Sagittal bending of the optic nerve at the entrance from the intracranial to the optic canal and ipsilateral visual acuity in patients with sellar and suprasellar lesions

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OBJECTIVE Visual acuity impairment due to sellar and suprasellar tumors is not fully understood. The relationship between these tumors and disturbance of visual function was examined using preoperative MRI.

METHODS This study reviewed 93 consecutive patients with sellar and suprasellar tumors. Best-corrected visual acuity (BCVA) and visual impairment score (VIS) were used for estimation of visual impairments. Preoperative MR images were examined to obtain several values for estimation of chiasmatic compression. Additionally, the optic nerve–canal bending angle (ONCBA) was newly defined as the external angle formed by the optic nerve in the optic canal and the optic nerve in the intracranial subarachnoid space at the junction, using preoperative sagittal T2-weighted MR images.

RESULTS The mean ONCBA was about the same on the right ($44^\circ \pm 25^\circ$) and the left ($44^\circ \pm 24^\circ$). Sagittal ONCBA was defined as large ($> 45^\circ$) and moderate ($\leq 45^\circ$) on each side. Preoperative VIS was found to be significantly worse if the right or left ONCBA (or both) was large (right side: ONCBA large [median 20, IQR 8–30] $>$ ONCBA moderate [median 10, IQR 3–17], $p = 0.003$, Mann-Whitney U-test; left side: ONCBA large [median 22, IQR 9–30] $>$ ONCBA moderate [median 10, IQR 2–16], $p = 0.001$). A large ONCBA showed a significant relationship with unfavorable ipsilateral BCVA ($> \log\text{MAR}, 0$; right side, $p = 0.001$, left side, $p = 0.001$, chi-square test). The ONCBA had a positive correlation with ipsilateral BCVA (right: $r = 0.297$, $p = 0.031$; left: $r = 0.451$, $p = 0.000$, Pearson's correlation coefficient). Preoperative BCVA was significantly lower on the same side in the large ONCBA group compared with the moderate ONCBA group (right side: large ONCBA 0.169 ± 0.333 [logMAR, mean $\pm$ standard deviation] vs moderate ONCBA 0.045 ± 0.359 , $p = 0.026$, Student t-test; left side: large ONCBA 0.245 ± 0.346 vs moderate ONCBA 0.025 ± 0.333 , $p = 0.000$). This visual acuity impairment improved after resection of the tumors.

CONCLUSIONS Sagittal bending of the optic nerve at the entrance from the intracranial subarachnoid space to the optic canal may be related to ipsilateral deterioration of visual acuity in sellar and suprasellar lesions. Sagittal T2-weighted MRI is recommended for preoperative estimation of the optic nerve bending.

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KEYWORDS visual function; visual acuity; sellar and suprasellar lesions; MRI; pituitary surgery

SELLAR and suprasellar tumors occur close to the optic apparatus and often manifest as visual disturbances, varying from visual field defects and decreased visual acuity to blindness.^{8,9,36,37} Visual disturbances associated with sellar and suprasellar lesions are believed to be the result of chiasmatic compression.^{2,8,9,11,23,33,34,36,37,44} Pituitary adenomas with suprasellar extension can com-

press the crossing fibers in the optic chiasm and disturb the local blood supply, leading to uni- or bitemporal quadrantanopia or hemianopia.^{8,24} Suprasellar extension of the tumor extending for more than 12–13 mm on the coronal MR image, or 8 mm on the sagittal image,^{16,38} and tumor size are also related to visual field defect if the tumor height is 20–30 mm or more.¹ Other sellar and suprasel-

ABBREVIATIONS BCVA = best-corrected visual acuity; FSE = fast spin-echo; IQR = interquartile range; ONCBA = optic nerve–canal bending angle; OR = odds ratio; VIS = visual impairment score.

