·Investigation·

Magnetic resonance diffusion tensor imaging of optic nerve and optic radiation in healthy adults at 3T

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Abstract

• AIM: To investigate the diffusion characteristics of water of optic nerve and optic radiation in healthy adults and its related factors by diffusion tensor imaging(DTI) at 3T.

• METHODS: A total of 107 healthy volunteers performed head conventional MRI and bilateral optic nerve and optic radiation DTI. The primary data of DTI was processed by post-processing software of DTI studio 2.3, obtaining fractional anisotropy value, mean diffusivity value, principal engine value, orthogonal engine value by measuring, and analyzed by the SPSS13.0 statistical software.

• RESULTS: The bilateral optic nerve and optic radiation fibers presented green color in directional encoded color (DEC) maps and presented high signal in fractional anisotropy (FA) maps. The FA value of the left optic nerve was 0.598±0.069 and the right was 0.593±0.065; the mean diffusivity (MD) value of the left optic nerve was (1.324±0.349)×10^{-3}mm^2/s and the right was (1.312±0.350)×10^{-3}mm^2/s; the principal engine value ($\lambda_{\parallel}$) of the left optic nerve was (2.297±0.522)×10^{-3}mm^2/s and the right was (2.277±0.526)×10^{-3}mm^2/s; the orthogonal engine value ($\lambda_{\perp}$) of the left optic nerve was (0.838±0.285)×10^{-3}mm^2/s and the right was (0.830±0.280)×10^{-3}mm^2/s; the FA value of the left optic radiation was 0.636±0.057 and the right was 0.628±0.056; the mean diffusivity (MD) value of the left optic radiation was (0.907±0.103)×10^{-3}mm^2/s and the right was (0.889±0.125)×10^{-3}mm^2/s; the principal eigenvalue ($\lambda_{\parallel}$) of the left optic radiation was (1.655±0.210)×10^{-3}mm^2/s and the right was (1.614±0.171)×10^{-3}mm^2/s; the orthogonal enginvalue ($\lambda_{\perp}$) of the left optic radiation was (0.531±0.103)×10^{-3}mm^2/s and the right was (0.524±0.152)×10^{-3}mm^2/s. There was no obvious difference between the FA, MD, $\lambda_{\parallel}$, $\lambda_{\perp}$ of the bilateral optic radiation and the bilateral optic nerve (P>0.05) and no obvious difference between male and female group. The FA, MD, $\lambda_{\parallel}$, $\lambda_{\perp}$ of the bilateral optic radiation and the bilateral optic nerve had no obvious correlations to the age.

• CONCLUSION: DTI is sensitive to the optic nerve and radiation and the relevant DTI parameters of the optic nerve and radiation are established preliminarily in this study.

• KEYWORDS: magnetic resonance imaging; diffusion tensor imaging; optic nerve; optic radiation; fractional anisotropy; mean diffusivity

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INTRODUCTION

Optic nerve diseases are big threats to visual function, such as glaucoma (open angle or closed-angle), optic nerve neuritis, multiple sclerosis (demyelination and axonal injury), tumor and so on. Some lesions involving the visual central system can cause structural changes of the optic nerve or central visual pathways eventually leading to irreversible visual impairment, early diagnosis and treatment is particularly important. Diffusion tensor imaging (DTI) is currently the only noninvasive technique *in vivo* study of cerebral white matter and white matter tracts, which can measure and quantify the tissue microstructure change, providing the possibility for the early detection of visual pathway lesions. However, the large sample research for the diffusion characteristics of water of the optic nerve and the optic radiation is not at present [1]. In this study we collected 107 healthy volunteers for MR-DTI research to investigate the diffusion characteristics of water of the optic nerve and the optic radiation, which are basis for the quantitative study and early diagnosis and treatment of the optic nerve disease, providing some objectives.

