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Diffusion tensor imaging of the optic chiasm in patients with intra- or parasellar tumor using readout-segmented echo-planar☆

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ABSTRACT

Purpose: To evaluate the impact of surgery on the optic pathway of patients with intra- or parasellar mass lesions, as evidenced by readout-segmented DTI.
Materials and methods: Twenty-four patients with intra- or parasellar mass lesions were included in the study. Readout-segmented DTI and T2WI were obtained before and after surgery. The ROIs were set on the optic chiasm as well as the anterior and posterior optic tracts. For each ROI, axial diffusivity (AD), radial diffusivity (RD), fractional anisotropy (FA), and ADC values were calculated. DTI parameters in preoperative studies of all patients were compared and related to the presence of tumor compression. In patients who underwent surgery, pre- and postoperative DTI parameters were compared. The correlation between DTI parameters and visual function was determined.
Results: In the preoperative studies, the optic chiasm of patients with tumor compression showed significant lower AD and RD values. The optic chiasm of patients with visual field disorder showed significantly lower AD and RD values compared to patients without the disorder. There was a negative correlation with a trend toward significance between FA values and visual field disorder scores. The comparative analysis of patients in pre- and postoperative studies showed that the optic chiasm of patients with tumor compression presented a significant lower FA (0.41 versus 0.30, $p = 0.0068$) and higher RD values after surgery.
Conclusions: DTI is a useful tool to assess the impact of surgery on the optic chiasm and nerve.

1. Introduction

The evaluation of visual function is important for the clinical management of patients with intra- or parasellar mass lesion. Compression of the optic nerve and chiasm due to pituitary mass lesions often leads to impaired visual function. The evaluation and prognosis of visual function is important for patient management and previous studies investigated predictive factors of visual function. [1,2] A number of studies have reported on the MR findings of the optic nerves in the context of diseases [3–5]. Tokumaru et al. reported that signal hyperintensity of the optic nerves ventral to the pituitary macroadenoma was associated with visual acuity impairment [3]. Several studies suggested the use of new techniques such as extended echo-train acquisition fluid-attenuated inversion recovery and contrast-material-enhanced fast imaging employing steady-state acquisition [4,5].

Variations in the DTI parameters of the optic pathway, resulting from compressive mass lesion, may be a useful marker for the prognosis of visual function. DTI allows the noninvasive examination of fine anatomical structures. The diffusion parameters such as fractional anisotropy (FA), axial diffusivity (AD) and radial diffusivity (RD) obtained using DTI, may reflect properties such as myelination and axonal density [6]. Previous studies have reported that variations in DTI parameters could reflect the presence of intracranial mass lesions due to compression or degeneration [7–10]. Evaluation of the optic pathway using DTI may thus be useful for the assessment of patients with intra- or parasellar mass lesions. Anik et al., in particular, reported that reduced FA and elevated mean diffusivity of the optic nerve after endoscopic pituitary surgery were associated with the absence of visual improvement [11].

Few DTI studies have investigated the optic chiasm because the use of single shot echo planar imaging suffers from strong image