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lar tumors, including craniopharyngiomas, Rathke's cleft cysts, tuberculum sellae meningiomas, and chordomas, show some variations in the compression pattern to the optic chiasm.^{10,11,36} Even these tumors often cause uni- or bitemporal quadrantanopia or hemianopia due to compression of the crossing fibers of the optic chiasm.^{11,36,37} Surgical management decisions often depend principally on the extent of deterioration of the visual fields.²⁵ However, severe unilateral vision loss sometimes occurs even with relatively small suprasellar extension. In this study we examine the relationship between preoperative visual disturbance and preoperative MRI findings in patients with sellar and suprasellar tumors.

Methods

This study was approved by the IRB of Gunma University Graduate School of Medicine. This study reviewed the clinical records of 184 consecutive patients with sellar and suprasellar tumors who underwent endoscopic trans-sphenoidal surgery, including the classic sellar approach and extended transtuberular transplanum approach, from April 2010 to August 2017 at Gunma University Hospital, a teaching and tertiary care hospital and a major referral site for patients with brain tumors. All endoscopic trans-sphenoidal surgeries were performed by the senior author (M.T.). Sixty patients with tumors not in contact with the optic nerve pathway, including microadenoma, were excluded, and some were included as visually normal controls as described below. We also excluded 25 cases in which identification of the optic nerve was difficult using preoperative MRI, 3 cases with unilateral blindness, and 3 cases in which data were not available. Ninety-three patients were ultimately included in this study, comprising 42 women and 51 men, with a mean age of 53.7 ± 16.6 years. A normal control series was needed to establish the radiologically measured value. Among the 60 patients with normal vision who were excluded, including those with microadenomas, 48 patients (33 women and 15 men, with a mean age of 52.9 ± 15.5 years) with an optic nerve completely unaffected on MRI were used as normal controls for investigation of the optic apparatus.

Ophthalmological Evaluation

Ophthalmological examination consisted of testing the patient's visual acuity with optimum correcting lenses and Goldmann perimetry for both eyes. Ophthalmological findings of visual acuity and visual fields were analyzed independently. The best-corrected visual acuity (BCVA) was recorded as Snellen acuity fraction and converted to logMAR notation.^{13,22} Goldmann perimetry was performed using white dots of different sizes and brightness. Postoperative BCVA was examined within 3 months after surgery.

The visual impairment score (VIS) according to the German Ophthalmological Society was calculated by adding the scores of the tables for assessing BCVA and the visual field defects; each table combined the findings for both eyes.^{11,20,32} VIS shows the overall visual function as the sum of the scores of BCVA and visual field defects (ranging from 0 to 100). The scores of BCVA and visual

field defects were determined using the table combining the left and right findings before summing (Fig. 1).^{11,32}

MRI

MRI was performed with a 1.5- or 3-T system, imaging the sellar and suprasellar lesions in all patients. Coronal and sagittal T1-weighted fast spin-echo (FSE) MR images with or without gadolinium enhancement, and coronal T2-weighted FSE images were obtained in all patients. The sequential parameters were previously reported.³⁹ Section thickness was 3 mm and the intersection gap was 0 mm. Sagittal T2-weighted FSE MRI of the pituitary adenoma was obtained in 89% of patients (TR 3500–4500 msec, TE 85–98 msec, flip angle 90°–150°, section thickness 3 mm, intersection gap 0 mm, matrix 384 × 224–307, and field of view 180–220 mm).

