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Contralateral subfrontal approach for tuberculum sellae meningioma: techniques and clinical outcomes

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OBJECTIVE Tuberculum sellae meningiomas (TSMs) present a burdensome surgical challenge because of their adjacency to vital neurovascular structures. The contralateral subfrontal approach provides an outstanding corridor for removing a TSM with an excellent visual outcome and limited complications. The authors present their long-term surgical experience in treating TSMs via the contralateral subfrontal approach and discuss patient selection, surgical techniques, and clinical outcomes.

METHODS Between 2005 and 2021, the authors used the contralateral subfrontal approach in 74 consecutive patients presenting with TSMs. The surgical decision-making process and surgical techniques are described, and the clinical outcomes were retrospectively analyzed.

RESULTS The mean patient age was 54.4 years, with a female predominance (n = 61, 82%). Preoperatively, 61 patients (82%) had vision symptoms and 73 (99%) had optic canal invasion by tumor. Gross-total resection was achieved in almost all patients (n = 70, 95%). The visual function improvement and stabilization rate was 91% (67/74). Eight patients (11%) showed a worsening of visual function on the less-compromised (approach-side) optic nerve. There was no occurrence of cerebrospinal fluid leakage. Four patients (5%) experienced recurrences after the initial operation (mean follow-up duration 63 months). There were no deaths in this study.

CONCLUSIONS The contralateral subfrontal approach provides a high chance of complete tumor removal and visual improvement with limited complications and recurrences, especially when the tumor is in a unilateral or midline location causing unilateral visual symptoms or bilateral asymmetrical visual symptoms, regardless of tumor size or encasement of major vessels. With the appropriate patient selection, surgical technique, and familiarity with surrounding neurovascular structures, this approach is reliable for TSM surgery.

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KEYWORDS tuberculum sellae meningioma; contralateral subfrontal; visual outcome; tumor relapse; oncology

Tuberculum sellae meningiomas (TSMs) are challenging tumors given their proximity to the optic nerve, internal carotid artery (ICA), anterior cerebral artery (ACA), and infundibulum. Almost all TSMs invade the optic canal and displace the optic nerve superiorly and laterally, causing visual impairment.[1] Consequently, complete tumor removal and the preservation of visual function without complications are the important goals of TSM treatment.

Various surgical approaches are currently used for the treatment of TSMs. Both transcranial and transsphenoidal approaches have remarkably advanced over the decades to accomplish their surgical goals. Each type of surgical approach provides certain superiority or inferiority, and the optimal surgical approach remains controversial.

Although the contralateral subfrontal approach has been used for the resection of TSMs, previous reports have included only a small number of patients or short-term follow-up data.[2] The purpose of this study was to analyze the long-term surgical outcomes of patients with TSMs treated via the contralateral subfrontal approach and to present surgical tips for this approach.

Methods

This study was approved by the institutional review

ABBREVIATIONS ACA = anterior cerebral artery; CSF = cerebrospinal fluid; EMF = electromagnetic field; ICA = internal carotid artery; ICH = intracranial hematoma; GTR = gross-total resection; MRI = magnetic resonance imaging; OCI = optic canal invasion; RT = radiotherapy; STR = subtotal resection; TSM = tuberculum sellae meningioma; VIS = visual impairment score; WHO = World Health Organization.

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board of the Chonnam National University Hwasun Hospital. The clinical records and imaging data of patients who had undergone the contralateral subfrontal approach for TSM at our institution between 2005 and 2021 were retrospectively reviewed. Medical records and pre- and postoperative magnetic resonance imaging (MRI) data were also reviewed. Patients with planum sphenoidale meningioma and clinoidal meningioma were excluded from this study. Seventy-four consecutive newly diagnosed patients matched the inclusion criteria. Although a wait-and-see approach was possible in asymptomatic patients, given the characteristics of TSM, we supposed that early proactive surgery could achieve better surgical outcomes in patients with relatively small tumors and no visual symptoms. And the close proximity of TSMs to the optic nerve excluded radiosurgery as the first treatment option. Some patient data on visual outcomes have been used in our previous study.[2]

Preoperative MR images with a standard 1.5- and 3.0-T MRI system and preoperative CT images with 1.2-mm-thick slices were obtained in all patients. Multiplanar reconstruction imaging enabled identification of the relationship between tumor and surrounding anatomical structures such as the optic canal, optic nerve, infundibulum, ICA, and ACA. The size of the tumor was measured as the maximal tumor diameter based on axial T1-weighted images with contrast. “Major vessel involvement” was regarded as a contact area of the tumor around the ICA and ACA of more than 270°. Optic canal invasion (OCI) was evaluated with postcontrast MR and CT images. The distance between optic canals was measured on the basis of CT images at the tuberculum sellae level. Follow-up MRI scans were acquired 6 and 18 months after surgery and biennially thereafter. Gross-total resection (GTR) was defined as Simpson grade I or II removal in the surgical record and was confirmed by an independent radiologist on enhancing MR images within 6 months after surgery. Tumors that did not remain radiologically visible but were reported as residual tumors during surgery were considered as cases of subtotal resection (STR). Tumor relapse was defined as a recurrence in GTR cases or as tumor growth in cases of incomplete resection.

