Sphenoid Wing Meningiomas: Surgical Outcomes in a Series of 141 Cases and Proposal of a Scoring System Predicting Extent of Resection

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■ OBJECTIVE: **Sphenoid wing meningiomas are the third most common group of intracranial meningiomas. Their management is a challenge because of their bone invasion potential and their proximity to neurovascular structures and the cavernous sinus.**

■ METHODS: **A cohort of 141 patients with sphenoid wing meningioma who were operated on and followed up between 1986 and 2018 were retrospectively analyzed. Demographic data, clinical and radiologic features, surgical results, and follow-up data are presented. The effects of adjuvant treatments (radiosurgery, radiotherapy, and chemotherapy) are reviewed. The invasion pattern of tumors and other factors were noted to analyze the extent of resection. Recurrence/regrowth rates were also analyzed.**

■ RESULTS: **There were 96 female and 45 male patients with a median age of 51 years (range, 17–87 years). The median follow-up was 62 months (range, 1–303 months). Tumors were grouped as spheno-orbital (31 patients), lateral (34 patients), middle (35 patients), and medial (41 patients). Gross total resection was achieved in 98 patients, and 43 tumors were resected subtotally. One hundred and twenty of these cases had World Health Organization grade I pathology, whereas the remainder had grade II. In the follow-up, there were 14 recurrences of totally resected tumors, and 24 regrowths were observed in the subtotally resected group. No invasion pattern was strongly predictive of extent of resection alone, and a scoring system was built up and proposed.**

■ CONCLUSIONS: **Sphenoid wing meningioma is a large group with characteristics associated with skull base meningiomas and convexity meningiomas. The results of surgery and other adjuvant treatments are heterogeneous.**

INTRODUCTION

Sphenoid wing meningiomas (SWM) account for 11%–20% of intracranial meningiomas and were first classified in detail by Cushing and Eisenhardt as "globoid" and "en plaque" tumors. Based on their location of origin along the sphenoid wing, globoid tumors were further categorized into 3 groups: 1) medial; 2) middle; and 3) lateral. En plaque meningiomas are characterized by sheetlike dural involvement and bone hyperostosis.[1] The term spheno-orbital meningiomas (SOM) has been used to describe en plaque meningiomas that arise at the greater sphenoid wing and extend to the orbit with hyperostosis or bone invasion.[2-6]

Management of the SWM is challenging because of invasion of the bone and proximity to the cranial nerves, anterior circulation arteries, and cavernous sinus (CS).

The objective of this work was to present our experience of SWM.

Key words
- Meningiomas
- Skull base tumors
- Sphenoid ridge meningiomas
- Sphenoid wing meningiomas

Abbreviations and Acronyms
ACA: Anterior cerebral artery
CI: Confidence interval
CS: Cavernous sinus
CT: Computed tomography
GKR: Gamma Knife radiosurgery
GTR: Gross total resection
ICA: Internal carotid artery
MCA: Middle cerebral artery
MRI: Magnetic resonance imaging
SOF: Superior orbital fissure
SOM: Spheno-orbital meningioma
STR: Subtotal resection
SWM: Sphenoid wing meningioma
WHO: World Health Organization

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METHODS

Patient Population

Our meningioma database was retrospectively reviewed. A total of 1372 meningioma cases were operated on by the senior author (M.N.P.) at the Marmara University Hospital and Acıbadem University Hospital between September 1986 and July 2018. A total of 141 patients with SWM, constituting 10.3% of the patients with meningioma, were included in this study. Patients with anterior clinoidal, primary CS, optic nerve sheath, and sphenopetroclival meningiomas were excluded.

Patient demographics, presenting symptoms and signs, neurologic and neuro-ophthalmologic findings, radiologic findings, surgical details, extent of resection, histopathologic characteristics, adjuvant therapies, and recurrence or regrowth characteristics were collected.

Preoperative Radiologic Findings

Preoperative computed tomography (CT) was performed in all cases, and magnetic resonance imaging (MRI) with contrast series was obtained in cases from 1992 on. Bone invasion was examined by using bone window CT studies. Tumor diameter was considered to be the maximal diameter at orthogonal planes in gadolinium-enhanced T1-weighted MRI or CT with contrast. CS involvement was defined as infiltration of the tumor into the CS. Internal carotid artery (ICA), middle cerebral artery (MCA), or anterior cerebral artery (ACA) encasement is characterized by surrounding the vessel by the tumor over more than 180°. Degree of peritumoral edema was evaluated and graded as absent (no edema), mild (<2 cm), moderate (≥2 to <4 cm), and severe (≥4 cm) according to maximum size of the edema extending from the tumor.

Classification of Tumors

Tumors were basically classified using the Cushing classification system as spheno-orbital, medial, middle, or lateral meningiomas according to radiologic and intraoperative findings. Classification of extensive and giant tumors was determined based on the origin or the epicenter of the tumor.

Microsurgical Technique and Perioperative Management

Pterional craniotomy was the standard approach for all cases. After craniotomy, the greater sphenoid wing was drilled out medially to the lesser sphenoid wing. Extradural bone removal was performed to a more medial limit, including the anterior clinoid, optic canal, and lateral or superior wall of the orbit for medially located giant tumors or tumors with extensive bone invasion. In all cases with optic canal involvement, anterior clinoidectomy and unroofing of the optic canal were performed with a diamond drill. After the dura was opened, the sylvian cistern was dissected and opened under an operating microscope. The tumor was detached from the dura, and internal tumoral debulking was performed. After debulking of the tumor, pial dissection was performed with caution to preserve the major vessels and neural structures. If dissection of the tumor was not feasible because of an apparent risk to these structures, resection was limited to the minimal residual tumor. CS exploration was not performed in any case. The parts of the bone flap with tumoral infiltration were drilled out.