Measurements on MRI in patients with sellar and suprasellar tumors were defined as follows. The maximum diameter on the craniocaudal axis was defined as tumor height (Fig. 2A).⁴¹ The tumor top–anterior skull base distance was obtained by measuring from the anterior skull base to the apex of the tumor perpendicular to the frontal cranial base (Fig. 2B).²⁸ Chiasm height was defined as the shortest distance between the line connecting the frontal skull base and the posterior clinoid process to the chiasm (Fig. 2C).²⁷ The prefixed chiasm (located above the tuberculum sellae), the postfixed chiasm (situated superior to the dorsum sellae), and the remaining normal chiasm were defined as previously explained (Fig. 2D–F).³⁶ The sagittal optic nerve–canal bending angle (ONCBA) was defined as follows. The external angle formed by the optic nerve in the optic canal and the optic nerve in the intracranial subarachnoid space was measured at the entrance of the optic canal. This external angle is common in the evaluation of the bending angle of various materials (Figs. 2G and 3).¹⁸ The optic nerve is fixed in the optic canal.²⁶ The optic nerve sometimes bends three-dimensionally at the exit of the optic canal in patients with sellar and suprasellar tumors. The ONCBA is the angle obtained by measuring this bending on the sagittal MR images. The mean ONCBA was approximately 45° on both the right ($44^\circ \pm 25^\circ$) and the left ($44^\circ \pm 24^\circ$). A large bending angle was defined as more than 45° (Fig. 2H) and a moderate bending angle was defined as 45° or less (Fig. 2I). Two independent observers (R.Y. and T.M.) reviewed the conventional and sagittal T2-weighted MR images, and assessed these measurements. Both observers made initial evaluations independently, and consensus resolved any disagreements regarding the final measurement.

Statistical Analysis

Tumor height, tumor top–anterior skull base, chiasm height, and ONCBA were divided by the mean value, and compared using VISs (Table 1). The relationships between clinical and MRI variables and VIS were examined using the Mann-Whitney U-test or 1-way ANOVA (Table 1). The relationships between preoperative unfavorable BCVA on the left and right and selected MRI variables—including tumor height, tumor top–anterior skull base, chiasm height, and ONCBA—were examined using the chi-square

Visual acuity															
L \ R	R	1,0	0,8	0,63	0,5	0,4	0,32	0,25	0,2	0,16	0,1	0,08	0,05	0,02	0
		5/5	5/6	5/8	5/10	5/12	5/15	5/20	5/25	5/30	5/50	1/12	1/20	1/50	0
1,00	5/5	0	2	4	6	8	10	12	15	17	20	22	25	27	30
0,8	5/6	2	4	8	10	12	15	17	20	22	25	27	30	32	35
0,63	5/8	4	8	15	17	20	22	25	27	30	32	35	37	40	42
0,5	5/10	6	10	17	20	22	25	27	30	32	35	40	42	45	47
0,4	5/12	8	12	20	22	25	30	32	35	37	40	42	47	50	52
0,32	5/15	10	15	22	25	30	35	40	45	47	50	55	57	60	62
0,25	5/20	12	17	25	27	32	40	50	52	55	57	60	65	67	70
0,2	5/25	15	20	27	30	35	45	52	55	57	60	65	70	75	80
0,16	5/30	17	22	30	32	37	47	55	57	60	65	70	75	80	85
0,1	5/50	20	25	32	35	40	50	57	60	65	75	80	85	87	90
0,08	1/12	22	27	35	40	42	55	60	65	70	80	85	90	92	95
0,05	1/20	25	30	37	42	47	57	65	70	75	85	90	98	100	100
0,02	1/50	28	32	40	45	50	60	67	75	80	87	92	100	100	100
0	0	30	35	42	47	52	62	70	80	85	90	95	100	100	100

Visual field defect															
L \ R	R	0	2	4	5	5	5	5	5	5	5	5	5	5	0
		0	2	4	5	5	5	5	5	5	5	5	5	5	0
0	0	0	2	4	5	5	5	5	5	5	5	5	5	5	0
2	2	2	6	8	8	10	14	18	19	20	25	25	25	25	2
4	4	4	8	10	12	14	16	20	21	22	27	27	27	27	4
5	5	5	8	12	14	16	18	22	22	23	28	28	28	28	6
5	5	5	10	14	16	18	20	22	23	24	29	29	29	29	8
5	5	5	14	16	18	20	22	24	25	26	31	31	31	31	10
5	5	5	18	20	22	22	24	26	28	35	40	40	40	40	15
5	5	5	19	21	22	23	25	28	30	40	45	45	45	45	20
5	5	5	20	22	23	24	26	35	40	45	48	48	48	48	25
5	5	5	25	27	28	29	31	40	45	48	50	50	50	50	25
0	0	0	2	4	6	8	10	15	20	25	25	25	25	25	0

