Orientation-specific Degeneration of the Cerebral White Matter in Aging Brain Investigated by Geometric DTI

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Introduction

Magnetic resonance diffusion tensor imaging (DTI) is a sensitive tool for in vivo detecting the human cerebral white matter degeneration, which might cause dementia clinically. The diffusion change of the aging brain is commonly investigated by apparent diffusion coefficient (ADC) and fractional anisotropy (FA), showing declined FA and increased ADC of the degenerated cerebral white matter [1], even when the volume change is not detectable yet [2]. Because of the anatomical variation of susceptibility of cerebral white matter to the degeneration, the diffusion change of cerebral white matter also different between anterior and posterior brain [3]. Containing linear (CL), planar (CP) and spherical (CS) coefficients, geometric DTI could characterize the geometric orientation of the diffusion of the healthy cerebral white matter [4]. By applying the geometric DTI, the aim of this study is to investigate the directional change of the aging cerebral white matter and its anatomic variation.

Theory

The diffusion tensor is calculated on a voxel-by-voxel basis by using the known relationship with the b matrix. The elements of the diffusion tensor D (Dxx, Dyy, Dzz, Dxy, Dxz, Dyz) from the encoded diffusion coefficients are derived as described by Basser et al. [5]. Eigenvalue decomposition of each voxel tensor is performed to determine the principle ordered eigenvalues, λ1, λ2, and λ3. The diffusion anisotropy is represented by fractional anisotropy (FA) :

$FA = \sqrt{\frac{3}{2}}\frac{\sqrt{(\lambda_1-\bar{\lambda})^2+(\lambda_2-\bar{\lambda})^2+(\lambda_3-\bar{\lambda})^2}}{\sqrt{(\lambda_1^2+\lambda_2^2+\lambda_3^2)}}$ where $\bar{\lambda}=\frac{(\lambda_1+\lambda_2+\lambda_3)}{3}$ The shape of the diffusion tensor is characterized by a combination of linear, planar and spherical measures:

$CL=\frac{\lambda_1-\lambda_2}{\lambda_1},\ CP=\frac{\lambda_2-\lambda_3}{\lambda_1},\ CS=\frac{\lambda_3}{\lambda_1}$ All the metrics falls in the range between 0 and 1 and they sums to unity: CL+CP+CS=1

Material and method

A total of 24 healthy subjects were recruited in this study, including a young-aged group (12 subjects, M:F=7:5, 34.1 ± 7.4 years) and an old-aged group (12 subjects, M:F=7:5, 69 ± 13.5 years). All MR scans were performed on a 1.5 Tesla MR scanner (Siemens Vision; Erlangen, Germany). In this study, we used a spin-echo echo-planar imaging sequence with the following parameters: TR/TE/NEX = 5000/100/2, FOV = 24 cm, slice thickness = 5 mm (no intersection gap), matrix size = 128 × 128, b-value = 707 s/mm2 along six non-collinear directions and plus one reference image with b = 0 s/mm2. Trace ADC (tADC), FA and three geometric parameters (CL, CP, and CS) were derived from the three eigenvalues. Six region-of-interest (ROIs), including genu (CCG) and splenium (CCS) of corpus callosum, anterior and posterior periventricular white matter (PVWM) were drawn by a senior neuroradiologist based on the FA map and T2-weighted images (Fig. 1). Student t-test was used for statistically analyzing the difference between the young- and old-aged groups. The percentage change ratio for each parameters was calculated by $(S_{elder}-S_{young})/S_{young} \times 100\%$. Pearson correlation and linear regression analysis were applied to correlate the age and diffusion parameters.

Results

In general, there was a trend of increased ADC and CS, decreased FA, CL and CP of cerebral white matter as the age increases (Fig. 2). FA and CS were best correlated with age regarding the location of CCG, anterior and posterior PVWM (Table 2). For all diffusion parameters, significant percentage change (p value <0.01) was mostly observed at CCG, anterior and posterior PVWM in old-aged group (Table 1). More specifically, largest percentage changes in CCG, anterior PVWM and posterior PVWM were demonstrated by CS, CL and CP, respectively. CCS showed smallest percentage of diffusion change and without statistical significance.

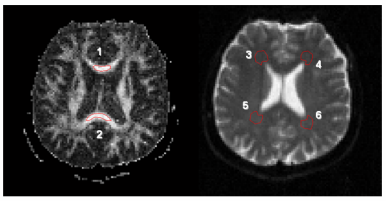

Fig. 1. ROI selection on FA map (left) and T2WI (right) (1) CCG, (2) CCS, (3) & (4) anterior PVWM, (5) & (6) posterior PVWM.

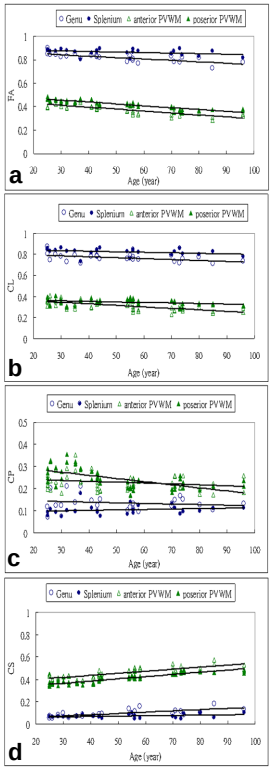

Fig. 2. Correlations between age and diffusion parameters (a) FA, (b) CL, (c) CP, and (d) CS

Discussion & Conclusion

The regional variations of cerebral white matter degeneration are demonstrated on either conventional or geometric DTI, showing greater loss of anisotropy in the anterior brain (CCG and anterior PVWM) than the corresponding posterior brain (CCS and posterior PVMW). CCG, anterior and posterior PVWM are more susceptible to aging-related degeneration with good correlation with the diffusion parameters of FA and CS. Among all cerebral white matter selected in this study, CCS is most resistant to the age-related degeneration. In addition to the decreased anisotropy on FA, geometric DTI better characterizes the microstructural change of cerebral white matter. For example, CCG and posterior PVWM show greater loss of the planar component comparing to the linear component, while anterior PVWM shows greater loss of the linear component than planar component. In conclusion, geometric DTI is at least as good as the conventional DTI in disclosing the overall loss of diffusion anisotropy, and moreover, is superior to conventional technique in depicting the directional anisotropic changes of the cerebral white matter regarding the age-related degeneration.

Table 1. Pearson correlation coefficients (* p<0.01)

	ADC	FA	CL	CP	CS
CCG	0.43	-0.71*	-0.49	0.15	0.71*
CCS	0.33	-0.34	-0.3	0.17	0.35
anterior PVWM	0.56*	-0.82*	-0.65*	-0.23	0.81*
posterior PVWM	0.67*	-0.92*	-0.37	-0.65*	0.93*

Table 2. percentage change ratio (* p<0.01)

	ADC	FA	CL	CP	CS
CCG	4%*	-5%*	-3%*	-14%*	54%*
CCS	1%	-1%	-1%	7%	5%
anterior PVWM	4%*	-16%*	-17%*	-5%*	16%*
posterior PVWM	8%*	-11%*	-1%	-25%*	18%*

References

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