Preoperative tumor embolization was not needed in any patient.

Patient Follow-Up

All patients underwent radiologic imaging studies with CT within 2 hours after surgery. Postoperative imaging within 24 hours was obtained with CT in all cases before 1992, and MRI with contrast series from 1992 on. Four months after surgery, all patients were evaluated by clinical examination and postoperative CT (before 1992) or MRI (from 1992 on).

Clinical and radiologic follow-up of patients was scheduled according to pathologic grade and extent of resection. Yearly follow-up examinations were performed for patients with World Health Organization (WHO) grade I disease and gross total resection (GTR), whereas patients with subtotal resection (STR) or WHO grade II disease were scheduled every 6 months. If there was no recurrence after 5 years, the follow-up intervals of the patients with GTR WHO grade I meningiomas were extended to every 2 years.

Extent of Resection

The extent of tumor resection was determined by analyzing the operative notes and was confirmed with postoperative imaging studies, followed by categorization based on the Simpson grading of extent of resection. Simpson grade I or II resections were grouped as GTR, whereas Simpson grade III, IV, and V resections were grouped as STR.[7]

Gamma Knife Radiosurgery and Adjuvant Treatments

Gamma Knife Model B and 4C software from 1997 to May 2017 and then the Gamma Knife Icon model were used for Gamma Knife radiosurgery (GKR) (Elekta, Stockholm, Sweden). Radiotherapy and/or chemotherapy were used as other adjuvant treatment modalities if necessary.

Statistical Analyses

Clinical, pathologic, and radiologic factors potentially associated with incomplete tumor resection were statistically analyzed. These factors included previous surgery, tumor size, CS involvement, ICA encasement, ACA encasement, MCA encasement, bone invasion of the orbit or optic canal or superior orbital fissure (SOF), and any other bone invasion on the sphenoid ridge, peritumoral edema, location of the tumor, and pial invasion.

The relationship between the extent of resection and clinical, radiologic factors was analyzed by univariate analysis tests (χ^2 and Fisher exact tests). Statistically significant variables identified by univariate analysis were analyzed with logistic regression.

A scoring system was developed to predict the extent of resection preoperatively. Only statistically significant factors that it was possible to know preoperatively from CT or MRI studies were incorporated into the scoring system.

Kaplan-Meier survival curves for time to recurrence/regrowth were plotted. The results were evaluated at 95% confidence level and $P < 0.05$ was considered as statistically significant. Statistical

analyses were performed using SPSS version 22 software (IBM Corp., Armonk, New York, USA).

RESULTS

Study Population and Preoperative Findings

Ninety-six female and 45 male patients (female/male ratio, 2.1) with a median age of 51 years (range, 17–87 years) were included in the study. The mean follow-up was 70.6 ± 49.3 months, and median follow-up duration was 62 months (range, 1–303 months).

Seventeen patients (12.1%) had previous surgery for SWM in another center.

The most frequent symptom was headache ($n = 57$, 40.4%) followed by seizures ($n = 29$, 20.6%) and visual deterioration ($n = 26$, 18.4%). Patient population and characteristics are summarized in Table 1.

Neuro-Ophthalmologic Findings

Five patients (3.5%) had loss of vision in the eye on the tumor side. Visual field defects were present in 10 patients (7.1%) on the same side as the tumor. Four patients had constricting visual field defects, 2 patients had superior temporal quadrantanopia, and 2 patients had inferior peripheric field defects. One patient had temporal hemianopia and 1 patient had blind spot enlargement.

Preoperative ophthalmoplegia was seen in 13 patients (9.2%); 7 patients had oculomotor palsy, 4 patients had oculomotor and abducens palsy, and 2 patients had pure abducens palsy.

Sixteen patients (11.3%) had proptosis.

Radiologic Findings

The groups of tumors were as follows: 41 medial (29.1%), 35 middle (24.8%), 34 lateral (24.1%), and 31 SOMs (22.0%). The side of the lesion was almost equally distributed (71 right side, 70 left side). Peritumoral edema was observed in 70 patients (49.6%) (38 mild, 23 moderate, 9 severe). Multiple meningiomas were seen in 14 patients (9.9%) and 2 of these patients had been diagnosed with neurofibromatosis type 2.

The details of size and vascular and bone invasion patterns of tumors are presented in Table 1.

Histopathologic Data

According to the WHO classification, 120 tumors were grade I and 21 were grade II. There was no grade III meningioma. The most common histologic subtype of meningioma was meningothelial ($n = 80$, 56.7%), followed by atypical ($n = 16$, 11.3%). Table 2 summarizes the details of the pathologic results.

Surgical Results

Extent of Tumor Resection. Simpson I resection was achieved in 26 patients (18.4%), whereas 72 tumors (51.1%) had Simpson II resection. A total of 98 GTRs (69.5%) were performed, and 43 tumors (30.5%) were resected subtotally. Twenty-seven tumors (19.2%) had Simpson III resection, and 16 tumors (11.4%) had Simpson IV resection. There was no Simpson V resection (Table 3).