FIG. 1. Tables of visual acuity and visual field defect used for calculation of the VIS. The marked numbers provide an example of the calculation made in a patient with a visual acuity of 4/10 in the left eye and 2/10 in the right eye, together with a bitemporal visual field defect. The numbers 35 and 22, added together, total 57. This number represents the VIS, which reaches 100 as a maximum. Reprinted with permission from Fahlbusch R, Schott W: Pterional surgery of meningiomas of the tuberculum sellae and planum sphenoidale: surgical results with special consideration of ophthalmological and endocrinological outcomes. *J Neurosurg* 96:235–243, 2002.

test (Table 2). The correlation between ONCBA and visual acuity was examined using logMAR vision on the left and the right with the Pearson correlation coefficient (Fig. 4). The difference between preoperative logMAR visual acuity on large and moderate sides was examined using the Student t-test. The difference between pre- and postoperative logMAR visual acuity was examined using the paired Student t-test (Fig. 5). A p value < 0.05 was considered statistically significant. Statistical analyses were performed with SPSS for Mac OS (version 24.0, IBM Corp.).

Results

All tumors included suprasellar extension causing deviation of the optic nerve pathway, and visual dysfunction was recognized before surgery. Pituitary adenoma was found in 74 cases, and craniopharyngioma in 13 Rathke's cleft cysts in 6 cases. Eleven cases were recurrences, all nonfunctional pituitary adenomas. Good visual acuity with a BCVA of logMAR of 0 or less was found in 58 cases on the right and 50 cases on the left. Median VIS values (interquartile range [IQR]) of visual acuity, visual field defect, and the total were 4 (IQR 0–10), 8 (IQR 2–14), and 12 (IQR 6–25), respectively. The mean tumor height, tumor top–anterior skull base, and chiasm height were 27.0 ± 6.7 mm, 11.7 ± 5.4 mm, and 0.7 ± 3.5 mm, respectively. The chiasm position was prefixed, normal, or postfixed in 12, 71, and 10 cases, respectively. The mean ONCBA was approximately 45° on the right ($44^\circ \pm 25^\circ$) and left ($44^\circ \pm 24^\circ$; Table 1). The mean ONCBA in the normal control

group was approximately 5° or 6° on the left ($5.3^\circ \pm 4.8^\circ$) and right ($6.3^\circ \pm 4.9^\circ$), respectively.

Visual Impairment Score

Relationships were examined between clinical observations, imaging variables, and VISs (Table 1). The VIS field defect score tended to be higher in the group with a tumor top–anterior skull base of 12 mm or more compared to the other group ($p = 0.007$). The VIS total score was significantly higher in the large right ONCBA group (median 20, IQR 8–30) compared to the moderate right ONCBA group (median 10, IQR 3–17; $p = 0.003$, Mann-Whitney U-test). Similarly, VIS was significantly higher in the large left ONCBA group (median 22, IQR 9–30) compared to the moderate right ONCBA group (median 10, IQR 2–16; $p = 0.001$). Other clinical and imaging variables were not related to preoperative VIS (Table 1).

Visual Acuity

Investigation of the relationship between ONCBA and unilateral unfavorable visual acuity found that large ONCBA ($> 45^\circ$) showed a significant relationship to ipsilateral unfavorable BCVA ($> \log\text{MAR}, 0$; right side: odds ratio [OR] 4.405, $p = 0.001$; left side: OR 3.968, $p = 0.001$, chi-square test; Table 2). Tumor height, tumor top–anterior skull base, and chiasm height were not significantly related to preoperative BCVA (Table 2). ONCBA had a positive correlation with ipsilateral BCVA (right: $r = 0.297$, $p = 0.031$; left: $r = 0.451$, $p = 0.000$, Pearson's cor-