The visual impairment score (VIS) was used to quantify the patient’s visual status in the pre- and postoperative periods. The VIS, created by the German Ophthalmological Society, is a practical scoring system reflecting visual field, visual acuity, and balance of both eyes.[3] Visual acuity was tested with best-correcting glasses (Snellen notations), and visual field defects were evaluated using Goldmann perimetry. The postoperative visual outcomes were graded as improved, stable, or deteriorated, according to the changes. For statistical analysis, the improved or stable group was classified as a “favorable” outcome and the deteriorated group was classified as an “unfavorable” outcome.

Surgical Technique

The contralateral subfrontal approach was performed via a unilateral subfrontal approach. The patient was placed supine with the head fixed in a Sugita head holder. The head was rotated 20°–30° toward the side of the tumor with mild extension to allow the frontal lobe to fall away from the anterior cranial fossa. Excessive head rotation of more than 30° resulted in less surgical space and interfered with the surgical procedure. A frontotemporal curvilinear skin incision was made, and a frontotemporal craniotomy was performed. The sphenoid wing was flattened with a drilling procedure until the meningo-orbital band was exposed. The dura mater was incised in a curvilinear fashion over the inferior frontal and anterior temporal areas. The sylvian fissure was dissected to provide cerebrospinal fluid (CSF) drainage for relaxation of the brain. The use of lumbar drainage for brain relaxation was unnecessary. A self-retaining retractor was not needed to retract the brain. The olfactory nerve was dissected from the frontal lobe for preservation. After identifying the approach-side optic nerve and ICA, the tumor capsule was opened, followed by internal debulking. Dural attachment of the tumor was coagulated and dissected to devascularize the tumor. Internal debulking facilitated separation of the tumor-arachnoid plane, which detached the tumor from the approach-side optic nerve spontaneously without manipulation of the optic nerve. Reduction of the tumor in a piecemeal fashion was continued until the affected-side optic nerve, optic chiasm, and pituitary stalk were identified. The posterior part of the tumor was removed, preserving the pituitary stalk. Then, sharp dissection was performed along the tumor-arachnoid plane with a direct view of the inferomedial aspect of the optic nerve. A direct view of the inferomedial aspect of the lesion-side optic nerve enabled dissection between the tumor and the affected-side optic nerve without manipulation of the optic nerve. The falciform ligament, the medial roof of the optic canal, was cut to release tension on the optic nerve and unroof the optic canal. Tumor invading the optic canal was easily removed by widening the optic canal using an electromagnetic field (EMF) system. There was no need to drill out the bony structures surrounding the optic nerve to remove tumor invading the optic canal. After tumor removal, the origin site of the tumor was coagulated using bipolar cautery or an EMF system.

Statistical Analysis

Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS) version 27 (IBM Corp.) and R software (R Foundation for Statistical Computing). The patient and tumor characteristics and postoperative outcomes, including visual outcomes, tumor relapse, and complications, were analyzed using descriptive statistics. The means of numeric variables and the distribution of categorical variables between groups were compared using the Wilcoxon rank-sum test and Fisher’s exact test, respectively. Firth’s logistic regression model was used to adjust for possible confounding in the analysis of visual outcomes, tumor relapse, and complications. Probability values < 0.05 were considered statistically significant.

Results

Characteristics of the Patients and Tumors

The 74 patients included in the study consisted of 13 males and 61 females. The mean patient age at the time of surgery was 54.4 years (range 25–83 years), and the median follow-up duration was 63 months (range 2–185 months). The main presenting symptoms included visual impairment (61 patients, 82%), headache (5 patients, 7%), and dizziness (1 patient, 1%). Seven patients (9%) were asymptomatic. The mean maximum tumor diameter was 21.1 mm (range 8–43 mm). Major vessel encasement was evident in 20 patients (27%), and OCI was identified in 73 patients (99%). The mean distance between optic canals was 15.2 mm (range 11–19 mm). Most patients (68 patients, 92%) had a histologically confirmed World Health Organization (WHO) grade I meningioma, whereas only 6 patients (8%) had confirmed WHO grade II meningioma. The pathological diagnoses included meningothelial (70%), transitional (7%), fibrous (5%), psammomatous (4%), syncytial (3%), angiomatous (3%), chordoid (4%), and atypical (4%) types. Clinical and radiological characteristics are summarized in Table 1.

TABLE 1. Clinical characteristics and surgical outcomes in 74 patients with TSMs treated via the contralateral subfrontal approach

Variable	Value
Mean age in yrs (range)	54.4 (25–83)
Female gender (%)	61 (82)
Mean MRI FU duration in mos (range)	63 (2–185)
No. of patients w/ preop visual disturbance (%)	61 (82)
Mean duration of symptoms in mos (range)	4 (1–120)
Mean max tumor diameter in mm (range)	21.2 (8–43)
No. of major vessel encasements (%)	20 (27)
No. of OCIs (%)	73 (99)
No. of lateralized tumors (%)	40 (54)
No. of diaphragm sella invasions (%)	31 (42)
No. w/ high SI on T2-weighted images (%)	50 (68)
Mean distance btwn optic canals in mm (range)	15.2 (11–19)
Mean op time in mins (range)	292 (125–470)
Histological WHO grade, no. (%)	
I	68 (92)
II	6 (8)
III	0
Extent of resection, no. (%)	
GTR	70 (95)
STR	4 (5)
Adjuvant RT, no. (%)	4 (5)
Visual outcome, no. (%)	
Improved	41 (55)
Stable	26 (35)
Deteriorated	7 (9)
Recurrence, no. (%)	4 (5)
Complication, no. (%)	10 (14)

FU = follow-up; SI = signal intensity.