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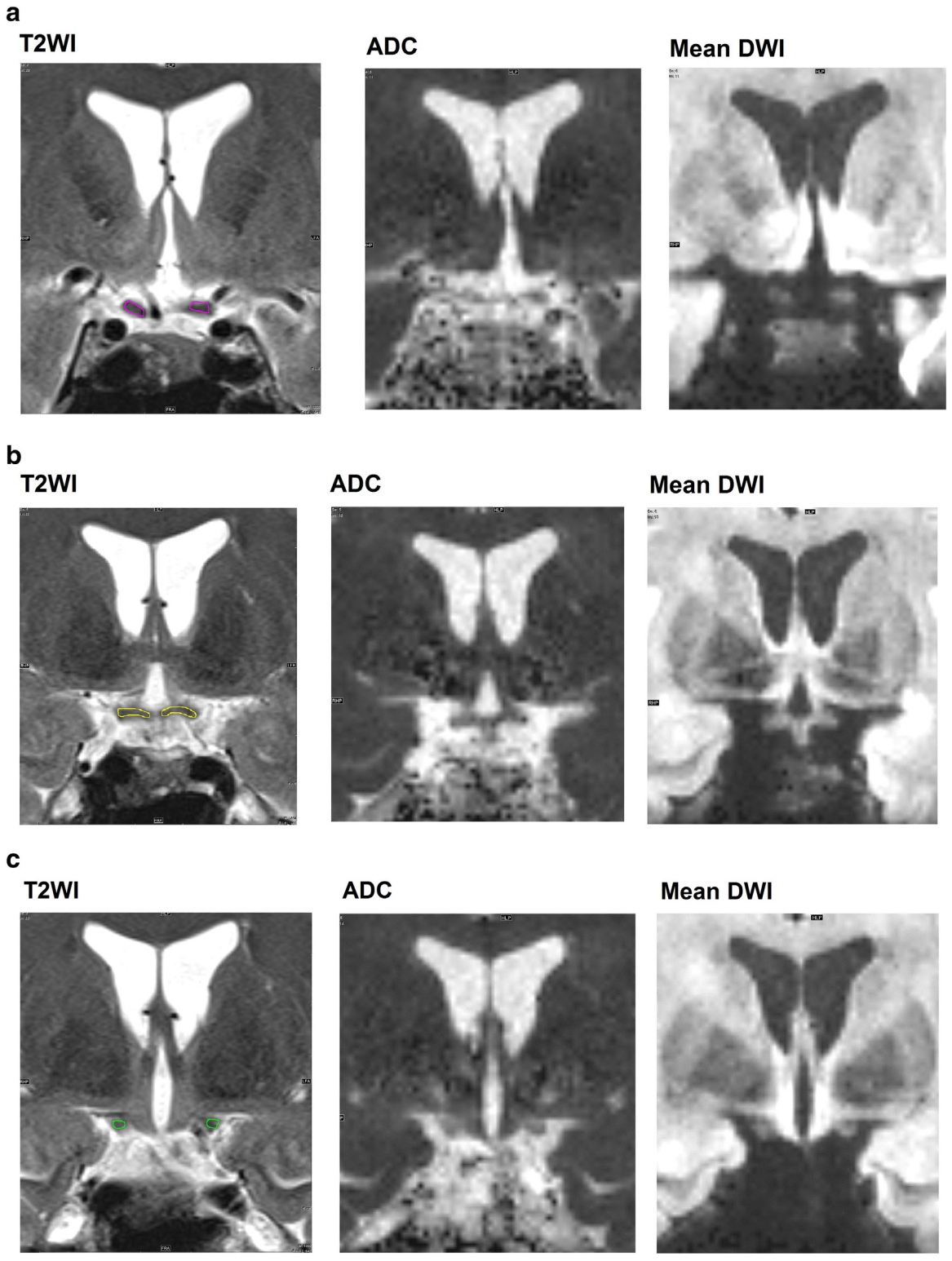

Fig. 1. ROI delineation on T2WI maps, and DTI images (ADC maps and mean DWI) on the corresponding slices. Color ROIs are drawn on (a) the anterior optic tracts, (b) the optic chiasm and (c) the posterior optic tracts.

distortion and T2*-induced blurring [12]. On the other hand, readout-segmented echo-planar imaging reduces distortion and accomplishes higher spatial resolution than single shot echo-planar imaging [13–17]. The accurate evaluation of fine structures, such as the optic pathway, by readout-segmented DTI is thus expected.

We hypothesized that the compression resulting from intra- or parasellar mass lesion causes variations in the DTI parameters of the optic chiasm. To test this hypothesis, we examined the DTI parameters of the optic pathway on pre- and postoperative DTI of patients with intra- or parasellar mass lesion.

Table 1
Demographic and clinical characteristics of patient cohort.