GTR was achieved in 34 lateral meningiomas (100%), in 33 middle meningiomas (94.3%), 27 medial meningiomas (65.9%), and 4 SOMs (12.9%). The spheno-orbital and medial groups of

Table 1. Demographics, Clinical, and Radiologic Characteristics of 141 Patients

Female	96 (68.1)
Male	45 (31.9)
Median age of patients (years), range	51 (17–87)
Mean follow-up (months), (median follow-up)	70.6 ± 49.3 (62; range, 1–303)
Symptoms/signs	
Headache	57 (40.4)
Retro-orbital pain	8 (5.7)
Seizures	29 (20.6)
Dizziness	23 (16.3)
Facial pain/numbness	3 (2.1)
Visual deterioration	26 (18.4)
Proptosis	16 (11.3)
Ophthalmoplegia	13 (9.2)
Visual field defects	10 (7.1)
Group of tumors	
Medial	41 (29.1)
Middle	35 (24.8)
Lateral	34 (24.1)
Spheno-orbital	31 (22.0)
Size of tumors (cm)	
≤3	22 (15.6)
3 to ≤5	68 (48.2)
>5	51 (36.2)
≤4	42 (29.8)
>4	99 (70.2)
Mean tumor diameter (cm) (median tumor diameter)	4.9 ± 1.5 (4.5; range, 2–10)
Invasion patterns	
Pial invasion	25 (17.7)
Cavernous sinus involvement	13 (9.2)
Internal carotid artery encasement	18 (12.8)
Anterior cerebral artery encasement	5 (3.5)
Middle cerebral artery encasement	28 (19.9)
Optic canal invasion	21 (14.9)
SOF invasion	17 (12.1)
Orbital invasion	31 (22.0)
Bone invasion of SOF and/or optic canal and/or orbita	39 (27.7)
Bone invasion on the sphenoid ridge not involving SOF or optic canal or orbita	25 (17.7)

Values are number (%) except where indicated otherwise.
SOF, superior orbital fissure.

Table 2. Distribution of Pathologic Grades and Subtypes of 141 Meningiomas

Pathologic Grade and Subtype	n (%)
WHO grade I	120 (85.1)
Meningothelial	80 (56.7)
Transitional	15 (10.6)
Secretory	9 (6.4)
Mixed*	6 (4.3)
Microcystic	3 (2.1)
Psammomatous	2 (1.4)
Angiomatous	2 (1.4)
Fibrous	2 (1.4)
Metaplastic	1 (0.7)
WHO grade II	21 (14.9)
Atypical	16 (11.3)
Chordoid	3 (2.1)
Clear cell	2 (1.4)
WHO grade III	0 (0)

WHO, World Health Organization.
*Includes meningothelial/angiomatous, meningothelial/lymphoplasmacytic, meningothelial/metaplastic, angiomatous/microcystic, and meningothelial/secretory/metaplastic subtypes.

meningiomas were significantly associated with STR compared with the other groups ($P < 0.05$). GTR rates were similar in lateral and middle SWM, and there was no statistically significant difference ($P > 0.05$).

Surgical Complications. Eighteen reoperations for recurrences/regrowths were performed; therefore, 159 surgeries were performed for resection of SWM. Neurosurgical complications occurred in 13 of these 159 operations (8.2%), and 10 patients (6.2%) required surgery for these complications. Four patients (2.5%) underwent surgery for hemorrhagic complications, including 1 epidural hematoma, 1 acute subdural hematoma, 1 chronic subdural hematoma, and 1 intracerebral hematoma. One patient underwent left frontal lobectomy as a result of venous infarction. Three patients (1.9%) had a bone infection that required bone flap removal. A cerebrospinal fluid fistula developed in 1 patient, which resolved after surgical repair. One patient with soft tissue wound infection underwent surgical debridement.

Intraoperative vascular injury occurred in 4 of these 159 operations (2.5%). Three MCA tears and 1 ACA tear occurred. All these vascular injuries were repaired intraoperatively by suturing with 10/0 prolene. One of the patients with an MCA tear required surgery for intracerebral hematoma.

Oculomotor palsy developed after surgery in 2 medial group cases (1.3%) and hemiparesis was an additional complication in 1 of these 2 patients. The hemiparesis and oculomotor palsies were permanent.

There was no worsening of vision and 2 patients reported better visual acuity postoperatively.

There was 1 death (0.6%) as a result of massive pulmonary embolism at postoperative day 9.

Table 3. Distribution of the Number of Tumors Based on Simpson Extent of Resection and the Proposed Invasion Score

	Simpson Extent of Resection, n (%)				
Invasion Score	Grade I	Grade II	Grade III	Grade IV	Grade V
0	8 (5.7)	19 (13.5)	0 (0)	0 (0)	0 (0)
1	13 (9.2)	32 (22.7)	0 (0)	0 (0)	0 (0)
2	4 (2.8)	14 (9.9)	0 (0)	0 (0)	0 (0)
3	1 (0.7)	5 (3.5)	21 (14.9)	3 (2.1)	0 (0)
4	0 (0)	2 (1.4)	4 (2.8)	3 (2.1)	0 (0)
5	0 (0)	0 (0)	2 (1.4)	8 (5.7)	0 (0)
6	0 (0)	0 (0)	0 (0)	2 (1.4)	0 (0)
All cases (N = 141)	26 (18.4)	72 (51.1)	27 (19.1)	16 (11.3)	0 (0)

Follow-Up and Adjuvant Treatments

Recurrences. Five of the 9 recurrent cases of WHO grade I meningiomas (6.4%) were given GKR, and 1 of these patients needed further reoperations and radiotherapy because the tumor growth could not be controlled. Three patients had reoperation; 1 of these patients was given further radiotherapy because of pathologic upgrading. One patient had a diagnosis of neurofibromatosis type 2, with a history of multiple operations and comorbidities; no further treatment was accepted by the patient.