Visual Outcomes

Sixty-one patients (82%) had preoperative visual impairment related to TSMs, and the median symptom duration was 4 months (range 1–120 months). Thirty-three patients (45%) had unilateral visual impairment, and 28 (38%) had bilateral visual impairment. The mean preoperative VIS was 23.2 ± 22.53 (range 0–100). Of the 61 patients with preoperative visual impairment, 41 (67%) had improved visual function, 13 (21%) had stable visual function, and 7 (11%) experienced deterioration after surgery. All patients without preoperative visual impairment had visual function that remained stable. The less-compromised-side or approach-side visual function was deteriorated in 8 patients (11%). The mean postoperative VIS was 15.1 ± 18.45 (range 0–100). The results of an analysis of variables that could be correlated with the preservation of visual function are shown in Table 2. Variables such as preoperative visual symptoms, tumor size, signal intensity on T2-weighted MRI, and extent of resection did not reach statistical significance in visual outcomes. A WHO grade I ($p = 0.009$) and the absence of adjuvant radiotherapy (RT; $p = 0.042$) resulted in favorable visual outcomes on univariate analysis. The absence of adhesion to the optic nerve (OR 7.81, 95% CI 1.13–152.27, $p = 0.036$) and a left-side subfrontal approach (OR 66.57, 95% CI 2.47–1.01e^{+4}, $p = 0.006$) were related to favorable visual outcomes as independent prognostic factors.

Complications

Surgery-related complications were observed in 10 patients (14%). Two patients experienced early-onset seizures and were in a seizure-free state without antiepileptic drugs at the last follow-up. Two patients had decreased olfactory function. Three patients developed postoperative intracranial hematoma (ICH) accompanying ischemic stroke, and 2 of the 3 underwent surgical intervention. Only 1 of the patients with postoperative ICH had sequelae (hand-grasp difficulty) at the last follow-up. There were no other stroke events or restricted diffusion on the MR images. Two patients had endocrinological disorders, one of whom had hypopituitarism after postoperative meningitis. However, none of the patients experienced transient or permanent diabetes insipidus. Hydrocephalus was observed in 1 patient and improved after lumbar drainage. There were no instances of CSF leakage in our series. On univariate analysis, symptom duration, tumor size, and proximity to surrounding structures were statistically significantly related to the occurrence of complications. However, on further multivariate logistic regression analysis, no factor showed statistical significance (Table 3).

Tumor Control

GTR was achieved and confirmed during surgery and by postoperative MRI in 70 patients (95%). Four patients (5%) underwent STR. The specific cause of STR included tight adhesion to the surrounding structure, such as the lesion-side optic nerve (n = 2, each remnant was < 8% of the total volume) or pituitary stalk (n = 1, the remnant was < 1% of the total volume) and invasion of the cavernous sinus (n = 1, remnant was 19% of the total volume). There were no statistically significant factors affecting the ex-

TABLE 2. Factors predictive of favorable visual outcomes

Factor	Visual Outcome		Univariate Analysis	Multivariate Analysis		
	Favorable	Unfavorable		p Value	OR	95% CI
Age in yrs	56 (47–61)	57 (47–58)	0.448			
Gender						
Male	12	1	0.814			
Female	55	6				
Visual disturbance						
Yes	54	7	0.095			
No	13	0				
Duration of symptoms in mos	3 (2–9)	13 (3–43)	0.244			
Tumor diameter in mm	20 (15–25)	23 (20–30)	0.18			
Major vessel encasements						
No	51	3	**0.08**	0.072	5.89	0.86–68.64
Yes	16	4				
OCIs						
None	1	0	0.649			
Unilat invasion	54	5				
Bilat invasion	12	2				
Laterality of tumor						
Midline tumor	30	4	0.408			
Lateralized tumor	37	3				
Diaphragm sella invasion						
No	41	2	0.122			
Yes	26	5				
T2 SI						
Isointense or low	21	3	0.675			
High	46	4				
Distance btwn optic canals in mm	15 (14–16)	15 (15–18)	0.307			
Histological WHO grade						
I	64	4	**0.009**	0.079	63.61	0.70–3.23e+07
II	3	3				
Extent of resection						
GTR	64	6	0.334			
STR	3	1				
Adjuvant RT						
No	65	5	**0.042**	0.923	0.65	1.36e-04 to 1.32e+03
Yes	2	2				
Preop VIS	14 (7–35)	17 (4–30)	0.743			
Adhesion						
No	47	2	**0.04**	**0.036**	7.81	1.13–152.27
Yes	20	5				
Approach side						
Lt	29	0	**0.038**	**0.006**	66.57	2.47–1.01e+04
Rt	38	7				

The median and interquartile range of the numeric variables and the number of categorical variables are represented. Boldface type indicates statistical significance.

tent of resection, including tumor size, OCI, and artery encasement. There was no remnant near the approach-side optic nerve. One patient with a residual tumor had atypical meningioma and received adjuvant RT. Another had fibrous meningioma and underwent adjuvant stereotactic radiosurgery. All residual tumors remained stable at the last follow-up. Recurrence after GTR was observed in 4 (5%) patients 38, 55, 78, and 119 months after surgery

