REKINDLE: ROBUST EXTRACTION OF KURTOSIS INDICES WITH LINEAR ESTIMATION

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Introduction

For clinical applications, it is challenging to get an accurate and complete picture of diffusion characteristics within a limited acquisition time. In addition to the metrics obtained with diffusion tensor imaging (DTI) [1], diffusion kurtosis imaging (DKI) [2] can quantify the degree of non-Gaussian diffusion by means of the kurtosis tensor (KT) and has shown to be more sensitive to tissue microstructural changes in both normal and pathological neural tissue (e.g., [3]). Furthermore, DKI is able to estimate DTI measures such as fractional anisotropy (FA) more accurately [4]. In a clinical setting, however, such benefits are often nullified by numerous acquisition artifacts, such as signal dropouts due to subject motion or cardiac pulsation [5]. The popular Robust Estimation of Tensors by Outlier Rejection (RESTORE) method improves tensor estimation in the presence of such artifacts and has been widely used in DTI [6]. In this work, we rekindle this robust estimation procedure, but then in the context of DKI. Due to its increased model complexity, higher acquisition demands, and longer scanning times, DKI is even more sensitive to data outliers than DTI and, therefore, will benefit from robust estimation procedures. In addition to the extension of the conventional RESTORE approach to DKI, we propose a linearized framework, coined REKINDLE (**R**obust **E**xtraction of **K**urtosis **IND**ices with **L**inear **E**stimation), that reduces computational cost drastically without any significant reduction in accuracy.

Methods

Estimation framework: The DT and KT can be computed from their relation with the signal attenuation as follows:

$$S_{\mathbf{g}} = S_0\, e^{-b_{\mathbf{g}}\, \mathbf{g}^T \mathbf{D}\mathbf{g} + \frac{1}{6}(b_{\mathbf{g}})^2 \left(\frac{1}{3}\sum_{i=1}^{3} D_{ii}\right)^2 \sum_{i=1}^{3}\sum_{j=1}^{3}\sum_{k=1}^{3}\sum_{l=1}^{3} g_i g_j g_k g_l W_{ijkl}},$$

with $S_{\mathbf{g}}$ the diffusion-weighted signal along gradient direction $\mathbf{g} = [g_1\ g_2\ g_3]^T$, S_0 the $b = 0$ s/mm^2 image, $b_{\mathbf{g}}$ the diffusion weighting along direction $\mathbf{g}$, and W_{ijkl} the kurtosis tensor elements. Similar to the DTI based RESTORE [6] algorithm, the robust DKI estimation frameworks, i.e. the RESTORE based extension (nonlinear/slow) and REKINDLE (linear/fast), consist of the following steps: 1) Initial fit gives initial DT and KT estimates; 2) If the residuals are not within a confidence interval, weights are recomputed using the bisquare function; 3) Fit is repeated with new weights; 4) Steps 2) and 3) are repeated until convergence criteria are satisfied; 5) Outliers are removed from the data; 6) Final fit with equal weights results in the DT and KT.

Data acquisition and image-processing: One DWI data set was acquired from a healthy volunteer (female, 25 y) on a 3T Philips Achieva MR scanner using an eight-channel head coil and a single-shot spin echo EPI sequence with the following parameters: 60 diffusion-weighted images with *b*-values of 1200 s/mm^2 and 2500 s/mm^2 with the gradient directions uniformly distributed over the sphere [7]; TR/TE = 10265/107 ms; 2 mm isotropic voxel size. A ground truth DWI dataset was created from the acquired data and an interleaving motion artifact was simulated by corrupting the signal intensities in 10% of the DW images. Such an artifact is common when a subject moves during Echo-Planar Imaging (EPI), in which the even/uneven slices are collected sequentially. Rician noise was added with SNR 20. The DT and KT were estimated from this corrupted dataset using 1) Linear least-squares, 2) Non-linear RESTORE-DKI, and 3) REKINDLE.

Results

Fig. 1 displays the simulated direction-encoded color FA map (top) and the interleaving artifact in the DW images with low (middle) and high (bottom) b-value. In Fig. 2, this motion artifact is clearly visible in the cerebellum for the FA, mean diffusivity (MD) and radial kurtosis (RK) maps for the linear fitting approach (similar results were obtained for the other kurtosis/diffusion maps). Both RESTORE and REKINDLE are able to deal with the artifact by excluding the signal perturbations as outliers (computation times were 90 and 10 minutes, respectively).

Discussion and Conclusion

DKI provides avenues for more complete tissue characterization within clinically feasible scanning times, with increased risk of artifacts due to longer scanning times and higher acquisition demands. We have investigated the performance of RESTORE-DKI and the linearized version REKINDLE in presence of a commonly seen interleaving motion artifact. REKINDLE, in particular, can estimate the diffusion and kurtosis tensors robustly with roughly a tenfold reduction in computation time, and is therefore a feasible method for robust DKI tensor estimation in clinical applications.

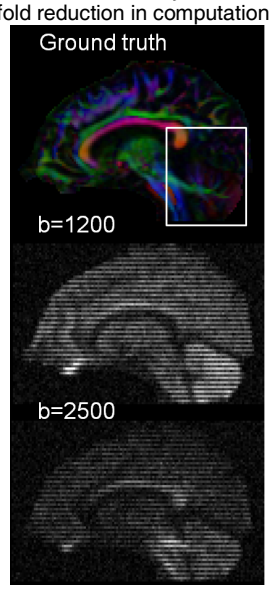

Fig. 1

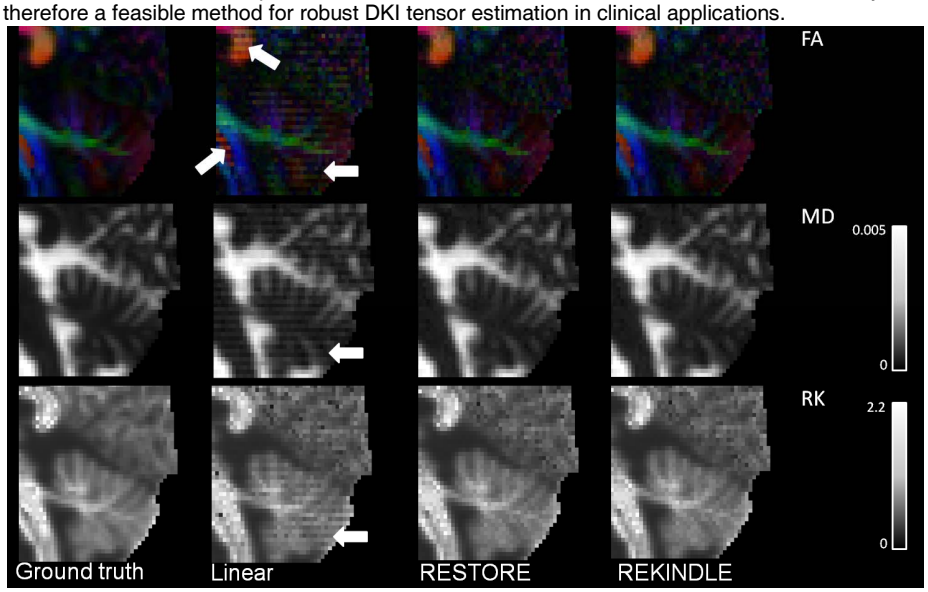

Fig. 2

References

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