SUBJECTS AND METHODS

Subjects Initially 115 healthy volunteers studied but due to severe image artifacts eight cases were excluded and finally 107 cases selected for our study. Fifty-six females and fifty-one males, mean age=40.27±12.49(18-62) years. Exclusion

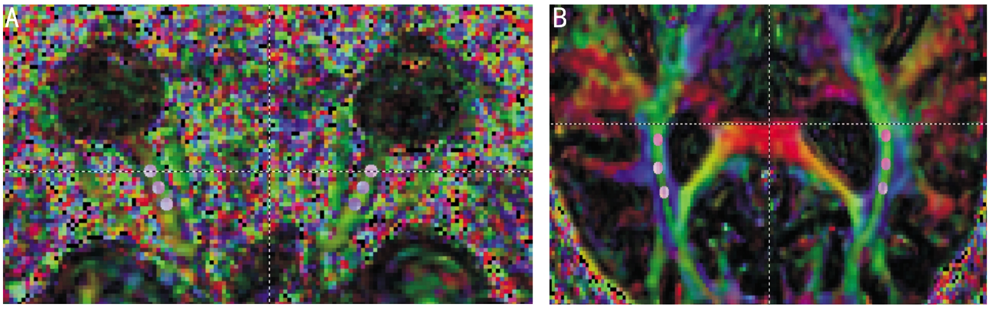

Figure 1 DEC map of bilateral optic nerve and radiation A: DEC map of bilateral optic nerve; B: Bilateral optic radiation. Three equal-sized ROIs in the middle of bilateral optic and bilateral optic radiation.

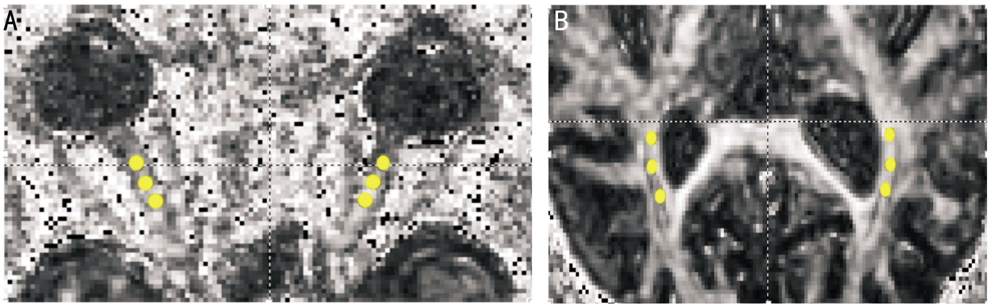

Figure 2 FA map of bilateral optic nerve and radiation A: FA map of bilateral optic nerve; B: Bilateral optic radiation.

criteria: 1) No history of eye diseases, intraocular surgery, optic neuropathy diseases and other diseases that affect the visual field; 2) No sellar region lesions; 3) No congenital developmental disorders; 4) Normal visual function tests such as visual field, visual acuity and color vision 5) No neurological signs and symptoms; 6) Head conventional MRI (T1WI, T2WI, FIAIR) showed no abnormality. Informed consent was taken from all the volunteers.

Methods

MRI examination All MR examinations were performed with a 3.0T scanner (GE Sigma HDxt), a dedicated eight-element head coil was used for radiofrequency signal transmission and reception. In the start, all the subjects were performed head conventional MRI, those subjects which were found no abnormality performed bilateral optic nerve and optic radiation DTI, diffusion tensor imaging was acquired on each patient with a single-shot echo planar imaging sequence: TR=10 600ms, TE=86ms, slice thickness=2mm, intersection gap=0, FOV=24, NEX=2, 12 directions, b=0 and 1 000s/mm^3; During the scanning range though the maxillary sinus to the parietal lobe, volunteers were asked to close their eyes gently and try not to move the eyeball.

Data processing The primary data of diffusion tensor imaging were processed with post-processing software of the DTI studio 2.3 (Hopkins University development) to get the directional encoded color map and the fractional anisotropy map. Fiber directions on directional encoded color (DEC) map: red=left-right; blue=superior-inferior; green=anterior-posterior. Three regions of interests (ROIs) of fixedly approximately 5mm^2 were manually drawn on the reference DEC images (Figure 1A) at the level of the middle part of the orbital optic nerve (to avoid the eye movement artifact and the effect of the posterior chiasm, the surrounding bone and gas), and then get the fractional anisotropy (FA) value on the FA map (Figure 2A), get the λ_1 value, λ_2 value and λ_3 value respectively on each map, MD= $[(\lambda_1、\lambda_2、\lambda_3)/3]$, $\lambda_{\parallel}$(AD)= λ_1, $\lambda_{\perp}$(RD)= $[(\lambda_2+\lambda_3)/2]$; ROIs were also manually drawn on the reference DEC images (Figure 1B) at the level of the middle part of the radiation of the trigone of bilateral lateral ventricle (on this section the intuitive structure is corpus callosum and trigone of lateral ventricles, optic radiation constituting the outer side wall of the posterior horn of the lateral ventricle, presenting green ribbon thin layer running from anterior to posterior), and then get the FA value (Figure 2B), $\lambda_{\parallel}$, $\lambda_{\perp}$ and MD value according to the above methods. $\lambda_{\parallel}$ (AD) map and $\lambda_{\perp}$(RD) map shown as below (Figures 3, 4)[2].