TABLE 3. Factors predictive of complications

Factor	Complication No	Complication Yes	Univariate Analysis	Multivariate Analysis p Value	OR	95% CI
Age in yrs	56 (48–61)	57 (42–69)	0.943			
Gender						
Male	53	8	0.831			
Female	11	2				
Visual disturbance						
Vision	52	9	0.737			
Other	12	1				
Duration of symptoms in mos	3 (1–8)	15.5 (5–63)	**0.005**	0.31	1.02	0.98–1.05
Tumor diameter in mm	19.5 (15–25)	29 (23–35)	**0.003**	0.709	1.03	0.88–1.19
Major vessel encasements						
No	51	3	**0.003**	0.273	2.33	0.5–11.86
Yes	13	7				
OCIs						
None	1	0	0.214			
Unilat invasion	53	6				
Bilat invasion	10	4				
Laterality of tumor						
Midline tumor	28	6	0.344			
Lateralized tumor	36	4				
Diaphragm sella invasion						
No	41	2	**0.014**	0.931	1.09	0.14–8.16
Yes	23	8				
T2 SI						
Isointense or low	22	2	0.484			
High	42	8				
Distance btwn optic canals in mm	15 (14–16)	15 (14–16.75)	0.753			
Histological WHO grade						
I	60	8	0.184			
II	4	2				
Extent of resection						
GTR	61	9	0.448			
STR	3	1				
Adjuvant RT						
No	62	8	0.086	0.57	2.81	0.1–164.98
Yes	2	2				
Preop VIS	14 (7–33)	30 (6–77)	0.226			
Adhesion						
No	43	6	0.725			
Yes	21	4				
Approach side						
Lt	25	4	0.956			
Rt	39	6				

The median and interquartile range of numeric variables and the number of categorical variables are represented. Boldface type indicates statistical significance.

(Fig. 1). The recurrence sites included the inferomedial side of the approach-side optic nerve with tumor invading the approach-side optic canal (n = 2) and the inferolateral side of the lesion-side optic nerve with tumor encasing the ICA (n = 2). One patient had chordoid meningioma and received adjuvant RT but experienced recurrence. The tumor size (mean 28.5 mm, range 22–43 mm) in recurrence cases was relatively larger than that in the other cases, but

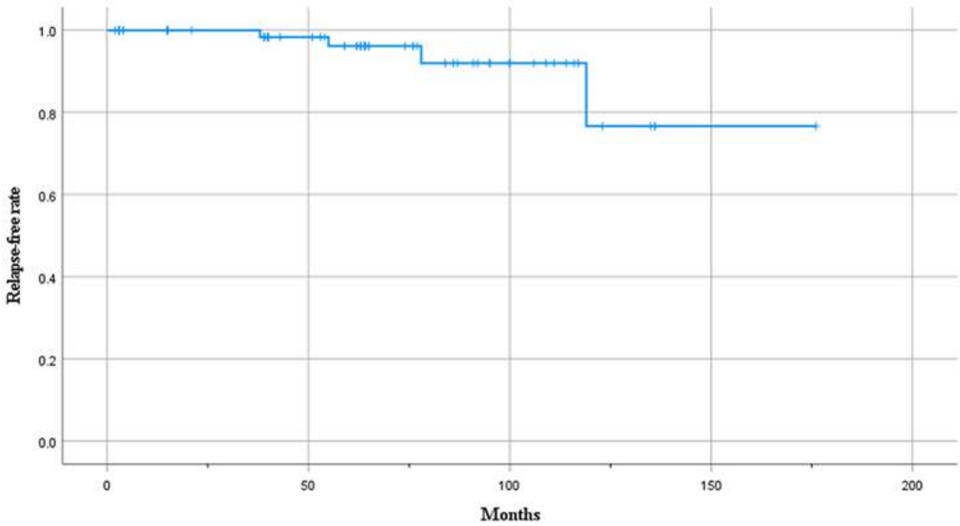

FIG. 1. Kaplan-Meier estimates of relapse-free survival after the contralateral subfrontal approach for the treatment of TSM. Figure is available in color online only.

there was no statistically significant difference between the two groups. Other preoperative anatomical factors, such as optic canal involvement and vessel encasement, did not affect tumor recurrence.

Surgical Outcomes Associated With Tumor Scoring

We divided our TSM series into 14 subtypes, according to the tumor-canal-artery subtype classifications (Supplemental Fig. 1).[4] Tumor control and visual outcomes were not significantly affected by scale scores. The incidence of complications was affected by artery scores ($p = 0.029$) and total scores ($p = 0.009$) in the univariate analysis. Patients with a scale score of 4 or higher tended to have poor tumor control and visual outcomes (not significant) as well as complications ($p = 0.014$).

Discussion

Although previous studies on surgical approaches for TSM have reported favorable results, the optimal surgical approach for TSM remains controversial (Tables 4 and 5). Various surgical approaches are available for the management of TSM, including the transcranial approach and the transsphenoidal approach. Considering the anatomical specialty in TSM, the optimal surgical approach for TSM should be modulated according to patient and tumor characteristics. Because of the specific location of TSMs, complete tumor removal, lower complication rates, and favorable visual outcomes are the major concerns in adopting the optimal surgical approach. The key to preserving visual function is to minimize the manipulation of optic nerves and avoid injury to the blood supply to the optic nerves. Exact preoperative assessments for selecting the proper surgical approach and fine intraoperative techniques have made it possible to achieve the surgical goals. The contralateral subfrontal approach could be an excellent choice for removing a TSM when the tumor is in a unilateral or midline location causing unilateral visual symptoms or bilateral asymmetrical visual symptoms. The contralateral subfrontal approach provides a direct view of the tumor and OCI with less manipulation of the optic nerve and reduces the possibility of CSF leakage, regardless of tumor size, extent, or vascular encasement. Tumor scoring is a detailed objective parameter and gives more persuasive criteria for selecting surgical approaches and anticipating outcomes. In our series, patients with a tumor score of 3 or lower tended to have excellent surgical outcomes (Supplemental Fig. 1). Even in high-score tumors, the contralateral subfrontal approach demonstrated surgical outcomes comparable to those obtained with other transcranial approaches and transsphenoidal approaches.[4]

