Sensitivity of motion estimation to the anisotropic diffusion of white matter in diffusion MRI

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Introduction: Motion correction is critical in diffusion imaging to obtain correct fiber analysis and tracts (1). Motion correction is required due to the prolonged scan time of the high angular resolution diffusion imaging with a larger b value above 1000 s/mm^2. The quality of motion correction depends on the accurate motion estimation from the diffusion weighted (DW) images. However, it has been noted that the motion estimation from the DW images is not reliable due to a lower signal-to-noise ratio (SNR), eddy current and anisotropic diffusion of white matter (WM) (2-4). Therefore, images without the diffusion weighting (b=0) have been acquired periodically during the angular sampling of the DW gradient vectors (b vector) to be used as a reference image set for the motion estimation (5). However, it is still unclear how much the WM anisotropy affects the accuracy of the motion estimation if other factors are removed. To address this question, DW images were acquired from the head of an anesthetized, immobilized monkey and the head of a volunteer using an eddy-current compensated sequence. The data were averaged to increase the SNR, but the estimated motion still fluctuated depending on the b vector, demonstrating the sensitivity of the motion estimation to the anisotropic diffusion of WM.

Methods: The DW images were acquired from the head of a monkey (Cebus, 3 years old, 2.1 kg weight) and a volunteer at 3T by use of the double-refocused spin echo EPI sequence which is known to compensate for the eddy current (6). The monkey was anesthetized by isoflurane gas and was immobilized by a stereotaxic frame which was attached to the 12 cm RF coil. The acquisition of one b=0 and 6 b vectors were repeated 8 times for each b value of 1200 and 2400 s/mm^2. The voxel size was 1.6x1.6x1.6 mm^3 and 2.5x2.5x2.5 mm^3 for the monkey and volunteer, respectively. For both subjects, the image drift in the phase-encoding direction was corrected first. The volunteer data were corrected for the motion which was estimated from the interleaved b=0 images. For both subjects, the 8 repeats were averaged to improve the SNR, resulting in one b=0 and 6 DW image sets. The effect of the anisotropic WM on the motion estimation was studied by estimating the motion from the averaged images by use of the 'mcflirt' of FSL with a cost function of mutual information and a rigid body transformation in reference to the b=0 image (7). To see the effect of the false motion estimation on the diffusion analysis, another set of images was obtained by applying the spatial transformation to the averaged images with the estimated motion parameters. For each of the uncorrected and corrected image sets, the diffusion tensor was linearly fitted and the fiber tracts were obtained from a seed in the corpus callosum, using ExploreDTI (8).

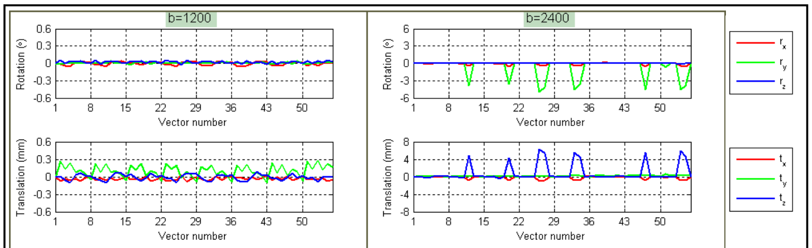

Fig. 1. Estimated motion of the monkey head after a correction of the image drift. The *x* grids represent the vector number of b=0. Note the different vertical scales.

Results: There was a significant amount of false motion estimated from the monkey DW images before the averaging as shown in **Fig. 1**. The estimated motion was quasi periodic in the repetition cycle, particularly at b=1200. The motion was significantly pronounced at b=2400, which could be attributed to both the lower SNR and enhanced contrast of the WM. The SNR was improved on the averaged images as shown in **Fig. 2**. As expected, the WM intensity varied with the b vector direction due to anisotropic diffusion of the WM. The WM contrast was pronounced at b=2400 due to the increased diffusion attenuation. The false motion was also detected from the averaged images as shown in **Fig. 3**. The motion estimated from the monkey head was similar at both b=1200 and 2400. However, the motion estimated from the human head was significantly increased at b=2400 compared to that at b=1200. The motion correction based on the false motion estimation resulted in a reduction of the FA value (from 0.71 to 0.69) and the number of tracts (from 2257 to 2162) in the corpus callosum of the volunteer head. The false motion correction had also altered the tract pathways. However, there was not a noticeable change of the residual error in tensor fitting for the averaged images of the volunteer at b=2400, suggesting that the residual error may not be sufficient as a cost function for the motion estimation (9).

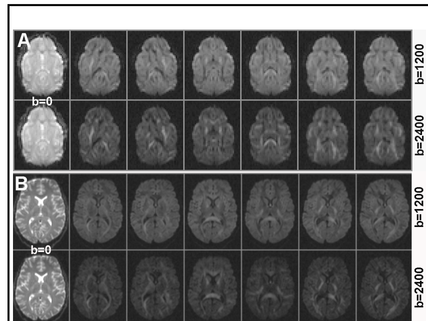

Fig. 2. A set of averaged slice from a monkey (A) and volunteer (B) head. The image contrast was enhanced by a gamma function (0.5).

Conclusions: The anisotropic attenuation of the WM by the DW gradient can induce a false motion estimation when the motion is estimated by the available method. This has to be considered in correcting the motion of the DW images in particular at a higher b value. Therefore, it is necessary to develop a new motion estimation method that can detect the motion reliably from the DW images without the need of the acquisition of b=0 images. Besides, a new motion estimation method is important for the new DTI analysis method which does not require the b=0 images.

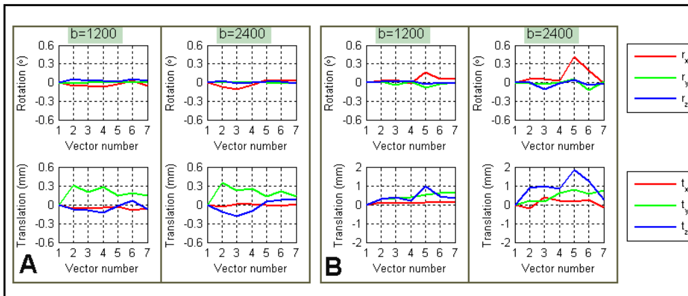

Fig. 3. Estimated motion from the averaged images of the monkey (A) and volunteer (B).

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References: 1. Leemans A, Jones DK. Magn Reson Med 2009;61(6):1336-1349. 2. Bastin ME. Magn Reson Imaging 1999;17(7):1011-1024. 3. Horsfield MA. Magn Reson Imaging 1999;17(9):1335-1345. 4. Rohde GK, et al. Magn Reson Med 2004;51(1):103-114. 5. Haselgrove JC, Moore JR. Magn Reson Med 1996;36(6):960-964. 6. Reese TG, et al. Magn Reson Med 2003;49(1):177-182. 7. Jenkinson M, et al. Neuroimage 2002;17(2):825-841. 8. Leemans A, et al. 17th ISMRM; 2009. p 3537. 9. Andersson JL, Skare S. Neuroimage 2002;16(1):177-199.