GKR was performed on 1 of the 5 recurrent grade II meningiomas (3.5%). The tumor continued to grow throughout the follow-up period. The patient had previous multiple operations and adjuvant treatments for meningiomas in different locations. This patient died because of meningiomatosis with grade III meningiomas. One patient was advised to undergo GKR, but he accepted no further treatment.

One patient was advised to undergo reoperation, but she did not accept any further treatment because of her general medical conditions.

Two patients had radiotherapy; 1 received radiotherapy before the GKR facility was available and this patient's tumor is still under control. The other patient who had radiotherapy was later given GKR twice, but tumor growth could not be controlled and then reoperation and total resection were performed. A third session and then a fourth session of GKR were given.

Regrowth Cases. Reoperation was performed on 3 of the 20 WHO grade I tumor regrowth cases in the follow-up period. The tumor was under control in 1 patient, but 2 of these 3 cases required a third operation because of regrowth.

Eleven of the grade I cases received GKR as first-line adjuvant treatment, and tumor control was achieved in 7 patients. Tumor growth could not be controlled in 4 of these cases, and 1 patient

had a second GKR. Reoperation was performed in 3 patients, and GKR was performed for a second time in 3 patients. One of these 3 patients needed radiotherapy.

Radiotherapy was given to 6 of these 20 patients with grade I regrowth. One of these patients was operated on before the GKR facility was available, 1 patient had neurofibromatosis type 2 with meningiomatosis, and the remaining 4 patients received radiotherapy because of the extracranial and bony components of their residues. Tumor control was achieved in 5 of these 6 patients, but 1 patient needed reoperation, then GKR, then reoperation followed by GKR, reoperation, and a third session of GKR with a follow-up of 303 months.

Three of the 4 patients with grade II meningioma regrowth were given GKR, and 1 patient received radiotherapy. Two of the patients who received GKR also required radiotherapy and then 1 of these patients required reoperation. The other patient who received GKR required a second GKR session, but tumor growth could not be controlled locally. Because of the patient's advanced age and general medical condition, radiotherapy combined with chemotherapy was administered.

Seven patients (5.0%) received radiotherapy as the only adjuvant treatment. Six of these patients had extracranial residual components. One patient had pathologic upgrade and meningiomatosis, so radiotherapy was preferred.

GKR. A total of 22 patients (15.6%) received GKR (33 GKR sessions) during the follow-up period. Fourteen of these patients received 1 session of GKR, whereas 2, 3, and 4 sessions of GKR were performed on 6, 1, and 1 patient, respectively. The mean tumor volume was 5.4 ± 4.1 cm^3. A mean dose of 12.8 ± 1.2 Gy. for 50% isodose was given. Tumor control was achieved in 12 patients (54.5%), whereas the remaining 10 patients (45.5%) required reoperation or other adjuvant treatments.

Follow-up data of the patients with recurrence after the first surgery are summarized in Table 4 and data of patients with regrowth are summarized in Table 5.

Time to Recurrence/Regrowth

The mean follow-up was 70.6 ± 49.3 months (median, 62 months; range, 1–303 months) of the whole series ($n = 141$). There were 14 recurrences and 24 regrowths, and median time to recurrence/regrowth of the overall series was 101 ± 11 months (mean, 105.9 ± 7.8 months; 95% confidence interval [CI], 1–303 months).

The median time to recurrence/regrowth for WHO grade I meningiomas ($n = 120$) was 159 months (mean, 113.4 ± 8.1 months), and 51 ± 2.9 months (mean, 53.3 ± 8.2 months) for grade II meningiomas ($n = 21$). The difference between pathologic grades was statistically significant (95% CI; $P = 0.002$) (Figure 1A).

When the follow-up was analyzed based on the extent of resection (GTR vs. STR) for the whole patient cohort ($n = 141$), the mean time to recurrence of GTR meningiomas ($n = 98$) was 103.0 ± 5.5 months, and the mean time to regrowth of STR meningiomas ($n = 43$) was 69.5 ± 11.4 months (median, 51 ± 11.3 months). The difference between the GTR and STR groups was statistically significant (95% CI; $P = 0.000$) (Figure 1B).

We analyzed the time to recurrence and time to regrowth of grade I meningiomas ($n = 120$) alone, based on the extent of resection. The mean time to recurrence of GTR grade I tumors ($n = 83$) was 109.5 ± 4.9 months (range, 7–303 months), and time to regrowth of STR grade I tumors ($n = 37$) was 72.8 ± 12.5 months (median, 59 ± 29.1 months; range, 7–303 months). The difference was statistically significant (95% CI; $P = 0.000$) (Figure 1C), pointing out the importance of extent of resection of grade I meningiomas.