Case no.	Age, sex	Visual field disorder (Score)	Visual acuity disorder	Operation	Diagnosis	Compression on preoperative MRI	Postoperative image	Decompression on postoperative DTI	Postoperative visual function
1	62, M	0	+	Hardy	Pituitary adenoma	−	+		Stable
2	67, F	0		Hardy	Pituitary adenoma	−	+		Stable
3	85, M	2	+	Hardy	Pituitary adenoma	+			Deteriorated
4	51, M	1		Hardy	Pituitary adenoma	+	+	+	Deteriorated
5	64, F	6	+	–	Undiagnosed	+			
6	43, M	0		Hardy	Pituitary adenoma	+			Stable
7	53, F	3	+	Craniotomy	meningioma	+			improved
8	69, F	0		–	s/o Pituitary adenoma	−			
9	60, F	4	+	–	s/o Rathke cleft cyst	+			
10	69, F	4		Craniotomy	Pituitary adenoma	+	+	−	Improved
11	70, F	0		–	Undiagnosed	−			
12	62, F	2		Hardy	Pituitary adenoma	+	+	+	Improved
13	57, M	2		–	s/o Pituitary adenoma	+			
14	77, F	4	+	Hardy	Craniopharyngioma	+	+	−	Improved
15	63, F	1	+	Hardy	Pituitary adenoma	−	+		Improved
16	67, F	4		–	s/o Pituitary adenoma	−			
17	25, F	0		Hardy	Pituitary adenoma	−	+		NA
18	57, F	4		Hardy	Pituitary adenoma	+			Improved
19	66, F	2		Hardy	Pituitary adenoma	+	+	+	Improved
20	61, M	2		Hardy	Pituitary adenoma	+	+	+	Stable
21	45, F	4	+	Hardy	Pituitary adenoma	+	+	+	Improved
22	57, F	0		–	Undiagnosed	+			
23	59, M	2		–	Undiagnosed	+			
24	45, F	1	+	Hardy	s/o Pituitary adenoma (undiagnosed by pathological examination)	+	+	+	Improved

NA: not available.

2. Materials and methods

2.1. Subjects

Study protocols were approved by the local ethics committee and written informed consent was waived in the retrospective study.

Subjects included 24 consecutive patients (7 male and 17 female, mean age of 60 years, ranging from 25 to 77 years) presenting intra- or parasellar mass lesion (pituitary adenoma, 17 patients; craniopharyngioma, 1 patient; meningioma, 1 patient; Rathke's cleft cyst, 1 patient; pituitary apoplexy, 1 patient; undiagnosed, 3 patients) between 2011 and 2014. Sixteen patients of subjects underwent surgery and 12 patients additionally underwent postoperative DTI.

For each patient, the time of onset, best-corrected visual acuity and visual field scores were recorded before and after surgery. Best-corrected visual acuity was examined by orthoptists using the Landolt C-ring test and the visual field was assessed using the Humphrey visual field analyzer. Visual field disorder was scored from 0 to 8 by the ratio of disorder in visual field. For example bitemporal hemianopia was scored 4. In the case of patients who underwent postoperative DTI, we also confirmed interval between surgery and postoperative DTI. With regard to outcomes of the surgery, we defined “deteriorated” as one or more increase of visual field disorder score, or 0.1 or more reduction of visual acuity of either eye. “Improved” was defined as one or more reduction of visual field disorder score, or 0.1 or more increase of visual acuity of either eye without deterioration. “Stable” was defined when neither holds.

Based on the presence or absence of compressive mass lesion on the optic nerve and postsurgical DTI, the patients were divided into four subgroups. Groups 1 and 2 included the patients with and without compressive mass lesion, respectively. Group A included the patients who underwent postoperative DTI while group B did not. For example, the subgroup of patients with compressive mass lesion and postoperative DTI was coined group 1A.

2.2. Data acquisition

DTI was performed using a 3 T MR imaging scanner (MAGNETOM Trio, A Tim System, Siemens Healthcare, Erlangen, Germany), Version B17 equipped with a 32-channel head coil.

The enrolled subjects were examined by a readout-segmented EPI sequences (RESOLVE) with 2D navigator-based reacquisition and parallel imaging. [15] Coronal DTI covering the sella turcica was performed. The following parameters were used: TR = 5000 ms; TE = 64 ms; matrix = 200 × 200; FOV = 220 mm × 220 mm; pixel size = 1.1 mm × 1.1 mm; slices = 25; readout segments = 15; echo spacing = 0.32 ms; scan time = 17 min; and slice thickness = 3.0 mm without gap. The DTI protocol was performed with $b = 0$ and $b = 1000$ s/mm^2 in 12 motion probing gradient directions.

On the same FOV, T2 weighted images were acquired on the same slices to allow comparison with DTI. The parameters were as follows: TR = 3280 ms; TE = 75 ms; matrix = 372 × 448; FOV = 183 mm × 220 mm; pixel size = 0.49 mm × 0.49 mm; and slice thickness = 3.0 mm without gap.

2.3. DTI calculation

DTI analyses were performed using DTIstudio software version 3.0.3 (H. Jiang, S. Mori; Department of Radiology, Johns Hopkins University). AD, RD, FA, ADC images were calculated. Matrix and FOV of T2 weighted images were adjusted to those of DTI by DiffeoMap version 1.8.

