Optimization of b-values for diffusion kurtosis imaging in patients with glioblastoma

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Introduction: Glioma tissues are heterogeneous in nature, and during malignant transformation the histopathologic features of the tumors change substantially, reflecting alterations in tumor microstructure. Diffusion MRI has been used for the characterization of gliomas, and has proven to be of additional value in glioma grading. Diffusional kurtosis imaging (DKI) is a clinically feasible extension of diffusion tensor imaging (DTI) that quantifies non-Gaussian diffusion properties. As described in previous literature [1], the diffusional kurtosis is related to the diffusion-weighted signal intensity by the following Eq.:

$$\ln[S(b)] \approx \ln[S(0)] - bD + \frac{1}{6}(bD)^2 K \qquad (1)$$

where $S(b)$ is the signal intensity as a function of the b-value, D is the diffusion coefficient for the given direction and K is the kurtosis coefficient, which is dimensionless. If $S(b)$ in Eq. (1) is measured for three different b-values (b_1, b_2, and b_3), then one may obtain D and K from

$$D = \frac{(b_3+b_1)D^{(12)} - (b_2+b_1)D^{(13)}}{b_3-b_2}; \quad K = 6\frac{D^{(12)} - D^{(13)}}{(b_3-b_2)D^2} \qquad (2)$$

with $D^{(ij)} \equiv \ln[S(b_i) / S(b_j)] / (b_j - b_i)$. For MRI of the brain, empirical evidence indicates that maximum b-values of about of 2000 to 3000 s/mm^2 for DKI are appropriate [2], and a recent study also suggests the feasibility of simply using the 3 b-values of 0, 1000, and 2000 s/mm^2 [3]. However, these assumptions are usually based on data from normal brain tissue [2]. The optimum choice of b-values for pathologic brain tissue such as brain tumor remains unclear, and it is crucial that an appropriate b-value range be independently established before applying Eq. (1) & (2).

Purpose: To investigate the optimum choice of b-values for DKI in patients with glioblastoma.

Methods: We investigated the preoperative DKIs of five patients with glioblastoma (2 males, 3 females; mean age, 54.6 years). The preoperative images were acquired using a 3T Achieva MR system (Philips). DKI acquisition was performed with 6 b-values (0, 500, 1000, 1500, 2000 and 2500 s/mm^2) along 32 diffusion encoding directions. Other imaging parameters were: TR = 3000 ms, TE = 80 ms, averages = 1, FOV = 256×256 mm^2, matrix size = 128×128, slice thickness = 5 mm. From the full set of b-values (0, 500, 1000, 1500, 2000 and 2500 s/mm^2), b=0 and two other b-values were chosen (i.e. 3 b-values per each analysis, 10 combinations [=$_5C_2$] of b-values), and DKI fitting analyses were performed on a Matlab-based program (MathWorks Inc.) to calculate the mean kurtosis (MK). Regions of interest (ROIs) were manually drawn in the solid part of the tumor (ROI 1, contrast-enhancing part; ROI 2, non-enhancing part), and the contralateral normal white matter (ROI 3). Cystic, necrotic or hemorrhagic areas of the tumor were carefully avoided. Student's t-tests were applied for testing significant changes between MK obtained from the full set of b-values and from each combination. A P value < 0.05 was seen as significant.

Results: Figure 1 shows the kurtosis values in each ROI. In ROI3 (normal white matter), MK obtained from b = 0, 2000, 2500 was significantly lower than that obtained from the full set. In ROI1 (enhancing part), MK obtained from combinations that include b = 500 and from b = 0, 1000, 1500 were significantly lower than the MK from the full set. In other b-value combinations (b = 0.1000, 2000; b = 0, 1000, 2500; b = 0, 1500, 2000; b = 0, 1500, 2500), MK values in ROI1 and ROI3 did not significantly differ from the full set data, while MK values in ROI2 were significantly higher.

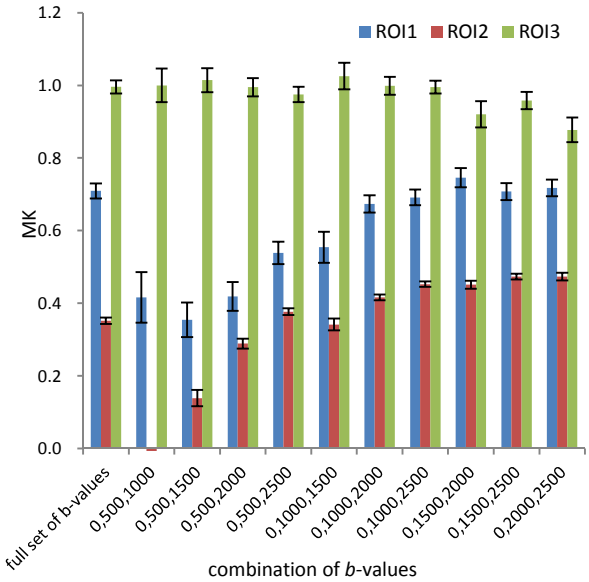

Figure 1. The mean kurtosis (MK) in each region of interest (ROI) obtained from each combination of b-values. Bars represent standard error.

Discussion: In the current study on clinical cases with glioblastoma, we performed DKI fitting analyses by applying different combination of b-values. The significant decrease of MK in normal white matter obtained from b = 0, 2000, 2500 may due to an inadequate signal-to-noise ratio in relatively high b-value images. The significant decrease of MK in enhancing part of the tumor obtained from combinations that include low b-values may reflect the influence of increased blood volume. The contrast of MK between the enhancing part and the non-enhancing part, or the non-enhancing part and normal white matter, tended to become lower with the use of high b-values. It is crucial that an appropriate b-value combination be independently established for pathologic brain tissue before applying DKI to clinical practice.

References: [1] Jensen JH et al. Magn Reson Med 2005;53:1432-1440. [2] Jensen JH, et al. NMR Biomed 2010;23: 698–710. [3] Jensen JH et al. Proceedings of the 17th Annual Meeting of ISMRM 2009;1403.