Total tumor removal without recurrence is the one of the most important goals in TSM treatment. In recent series, the GTR rate was 53%–96% with other transcranial approaches and 50%–95% with transsphenoidal approaches (Tables 4 and 5). In our study, the GTR rate was 95% (70/74). Through the contralateral subfrontal approach, the inferomedial portion of the affected optic nerve and tumor invading the optic canal are clearly exposed. Opening the optic canal via the contralateral subfrontal approach is easy because the tumor compresses the optic nerve from the inferomedial side of the optic nerve. A small volume of tumor invasion into the optic canal causes severe compression of the optic nerve because of the intrinsically restricted space of the optic canal. A direct view of the optic canal and simple removal of the falciform ligament enable removal of the tumor without bone drilling (Fig. 2). The optic canal is not the center of the tumor, and an OCI tumor could be easily removed without damage to the compromised optic nerve.[5]

Blind spots in the surgical field may result in STR because of blind resection and unexpected manipulation of the neurovascular structures. During the contralateral subfrontal approach, the inferomedial side of the approach-side optic nerve and the inferolateral side of the affected-side optic nerve are less exposed, and the removal of tumor in this site is a little more difficult than tumors in other locations. There are specific considerations in overcom-

TABLE 4. Literature review of transcranial series and clinical outcomes

Authors & Year	No. of Patients	Visual Assessment	Improved After Surgery (%)	Unchanged After Surgery (%)	Worsened After Surgery (%)	GTR (%)	Complication (%)	Recurrence (%)	CSF Leakage (%)	Hypopituitarism (%)	No. of Deaths (%)	Mean FU (mos)
Wang et al., 2011[21]	45	45	27 (60)	12 (27)	6 (13)	40 (89)	16 (36)	3 (7)	2 (4)	2 (4)	1 (2)	39
Chokyu et al., 2011[22]	34	32	28 (87)	4 (13)	0	27 (79)	2 (6)	NA	0	0	0	96
Li-Hua et al., 2011[23]	67	67	43 (64)	20 (30)	4 (6)	62 (93)	19 (28)	NA	1 (1)	4 (6)	0	29
Curey et al., 2012[24]	20	20	14 (70)	4 (20)	2 (10)	19 (95)	10 (50)	0	0	1 (5)	0	56
Palani et al., 2012[25]	41	41	11 (27)	27 (66)	3 (7)	30 (73)	5 (12)	NA	2 (5)	1 (2)	2 (5)	NA
Romani et al., 2012[26]	52	52	22 (42)	22 (42)	8 (16)	45 (87)	17 (33)	1 (2)	3 (6)	5 (10)	1 (2)	59
Mortini et al., 2012[27]	36	36	31 (86)	4 (11)	1 (3)	32 (89)	9 (25)	4 (11)	1 (3)	5 (14)	0	30
Margalit et al., 2013[28]	51	43	20 (46)	21 (49)	2 (5)	45 (88)	10 (20)	0	3 (6)	0	1 (2)	42
Seol et al., 2013[29]	86	73	32 (44)	27 (37)	14 (19)	74 (86)	35 (40)	5 (6)	NA	2 (2)	NA	39
Mariniello et al., 2013[30]	44	44	27 (61)	11 (25)	6 (14)	38 (86)	NA	2 (4)	NA	NA	NA	120
Liu et al., 2015[31]	21	21	13 (62)	7 (33)	1 (5)	NA	5 (24)	NA	5 (24)	NA	0	15
Lee et al., 2016[10]	100	100	70 (70)	25 (25)	5 (5)	96 (96)	12 (12)	2 (2)	0	0	0	58
Zhou et al., 2016[32]	56	56	47 (84)	7 (12)	2 (4)	50 (89)	23 (41)	NA	2 (4)	12 (21)	0	27
Karsy et al., 2017[33]	49	46	17 (37)	28 (61)	1 (2)	42 (86)	16 (36)	NA	2 (4)	4 (8)	0	42
Song et al., 2018[9]	40	38	15 (39)	14 (37)	9 (24)	26 (65)	18 (45)	13 (33)	0	6 (15)	1 (3)	44
Kong et al., 2018[34]	94	77	43 (56)	21 (27)	13 (17)	75 (80)	6 (8)	NA	0	0	1 (1)	28
Xu et al., 2019[35]	23	22	12 (55)	8 (36)	2 (9)	23 (100)	8 (35)	0	0	3 (13)	0	40
Cai et al., 2019[15]	30	29	17 (59)	8 (28)	4 (13)	27 (90)	5 (17)	1 (3)	0	1 (3)	0	NA

NA = not available.