The same analysis, comparing time to recurrence of GTR grade II meningiomas ($n = 15$) and time to regrowth of STR grade II meningiomas ($n = 6$), was performed. The median time to recurrence was 84 months (mean, 60.1 ± 10.8 months; range, 1–150 months), whereas median time to regrowth was 47 ± 33 months (mean, 36.8 ± 8.7 months; range, 1–150 months), but the difference was not statistically significant (95% CI; $P = 0.367$) (Figure 1D).

We performed analysis for GTR and STR tumors separately as a function of WHO grade. The mean time to recurrence was 109.5 ± 4.9 months (range, 1–157 months) for GTR grade I meningiomas ($n = 83$), whereas mean time to recurrence was 60.1 ± 10.8 months (median, 84.0 ± 0 months; range, 1–157 months) for GTR grade II meningiomas, and the difference was statistically significant (95% CI; $P = 0.000$) (Figure 1E), clarifying the importance of pathologic grade of tumors for recurrence. The same analysis was then carried out for STR tumors ($n = 43$). The median time to regrowth was 59 ± 29.1 months (mean, 72.8 ± 12.5 months; range, 7–303 months) for STR grade I meningiomas ($n = 37$), and the median time to regrowth was 47 ± 33 months (mean, 36.8 ± 8.7 months; range, 7–303 months) for STR grade II meningiomas ($n = 6$). There was no statistically significant difference (95% CI; $P = 0.533$) (Figure 1F).

Evolution and Analysis of the Proposed Scoring System

Univariate analysis showed that all the parameters were significantly associated with Simpson grade of resection ($P < 0.05$) except ACA encasement and grade of edema.

However, no statistically significant relationships were detected by logistic regression analysis for any of the parameters, and then, a scoring system incorporating parameters that can be assessed radiologically was planned.

A 4-tiered scoring system, based on largest tumor diameter, proximal arterial encasement (including supraclinoid ICA encasement and CS involvement), distal arterial encasement (including ACA or MCA encasement), and bone invasion pattern, was developed to predict the extent of resection. The details of the scoring system are described in Table 6. Per patient, scores ranging between 0 and 6 were possible. The proposed scoring system predicts that as score increases, the STR probability increases (Table 3).

DISCUSSION

Surgical management of SWM is challenging because of nearby critical anatomic structures, including major cerebral arteries and the CS. Therefore, these neurovascular structures can limit the extent of resection, which is a determinant for recurrence.[8] In this study, we translated our experience with the SWMs into a scoring system that may provide a preoperative estimation of the extent of resection.

Table 4. Follow-Up Data of the Patients Who Had Recurrence After the First Surgery

	Age/Sex	Group	First-Line Tx*	Time of First-Line Tx†	Second-Line Tx*	Time of Second-Line Tx†	Third-Line Tx*	Time of Third-Line Tx†	Fourth-Line Tx*	Time of Fourth-Line Tx†	Fifth-Line Tx*	Time of Fifth-Line Tx†	Sixth-Line Tx*	Time of Sixth-Line Tx†	Follow-Up (Months)
World Health Organization grade I cases															
1	51/M	Middle	Re-op	32											135
2	17/F	Middle	GKR	69											157
3	37/F	Lateral	Re-op	51											106
4	46/F	SOM	GKR	23											133
5	65/M	Lateral	GKR	53	Re-op‡	77	Re-op	85	RTx§	86					130
6	24/F	Lateral	Re-op advised‖	38											104
7	39/F	Lateral	GKR	47											124
8	17/M	Lateral	GKR	53											114
9	37/F	Lateral	Re-op	75	RTx¶	76									94
World Health Organization grade II cases															
10	20/M	SOM	RTx	49											146
11	58/F	Lateral	Re-op advised#	84											84
12	20/F	Middle	RTx**	7	GKR	51	GKR	79	Re-op	97	GKR	118	GKR	121	150
13	56/M	Medial	GKR advised††	13											64
14	64/F	Medial	GKR	11	GKR	23	RTx‡‡	28							35 (Exitus)

Tx, treatment; M, male; Re-op, reoperation; F, female; GKR, Gamma Knife radiosurgery; SOM, spheno-orbital meningioma; RTx, radiotherapy.
*After the first operation.
†Months after the first operation.
‡Disease upgraded to grade II.
§Disease upgraded to grade III.
‖Patient had neurofibromatosis type 2 with a history of multiple operations and morbidities. The patient accepted no further treatment.
¶Tumor upgrade and meningiomatosis was present in surgeries for meningiomas in different location.
#Reoperation was advised, but the patient accepted no further treatment.
**Disease was grade II and Simpson II resection was achieved. The recurrent tumor was large and had a sheetlike growth along the sphenoid ridge and radiotherapy was given as the first line of treatment.
††The patient did not accept any further treatment.
‡‡The patient had multiple operations for cranial and spinal meningiomas in different locations and the disease was grade III.

