Diffusion-Tensor-based Method for Robust and Accurate Estimation of Axial and Radial Diffusional Kurtosis

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Target audience: Any audience interested in Diffusional Kurtosis Imaging.

Background and Purpose: Long acquisition time of diffusional kurtosis imaging (DKI)[1] due to the requirement of multiple b-values and many motion probing gradients (MPG) encoding directions (minimum 15, usually at least 20-30) remains a problem for its daily application. In addition, the parameter assessed in DKI was mostly limited to "mean diffusional Kurtosis (mean K)" in previous reports, because the post-processing of small data acquired in clinics usually generates great noise and errors, so that the parameters except mean K were inadequate for evaluation. In this study, we designed a new method (estimated DKI: eDKI) based on diffusion tensor imaging (DTI) and quadratic function fitting that can robustly estimate diffusional kurtosis parallel and perpendicular to neuronal fibers (axial, radial K) from even smaller data than usual. The purpose of this study is to assess the robustness and the accuracy of eDKI.

Methods: Eight healthy female volunteers were scanned for this study (20-39 years, mean 26.8) by 3T clinical MRI system (Skyra, Siemens, Germany). DWI of their brains was acquired by segmented EPI method, five b-values (0, 500, 1500, 2000, 2500s/mm^2), and diffusion encoding in 64 directions. Images were processed by median filters. Then, axial K and radial K were obtained by both the conventional method and the proposed eDKI method (Fig. 1) for comparison. They were first calculated using the whole acquired image data with 64 MPGs, and then from the partial data sets each consisting of 32, 21, 15, and 6 MPG data abstracted from the original data. Axial and radial K calculated by the conventional Jensen method with 64 MPGs were regarded as standards in this study. The eDKI values were corrected automatically by leave-one-out method[2] to make the values and the contrast closer to the standard. Finally, the pixels with K values under zero, or over 1.5 and 3 in axial K and radial K, respectively, were regarded as errors. In addition, the pixels with values satisfying $3/(D\times K) > 2500$ (2500 is max b-value in this study) were also regarded as errors according to the basic assumption of the DKI theory[1].

To compare the robustness of the methods, ratios of the error pixels in the scanned brain parenchymal region were obtained for each image. To assess the accuracy of the eDKI estimation, root mean square errors (RMSE) compared to the standards were calculated across the whole scanned brain parenchymal region in both methods. In this accuracy assessment, the error pixels defined above were excluded. For statistical comparison between groups, the Wilcoxon test was applied for a significant difference of P<0.05.

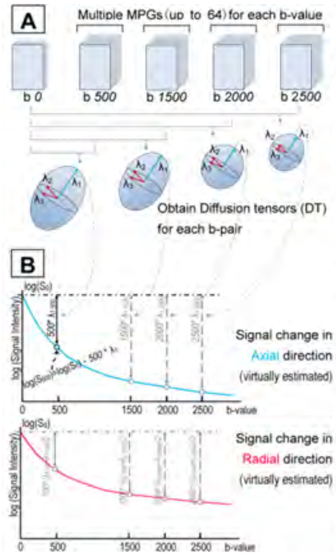
Results: eDKI improved the map quality. The map had small noise and errors compared to the conventional Jensen method even when the MPG encoding number was reduced to six (Fig. 2). This result was also supported by the comparison of the ratios of error pixels (Fig. 3). Mean RMSE in comparison with the standard (Jensen method with 64 MPGs) was consistently smaller in eDKI when the MPG number was under 32, and the differences were significant except for axial K with 32 MPGs (Fig. 4).

