Effect of Diffusion Time and B-value on Quantitative DTI

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Introduction

Diffusion tensor imaging (DTI) provides valuable microstructural information in characterizing tissue microanatomy (1, 2) that other non-invasive modalities cannot offer. It has been employed extensively to study the WM associated with both normal physiological and pathophysiological changes, including brain development and aging (3, 4), neurological and psychiatric disorders (5, 6), brain injuries and tumor (7, 8), and cognitive functions (9, 10). Recently, efforts have been made to optimize the b-value used in DTI by varying the diffusion gradient strength for improved characterization of the diffusion behaviors and/or their changes associated with specific cellular microstructure or pathology (11, 12). Diffusion-weighted (DW) signal attenuation not only depends on diffusion gradient strength but also the timing parameters of the pair of diffusion gradients (13). Thus DTI acquisition can be further optimized by examining the effect of the separation between 2 diffusion gradients, i.e., diffusion time (Δ). In this study, the effect of Δ on various conventional DTI indices was examined by acquiring DW signals with various b-values at different Δ in adult normal rat brains in vivo.

Methods

All experiments were performed using a Bruker 7T scanner on normal adult SD rats (N=4) in vivo. DW images (DWIs) with 4 different b-values (0.5, 1.25, 2.0 and 2.5ms/μm^2) along 15 gradient encoding directions were acquired with a respiration-gated 2-shot stimulated-echo-EPI sequence. DW experiments were repeated with Δ=40, 70, 95, 125, 150 and 190ms. Imaging parameters were TR/TE=3000/25.1ms, δ=6ms, slice thickness=1.2mm, FOV=60x40mm^2, data matrix=96x64 (zero-filled to 128x128), NEX=2. DWIs were coregistered using AIR5.2.5. Four sets of DTI index maps, fractional anisotropy (FA), mean diffusivity (MD), axial ($\lambda_{//}$) and radial diffusivity ($\lambda\perp$), were computed from b-values of 0.5 vs. 1.25, 0.5 vs. 2, and 0.5 vs. 2.5ms/μm^2 for each Δ. For quantitation of these DTI indices, multi-slice region-of-interests (ROIs) were defined in the FA and $\lambda\perp$ maps as previously described (14, 15), including 2 white matter (WM) structures, corpus callosum (CC, 44±5 pixels) and internal capsule (IC, 20±5), and 3 gray matter (GM) structures, cortex (CT, 768±107), hippocampus (HP, 30±2) and caudate putamen (CU, 111±11).

Results

ROI quantifications of MD, FA, $\lambda_{//}$ and $\lambda\perp$ obtained from DWIs with b-value 0.5 vs. 1.25, 0.5 vs. 2, and 0.5 vs. 2.5ms/μm^2 (column in each subplot) at different Δ (row in each subplot) in different neural tissues are shown in Fig. 1(a), (b), (c) and (d), respectively. Note that the color maps in the same row are displayed in the same scale (as shown on the right of each subplot). MD, $\lambda_{//}$ and $\lambda\perp$ generally decreased with b-value and Δ for all tissues, whereas FA generally increased with Δ for all structures (except CC) and moderately decreased with b-value (except CC). Notice that the minimal signal-to-noise ratio of DWI is more than 12, and thus the quantification of DTI indices in the current study is not significantly biased (16).

Discussions and Conclusions

Despite the less discernable change in various contrasts between different neural tissues in MD, FA, $\lambda_{//}$ and $\lambda\perp$ maps (maps not shown), the ROI quantitation revealed several findings in the current study. First, the apparent FA generally increased with Δ in all neural tissue types except CC. In other words, the "true" anisotropy measured was underestimated at short Δ, suggesting that it might be valuable to perform DW experiments using longer Δ so to obtain relatively more reliable and accurate measurement. In addition, it is noteworthy that, despite the changes in diffusivities of CC, FA remained largely unchanged because the percentage change in $\lambda_{//}$ was largely comparable to that in $\lambda\perp$, thus resulting negligible change in FA with respect to the Δ values studied. Secondly, GM tissues had generally higher percentage increase in apparent FA with respect to Δ than WM tissues. Note that the GM structures close to cortical surface or ventricles may suffer from CSF partial volume contamination, causing FA underestimation to certain extent but unlikely the generally increasing trends of FA dependency on Δ observed in this study. This finding suggests that relatively longer Δ be used if one is to study GM with increased FA sensitivity. In summary, the current experimental study demonstrated the distinct effect of both diffusion time (Δ) and diffusion weighting b-value in quantitative DTI. Choice of Δ and b-value in conventional DTI may be optimized to gain more sensitive measurements regarding the tissue microstructures.

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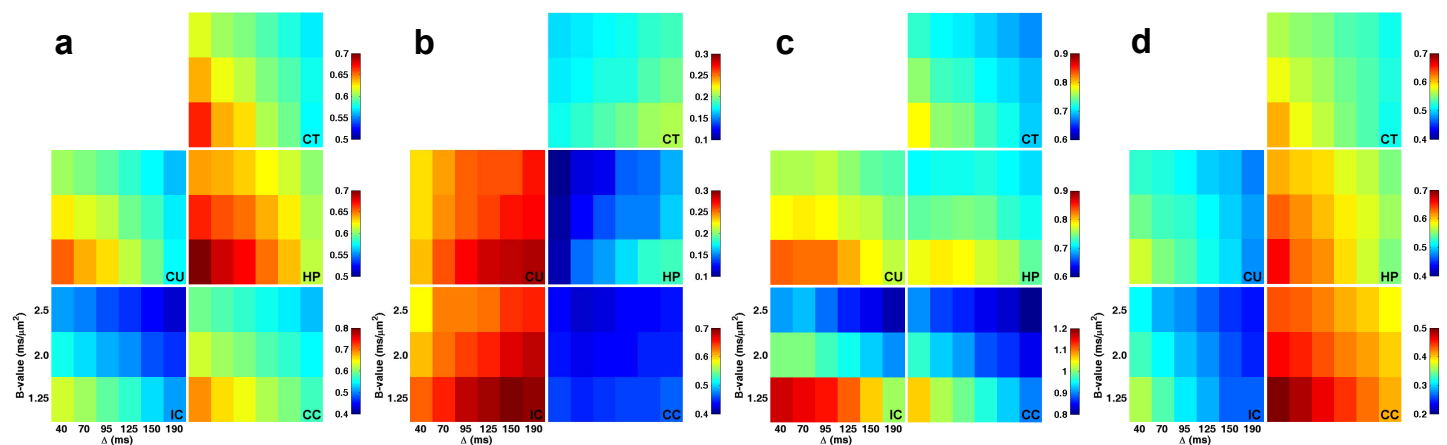
Fig.1 ROI quantifications of **(a)** MD, **(b)** FA, **(c)** $\lambda_{//}$ and **(d)** $\lambda\perp$ computed from b-values of 0.5 vs. 1.25, 0.5 vs. 2, and 0.5 vs. 2.5ms/μm^2 of all animals at different Δ in each neural tissue. Note that maps in the same row are displayed on the same scale as shown on the right. 2 white matter (WM) structures, corpus callosum (CC) and internal capsule (IC), and 3 gray matter (GM) structures, cortex (CT), hippocampus (HP) and caudate putamen (CU) were defined. MD, $\lambda_{//}$ and $\lambda\perp$ are in unit of μm^2/ms