TABLE 5. Literature review of transsphenoidal series and clinical outcomes

Authors & Year	No. of Patients	Visual Assessment	Improved After Surgery (%)	Unchanged After Surgery (%)	Worsened After Surgery (%)	GTR (%)	Complication (%)	Recurrence (%)	CSF Leakage (%)	Hypopituitarism (%)	No. of Deaths (%)	Mean FU (mos)
Van Gompel et al., 2011[36]	13	12	8 (67)	4 (34)	0	7 (54)	1 (8)	NA	0	0	0	21
Ogawa & Tominaga, 2012[37]	19	19	14 (73)	3 (16)	2 (11)	15 (79)	1 (5)	1 (5)	1 (5)	0	0	36
Khan et al., 2014[38]	17	14	9 (64)	5 (36)	0	11 (65)	5 (29)	NA	2 (12)	3 (18)	0	10
Ceylan et al., 2015[39]	23	20	14 (70)	6 (30)	0	17 (74)	4 (17)	NA	2 (9)	2 (9)	0	NA
Hayashi et al., 2017[40]	22	18	15 (83)	3 (17)	0	15 (68)	3 (14)	NA	0	2 (9)	0	NA
Bander et al., 2018[41]	17	16	10 (63)	6 (37)	0	14 (82)	13 (76)	2 (12)	2 (12)	0	0	25
Song et al., 2018[9]	44	44	43 (98)	0	1 (2)	37 (84)	24 (55)	6 (14)	1 (2)	3 (7)	0	27
Elshazly et al., 2018[42]	25	22	15 (68)	7 (32)	0	19 (76)	7 (28)	1 (4)	2 (8)	3 (12)	0	21
Kong et al., 2018[34]	84	80	68 (85)	8 (10)	4 (5)	70 (83)	10 (12)	NA	4 (5)	0	1 (1)	28
Youngerman et al., 2021[43]	51	46	31 (67)	12 (26)	3 (7)	40 (78)	14 (27)	9 (18)	5 (10)	2 (4)	0	40
Yu et al., 2021[44]	40	40	38 (95)	2 (5)	0	38 (95)	12 (30)	1 (3)	3 (8)	0	0	15

ing blind resection and unexpected manipulations. First, appropriate patient selection is important. A lateralized tumor or midline tumor with lateralized visual symptoms suggests that the tumor is located in a unilateral optic nerve without adhesion to the less-compromised optic nerve. These tumor characteristics reduce the requirement for blind resection. Second, the head rotation angle should be between 20° and 30° to maximize the surgical corridor between the optic nerves, and the approach-side optic nerve should be vertical to the operating room floor. Third, flattening of the sphenoid wing and anterior cranial fossa with the proper head extension makes sufficient space between the skull base and the frontal lobe with less brain retraction. These measures to maximize the surgical corridor are also related to good visual outcomes.

The recurrence rate is closely related to the postoperative follow-up duration.[6] In a recent series, the recurrence rate was 0%–33% in other transcranial approaches and 3%–18% in transsphenoidal approaches with quite different follow-up durations (Tables 4 and 5). Only a few studies using transcranial approaches have reported recurrence rates from more than 5 years' follow-up duration. There have been no studies on the transsphenoidal approach with more than 5 years of follow-up. The shortest interval between surgery and relapse was 38 months in the present series. Considering these results, the recurrence rate in this study is more convincing than in other studies in which the follow-up duration was shorter than in our series. We speculate that a high GTR rate and the use of an EMF system to remove involved dura mater through a clear, wide surgical view were related to the low recurrence rate in the long-term follow-up.

The contralateral subfrontal approach for TSM provides a clear view of OCI and the inferomedial side of the optic nerve without optic nerve manipulation and results in comparable visual outcomes with acceptable visual function on the approach-side optic nerve. The preservation of or improvement in visual function is an important goal for TSM treatment. In using other transcranial or transsphenoidal approaches, the visual deterioration rates were 0%–30% and 0%–11%, respectively, in recent large series (Tables 4 and 5). In our study, the preservation or improvement rate of visual function was 91% and the deterioration rate was 9%. These results were also demonstrated in previous reports on the contralateral approach for TSM (Table 6). Minimal optic nerve manipulation and the absolute preservation of vessels supplying the optic pathway are crucial for postoperative visual outcomes. The vascularization of the optic pathway in the cisternal segment is intricate, considering the ACA, ophthalmic artery, and superior hypophyseal artery. These arteries enter the arachnoid membrane of the optic nerve, which could be tightly adhered to the tumor capsule.[7,8] The contralateral subfrontal approach makes it comfortable to dissect the tumor-arachnoid plane and preserve fragile vascular structures. The OCI is also a cardinal concern in completely removing TSM without visual impairment. Optic canal decompression is an essential procedure to remove tumors in the optic canal. The contralateral subfrontal approach can provide sufficient space for safe unroofing of the involved optic canal. Various factors, such as age, preoperative visual symptoms,