FIG. 2. Preoperative sagittal T1-weighted gadolinium-enhanced (A) and T2-weighted (B–I) MR images. **A:** Tumor height was defined as the maximum diameter in the craniocaudal axis. **B:** Tumor top–anterior skull base was obtained by measuring the distance from the anterior skull base to the apex of the tumor perpendicular to the frontal cranial base. **C:** Chiasm height was defined as the shortest distance between the line connecting the frontal skull base and the posterior clinoid process to the chiasm. **D:** Prefixed chiasm was located above the tuberculum sellae. The optic chiasm is indicated by the arrow. **E:** A normal chiasm was defined as excluding the prefixed and postfixed chiasm. **F:** A postfixed chiasm is situated superior to the dorsum sellae. **G:** The ONCBA was formed by the optic nerve in the optic canal and the optic nerve in the intracranial subarachnoid space at the exit of the optic canal (angle indicated by white dotted lines). **H:** A large ONCBA angle was $> 45^\circ$. The optic chiasm and nerve path are indicated by arrowheads. The optic nerve is running at a right angle. **I:** A moderate ONCBA was $\leq 45^\circ$. The optic nerve is running almost in a straight line (arrowheads).

relation coefficient; Fig. 4). Visual acuity impairment may become severe as the ONCBA approaches a right angle. The preoperative BCVA was significantly lower on the same side in the large ONCBA group than in the moderate ONCBA group (right side: large ONCBA 0.169 ± 0.333 [logMAR] vs moderate ONCBA 0.045 ± 0.359 , $n = 49$ vs 44 , $p = 0.026$, Student t-test; left side: large ONCBA

0.245 ± 0.346 vs moderate ONCBA 0.025 ± 0.333 , $n = 44$ vs 49 , $p = 0.000$; Fig. 5). Ipsilateral BCVA improved on the large ONCBA side after surgery, with significant differences on both sides (right side: before 0.169 ± 0.333 [logMAR] vs after 0.071 ± 0.341 , $n = 49$, $p = 0.011$, Student t-test; left side: before 0.245 ± 0.346 vs after 0.083 ± 0.329 , $n = 44$, $p = 0.000$; Fig. 5). In contrast, ipsilateral

FIG. 3. Bending angle diagram. The ONCBA was defined as the external angle formed by the optic nerve in the optic canal and the optic nerve in the intracranial subarachnoid space at the entrance of the optic canal.¹⁸

BCVA was good before surgery on the moderate ONCBA side, and no change occurred after surgery on both sides (right: large angle 0.071 ± 0.341 vs moderate angle 0.021 ± 0.345 , $n = 44$, $p = 0.486$; left side: large angle 0.083 ± 0.329 vs moderate angle 0.007 ± 0.272 , $n = 49$, $p = 0.226$; Fig. 5). We provide images from two representative cases for demonstration of the relationship between ONCBA and ipsilateral BCVA (Fig. 6).

Discussion

Visual acuity impairment due to sellar and suprasellar lesions has been believed to generally result from chiasmatic compression.^{8,9,17,23,33,34,36,37} Chiasmatic compression passes through stages, starting as a supratemporal defect, spread of the defect to the inferotemporal quadrant, followed by peripheral constriction, then loss of central vision with residual nasal field, and finally loss of all vision.^{8,13,33,34} Conventional clinical neurosurgical practice considers visual field disturbance, such as temporal hemianopia, as an essential neurological symptom to consider for the surgical indication of sellar and suprasellar lesions. The high frequency of visual acuity disturbance has been believed to be part of the phenotype originating from chiasmatic compression.^{9,13,33} However, we sometimes see patients with very poor visual acuity on one side only (Fig. 6).