Discussion: The robustness of eDKI might result from its simplified calculation process. In this method, kurtosis tensor with 15 independent variables is not used. Instead, eDKI directly estimates the axial and radial b-value-dependent signal changes on the basis of DTI, and then fits this result to a quadratic function to obtain axial and radial K. It reduces the repetition number of quadratic fitting (which equals the number of MPGs in the conventional method, and twice (axial and radial) in eDKI), which contributes to the robustness. In addition, it reduces the theoretical requirement of MPG from 15 to 6. Furthermore, RMSE of eDKI compared to the standard was smaller than that of conventional DKI when the MPG number was same (Fig. 4), which means that eDKI is not only robust but is also an accurate estimation method. Of note, RMSE of eDKI in 6 MPGs was roughly equal to conventional DKI with 32 MPGs.

Conclusion: eDKI can estimate axial and radial K robustly and accurately from small clinical data.

Reference: 1. Jensen J, Helpern JA et al. Magn Reson Med 2005; 53: 1432-1440

2. Nouranian S, Mahdavi S S et al. Med Image Comput Comput Assist Interv 2013; 16 :173-80



$$S = S_0 \cdot exp\left(-bD + \frac{1}{6}b^2D^2 \cdot K\right)$$

Figure 1 Methods for obtaining axial /radial estimated DKI (eDKI): **A)** From the raw data with multiple b-values and motion probing gradient (MPG) directions, diffusion tensor image (DTI) was calculated for each b-value. The largest eigenvalue of this tensor (λ_1) was regarded as axial diffusion coefficient, and the average of the other two eigenvalues (λ_2, λ_3) was regarded as radial diffusion coefficient. **B)** For each axial and radial direction, the b-value-dependent signal change curve was calculated using the diffusion coefficients obtained above. **C)** Quadratic function fitting by Jensen et al[1] was used to calculate axial and radial K from these curves.

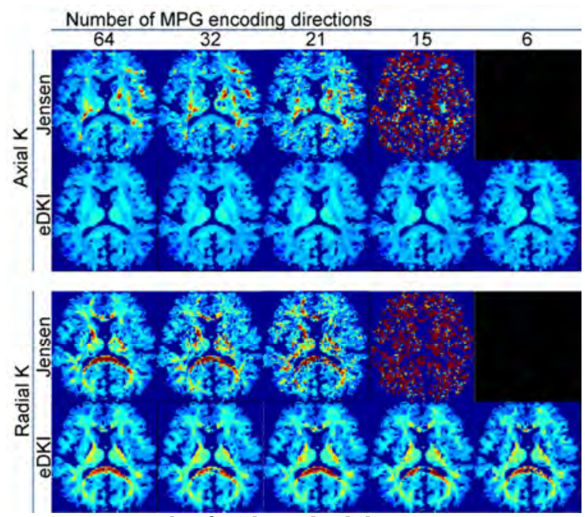


Figure 2: Samples of axial K and radial K maps: eDKI maps were less noisy compared to the conventional Jensen method, and were clearly obtained even with small MPG numbers.

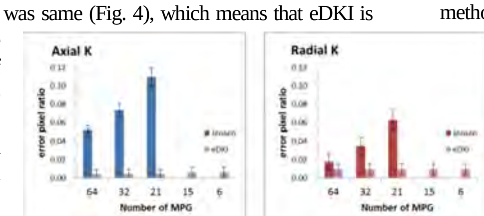


Figure 3: Comparison of error pixel ratios: The ratio of error pixels was much smaller in eDKI images compared to the Jensen method regardless of the number of MPG. There were significant differences all in 64, 32, and 21 MPG between the two methods (P<0.01, Wilcoxon test)

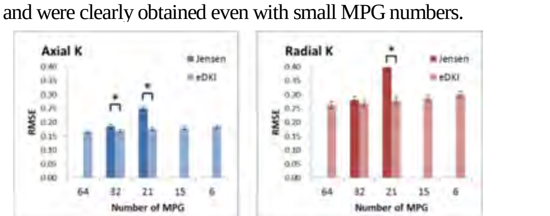


Figure 4: Comparison of root mean square errors (RMSE): The mean value of RMSE compared to the standard (Jensen method in 64 MPGs) was consistently smaller in eDKI.
*There were significant differences between the two methods (P<0.01, Wilcoxon test).