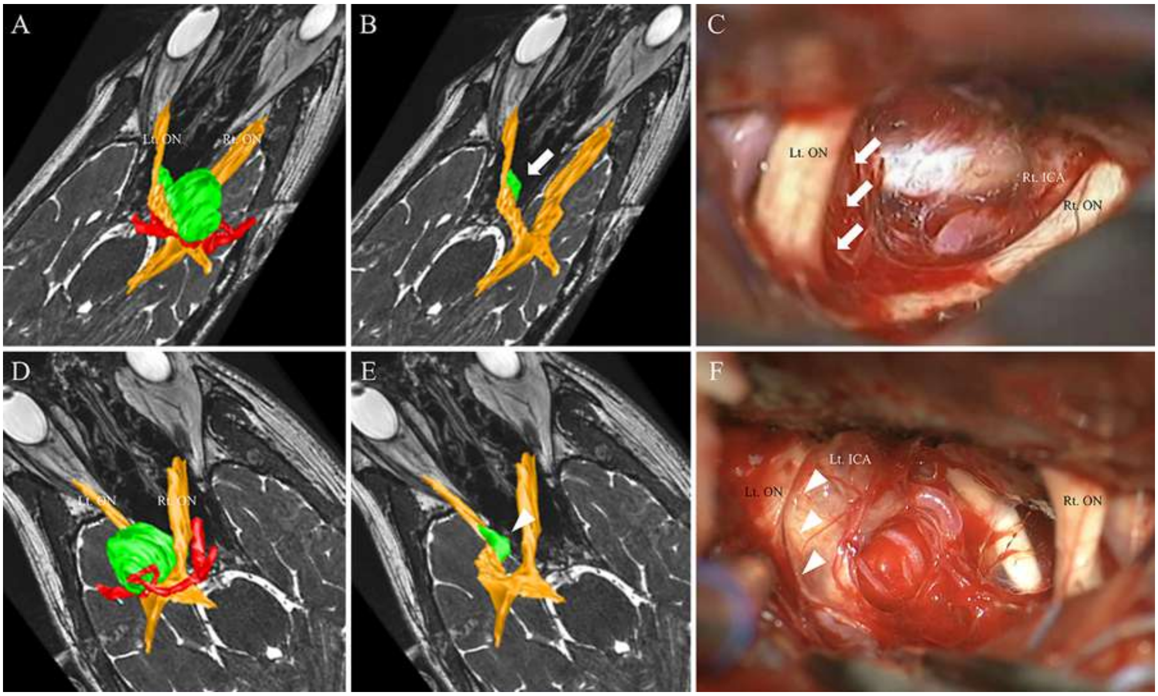

FIG. 2. The ipsilateral (A–C) and contralateral (D–F) subfrontal approaches in the 3D reconstruction model based on MRI and the intraoperative view. The 3D reconstruction model (**A and B**) shows the ipsilateral subfrontal approach. The approach for a tumor (*green*) located in the inferomedial aspect of the compromised optic nerve (*yellow*) is blocked by the optic nerve. *Red* indicates arteries (ICA, ACA, and middle cerebral artery). The intraoperative view (**C**) demonstrates the blind spot and hidden tumor (*white arrows*, B and C) in the inferomedial aspect of the optic nerve. The 3D reconstruction model (**D and E**) shows the contralateral subfrontal approach. The inferomedial aspect of the optic nerve is clearly exposed. The intraoperative view (**F**) demonstrates the clear view of the inferomedial aspect of the optic nerve. The *white arrowheads* (E and F) indicate the well-exposed inferomedial aspect of the optic nerve, indented by tumors. Lt. = left; ON = optic nerve; Rt. = right. Figure is available in color online only.

tumor size, tight adhesion to the optic nerve, and extent of resection, have been suggested as prognostic factors for postoperative visual outcomes in patients with TSM.[9–12] In our study, tight adhesion to the optic nerve and the surgical approach side were significant prognostic factors for postoperative visual outcomes in patients with TSM. Among right-handed surgeons, the operator usually holds and swaps the bipolar forceps, tumor forceps, microscissors, dissector, or pincette in the right hand. In contrast to the left hand, which continuously holds the suction device, the frequent swapping of surgical instruments and the relatively larger-sized instruments compared to the suction device cause insensate manipulation of the optic nerve. This tendency may be more prominent when the right optic nerve is located in the foremost surgical field and close to the surgeon's right hand, interfering with right-hand motion. Although adhesion is an unchangeable characteristic of the tumor, poor outcomes related to a right-sided subfrontal approach are correctable. In addition to the surgical technique for GTR described above, the operator keeps in mind that the surgical instruments should move parallelly to the approach-side optic nerve and the optic nerve should be vertical to the operating room floor to maintain a sufficient surgical field. It is postulated that, in the case of a tumor severely adhered to the optic nerve with an inconvenient working corridor, accidental manipulation of the optic nerve or injury to the vascular structure may occur with high probability and cause poor visual outcomes. To prevent undesirable, unexpected injury to the optic nerve, the surgical tips mentioned above should be kept in mind.

In recent series, the nonvisual complication rate was 6%–50% in other transcranial approaches and 5%–76% in transsphenoidal approaches (Tables 4 and 5). A relatively low incidence of complications and the absence of CSF leakage were observed in the present study. In particular, there was no chance of CSF leakage in the contralateral subfrontal approach given the intact barrier between the brain and paranasal sinus. Since optic canal unroofing is accompanied only by removal of the falciform ligament, there is no chance to open the paranasal sinus in the contralateral subfrontal approach. Furthermore, there was no CSF leakage in previous reports on the contralateral approach.[13,14] In contrast, CSF leakage and meningitis are still substantial concerns in the transsphenoidal approach.[9] Hypopituitarism was also a rare complication in our study. The pituitary stalk was identified in the early surgical phase because of tumor compressing the pituitary stalk posteromedially. Early detection of the pituitary stalk without blind dissection or detachment prevents hypopituitarism caused by pituitary stalk injury. Two postoperative cases of hypopituitarism in this series occurred in midline TSMs, in which the pituitary stalk was compressed far posteriorly and detected in the late surgical phase. In other transcranial and transsphenoidal approaches, the pituitary stalk is located in the back-most surgical corridor and identified in the late surgical phase with blind dissec-