Statistical Analysis The SPSS version 13.0 statistical program was used: 1) The paired t-test was used to analyze the DTI parameters of bilateral optic nerve and optic radiation; the group t-test was used to assess the impact of gender on the DTI parameters; Linear correlation analysis was used to assess the association between age and the DTI parameters; 2) P<0.05 was considered to indicate a significant difference.

RESULTS

One hundred and seven volunteers performed head conventional MRI and bilateral optic nerve and optic radiation DTI successfully, the bilateral optic nerve and optic radiation presented green signal in DEC maps distinctly,

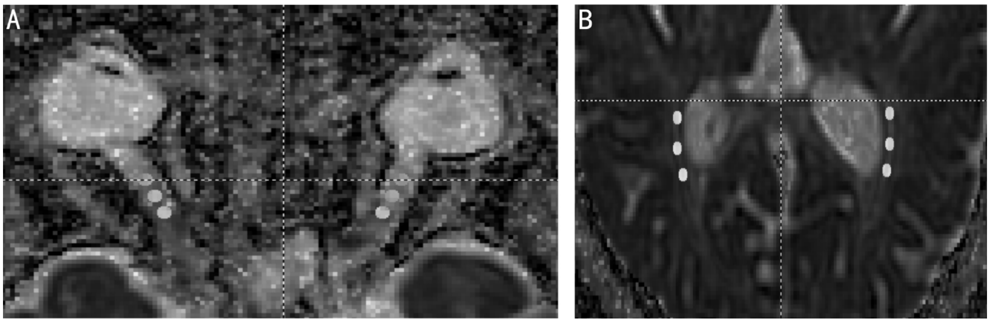

Figure 3 λ∥(AD) map of bilateral optic nerve and radiation A: λ∥(AD) map of bilateral optic nerve; B: Bilateral optic radiation.

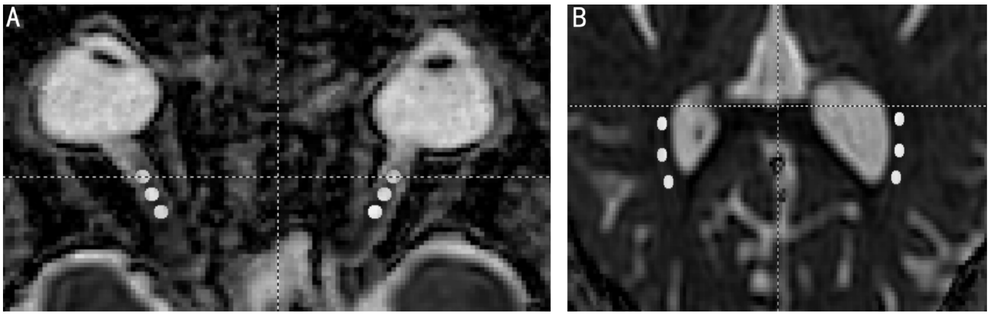

Figure 4 λ⊥(RD) map of bilateral optic nerve and radiation A: λ⊥(RD) map of bilateral optic nerve; B: Bilateral optic radiation.

Table 1 Analysis of DTI parameters of bilateral optic nerve and bilateral optic radiation

DTI	Bilateral optic nerve				Bilateral optic radiation			
	LON	RON	*t*	*P*	LOR	ROR	*t*	*P*
FA value	0.598±0.069	0.593±0.065	-0.142	0.887	0.636±0.057	0.628±0.056	1.215	0.227
MD value	1.324±0.349	1.312±0.350	0.583	0.461	0.907±0.103	0.889±0.125	1.169	0.245
λ∥	2.297±0.522	2.277±0.526	0.424	0.673	1.655±0.210	1.614±0.171	1.588	0.155
λ⊥	0.838±0.285	0.830±0.280	0.696	0.486	0.531±0.103	0.524±0.152	0.390	0.697

LON: Left optic nerve; RON: Right optic nerve; LOR: Left optic radiation; ROR: Right optic radiation. (FA value, MDvalue, λ∥, λ⊥)×10^{-3}mm^2/s.

