Regional values of the diffusional kurtosis in the healthy brain

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Introduction

Diffusional kurtosis imaging (DKI) is an extension of Diffusion Tensor Imaging (DTI), proposed for characterization of the non-Gaussian random motion of water molecules [1]. Mean and radial kurtosis are dimensionless measures that are sensitive to tissue complexity, i.e. the number, density, orientation, and degree of organization of structures with length scales comparable to those at which water molecule diffuse [2]. Hitherto, reports on kurtosis values in healthy brain cover a limited number of regions [2-4]. The purpose of the present work was to provide estimates of the kurtosis in a large number of anatomically defined areas in the healthy brain. Additionally, age-dependency was probed for, since DTI-parameters vary with age [5].

Method

Thirty-six healthy adults (mean age = 33.1 years, range 19-64 years, 16 male, 20 female) were imaged at a 3T Philips Achieva system. A single shot EPI pulse sequence was used with TE/TR = 76/5400 ms/ms, resolution = 2 x 2 x 2mm^3, b = 0, 0.5, 1.0, 2.5 and 2.75 ms/μm^2 and 15 diffusion encoding directions. The diffusion kurtosis tensor was nonlinearly fitted to the data using in-house developed software. The apparent mean kurtosis (MK) and radial kurtosis (RK) were calculated following the definitions in [2]; the fractional anisotropy (FA) and mean diffusivity (MD) were calculated from b = 0, 0.5, 1.0 ms/μm^2 as described in [6] (Fig 1).
The following anatomically defined structures were delineated in one representative slice on the directionally color-coded FA-map: the temporal part and the body of the cingulum; the anterior basal part of the inferior fronto-occipital fasciculus (IFO); the posterior part of the inferior longitudinal fasciculus (ILF); the corticospinal tract (CST) at the level of the cerebral crus; the genu, body and splenium of the corpus callosum; the anterior limb of the internal capsule (ALIC); the posterior limb of the internal capsule (PLIC); the external capsule; the corona radiata; the superior longitudinal fasciculus (SLF); the central part of the centrum semiovale; temporal subcortical white matter (sWM), frontal sWM and parietal sWM. For each parameter and area, age-dependency was probed for using Spearman's correlation (P < 0.05). In addition, quadratic correlation with age was tested for using an F-test, and compared to the linear fit (P < 0.01).

Results

Regional values of the parameter estimates are presented in Table 1; Mean kurtosis varied from 1.38 in the splenium of the corpus callosum to 0.66 in the caudate head while MD varied from 0.68 to 0.62 mm^2/s and the FA from 0.87 to 0.29 in these locations, respectively. MK showed a linear age dependency in the external capsule, temporal cingulate, SLF and putamen, and MD in the temporal cingulate, the IFO, putamen and temporal SWM (Fig 2). No quadratic relationship with age was found. The coefficient of variation, i e the ratio of the standard deviation to the average value from all areas was 0.18, 0,37, 0.06 and 0.39 for MK, RK, MD and FA.

Fig 1. Parameter maps from one individual.

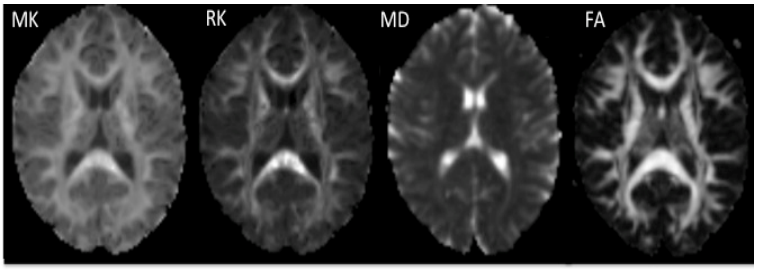

Fig 2. Mean kurtosis versus age for (a) the external capsule and (b) the putamen.

