-value (each motion shown in Fig 1). After eliminating the image drift by non-diffusion image registration, we extracted the image fluctuation pattern which is dependent with b-value intensity and inversely correlated with diffusion gradient polarity. This relation was used to correct the fluctuation in vivo DSI data after the drift correction. We performed motion correction for in vivo DSI data in two steps. *Step 1: Real animal motion + Drift correction* was based on the rigid body registration of the inserted non-diffusion images and extrapolating estimated under linearity assumption for diffusion weighted images. The rotation components of the transform matrix were used for transformation of the diffusion directions of b-matrix to correct the rotated portion [3]. *Step 2: Fluctuation correction:* was performed using y-translation component subtraction by the scaled values combined each diffusion intensity (b-value) and y direction vector of the updated b-matrix.

Results: In order to assess the effects of image shift correction on tractography, we demonstrate fiber tracking with thalamo (VPL)-cortical (S1) connectivity for healthy rats in each correction step (Fig 2). Fiber bundles become more discrete and better resolved after the complete postprocessing procedure. The little schematic insert depicts the view point from a caudal position with the location of the coronal slice marked in the schematic. To detect fiber pathway remodeling after stroke, we investigate DSI fiber tracking on the same connectivity region (VPL-S1) for before, one and four weeks after stroke (a representative result shown in Fig 3, note that slightly different imaging slice but same animal). The ipsilateral fiber pathway on stroke side shows significantly moved into rostral direction. We compare the fiber position to the segmented ischemic region, the ischemic volume was relatively shrunk at week four (compare to one week after stroke).

Discussion: The demonstrated fiber pathway alteration indicates that ischemic region could affect thalamo-cortical fibers and could be linked to the white matter reorganization as previously proposed studies [4-6]. In addition, inter-hemispheric connection maybe provides new insight into the relation between functional recovery and connection restructuring. Changed fiber pathway and functional recovery requires further validation.

References: [1] VJ Wedeen et al. (2005) MRM;54:1377-1386, [2] C Granziera et al.(2009) PLoS ONE;4:e5101 [3] A Leemans et al. (2009) MRM 61(6):1336-49, [4] C Po et al. (2010) ISMRM, [5] Jiang et al. (2006); 32:1080-9, [6] Li et al. (2009) Stroke;40:936-41

Figure 1

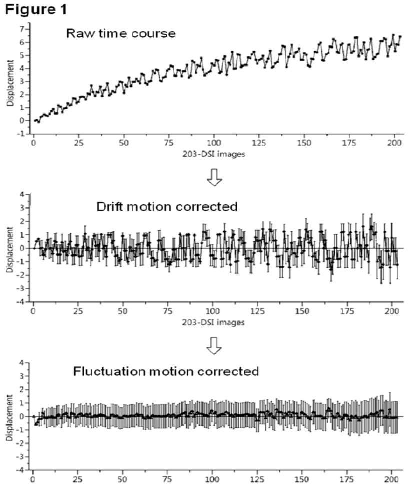
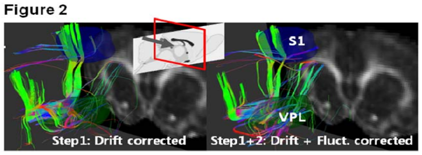


Figure 2



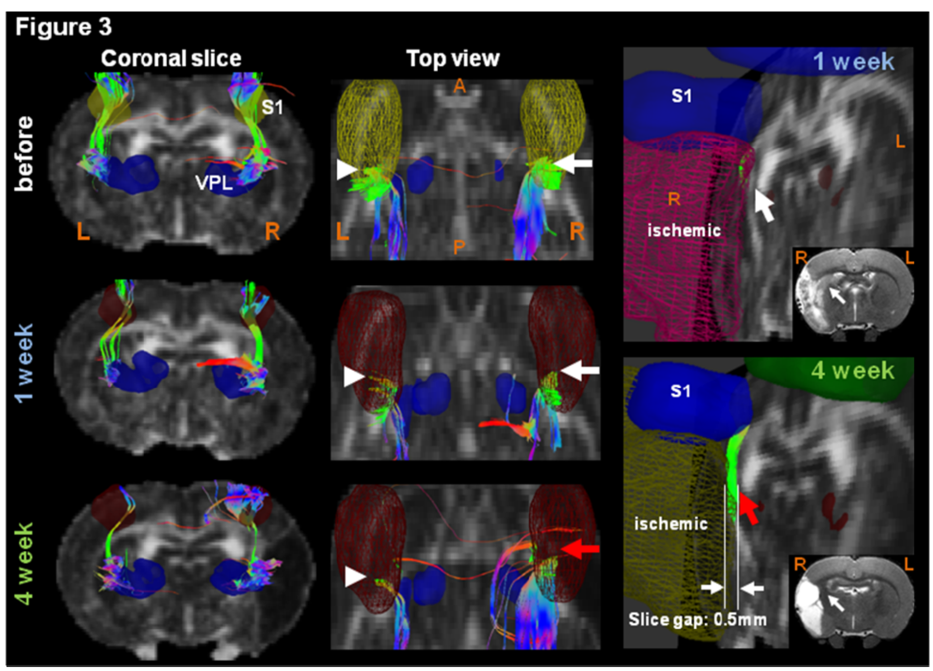


Figure 1: Apparent motion in phase-encoding direction observed in the time course of the 203 DSI images. (a) Original, uncorrected datasets exhibit a slow drift and a b-value related fluctuation of the image position. (b) Residual motion after drift correction; displacement parameters were averaged over 17 animals (error bars denote corresponding standard deviation). (c) Residual motion after the final correction step is markedly reduced.(one voxel size is occupying 2 in displacement scale of the vertical axis)
Figure 2: Comparison of fiber tracking results obtained after two different correction steps. Figure 3: Fiber pathways for three time points (before, one and four weeks after stroke) overlaid on gFA map