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SNR dependence of mean kurtosis and how to correct it

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Target audience

This abstract evaluates procedures for noise reduction and noise bias correction in MR images and their impact on DKI estimates. It is of interest to scientists processing diffusion-weighted and other low SNR MR images.

Introduction

In diffusion imaging, low signal-to-noise ratio (SNR) becomes critical, especially at high diffusion weightings (b-values). Complex images resulting from the combination of multichannel data are generally rendered as magnitude images, introducing a strong bias in the actual signal estimate at low SNR. This is particularly crucial for diffusion kurtosis imaging (DKI). Two correction methods are presented here: (1) power image correction[1] adapted for multichannel data and (2) look-up table correction based on the analytical expression of the central chi distribution of the noise[2]. The dependence of mean kurtosis (MK) on SNR is discussed in a first experiment while the inter-subject MK variability is discussed in a second experiment.

Materials and methods

Diffusion-weighted (DW) data were acquired on a 3T scanner (Allegra, Siemens Medical Solutions, Erlangen Germany) with an 8-channel receive head coil using a twice-refocused-spin-echo diffusion sequence. To study the noise correction and SNR impact on DKI results, two experiments were carried out. Protocol 1 (Number of repetitions (NR)=1, b=0/1000/2500 s/mm^2; TR/TE=7400/91 ms, FoV= 211 mm, matrix 88x88, voxel size 2.4x2.4x2.4 mm^3) was repeated 5 times on the same volunteer for different head positions (center of the coil, shift to the left, right, up and down) therefore varying the spatial distribution of SNR. Protocol 2 (NR=3; b=0/1000/2800 s/mm^2; TR/TE=7400/89 ms, FoV=192mm, matrix 96x96, voxel size 2x2x2 mm^3) was acquired on 25 healthy volunteers to track inter-subject MK variability. For both protocols, we acquired DW images along 60 directions at each b≠0 and 12 interleaved non-DW images. 5 extra volumes were acquired without RF pulses for noise standard deviation estimation in the first experiment.The following processing steps were applied: (1) intra-subject motion correction in SPM (Wellcome Trust Centre for Neuroimaging, UCL, UK), (2) optional denoising with a non-local mean filter[3] (BM4D), (3) noise bias correction, (4) estimation of DKI metrics. All non-DW images were realigned onto the first one using rigid body transform and parameters maps were realigned accordingly. Magnitude images were corrected for noise bias using two methods: (1) power image correction[1] (BE): $S_{corr}^2 = S^2 - 2L\sigma^2$ with S the averaged magnitude of the signal, S_{corr} the true magnitude, σ the noise standard deviation and L the number of coil elements; and (2) look-up table correction (ETA). The table was built from the expression of the first moment of the magnitude signal[2] M_L, as a function the true signal η_L, L and σ,

$$\overline{M_L} = \sqrt{\frac{\pi}{2}}\frac{(2L-1)!!}{2^{L-1}(L-1)!}\,{}_1F_1\left(-\frac{1}{2}, L, -\frac{\eta_L^2}{2\sigma_g^2}\right)\sigma_g .$$

The noise standard deviation was estimated from the non-RF images using the formula introduced by Constantinides *et al.* (1997) $\sigma = \sqrt{\frac{\sum_{i=1}^{N} S_i^2}{2LN}}$. To look at SNR dependence of the results, SNR maps were approximated as the mean signal of all DW images at b=1000 mm/s^2 divided by σ. 8 regions of interest (ROI) were defined in different white matter areas using the Harvard-Oxford subcortical structural atlas and the JHU white-matter tractography atlas available in FSL: temporal lobe, internal capsule, interior corona radiata and the globus pallidus, both left and right. MK from these ROI were extracted and compared.

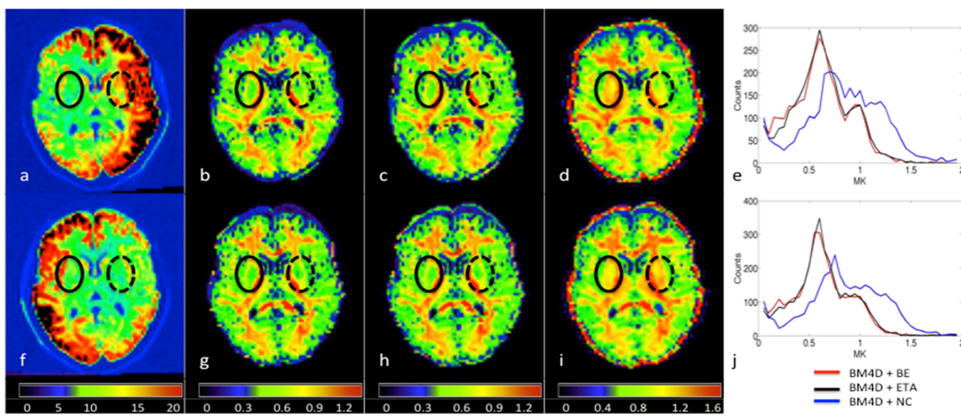

Figure 1: (a,f) SNR map. (b-d,g-i) Corresponding MK maps for 2 corrections: (b,g) BM4D+BE, (c,h) BM4D+ETA and with denoising only (d,i) BM4D+NC. (e,j) Histograms of the corresponding slice

Results and discussion

Figure 1 shows MK maps for two different SNR profiles (a,f) and different correction schemes: BM4D+BE (b, g), BM4D+ETA (c,h) and denoising only: BM4D+NC (d,i). MK maps are similar for both correction schemes, independent of the SNR, as emphasized by their practically coinciding histograms (e, j). Without noise correction, MK maps (d, i) exhibit systematically higher values, especially when SNR is lower, as delineated by the dashed circle and demonstrated by the histograms. Figure 2 shows the results from one of the ROI as an example. Without any noise bias correction, MK is globally higher and more dependent on SNR. For example, MK is significantly higher for SNR=8.1 than for SNR=10.6 in the left temporal lobe. When noise bias correction is applied, the MK estimate is globally lower and not dependent on SNR any longer. The results are further improved (lower variability) when the additional denoising step (BM4D) is applied. Basic denoising alone does not prevent overestimated MK values due to the remaining noise bias. Figure 3 illustrates the effect of noise correction on the inter-subject variability of the MK values. Without noise correction (c), the high MK variability in frontal areas is an artefact that could lead to biased conclusions from data analysis at the group level. This erroneous variability is reduced after noise correction (a,b).

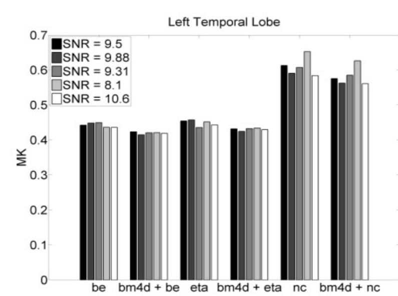

Figure 2: MK value from the left temporal lobe for 6 different corrections schemes and 5 different SNR

Conclusion

Our results show that noise bias correction has a strong impact and must be applied prior to kurtosis estimation. The simple and efficient procedures described herein reduce erroneous intra- and inter-subject variability which would otherwise bias any group analysis. It provides reliable and reproducible results independent of SNR and head position.

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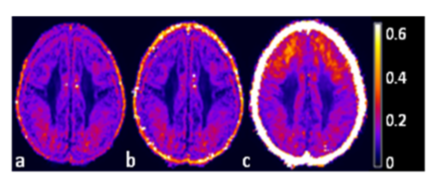

Figure 3: Standard deviation of MK maps across 25 subjects a)BM4D+BE b)BM4D+ETA c)BM4D+NC