Relevance of the information about the diffusion distribution in vivo given by kurtosis in *q*-space imaging

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Introduction

Molecular diffusion is a gaussian process in free medium. However, this gaussian assumption does not hold in complex biological tissues due to the presence of multiple compartments with or without exhange [1,2], restriction and hindrance effects, anisotropy, ... [3]. Indeed, several groups have observed non gaussian behaviors of the diffusion MRI signal [1,4,5] and the origin of the diffusion signal remains elusive. The aim of this study was to produce quantitative maps indicating by how much diffusion differs locally from a gaussian distribution in the human brain. An "index of gaussianity" was defined by measuring on a pixel-by-pixel basis the kurtosis excess index of the diffusion diplacement distribution, as obtained using the q-space approach (6). This approach was chosen because it allows the distribution to be directly obtained, without the need of prior model. In parallel, comparison was made with kurtosis derived from a regular biexponential model.

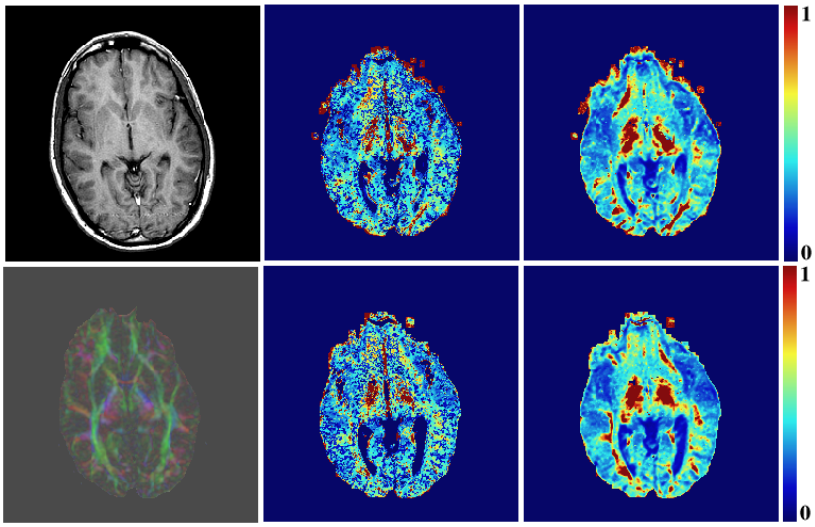

Figure1 – Left: T1 weighted anatomy, color coded FA (red R/L, green A/P, blue S/I). Center: kurtosis maps computed from q-space with diffusion along X,Y (top), and along X,-Y (bottom). Mask on pixels where fit failed was superimposed. Left: kurtosis maps computed from biexponential fit with diffusion along X,Y (top), and along X,-Y (bottom).

Method

Data Acquisition. Acquisitions were performed on 7 volunteers who gave informed written consent. Data were acquired on a 1.5T (GEMS, USA), with gradients up to 40 mT/m. Cardiac gating was used (TR=2RR). Resolution was 1.875 x 1.875 x 5 mm^3. Two perpendicular diffusion weighting directions were chosen {X,Y}, {X,-Y}. Q-values were spanned up to q_{max}=1106.8 cm^{-1} (corresponding to a b value of about 22000 s/mm^2) in 128 steps with 4 repetitions each. δ/Δ/TE were 59/ 66/ 165 ms. Baseline SNR was 16. In addition, T1-w images and standard diffusion tensor data sets (b=1000 s/mm^2, 55 directions) were acquired for comparison.

Data Analysis. The excess kurtosis index quantifies the degree of peakedness of a distribution, and will be zero for a gaussian. Kurtosis is extremely sensitive, therefore in order to compute it with as little noise contamination as possible a filtering step must first be undertaken. Kurtosis index from q-space, KIq, were computed as described in [8], using a rician noise approximation. For comparison, the same data sets were also analyzed according to the b values using a biexponential model. Kurtosis KIb was then evaluated from the fitted parameters (fast/slow) for the corresponding sum of two gaussians in the displacement space:

$$P = f_{fast} \Big/ \sqrt{4\pi D_{fast} t_d} \exp\left(\frac{-R^2}{4D_{fast} t_d}\right) + (1 - f_{fast}) \Big/ \sqrt{4\pi D_{slow} t_d} \exp\left(\frac{-R^2}{4D_{slow} t_d}\right)$$

with R standing for displacement, td for the diffusion time, f_{fast} for the fast diffusion fraction and $D_{slow/fast}$ for the slow and fast diffusion coefficients. Results significance was evaluated using ANOVA.

Results and Discussion

Figure 1 presents typical kurtosis maps obtained from q-space in the two diffusion directions. Although kurtosis maps based on q-space appear noisier than images derived from the b-value analysis, several structures appear clearly to deviate from a gaussian diffusion (high kurtosis index). Those structures are mainly located in white matter, in regions where fiber bundles are more or less perpendicular to the measurement direction (Table 1). Gaussianity was only found in CSF filled ventricles (kurtosis index not significantly different from 0). Gray matter exhibited some deviation from gaussianity (KI=0.30). In white matter KIq was generally close to 0.3 except when fiber bundles were perpendicular to the diffusion measurement direction (optic radiations, internal capsule). Kurtosis indices calculated from the biexponential fits followed the same trends, within the same range of values, but were higher than KIq in those regions. This gives confidence in our measures from q-space in spite of the short pulse gradient approximation not respected. Our KIq values differed from those obtained by Lätt et al. [5], but different acquisition parameters and methodology were used.

The larger deviation from gaussianity observed in white matter bundles perpendicular to the measurement direction suggests that additional effects occur, such as, for instance, restricted diffusion effects in or between myelinated axons. Modulation of KIq values is, thus, expected according to the angle between the fibers and the measurement direction (cf. optic radiations and internal capsule).

	Kurtosis from q space	Kurtosis from biexp.	Kurtosis from [5]
CSF (ventricules)	0. 16 ± 0.15	0.17 ± 0.16	1.41 ± 0.16
GM	0.30 ± 0.05	0.30 ± 0.03	2.68 ± 0.09
WM			3.16 ± 0.17
WM: Optic radiations, diffusion //	0.29 ± 0.09	0.42 ± 0.13	
WM: Optic Radiations, diffusion ⊥	0.59 ± 0.15	0.89 ± 0.26	
WM: Corpus Callosum, body	0.26 ± 0.04	0.29 ± 0.06	
WM: Internal Capsule	0.85 ± 0.19	1.16 ± 0.08	

Table 1 – Mean and std. dev. values of kurtosis from q-space analysis, from biexponential fit, and from [5]. ROI were positioned on T2 images.

Conclusion.

Diffusion appears to differ significantly from a gaussian process in the brain, both in gray and white matter. Using q-space, the degree of deviation from gaussian distribution can be assessed from kurtosis indices. The calculation, on a pixel-by-pixel basis, of this index appears as a promising approach to better characterize local structural effects which might affect the diffusion process.

References

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