2.4. ROI analysis

Manual ROIs were drawn by a neuroradiologist (Y. H., 9 years of experience). Both readout-segmented DTI and T2WI were obtained with the same FOV and position, so we used T2WI for ROI setting.

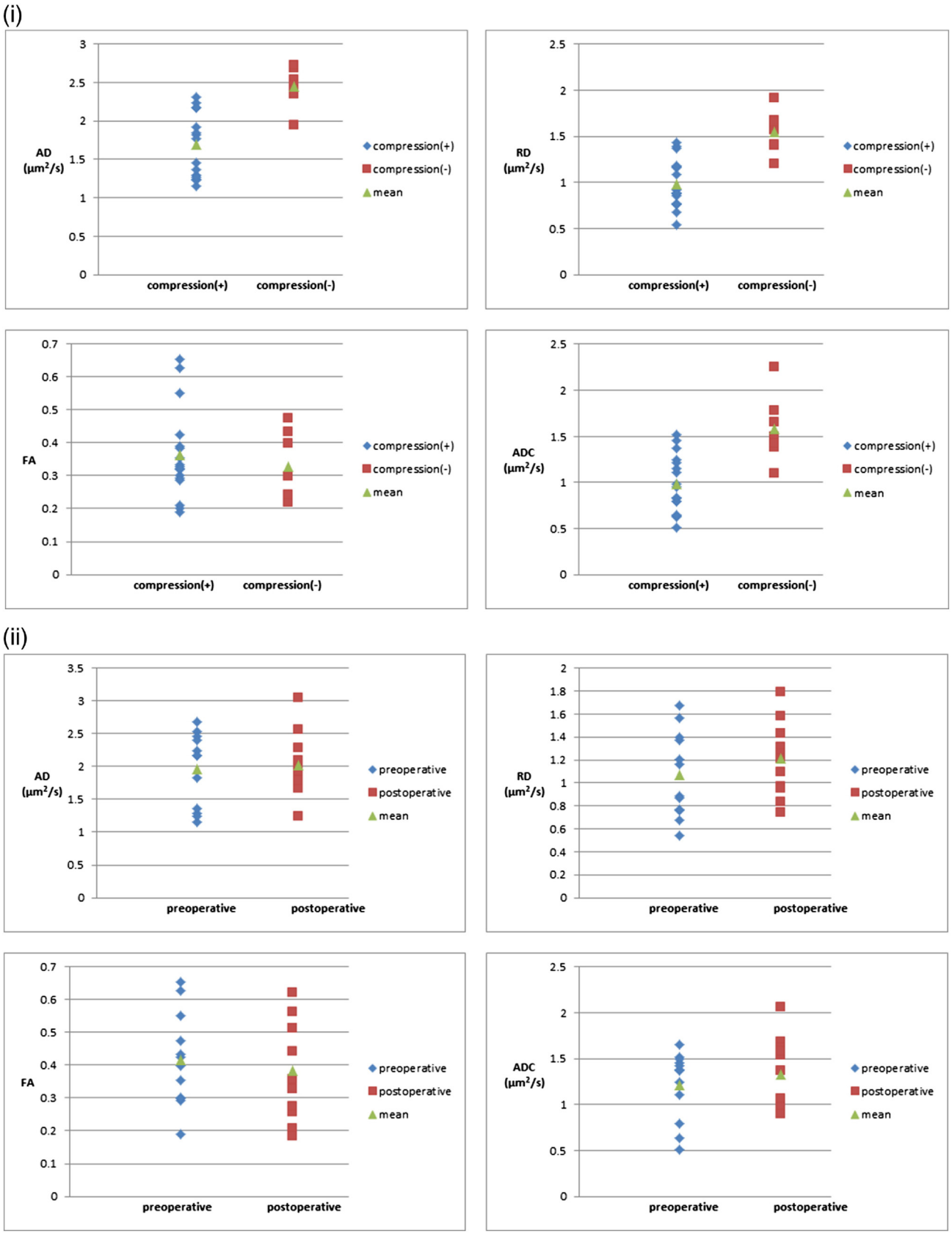

Fig. 2. Scatter diagrams showing the DTI parameters of the optic chiasm. The diagrams (i) show the comparison between preoperative DTI parameters of patients with versus without tumor compression. The diagrams (ii) show comparison between the pre- and postoperative DTI examination of patients who underwent surgery. Diagrams with asterisk showed significant difference. The diagrams (iii) show comparison between the pre- and postoperative DTI examination of patients who achieved decompression after surgery.

