Optimization of scan parameters for diffusion kurtosis imaging at 1.5 T

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INTRODUCTION Water molecules in biological structures often show non-Gaussian diffusion behavior due to the restriction caused by neighboring tissue membranes and compartments. Diffusion kurtosis imaging (DKI) can characterize the degree of non-Gaussian diffusion by estimating the kurtosis of the displacement probability distribution [1-2]. DKI has been reported to provide additional information that cannot be obtained by conventional diffusion tensor imaging (DTI) that assumes Gaussian diffusion [3-5]. However, the acquisition time of DKI is substantially long as compared with DTI because of the requirement of at least 3 b-values and 15 diffusion directions, and this may not be acceptable in a clinical setting, particularly when 1.5 T scanners are used. Although fewer b-values, diffusion directions, and numbers of signals averaged (NSA) can contribute to shorten the acquisition time [2], it remains unknown which combinations of these parameters are suitable for optimizing DKI. Hence, we investigated the effects of b-values, diffusion directions, and NSA on the accuracy of DKI metrics such as mean kurtosis (MK), axial kurtosis ($K_{//}$), and radial kurtosis ($K_{\perp}$), and attempted to determine the ideal combinations of these parameters to achieve both accuracy and time efficiency.

METHODS Two-dimensional spin-echo diffusion-weighted (DW) echo planner imaging (EPI) was performed on five healthy volunteers using a 1.5 T MRI system (ECHELON Vega®, Hitachi Medical Corporation, Japan) and an 8-channel head coil. Images of 30 gradient directions and 6 b-values (0, 500, 1000, 1500, 2000, and 2500 s/mm^2) were obtained. Other parameters were as follows: TR/TE, 3300/120 ms; FOV, 240 mm; matrix, 128 × 128; thickness/interval, 6/6 mm; number of slices, 12; NSA, 2; motion probing gradients with a duration (δ) of 30.3 ms and a separation (Δ) of 56.6 ms; and acquisition time, 16 min 37 s. Scans were repeated twice to provide a total NSA of 4. Post-processing was performed using in-house software developed in Mathematica 7.0 (Wolfram Research, Inc.). An unconstrained non-linear least squares method was used to estimate the diffusion coefficient (D) and kurtosis coefficient (K). The DKI maps with full datasets (6 b-values, 30 diffusion directions, and an NSA of 4) were used as a reference. Fourteen DKI maps with different combinations of b-values (with 30 diffusion directions and an NSA of 4), 13 maps with the same acquisition time (13 min 38 s) and different combinations of b-values and NSA (with 30 diffusion directions), and 16 maps with different diffusion directions (with b = 0, 1000, 2500, and an NSA of 4) were generated. The accuracy of each map was evaluated by comparison with the maps of the full datasets using an intraclass correlation coefficient (ICC). A significant level of accuracy was defined as ICC $\geq$ 0.97.

RESULTS The relationships of the combinations of b-values with the accuracies of DKI maps are shown in Figure 1. The effects of the b-value combinations on MK, $K_{//}$, and $K_{\perp}$ maps are similar. Regardless of the number of b-values, only combinations including b-values of 2500 s/mm^2 show accurate DKI values equivalent to the full dataset maps. The effects of combinations of the b-values and NSA on the accuracy of DKI maps under the same acquisition time are shown in Figure 2. The accuracies of DKI maps with three b-values (0, 1000, and 2500 s/mm^2) and an NSA of 4 were higher than those with any combinations with 4 or 5 b-values and with an NSA of 2 or 4. The effects of the number of diffusion directions on the accuracy of DKI maps are shown in Figure 3. Although the MK maps show significant similarities to the full dataset maps, $K_{//}$ and $K_{\perp}$ maps require more than 22 diffusion directions to achieve significant accuracies. Figure 4 shows the DKI maps obtained using full datasets (33 min 14 s) and those obtained using optimized scan parameters, i.e., b-values of 0, 1000, and 2500 s/mm^2, 23 diffusion directions, and an NSA of 4 (10 min 21 s). The image qualities of the latter configurations appear to be identical to those of the former, although the acquisition times are dramatically reduced.

