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Impact of noise correction on diffusion kurtosis estimation

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Introduction
MRI is, intrinsically, a low SNR technique and the acquired signal is often heavily influenced by noise. This problem becomes critical at low SNR. In particular, this is the case for diffusion kurtosis imaging (DKI), where the images acquired with high diffusion weightings (b-values up to 3000 s/mm^2) experience very low SNR. A few noise correction methods have been already introduced [1-4] to overcome this problem. Here, we discuss the use of power image correction [1] for low SNR images and the impact of the evaluation of the noise standard deviation on kurtosis estimation.

Materials and Methods
MR experiments were performed with a 3T head-only scanner (Magnetom Allegra, Siemens Medical Solutions, Erlangen, Germany) on three healthy volunteers. Diffusion-weighted images were acquired using a twice-refocused-spin-echo diffusion sequence. Two b-values were used (1000, 2800 s/mm^2) with 60 non-collinear diffusion encoding directions. A total of 12 non-weighted images were also acquired, interleaved with the weighted images. The acquisitions parameters were: TR/TE=7400/89 ms, FoV= 192mm, matrix 96x96, voxel size 2x2x2 mm^3. The acquisition was repeated three times. Images were first corrected for motion in SPM (Wellcome Trust Centre for Neuroimaging, UCL, UK). To correct for the bias induced by noise we use the power image correction introduced by Miller and Joseph [1]: $S_{corr}^2 = S^2 - 2\sigma^2$ where S is the averaged magnitude of the signal and S_{corr} is the true magnitude. For evaluating the noise standard deviation we used two methods: the background estimation (BE) [2], the histogram algorithm from Brummer [3] using non-central Chi-square distribution [4] (BH) $S = \frac{1}{\gamma(8)\sigma^2}\left(\frac{x}{2\sigma^2}\right)^7 x^8 \exp\left(-\frac{x^2}{2\sigma^2}\right)$. The DKI analysis, encompassing the calculation of typical diffusion and kurtosis tensor metrics, was realized with in-house Matlab scripts.

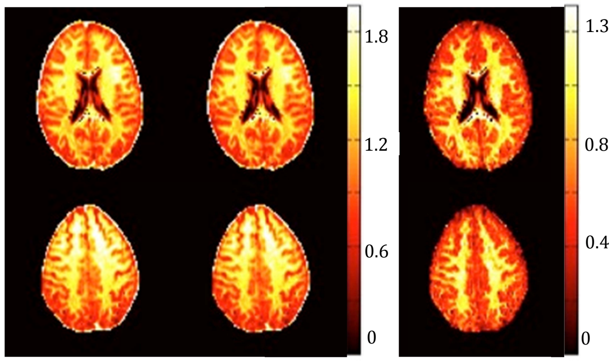

Fig.1. MK maps for slice 1 (upper row) and slice 2 (lower row). 2 different correction methods are used, from left to right: no correction, BH, BE

Results and discussion
Mean kurtosis (MK) maps for the different correction methods are shown in Figure 1 for two selected slices. These maps have been estimated from averaged data. All maps show a contrast between the different tissues (GM, WM, CSF) typical for DKI. BE correction (rightmost column) leads to maps with lower mean intensities but a somewhat higher contrast between tissues compared to the uncorrected maps (first column). No noticeable difference is observed between corrected maps BH (second column) and the uncorrected one. These observations are reinforced by the histogram analysis (Figure 2). The histograms are shown for slice 1, for both non-averaged (first row) and averaged data (second row). They were fitted with a sum of two Gaussian distributions, shown by solid lines. The histograms exhibit two peaks, which are shifted for corrected histograms BE (0.55 and 0.96) as compared to the uncorrected one (0.86 and 1.34). No shift is observed for the corrected histogram BH (0.82 and 1.28). Importantly, with BE correction, peaks are better resolved than in non-corrected and BH-corrected images. Averaging the data does not change the position of the peaks but further enhances the distinction between them for corrected histograms BE.

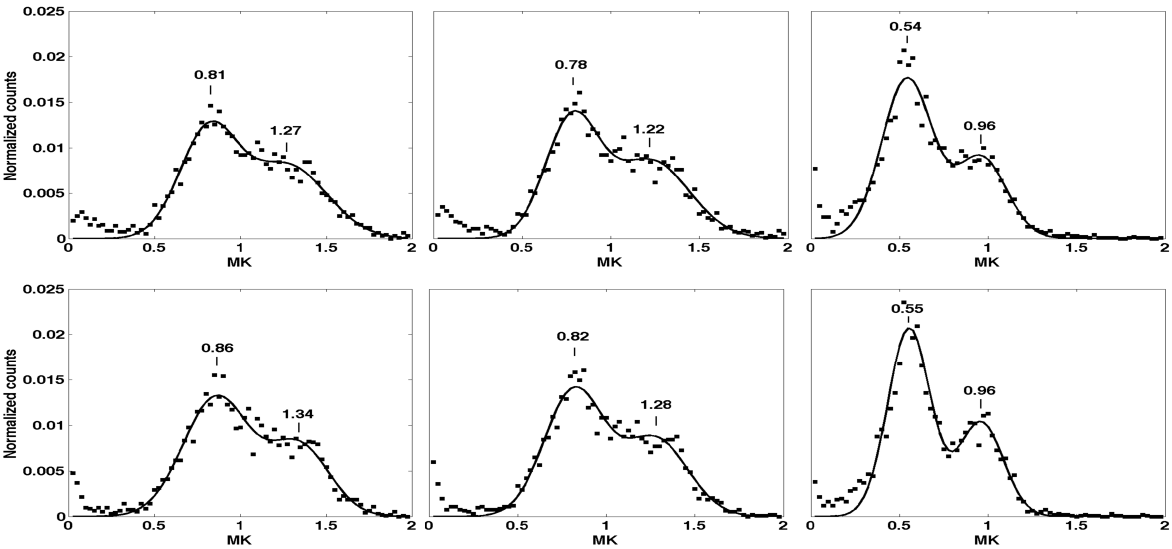

Figure 2: histograms of MK maps for slice 1. Upper and lower rows refer to non-averaged (one repetition) and averaged (three repetitions) data. Different correction methods are used, from left to right: no correction, BH and BE

Conclusion
We have shown that the presence of noise, especially in the high b-value DWI, involves an over-estimation of the kurtosis parameters and a lower contrast in MK maps. Noise correction is therefore an important step in kurtosis processing and should not be neglected. On the other hand, different correction schemes demonstrate different performance and must be selected carefully. In particular, based on this study, the background estimation was shown to be more favorable than the procedure based on the Brummer's histogram.

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References: [1] Miller AJ, Joseph PM. *Magn. Reson. Imaging* **11** 1051-1056 (1993); [2] Henkelman RM. *Med Phys* **12** 232–233 (1985); [3] Brummer ME et al. *IEEE Trans Med Imaging* **12** 153-156 (1993); [4] Dietrich O et al. *Magn. Reson. Imaging* **26** 754-762 (2008).