Table 2 Analysis of gender effect on the DTI parameters of bilateral optic nerve and bilateral optic radiation

DTI	Bilateral optic nerve				Bilateral optic radiation			
	F (*n*=56)	M (*n*=51)	*t*	*P*	F (*n*=56)	M (*n*=51)	*t*	*P*
LONFA	0.601±0.070	0.592±0.068	0.681	0.498	0.642±0.058	0.639±0.057	0.742	0.460
RONFA	0.601±0.063	0.595±0.072	0.417	0.678	0.625±0.054	0.631±0.058	0.495	0.622
LON λ∥	2.191±0.453	2.362±0.579	-1.702	0.092	0.918±0.096	0.895±0.019	-1.121	0.265
RON λ∥	2.253±0.469	2.241±0.588	0.122	0.903	0.905±0.138	0.872±0.106	-1.422	0.158
LONMD	1.300±0.305	1.365±0.383	-1.58	0.117	1.653±0.218	1.656±0.202	0.080	0.937
RONMD	1.287±0.300	1.293±0.399	-0.107	0.915	1.624±0.159	1.604±0.183	-0.608	0.544
LON λ⊥	0.794±0.253	0.867±0.307	-1.344	0.182	0.543±0.119	0.518±0.081	-1.277	0.204
RON λ⊥	0.803±0.231	0.820±0.324	-0.313	0.755	0.542±0.187	0.505±0.099	-1.230	0.222

(FA value, MD value, λ∥, λ⊥)×10^{-3}mm^2/s.

running from anterior to posterior, which can be clearly separated from surrounding cerebrospinal fluid, fat, gas and gray matter. The values for the FA, MD, λ∥, and λ⊥ measured in this cohort of volunteers plus or minus their SD, are shown in Table 1, there was no obvious difference with the FA, MD, λ∥, λ⊥ of the bilateral optic radiation and the bilateral optic nerve; No obvious difference was found between male and female group during the group test of gender effect on the DTI parameters of bilateral optic radiation and optic nerve which is mentioned as below (Table 2), The FA, MD, λ∥, λ⊥ of the bilateral optic radiation and the bilateral optic nerve had no obvious correlations to the age (Table 3).

DISCUSSION

Magnetic resonance diffusion tensor imaging, which is developed from diffusion weighted imaging (DWI), is an important part of the functional magnetic resonance imaging. If compared with conventional imaging methods, DTI makes magnetic resonance imaging study of the human body depth to a more micro level, which can not only reflect the

Table 3 Analysis of age effect on the DTI parameters of the bilateral optic nerve and bilateral optic radiation

DTI	LONFA	RONFA	LON $\lambda_{\parallel}$	RON $\lambda_{\parallel}$	LONMD	RONMD	LON $\lambda_{\perp}$	RON $\lambda_{\perp}$
Bilateral optic nerve								
R^2	0.001	0.012	0.024	0.031	0.018	0.002	0.010	0.002
P	0.815	0.253	0.112	0.069	0.073	0.684	0.295	0.616
Bilateral optic radiation								
R^2	0.001	0.001	0.007	0.026	0.000	0.000	0.001	0.004
P	0.742	0.768	0.403	0.095	0.853	0.911	0.778	0.517

diffusion characteristics of water more accurately but also show the travel direction of the fibrous structures *in viva*, especially it opens up new application prospects of the contact of the fibers and lesions in the brain, as a result it plays a leading part in the study of brain lesions and structure of white matter.