TABLE 6. Literature review of contralateral approach series and clinical outcomes

Authors & Year	No. of Patients	Visual Assessment	Improved After Surgery (%)	Unchanged After Surgery (%)	Worsened After Surgery (%)	GTR (%)	Complications (%)	Recurrence (%)	CSF Leakage	Hypopituitarism (%)	No. of Deaths	Mean FU (mos)
Jang et al., 2012[2]	24	24	17 (71)	5 (21)	2 (8)	24 (100)	4 (17)	2 (8)	0	0	0	20
Engelhardt et al., 2018[14]	20	20	14 (70)	3 (15)	3 (15)	18 (80)	5 (25)	1 (5)	0	0	0	66
Voznyak et al., 2021[13]	17	17	13 (76)	3 (18)	1 (6)	15 (88)	0	0	0	0	0	NA
Troude et al., 2021[45]	36	NA	NA	NA	NA	30 (83)	NA	NA	0	NA	0	59
Present study	74	74	46 (62)	21 (29)	7 (9)	70 (96)	10 (14)	4 (5)	0	2 (3)	0	63

tion or detachment, causing accidental pituitary stalk injury. A specific drawback of the contralateral approach is the possibility of damaging the approach-side optic nerve. However, damage to the less-compromised optic nerve can occur even after other transcranial or transsphenoidal approaches.[15–18] Furthermore, the tumor does not adhere to the approach-side optic nerve and can be separated only after internal debulking without manipulation of the optic nerve in most cases. Preoperative anxiety, postoperative fatigue, and memory difficulty in transcranial approaches and decreased olfactory function in transsphenoidal approaches are considerable issues that affect patient satisfaction.[19]

For patient selection, tumor laterality and visual symptoms are indicators to apply to the contralateral approach. In lateralized tumors, the approach-side optic nerve is expected to be free from tumor and the approach-side optic nerve does not interfere with the main working space. A lateralized tumor is considered an absolute indication for the contralateral subfrontal approach. In midline tumors, unilateral visual symptoms or asymmetrical bilateral visual symptoms suggest that the tumor does not adhere to the approach-side optic nerve and is expected to detach from the nerve by internal debulking and dissection without nerve manipulation. In our study, visual outcomes, complications, and tumor control were not significantly related to tumor laterality. However, 6 patients experienced deteriorated approach-side-only visual function with a favorable lesion-side visual outcome, and almost all tumors were located in the midline, except in 1 case. Considering asymmetrical visual impairment, the visual field defect in the approach-side optic nerve should be better than hemianopsia (< 50% visual field defect). There were 3 cases of tumor located in the midline with asymmetrical visual symptoms worse than hemianopsia in the approach-side optic nerve. One patient experienced worse visual function in the approach-side optic nerve, and 2 experienced surgical complications. Thus, a midline tumor is considered a relative indication for the contralateral subfrontal approach only when the less-compromised optic nerve has a visual field defect better than hemianopsia.

Compared to the transsphenoidal approach, the microsurgically available contralateral subfrontal approach is familiar to neurosurgeons and makes it easy to dissect the tumor from surrounding neurovascular structures in direct and wide surgical views. The contralateral subfrontal approach, like other transcranial approaches, also has the advantage of controlling lateralized tumor and accidental vascular injury.[20] However, the contralateral subfrontal approach has some weak points, which include the possibility of manipulating the approach-side optic nerve. In our series, 5 patients with complete vision loss on the lesion-side and intact vision on the approach-side were treated with the contralateral approach. Except for 1 patient with postoperative ICH, there were good surgical outcomes. Theoretically, it may seem that the normal optic nerve is at risk, but in practice such a risk can be avoided. Other approaches to the anterior skull base, such as cranioorbital and craniozygomatic approaches, could increase the angle of exposure and working space while reducing the need for brain retraction but still offer limited exposure of the inferomedial side of the lesion-side optic nerve. Thus, the choice of surgical approach should be based on the characteristics of the tumor and the knowledge of the surgeon. The tumors included in our study had unilateral locations or a midline location causing unilateral visual symptoms or bilateral asymmetrical visual symptoms. Other tumors, such as midline tumors with bilateral symmetrical visual symptoms, were treated using other transcranial approaches, such as a bifrontal interhemispheric approach; however, those tumors were beyond the scope of this study. This retrospective study had certain limitations, such as a single institution's experience. A larger patient group with a longer follow-up duration and a similar patient group undergoing surgery via the transsphenoidal approach or other transcranial approaches are required for further studies. Although further prospective studies are necessary to verify the optimal surgical approach, the present study will help neurosurgeons treat TSMs properly.

Conclusions

The contralateral subfrontal approach provides an outstanding surgical field for TSM surgery with excellent visual outcomes and limited complications. Tumors presenting at a unilateral location or a midline location causing unilateral visual symptoms or bilateral asymmetrical visual symptoms are suitable for this approach. Based on an exact preoperative assessment to select appropriate patients and fine intraoperative techniques, the contralateral subfrontal approach may be a good choice for treating TSMs, as presented here.

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Disclosures

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Conception and design: S Jung, Jang. Acquisition of data: YJ Kim, Jang. Analysis and interpretation of data: YJ Kim. Drafting the article: YJ Kim. Critically revising the article: Moon, IY Kim. Reviewed submitted version of manuscript: Moon, TY Jung. Statistical analysis: YJ Kim. Administrative/technical/material support: TY Jung, IY Kim.

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