Table 5. Follow-Up Data of the Patients Who Had Regrowth After the First Surgery

	Age/ Sex	Group	First-Line Treatment*	Time of the First-Line Treatment†	Second-Line Treatment*	Time of the Second-Line treatment†	Third Line Treatment*	Time of the Third-Line Treatment†	Fourth-Line Treatment*	Time of the Fourth-Line Treatment†	Fifth-Line Treatment*	Time of the Fifth-Line Treatment†	Sixth-Line Treatment*	Time of the Sixth-Line Treatment†	Seventh-Line Treatment*	Time of the Seventh-Line Treatment†	Follow-Up (Months)
World Health Organization grade I cases																	
15	39/F	SOM	Re-op	95													121
16	58/F	SOM	Re-op	11	Re-op	65											98
17	41/F	Medial	Re-op	59	Re-op	82											130
18	51/F	SOM	RTx‡	7	Re-op	17	GKR	118	Re-op	146	GKR	154	Re-op	177	GKR	172	303
19	58/F	Medial	GKR	159													302
20	65/F	Medial	GKR	13													90
21	42/F	SOM	GKR	25	GKR	100											234
22	52/F	Medial	GKR	43													132
23	50/F	Middle	GKR	8													182
24	52/F	SOM	GKR	101													168
25	39/F	SOM	GKR	25	Re-op	35	GKR§	38									154
26	38/F	SOM	RTx$^{\$\$\$}$	10													118
27	67/F	Medial	GKR	30	Re-op	48	GKR§	56	RTx‖	69							114
28	65/F	Medial	GKR	13													89
29	51/F	SOM	RTx¶	23													125
30	52/ M	Medial	GKR	8	Re-op	33	GKR	40									107
31	40/F	SOM	RTx#	11													43
32	40/F	SOM	GKR	19													62
33	48/F	SOM	RTx¶	7													48
34	43/F	SOM	RTx¶	10													49
World Health Organization grade II cases																	
35	70/F	Middle	GKR	47	RTx	55											66
36	67/F	Medial	GKR	14	RTx	28	Re-op	47									93
37	58/F	Medial	GKR	51	GKR	74	RTx+CTx**	97									145
38	42/ M	SOM	RTx¶	8													31

F, female; SOM, spheno-orbital meningiomas; Re-op, reoperation; RTx, radiotherapy; GKR, Gamma Knife radiosurgery; M, male; CTx, chemotherapy.

*After the first operation.

†Months after the first operation.

‡Gamma Knife facility was not available then.

§Subtotal resection was achieved, regrowth was observed, and GKR was given.

‖Tumor control could not be achieved; reoperation was not advised because of the patient's medical condition.

¶Regrowth was seen in the extracranial residual part of the tumor.

#The patient had neurofibromatosis type 2 with a history of multiple operations for meningioma and schwannoma. Radiotherapy was given as a last measure for her meningiomatosis.

**Tumor growth could not be controlled; reoperation could not be performed because of the patient's medical condition. Radiotherapy and CTx. (bevacizumab) were given in the same session.

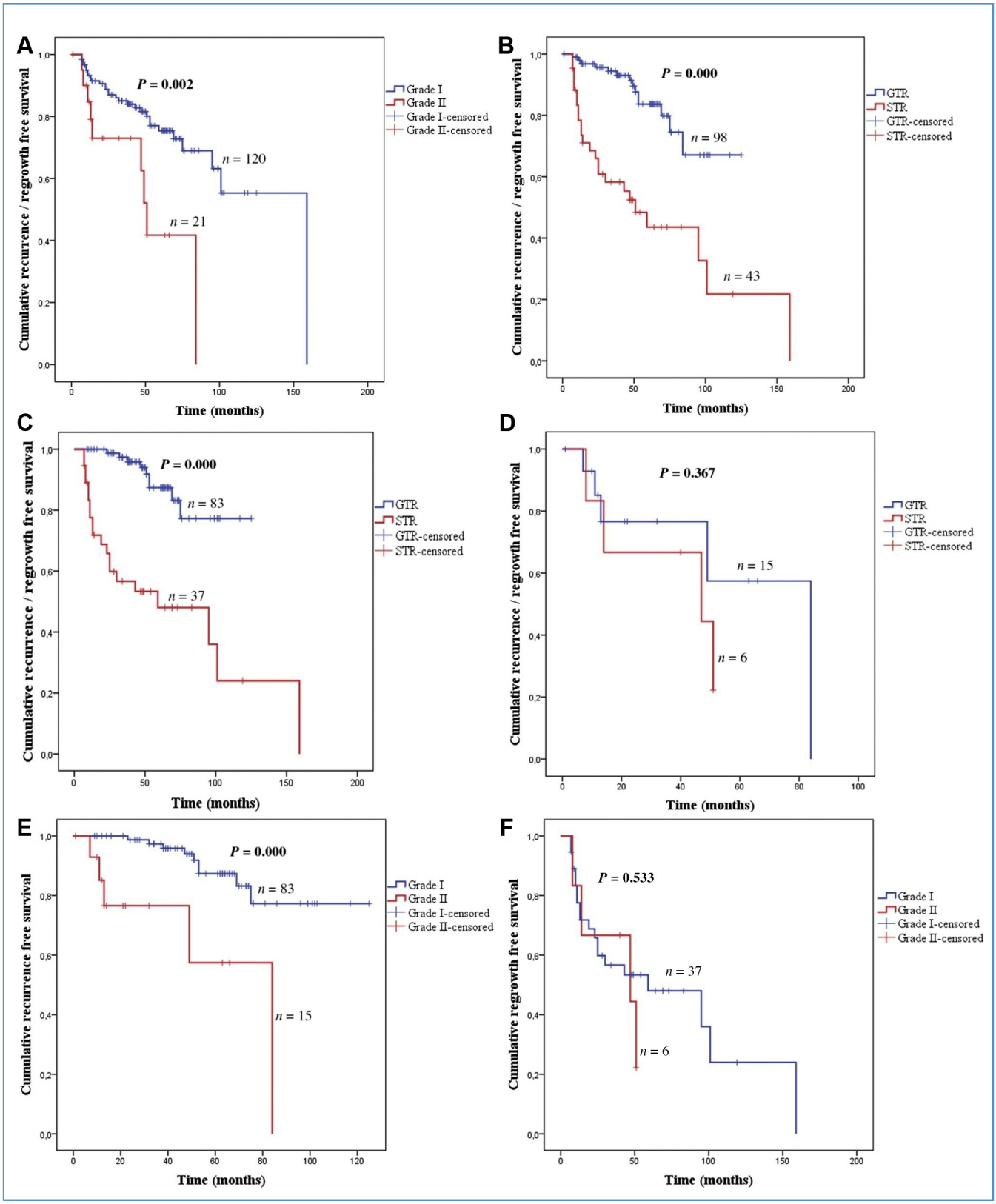
A
P = 0.002
n = 120
n = 21
Grade I
Grade II
Grade I-censored
Grade II-censored
Cumulative recurrence / regrowth free survival
Time (months)
B
P = 0.000
n = 98
n = 43
GTR
STR
GTR-censored
STR-censored
Cumulative recurrence / regrowth free survival
Time (months)
C
P = 0.000
n = 83
n = 37
GTR
STR
GTR-censored
STR-censored
Cumulative recurrence / regrowth free survival
Time (months)
D
P = 0.367
n = 15
n = 6
GTR
STR
GTR-censored
STR-censored
Cumulative recurrence / regrowth free survival
Time (months)
E
P = 0.000
n = 83
n = 15
Grade I
Grade II
Grade I-censored
Grade II-censored
Cumulative recurrence free survival
Time (months)
F
P = 0.533
n = 37
n = 6
Grade I
Grade II
Grade I-censored
Grade II-censored
Cumulative regrowth free survival
Time (months)