We first investigated the relationship between VIS and MRI variables. The degree of chiasmatic compression (tumor top–anterior skull base distance) affected only the visual field score of VIS, consistent with previous reports. Suprasellar extension of the tumor^{17,38} and tumor size are

TABLE 1. Relationship between clinical and MRI variables and the VIS

Variable	No. of Pts	Visual Acuity		Visual Field Defect		Total	
		Median (IQR)	p Value	Median (IQR)	p Value	Median (IQR)	p Value
Sex			0.059		0.780		0.244
Male	51	2 (0–8)		6 (2–14)		12 (6–24)	
Female	42	5 (0–18)		8 (2–14)		16 (8–26)	
Tumor recurrence			0.883		0.429		0.551
Yes	11	2 (0–20)		10 (2–20)		18 (2–38)	
No	82	4 (0–10)		7 (2–13)		12 (6–24)	
Tumor height, mm			0.934		0.096		0.251
≥27	44	4 (0–14)		8 (6–20)		16 (8–26)	
<27	49	4 (0–10)		6 (2–11)		10 (4–23)	
Tumor top–anterior skull base, mm			0.479		0.007†		0.045*
≥12	39	4 (0–15)		10 (6–22)		18 (8–26)	
<12	54	2 (0–9)		6 (2–10)		10 (2–23)	
Chiasma height, mm			0.147		0.907		0.536
≥0.7	40	4 (0–15)		6 (4–10)		12 (6–24)	
<0.7	53	2 (0–9)		8 (2–14)		12 (2–26)	
Chiasma position			0.611		0.014*		0.252
Prefixed	12	4 (1–10)		15 (7–24)		21 (13–26)	
Normal	71	2 (0–10)		6 (2–10)		10 (4–24)	
Postfixed	10	8 (2–21)		7 (4–16)		23 (8–30)	
Rt ONCBA			0.007†		0.043*		0.003†
Large (>45°)	49	6 (0–19)		10 (4–18)		20 (8–30)	
Moderate (≤45°)	44	0 (0–8)		6 (2–10)		10 (3–17)	
Lt ONCBA			0.006†		0.031*		0.001†
Large (>45°)	44	8 (1–17)		9 (5–18)		22 (9–30)	
Moderate (≤45°)	49	0 (0–8)		6 (2–11)		10 (2–16)	

Pts = patients.

* $p < 0.05$.

† $p < 0.01$.

TABLE 2. Relationship between unilateral unfavorable BCVA and MRI variables

Variable	OR	95% CI	p Value
Rt side (BCVA > logMAR, 0)			
Tumor height (≥ 27 mm)	1.608	0.687–3.759	0.273
Tumor top–anterior skull base (≥ 12 mm)	0.941	0.403–2.198	0.889
Chiasma height (≥ 0.7 mm)	0.838	0.360–1.953	0.682
Large ONCBA ($>45^\circ$)			
Rt	4.405	1.748–11.111	0.001*
Lt	0.903	0.389–2.092	0.811
Lt side (BCVA > logMAR, 0)			
Tumor height (≥ 27 mm)	0.750	0.331–1.721	0.490
Tumor top–anterior skull base (≥ 12 mm)	0.705	0.308–1.613	0.407
Chiasma height (≥ 0.7 mm)	0.537	0.234–1.233	0.141
Large ONCBA ($>45^\circ$)			
Rt	1.503	0.623–3.425	0.329
Lt	3.968	1.672–9.433	0.001*

* $p < 0.01$.

also related to visual field defect.¹ We found that severe sagittal bending of the optic nerve at the left or right exit of the optic canal greatly affects the VIS, or total visual function. The influence of the visual acuity score might be an important factor in the increase in VIS in patients with sellar and parasellar lesions (Table 1). VIS was calculated from the numerical values of visual acuity and field using a special formula combining left and right sides, and summing the values of visual acuity and field.¹¹ Therefore, VIS does not show the individual function of the left and right eyes. We investigated the relationship between ONCBA and ipsilateral BCVA. Large ONCBA was clearly related

to unfavorable ipsilateral visual acuity (Table 2). ONCBA was correlated with logMAR visual acuity (Fig. 4). Ipsilateral BCVA improved after surgery on the side with large ONCBA (Fig. 5). All these findings indicated that large ONCBA due to sellar and parasellar lesions may be related to the ipsilateral visual acuity impairment (Fig. 6).