The optic nerve, which is similar to the white matter extension, is a simple and well-defined white matter tract emanating from retinal ganglion cells, with high density and directionality, it is an ideal object of DTI study[3,4] . Wheeler-Kingshott *et al*[5] used a shortened echo planar imaging(EPI) echo train reducing the bright signal from the fat and cerebrospinal fluid (CSF) surrounding the nerve, which further improved the accuracy of DTI study of optic nerve, they had a small sample volunteers, their obtained FA value was (0.57-0.64)$\times 10^{-3}$mm^2/s, MD value was (1266-1173)$\times 10^{-6}$mm^2/s, $\lambda_{\parallel}$ was (2088-2109)$\times 10^{-6}$mm^2/s, $\lambda_{\perp}$ was (841-847)$\times 10^{-6}$mm^2/s, there was no obvious difference between the FA, MD, $\lambda_{\parallel}$, $\lambda_{\perp}$ of the bilateral optic nerve ,the result is similar to this study.

Terminating in the lateral geniculate, the optic tract forms a new fiber bundles called optic radiation, it's prominent ribbon like lamina about 2mm wide in the temporal, parietal, and occipital lobes, ending on the visual cortex, running from anterior to posterior, we chose the middle part of the radiation on the level of the of the trigone of bilateral lateral ventricle as the ROIs [6]. It is reported that the FA value of white matter was decreasing with aging except the corpus callosum, while we found no effect of age on the FA value of bilateral optic nerve and optic radiation, the result may have something to do with the choice of the subject [7,8]. All the volunteers did not had any effect of organic disease in brain including mild degeneration of cerebral white matter and relevant degenerative disease of eyes including age-related macular degeneration, thus we did not found any age-related degeneration of white matter and optic nerve.

Optic nerve disease is a major etiology of visual function lesions, commonly encountered clinically, such as: ischemic lesions, glaucoma (open angle or closed-angle), optic nerve neuritis, multiple sclerosis (demyelination and axonal injury), tumor and so on. Although MR scan is a kind of traditional examination method, for optic nerve and optic radiation, it's quite limited, by this method we can't distinguish pathological changes of the nerve fibers. DTI parameters, as FA value is sensitive to the structure of white matter and optic nerve, it is supposed to be characteristic of pathological changes such as edema and demyelination, DTI research of animal models and living tissues show the significance of analyzing anisotropy, $\lambda_{\parallel}$ and $\lambda_{\perp}$ which play equally important roles in judging different pathological changes such as demyelination and axonal injury[9-11]. Trip *et al* [12] found that the FA value of the optic nerve of 25 patients with unilateral optic neuritis decreased but MD value and $\lambda_{\perp}$ increased, indicating that the axons and myelin of the ipsilateral optic nerve damaged; Song *et al* [13] found that the $\lambda_{\perp}$ of the person with demyelination of whiter matter increased significantly but no obvious change on $\lambda_{\parallel}$, being consistent with the histological result, that is, when demyelination occurs the structural of axon keep integrity. The FA value of bilateral optic nerve and optic radiation measured in this study is a sensitive DTI parameter to the anisotropic of fibers of whiter matter, MD value reflects the mean velocity of diffusion of water molecules in each voxel, FA value combined with MD value can accurately reflect the characteristics of the fine structure of the fiber of white matter, Garaci *et al* [14] evaluated, with 3T-diffusion-tensor MR, the axonal architecture of the optic nerves and optic radiations in patients with glaucoma. The optic radiations and optic nerves of the patients had significantly higher MD and significantly lower FA, the nerve fiber of the optic nerve and optic radiation damaged. $\lambda_{\parallel}$ and $\lambda_{\perp}$ reflect diffusion characteristics of water parallel and perpendicular to fiber bundles respectively and can differentiate between axon loss and myelin damage at some extent. All kinds of optic nerve disease which are mentioned above are related with axon loss and myelin damage of nerve fibers, as a result, to investigate the reference values and related factors of above DTI parameters of the optic nerve and the optic radiation in healthy adults has important clinical significance and application prospects for better studying the diffusion characteristics of water of the optic nerve and the optic radiation in pathological conditions. The change of DTI parameters can reflect the pathological changes of the cerebral white matter microstructure, it can be used for monitoring the therapeutic efficacy of novel neuroprotective interventions[15].

In summary, we analyzed the FA value, MD value, $\lambda_{\parallel}$, $\lambda_{\perp}$ of bilateral optic nerve and optic radiation in 107 healthy volunteers, providing some objectives which are basis for the quantitative study of the optic nerve-related diseases, to offer an important reference for the early diagnosis and treatment of such diseases.

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