Robust estimation with suppressed image blurring for diffusion kurtosis imaging using selective spatial smoothing filter

Suguru Yokosawa[1], Hisaaki Ochi[1], Yoshitaka Bito[2], Kenji Ito[3], and Makoto Sasaki[3]

[1]*Central Research Laboratory,Hitachi, Ltd., Kokubunji-shi, Tokyo, Japan,* [2]*MRI System Division, Hitachi Medical Corporation, Chiba, Japan,* [3]*Division of Ultrahigh Field MRI, Institute for Biomedical Science, Iwate Medical University, Iwate, Japan*

TARGET AUDIENCE Scientists and physicians who are interested in non-Gaussian diffusion imaging.

PURPOSE Water molecules in biological structures often show non-Gaussian diffusion behavior due to the restrictions 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.[3-4] However, DKI is more sensitive to data outliers than DTI due to the complexity of the signal intensity model. Although the spatial smoothing procedure was found to be useful in improving the reliability of estimation, this procedure causes blurred images of DKI maps such as mean kurtosis (MK). In this study, we propose a robust estimation method that reduces noise while suppressing image blurring by selectively applying a spatial smoothing filter only to voxel dataset that contain outliers.

METHODS Instead of being applied to all image data, a spatial smoothing filter is applied only to voxel dataset that contain outliers. These outliers are detected by deviation of calculated DKI coefficient from constrained condition. The process of the proposed method is summarized in Figure 1. First, image data without smoothing at each gradient direction are fitted to equation (1) on a voxel-by-voxel basis to obtain apparent diffusion coefficient, D_{app}, and apparent kurtosis coefficient, K_{app}, using an unconstrained non-linear least squares algorithm.

$$S(b) = S_0 \exp[-bD_{app} + b^2 D_{app} K_{app} / 6] \qquad (1)$$

If the calculated value fails to satisfy constraint conditions defined as $D_{app} \geq 0$ and $0 \leq K_{app} \leq 3$, the D_{app} and K_{app} are recalculated from spatially smoothed voxel dataset. When the recalculated values still do not satisfy the constraint conditions, these are replaced with the nearest value in the condition range by using a constrained non-linear least squares fitting.

Two-dimensional spin-echo diffusion-weighted echo planner imaging was performed on five healthy volunteers using a 1.5 T MRI system (non-product software version, ECHELON Vega, Hitachi Medical Corporation, Japan) and an eight-channel head coil. Images of 21 gradient directions and three *b*-values (0, 1000, 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, 4 min 51 s. Scans were repeated twice to estimate reproducibility. Post-processing was performed using in-house software developed in C++ code. MK maps were generated using the proposed method, and two control MK maps were generated using the constrained non-linear least squares fitting method, with and without spatial smoothing. In each method, an intraclass correlation coefficient (ICC) was used to evaluate reproducibility of MK maps between two separate measurements. ICCs for each slice and each subject were calculated and then averaged.

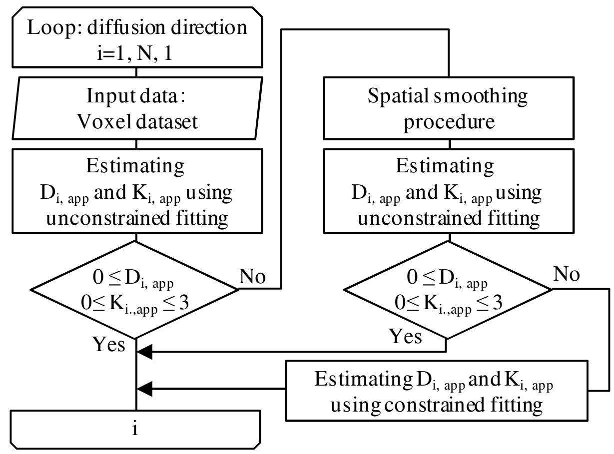

Figure 1. Process flowchart of propose method.

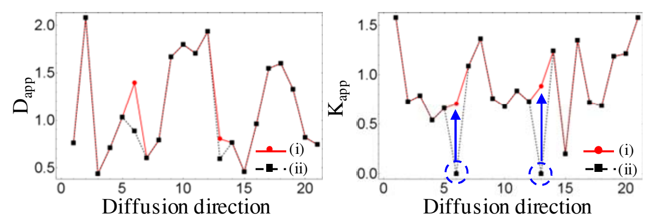

Figure 2. Estimated coefficients (D_{app} and K_{app}) of both proposed method (i) and constrained fitting without spatial smoothing (ii).

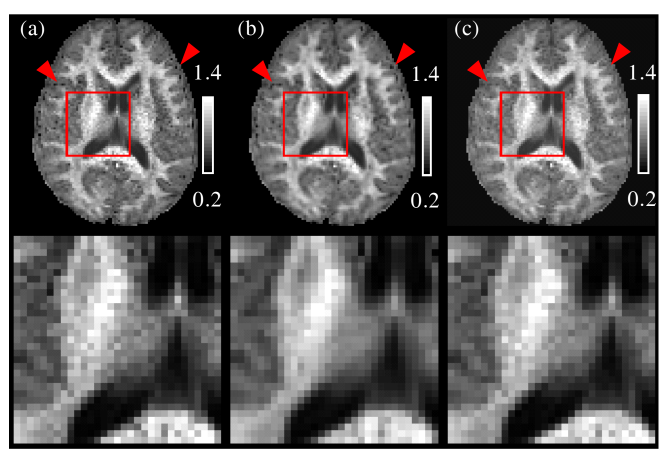

Figure 3. MK maps generated obtained by constrained fitting without spatial smoothing (a), constrained fitting with spatial smoothing(b) and proposed method (c).

RESULTS Figure 2 compares of the estimated coefficients (D_{app} and K_{app}) of the proposed method and constrained fitting method without spatial smoothing. The results show that the estimation error of K_{app}, calculated as "0", is corrected in the proposed method. Figure 3 shows that the MK maps generated from the three methods. The proposed method obtains a MK map with less blurring than the constrained fitting method with spatial smoothing (see (b) and (c)). Furthermore, pepper noises are reduced in the proposed method (see red arrows). The proposed method has an ICC value (0.77±0.076) that is significantly higher than that of the constrained fitting method without spatial smoothing (0.73±0.079) and not significantly different from that of the constrained fitting method with spatial smoothing (0.76±0.080).

DISCUSSION Although the spatial smoothing procedure can eliminate image noise, the degree of image blurring becomes greater in accordance with smoothing filter intensity. In our method, since a spatial smoothing procedure can be suppressed to a necessary minimum, image blurring can be suppressed while reducing image degradation caused by noise. Furthermore, the processing time of our method is not much different from that of the conventional method, because part of the DKI coefficient is calculated by unconstrained fitting, which has a shorter calculation time than constrained fitting.

CONCLUSION We demonstrated that MK maps can be robustly estimated with suppressed image blurring by selectively applying a spatial smoothing filter only to voxel dataset that contain outliers.

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.