Many sellar and parasellar lesions develop from the pituitary gland and pituitary stalks, and show approximately upward progression from the midline skull base. Therefore, coronal and sagittal MR images have been commonly used for the diagnosis of sellar and parasellar lesions.^{15,29} The standard imaging protocol of this part of the tumor still consists of coronal and sagittal T1-weighted MRI with or without gadolinium enhancement.^{3,40} Coronal T2-weighted imaging has been used to add qualitative assessment of lesions. However, sagittal T2-weighted imaging is not often used as the basic protocol because of the long imaging time.^{3,40} Generally, T2-weighted imaging is superior to T1-weighted imaging for the detection of cranial nerves in the subarachnoid space. Consequently, sagittal ONCBA has never been investigated until now.

Upward displacement of the intracranial part of the optic apparatus by the suprasellar tumor results in 3D bending of the optic nerve at the entrance to the optic canal from the intracranial subarachnoid space. Such bending will involve compression against the edge of the bony margin of the optic canal and local nerve stretching. Optic nerve compression leads to decreased conduction and to demyelination. The process of demyelination after nerve compression has been observed even after 2 days in animal experimental studies.^{4,5} Remyelination can be observed after several weeks under continuous nerve compression, although remyelinated fibers do not appear to attain the normal thickness and organizational structure, and coexist with completely demyelinated fibers.^{4,5,9,39} Such demyelination with partial chronic remyelination after regional optic nerve compression results in slowly progressive visual dysfunction. Local compression in the narrow peripheral

FIG. 4. Graphs showing the correlation between the ONCBA and visual acuity using logMAR vision on the right (A) and left (B) side. The ONCBA had a positive correlation with ipsilateral BCVA (A, right: $r = 0.297$, $p = 0.031$; B, left: $r = 0.451$, $p = 0.000$).

FIG. 5. Difference between pre- (white bar) and postoperative (black bar) visual acuity on the right (A) and left (B) sides. The preoperative BCVA was significantly lower on the same side in the large ONCBA group than in the moderate group (right side: large ONCBA group 0.169 ± 0.333 vs moderate ONCBA group 0.045 ± 0.359 , $n = 49$ vs 44 , $p = 0.026$, Student t-test; left side: large ONCBA group 0.245 ± 0.346 vs moderate ONCBA group 0.025 ± 0.333 , $n = 44$ vs 49 , $p = 0.000$). In the case of large ONCBA, visual acuity (logMAR) was improved after resection of the tumor with significant differences on both sides (right side: before 0.169 ± 0.333 vs after 0.071 ± 0.341 , $n = 49$, $p = 0.011$, Student t-test; left side: before 0.245 ± 0.346 vs after 0.083 ± 0.329 , $n = 44$, $p = 0.000$). In the case of moderate ONCBA, preoperative visual acuity was not impaired, with almost no change after resection of the tumor.

optic nerve may be more likely to cause functional disturbance of the whole optic nerve cord than local compression in the relatively strong and large chiasm.

On the other hand, regional optic nerve compression and stretching may be associated with regional nerve ischemia. The optic chiasm is supplied by branches from the internal carotid, anterior cerebral, and anterior communicating arteries.⁷ The distal intracranial and intracanalicular parts of the optic nerve are mainly supplied by the superior hypophyseal arteries. The contribution of the ophthalmic artery to this part of the nerve is negligible.⁴³ The distal intracranial to intracanalicular part of the optic nerve receives poorer arterial and arteriolar blood supply than the other parts of the optic nerve.^{12,16,43} This part may be prone to ischemic optic nerve neuropathy.³¹ The blood supplies from the arteries and arterioles in the optic nerve decrease in the order of chiasm, intracranial optic nerve, and intracanalicular optic nerve.¹² The optic nerve has poor blood flow at the exit of the optic canal, and local microscopic blood flow disturbance may be likely due to strong bending and compression by the edge of the optic canal bony margin and local nerve stretching. Consequently, regional ischemia may also be involved in visual disturbance.