(iii)

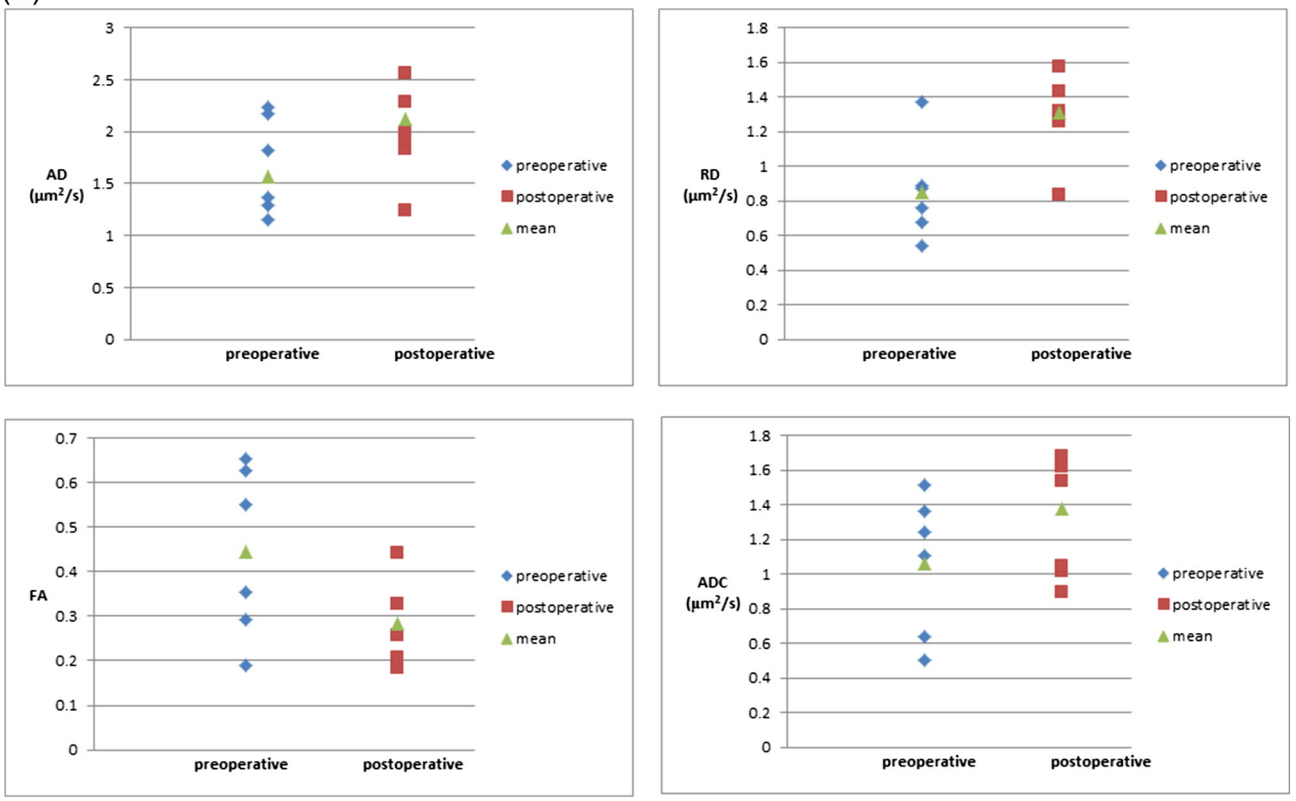

Fig. 2 (*continued*).

ROIs were set at the optic chiasm on two consecutive slices and the anterior and posterior optic tracts on each one slice. In the case of patients with compressive mass lesions, ROIs were set on the optic chiasm at the site compressed by the mass lesion. Fig. 1 shows an example of ROI delineation and DTI images. ROIs set on T2 weighted images were overlaid onto DTI parameter images.

AD, RD, FA and ADC values were calculated for each ROI. Preoperative DTI parameters found in group 2 were taken as reference value and compared with those obtained in previous studies.

Comparison of DTI parameters between groups 1 and 2 was performed in preoperative studies, as well as between pre- and postoperative studies, on the optic chiasm, the anterior optic nerve and the posterior optic tracts. To compare the DTI parameters pre- versus postoperative studies, we compared the DTI parameters of pre- versus postoperative images of patients of each group 1A and 2A by Student's paired t-test.