DISCUSSION Our quantitative analyses revealed that using a b-value of 2500 s/mm^2 and an NSA value of 4 improves the accuracies of DKI maps, particularly $K_{//}$ and $K_{\perp}$ maps, whereas the numbers of b-values and diffusion directions have no such influence on map accuracy. These results suggest that data with a high b-value and a high signal-to-noise ratio are crucial for accurate calculations of DKI maps, while the numbers of b-values and diffusion directions can be compromised to shorten acquisition times. Although a long acquisition time has been assumed to be needed to generate DKI maps at 1.5 T, the combination of optimized parameters that we revealed can yield excellent DKI maps with an acquisition time of approximately 10 min. Additional optimizations in terms of the spatial arrangement of the diffusion directions and the use of post-processing algorithms may contribute to further improvement of the accuracy of DKI maps.

CONCLUSION Accurate DKI maps can be obtained with an acceptable acquisition time even at 1.5 T when scan parameters are optimized by including high b-value data, increasing NSA, and reducing the number of b-values and number of diffusion directions.

REFERENCES [1] Jensen JH, et al. Magn Reson Med 2005;53:1432-40. [2] Jensen JH, et al. NMR Biomed 2010; 23:698-710. [3] Wang JJ, et al. Radiology 2011;261:210-7. [4] Helpern JA, et al. J Magn Reson Imaging 2011;33:17-23. [5] Cauter SV, et al. Radiology 2012;263:492-501.

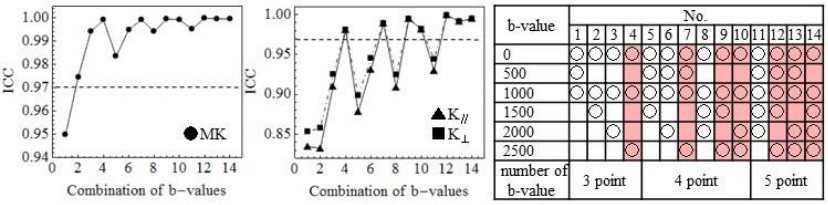

Figure 1. Effects of using different combinations of b-values on accuracies of DKI maps.

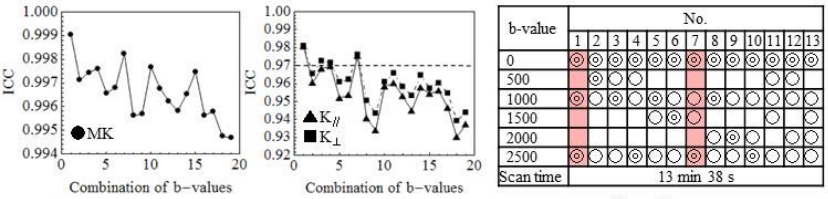

Figure 2. Effects of using different combinations of b-values and NSA (○, 2; ◎, 4), under the same acquisition time, on accuracies of DKI maps.

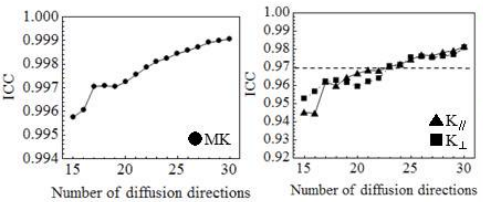

Figure 3. Effects of using a different number of diffusion directions on accuracies of DKI maps.

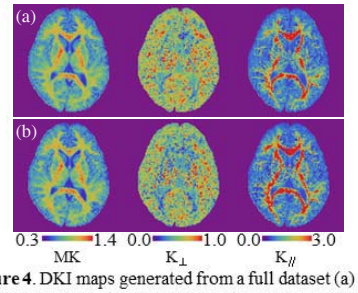

Figure 4. DKI maps generated from a full dataset (a) and those generated using optimized scan parameters (b).