Table 6. Proposed Scoring System for Sphenoid Wing Meningiomas

Scoring Parameter	Interpretation	Points	Maximum Score
Diameter category (cm)	≤4	0	1
	>4	1	
Proximal vascular category	No encasement	0	2
	Supraclinoidal internal carotid artery encasement	1	
	Cavernous sinus involvement	2	
Distal vascular category	No encasement	0	1
	Anterior cerebral artery or middle cerebral artery encasement	1	
Bone category	No invasion	0	2
	Hyperostosis or bone invasion*	1	
	Superior orbital fissure, orbita, optic canal invasion extracranial extension	2	

Diameter: 0, tumors with a maximum diameter ≤4 cm in any plane; 1, tumors with a maximum diameter >4 cm in any plane.

Proximal vascular category: 0, tumors with no extension to the cavernous sinus, or encasement of extracavernous internal carotid artery; 1, tumors encasing or enveloping extracavernous (supraclinoidal) internal carotid artery, 2, tumors with any involvement of the cavernous sinus.

Distal vascular category: 0, tumors with vascular encasement of anterior cerebral artery or middle cerebral artery; 1, tumors encasing or enveloping any of A1, A2, M1, M2, M3.

Bone category: 0, tumors with no hyperostosis or lytic bone invasion; 1, *tumors with hyperostosis or bone invasion but does not extend to superior orbital fissure, optic canal, or orbita; 2, tumors showing invasion of any of superior orbital fissure, orbita, or optic canal.

The Cushing classification is still used, but it was described before modern imaging technologies and microsurgical and skull base techniques. It includes anterior clinoidal, primary CS, and sphenopetroclival meningiomas in SWM, which should be considered separate entities because of their unique behavior.[4,9-11] Another drawback of Cushing classification is that it can be difficult to distinguish the exact classification for large tumors spanning >1 location.[12]

Since Cushing's proposal, several investigators have either modified this seminal monograph or suggested new classifications for SWM. Fohanno and Bitar[13] presented 18 cases and divided globoid SWM into 2 groups as medial (located in the medial 1/3 of the sphenoid ridge) and lateral (located in the outer 2/3 of the sphenoid ridge), which essentially was a modification of Cushing's classification. Al-Mefty[9] concluded that anterior clinoidal meningiomas must be grouped separately from medial SWM because of their unique behavior; however, Risi et al.[14] still classified anterior clinoidal meningiomas as medial SWM with 3 subgroups: pure clinoidal, clinoidal with lateral extension, and clinoidal with CS invasion. Lee et al.[15] reported 15 cases of pure anterior clinoidal meningiomas that were operated on using skull base techniques, but these investigators still grouped these anterior clinoidal meningioma cases in the medial SWM group. Abdel-Aziz et al.[16] discussed resectability of medial SWM with CS invasion and classified them into 3 groups, but this work added no new practical information that was different from the classification by Hirsch et al.[17] of CS meningiomas. Nakamura et al.[18] reported 108 medial SWMs out of a series of 256 SWMs and grouped them into 2 groups based on the presence or absence of CS invasion. Russell and Benjamin[12] used these same 2 groups to report their medial SWM series.