Correlation analysis by using the Pearson correlation coefficient was performed between the DTI parameters and the visual function scores, which included the visual acuity and the visual field disorder scores.

2.5. Statistical analysis

In all comparisons, p values <0.05 were considered statistically significant (2-tailed). Statistical analysis was performed using the JMP soft package (ver 8.0.2 SAS Institute. Cary, NC, USA).

3. Results

Details of the demographic characteristics of the enrolled patients are summarized in Table 1. Readout-segmented DTI of all 24 patients were successfully performed. The duration from onset to preoperative DTI ranged from about 1 month to 17 months. A total of 16 patients underwent surgery (Hardy operation, 14; craniotomy, 2) while the other 8 patients did not. In addition, 12 of these 16 patients underwent additional postoperative DTI. The interval from surgery to postoperative DTI ranged from 3 to 35 days (average 10.6 ± 8.9 days). Seventeen of the patients presented compressive mass lesion on the optic pathway, and 8 of these patients underwent postoperative DTI. The DTI examination showed that compression had been removed in 6 patients but remained in the other 2.

Of all the subjects involved, 9 patients had low scores in best-corrected visual acuity (either visual acuity <0.3) while 15 patients did not present any visual acuity disorder. Visual field disorder was observed in 17 patients while the other 7 did not. In the group of 8 patients who underwent postoperative MR and presented compression on the optic chiasm, 6 of them achieved decompression after surgery. Visual function was improved in 4 of these patients.

3.1. ROI analysis

Results obtained from the ROI analysis are shown in Fig. 2. The mean AD, RD, FA, and ADC values of the optic chiasm, in group 2, were 2.4 μm²/ms, 1.6 μm²/ms, 0.31, and 1.6 μm²/ms, respectively. For the purpose of comparison, the respective values reported in previous studies are summarized in Table 2. [18–26].

In preoperative DTI studies, the optic chiasm of patients in group 1 showed significantly lower mean AD, RD and ADC values than those of patients in group 2 [Fig. 2(i)]. When we performed a correlation analysis between the DTI parameters and the visual field disorder scores, we found a negative correlation with a trend toward statistical significance between the FA values and the visual field

Table 2
DTI parameters of the optic nerve in the present study compared to previous reports.

	AD (μm^2/ms)	RD (μm^2/ms)	FA	ADC (μm^2/ms)
Present study	2.44	1.55	0.31	1.58
Iwasawa et al. [18]	NA	NA	NA	1.56
Wheeler-Kingshott et al. [19]	NA	NA	NA	1.06
Vinogradov et al. [20]	NA	NA	0.6–0.8	0.5–0.8
Chabert et al. [21]	1.78	0.76	0.49	NA
Wheeler-Kingshott et al. [22]	2.10	0.86	0.61	NA
Trip et al. [23]	2.09	0.63	0.67	NA
Xu et al. [24]	1.66	0.81	0.46	NA
Sarlls et al [25]	NA	NA	0.57	NA
Smith et al. [26]	≈1.5	≈0.6	≈0.6	NA

NA: not available.

disorder scores ($r = -0.44$, $p = 0.07$)[Fig. 3]. The optic chiasm of patients with visual field disorder showed significantly lower AD and RD values than those without the disorder, whereas the FA and ADC parameters showed no significant difference. When comparing patients with visual acuity disorder and those without the disorder, none of the DTI parameters showed any significant difference. The DTI parameters of the anterior and posterior optic tracts did not show any significant difference between groups 1 and 2.

Using a paired t-test to compare between pre- and postoperative DTI of the 12 patients in group A, we found no significant difference in the DTI parameter on the optic chiasm and anterior and posterior optic tracts [Fig. 2(ii)]. We then compared the pre- and postoperative DTI parameters of the 6 patients who presented decompression after surgery. In the latter patients, the optic chiasm showed a significant lower FA ($p = 0.018$) and higher RD ($p = 0.020$) than preoperative DTI [Fig. 2(iii)]. The FA value was reduced on the optic chiasm of all the patients (group 1A) who presented decompression, regardless of visual improvement. Significantly higher AD, RD and lower FA values were observed upon postoperative DTI examination of the 5 patients in group 1A, who presented tumor decompression and no visual deterioration. Of the 4 patients presenting no compression, there was no significant difference between pre- and postoperative DTI. The DTI parameters of the anterior and posterior optic tracts showed no significant difference in any of the comparative analyses above. Fig. 4 shows DTI-derived maps for an exemplary case of pre- and postoperative results.