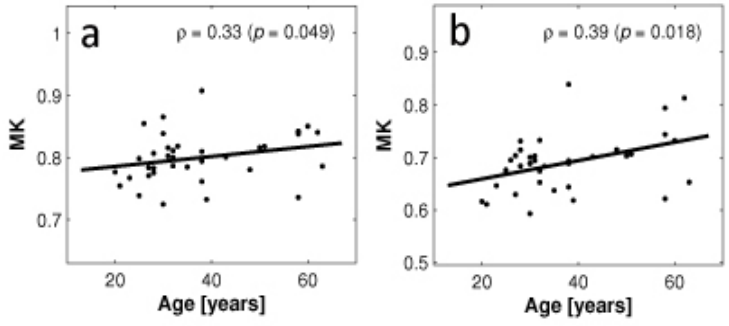

Table 1. Regional values of parameter estimates (mean and standard deviation). Linear correlation with age (P < 0.05) is shown by an asterisk (*).

ROI	MK	RK	MD [μm^2/ms]	FA
External capsule	0.80 ±0.05*	0.97 ±0.08	0.74 ±0.02	0.36 ±0.03
ALIC	1.01 ±0.09	1.50 ±0.26	0.68 ±0.05	0.60 ±0.06
PLIC	1.23 ±0.10	2.02 ±0.25	0.64 ±0.04	0.76 ±0.04
C callosum. body	1.14 ±0.08	2.30 ±0.30	0.77 ±0.04	0.76 ±0.04
C callosum. genu	1.06 ±0.10	1.99 ±0.40	0.75 ±0.06	0.81 ±0.04*
C callosum. splenium	1.38 ±0.08	2.86 ±0.40	0.68± 0.03	0.87 ±0.02
Centrum semiovale	1.12 ±0.06	1.73 ±0.21	0.64 ±0.02	0.63 ±0.04
Cingulate. body	1.04 ±0.09	1.56 ±0.32	0.64 ±0.03	0.62 ±0.06
Cingulate. temporal	0.83 ±0.09*	1.11 ±0.21	0.71 ±0.05*	0.51 ±0.07
Corona radiata	1.12 ±0.05	1.53 ±0.11	0.66 ±0.03	0.55 ±0.04
CST at cerebral crus	1.22 ±0.13	2.03 ±0.40*	0.65 ±0.04	0.80 ±0.04
IFO, anterior basal	0.82 ±0.08	1.16 ±0.15	0.72 ±0.02*	0.51 ±0.06
ILF, posterior	0.94 ±0.06	1.48 ±0.17	0.75 ±0.04	0.58 ±0.05
SLF, posterior	1.13 ±0.06*	1.77 ±0.24	0.65 ±0.03	0.61 ±0.05
Frontal sWM	0.92 ±0.06	1.17 ±0.17	0.71 ±0.04	0.47 ±0.05
Parietal sWM	0.99 ±0.08	1.35 ±0.18	0.66 ±0.04	0.52 ±0.05
Temporal sWM	0.95 ±0.07	1.24 ±0.16	0.69 ±0.03*	0.48 ±0.04
Caudate head	0.66 ±0.05	0.68 ±0.06*	0.75 ±0.04	0.13 ±0.03
Globus pallidus	1.09 ±0.10	1.12 ±0.14	0.62 ±0.04	0.29 ±0.06
Putamen	0.69 ±0.07*	0.66 ±0.08*	0.68 ±0.02*	0.13 ±0.03
Thalamus	0.87 ±0.07	0.96 ±0.09	0.69 ±0.02	0.32 ±0.04

Discussion and conclusions:

Knowledge of the normal variation in kurtosis throughout the brain is a first step in the evaluation of this parameter as a marker for disease. Here we present normal values of kurtosis in a wide range of anatomical areas. Our estimates of MK in the internal capsule (0.80), corpus callosum (1.38) and thalamus (0.87) are well in line with previous reports [4, 7]. Interestingly there is considerable overlap with values in pathologies, for example MK was 0.48,0.62 and 0.81 in gliomas grade II, III and IV [8], and was increased by 84% in subacute ischemic regions [9]. The lack of quadratic age-dependency found in the present study may be due to the interindividual variability of diffusion parameters and such a relationship may be present in a larger material. In conclusion we determined DTI-metrics in a large number of brain areas; no quadratic age-dependency was found; in addition, FA and RK showed the largest variation.

References

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