The postoperative improvement in visual acuity does not parallel changes in the visual field in every case.³⁵ Visual acuity improves in the first months after surgical treatment^{6,42} and visual field defects continue to improve for at least 1 year. Recovery of visual acuity may be fast, whereas recovery of the visual field occurs later.²¹ Postoperative visual acuity was greatly improved in the large ONCBA side within 3 months after surgery (Fig. 5). Such early recovery is probably due to restoration of the velocity

FIG. 6. Case presentations demonstrating optic nerve trajectory (arrow-heads) on sagittal T2-weighted MR images. **A and B:** Case 1, a 44-year-old woman with pituitary adenoma. A large ONCBA was indicated on the right side (A) and moderate ONCBA on the other side (B). Preoperative BCVA (logMAR) was 0.52 on the right side and -0.08 on the left side. Her right-side visual acuity improved to -0.08 after removal of the tumor. **C and D:** Case 2, a 61-year-old man with craniopharyngioma. A large ONCBA was indicated on the right side (C) and moderate ONCBA on the other side (D). Preoperative BCVA (logMAR) was 1.00 on the right side and -0.08 on the left side. His right-side visual acuity improved to -0.08 after removal of the tumor.

of conduction. In addition, local ischemia by bending of the optic nerve at the exit of the optic canal may contribute to ipsilateral visual acuity impairment. The recovery of the optic nerve local ischemia may improve ipsilateral visual acuity after removal of the tumor.

Craniopharyngioma is a highly variable tumor presenting with large or small cysts, calcification, and irregular shape. Visual symptoms are known to be often nonspecific and variable.^{2,14,19} Irregularly shaped pituitary adenoma sometimes presents with irregular visual field defect and severe decrease in visual acuity.³⁰ These disorders may be partially caused by bending of the optic nerve at the entrance to the optic canal from the intracranial subarachnoid space. Consequently, the importance of the ONCBA must be examined in various diseases, tumors, and lesion conformations.

The present study did not consider the temporal course related to compression of the visual pathway. Compression speed of the visual path may vary, depending on the tumor growth rate. Vision dysfunction could also be affected by this growth rate. However, the rate of change is difficult to accurately predict for individual cases. This study did not consider this issue. This study also did not investigate the long-term prognosis of visual acuity after surgery. However, the severity of preoperative ONCBA and the length of the compression period may be related to the long-term visual prognosis. Further study is needed in the future. The optic nerve angle at the exit of the optic canal was measured in the sagittal direction for 3D optic nerve bending. This angle is not completely representative of the 3D bending at the contact point between the free subarachnoid space and the optic canal. The 3D structure of the optic pathway and visual functions are subjects for investigation in the future.

Conclusions

Preoperative MRI findings of sagittal bending of the optic nerve at the entrance to the intracranial subarachnoid space from the optic canal might be involved in the decrease of ipsilateral visual acuity. Investigation of visual function problems caused by sellar and parasellar lesions needs to consider the combination of chiasmatic compression and this new concept.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

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Conception and design: Tosaka, Yamaguchi. Acquisition of data: Yamaguchi, Miyagishima, Osawa, Horiguchi, Honda. Analysis and interpretation of data: Tosaka, Yamaguchi, Miyagishima, Osawa. Drafting the article: Tosaka, Yamaguchi. Critically revising the article: Tosaka, Osawa, Horiguchi, Honda, Yoshimoto. Reviewed submitted version of manuscript: Tosaka, Miyagishima, Osawa, Horiguchi, Honda, Yoshimoto. Approved the final version of the manuscript on behalf of all authors: Tosaka. Statistical analysis: Yamaguchi. Administrative/technical/material support: Tosaka, Miyagishima, Horiguchi, Honda. Study supervision: Yoshimoto.

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