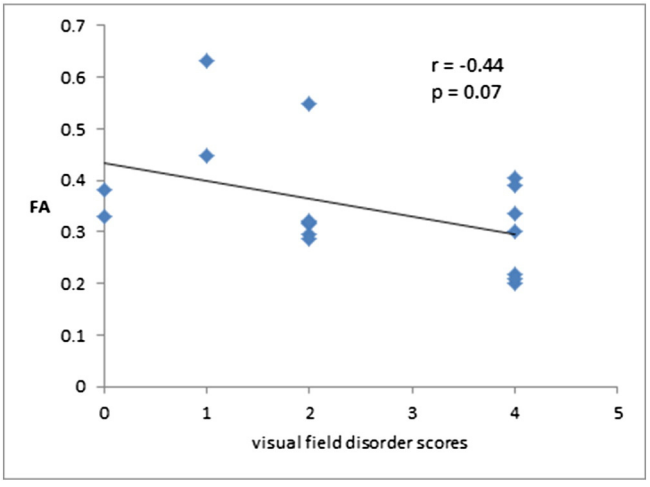

Fig. 3. A negative correlation with a trend toward statistical significance found between the FA values and the visual field disorder scores.

4. Discussion

In the present study, we revealed that, when using read-out-segmented DTI, the FA values of the optic chiasm in patients with tumor compression decreased following surgery. When compared to preoperative values in patients with and without tumor compression, significant differences were observed in the AD and RD values. The optic chiasm of patients with visual field disorder presented significantly lower AD and RD values than patients without the disorder.

4.1. Effects on the optic nerve by compression

Tumor compression often causes invasive changes such as demyelination, axonal loss, cell/tissue degeneration, gliosis, and so on. These invasive changes are expected to cause a reduction in FA values. On the other hand, previous studies reported that the displacement of white matter by a brain tumor mass resulted in higher FA values [8,9]. Edema-like changes related to the distension of normally present large Virchow-Robin spaces, adjacent to the optic tract, may also have an effect on DTI parameters [27,28]. In the present study, surgical intervention caused a reduction in the FA values of the optic chiasm in patients presenting tumor compression.

On the other hand, preoperative DTI conducted in patients with tumor compression showed significantly lower AD and RD values. In the present study, there was at least a one-month interval between the onset of disease and the preoperative DTI. As such, variations in the AD and RD values may reflect relatively long-term changes in the optic chiasm, starting from the occurrence of the tumor to its treatment. In a previous study, involving indirect traumatic optic neuropathy patients, the injured nerves showed a progressive decrease in mean FA values, and a progressive increasing in mean RD values. [29] These results differed from those of the present study. These differences may be explained in that these authors examined the indirect effects of contusive injury while our study investigated the direct effects in DTI parameters due to compression. Lower AD and RD values in patients with visual field disorder may thus reflect the effects of compression on the optic chiasm.

Hydrocephalus may also result in compression of the brain tissue. A prior study has shown that FA values were increased in patients presenting chronic hydrocephalus [30]. In our study, the preoperative FA value of the optic chiasm did not show a significant change. This suggests that, in hydrocephalus patients, the mechanisms leading to the variations in DTI parameters are different from those associated with compression.

4.2. Differences in the DTI parameters of the optic nerve in comparison to previous studies

The DTI parameters of the optic nerve of patients without compression are regarded normal. However, in the present study, the DTI parameters of patients without compression showed lower FA, and higher AD, RD and ADC values compared to previous studies [18–26]. These differences may be due to a number of determinants such as the partial volume effect of the surrounding CSF, the different ROI positions, signal-to-noise ratio, imaging orientations, spatial resolution, and CSF/fat suppression ratios as previously reported study. [24].

4.3. Effects of surgical decompression

In a previous study, the optic tracts of totally responded patients showed a higher increase in FA values while reduction in the mean diffusivity was observed on preoperative images. Postoperatively, the percentage of increase in the mean FA values of the affected areas was higher in totally or partial responding patients. [11] Our results

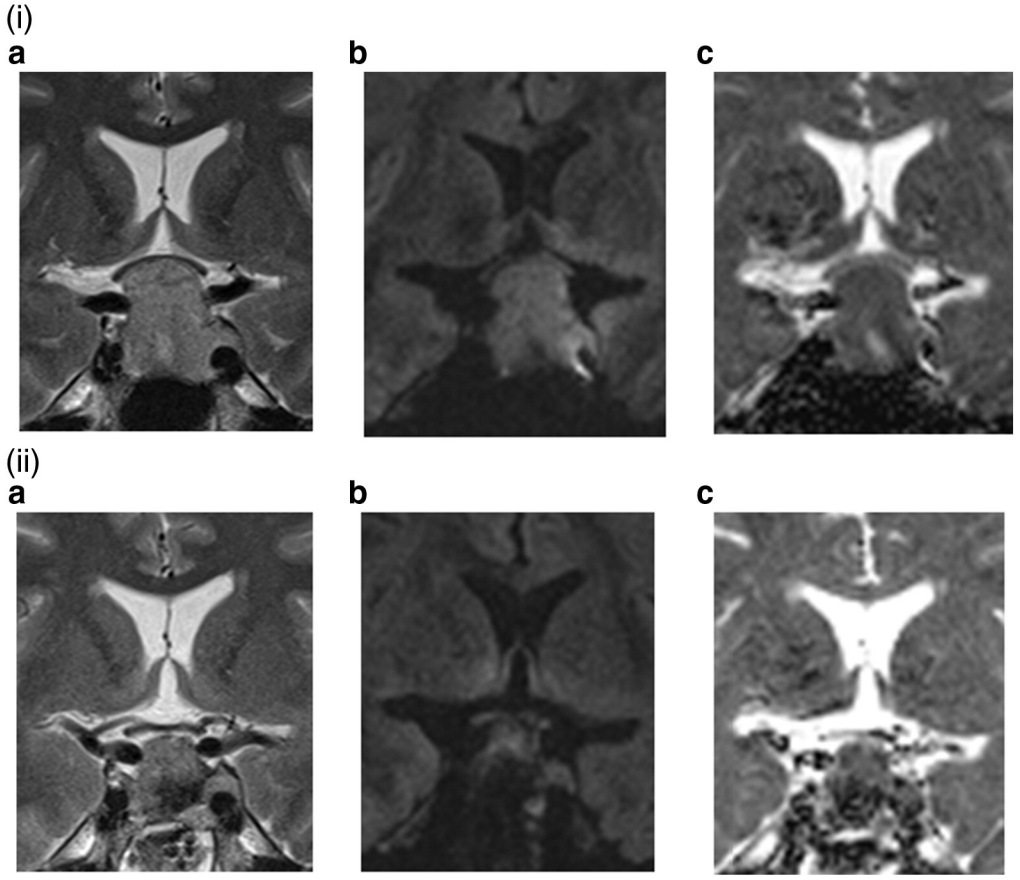

Fig. 4. DTI-derived maps for (i) pre- and (ii) postoperative results of a patient with pituitary adenoma that showed improvement of visual field disorder after Hardy operation. (a) T2WI. (b) Mean DWI. (c) ADC maps.

differ from those of a previous study, and this may be explained by the time interval between surgery and DTI examination. On the other hand, in a distinct DTI study of the arcuate fasciculus with tumor compression, the postoperative relative FA value of responding patients was decreased [10]. As such, the decrease in FA values observed in postoperative patients presenting tumor compression is supposed to reflect the changes resulting from surgical decompression. In the present study, the AD value was elevated in the postoperative DTI of patients with no visual deterioration. These results are consistent with a previous study showing that a reduction in AD values correlated with the extent of axonal loss and that a persistent AD reduction over a period of 3 months predicted poorer visual outcomes [31]. Therefore AD values may be a feasible marker for visual prognosis.

4.4. Readout-segmented DTI

In the present study, we used a readout-segmented DTI method developed by Porter and Mueller [13]. Readout-segmented DTI allows much higher spatial resolution with little distortion and blurring, compared to single-shot-DTI. It also allows determination of the DTI parameters of the fine structures of the brain such as the optic pathway [14,16]. The main drawback in using high-resolution readout-segmented DTI is the length of the acquisition time. That said, recent studies reported the possibility to reduce the scanning time of diffusion MRI applications [32–34].

A number of limitations should be considered in the present study. First, the patient sample size is small. Secondly, the ROIs were small and may have included contamination from the surrounding structures. Thirdly, the results were not classified by degree of improvement in visual function.

5. Conclusions

DTI is a useful tool to detect the impact of surgery on the optic tracts. In particular, variations in DTI parameters are good indicators for the clinical management of intra- or parasellar mass lesions.

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