SOMs are comparable to en plaque meningiomas of the sphenoid wing of the Cushing classification.[3-6] Castellano et al.[19] advised follow-up for en plaque meningiomas and recommended surgery as a last line of treatment. Bonnal[20] reported 7 cases of SOM out of 21 "invasive meningiomas of the sphenoid wing," describing details of the invaded structures. In Roser et al.'s review article,[21] SOMs were discussed under the heading of "SWMs with osseous involvement," whereas Bikmaz et al.[22] reviewed them under "bone-invasive, hyperostotic sphenoid wing meningiomas." Mariniello et al.[23] grouped SOM into 4 types according to the intraorbital tumor location.

Each of these classification schemes has disadvantages and limitations. Some classification systems are slight modifications of the Cushing classification without adding any significant contribution.[13] Other systems contain detailed subgroupings of SOM and medial SWM. In addition, some systems are complicated, impractical, and involve criteria that are difficult to recognize preoperatively. Such classification systems have not been accepted widely in clinical practice. None of these classification systems can predict the resectability of SWMs.[9,10,20,21]

Reported studies on SWM discuss mainly SOM and medial meningiomas.[2,9,12,14,15,18,19,21-38] Only a few studies have reviewed

Figure 1. Kaplan-Meier charts comparing probability of being recurrence free and regrowth free as a function of World Health Organization (WHO) grades and extent of resection. (**A**) Chart comparing probability of being recurrence/regrowth free as a function of pathologic WHO grade for the whole cohort of 141 patients. There were 29 recurrence/regrowths of WHO grade I meningiomas ($n = 120$), and 9 recurrence/regrowths of grade II meningiomas ($n = 21$). (**B**) Probability of being recurrence/regrowth free as a function of the extent of resection (gross total resection [GTR] vs. subtotal resection [STR]) of the whole cohort of SWM ($n = 141$). There were 14 recurrences of GTR SWM ($n = 98$), while 24 regrowths were observed in subtotally resected SWM ($n = 43$). In (**C**), function of extent of resection, for comparing probability of being recurrence free and regrowth free in WHO grade I SWM ($n = 120$), is presented. There were 9 recurrences of GTR WHO grade I meningiomas, and 20 regrowths of 37 STR WHO grade I meningiomas. (**D**) There were 5 recurrences of 15 GTR WHO grade II meningiomas, and 4 regrowths of 6 STR WHO grade II SWMs. Probability of being recurrence free and regrowth free is compared. (**E**) Probability of being recurrence free is plotted in GTR tumors ($n = 98$) as a function of pathologic WHO grade of SWM. There were 9 recurrent WHO grade I SWMs ($n = 83$), and 5 recurrent WHO grade II meningiomas ($n = 15$). (**F**) Probability of being regrowth free is presented compared with their pathologic WHO grade for STR SWM ($n = 43$). There were 20 regrowths of STR WHO grade I SWM (37) and 4 regrowths of WHO grade II STR meningiomas ($n = 16$) (95% confidence interval).

SWM as an entire group.[1,13,20,21,39,40] Comparing results across SWM studies is difficult, because of discrepant classification systems and divergent clinical and radiologic findings.[21]

Behari et al.[41] proposed a scoring system for predicting the extent of surgical resection in SWM, but their study included only giant medial SWM. Although Behari et al. stated that tumor diameter was an important factor for resection, the inclusion of only giant tumors may confound the results. Furthermore, they did not perform any statistical analyses of their scoring system. In our study, we described a preoperative scoring system that enables surgeons to predict surgical difficulty, resectability, and outcome for all groups of SWM. In this work, 90 patients (63.8%) had a score of 0–2, and all these patients had GTR. The remaining 51 patients (36.2%) had a score of 3–6, and only 8 of these 51 patients (15.7%) had GTR. In patients with a score from 3 to 6, STR can be planned and performed with residual tumor adherent to important neurovascular structures.

The Parameters of the Scoring System

Tumor Diameter. Larger tumors extend to critical neurovascular structures, jeopardizing total excision and increasing the risk of surgical failure.[15,41-43] Furthermore, increasing tumor size is associated with peritumoral edema and pial invasion of the tumor. Participation of pial vessels in the vascular supply of meningiomas can lead to violation of an extrapial dissection plane, which may result in cortical damage and vascular injuries.[44] Ouyang et al.[45] reported an improvement of the Karnofsky Performance Status in patients with smaller tumors. Based on univariate analysis, tumor size was significantly associated with the extent of resection in our study. Forty-two tumors (29.8%) had a diameter $\leq$4 cm and 40 of these (95.2%) were completely resected, whereas the remaining 99 tumors (70.2%) had a diameter >4 cm and GTR was achieved in 58 (58.6%).

CS Involvement. CS involvement is one of the main factors that affect complete resection of SWM. Aggressive resection of meningiomas involving the CS is associated with a high surgical morbidity and even mortality because of disruption of blood supply to cranial nerves and sacrifice or damage of the ICA.[12,14,16,20,42,46-49] Our surgical approach was to resect the intradural part of the tumor but not the intracavernous portion.[50] The dura is a strong barrier and even in huge tumors, we did not see CS involvement. In our series, only 13 patients (9.2%) had CS involvement. Complete resection was not possible in any of these patients.

Arterial Encasement. Injury to the anterior circulation arteries is one of the major causes of mortality and morbidity in previously reported series of SWM.[9,20,44,51,52] Cushing and Eisenhardt[1] suggested that the most important step of tumor removal is dissection of the tumor from vessels at the carotid bifurcation. McCracken et al.[52] described the complete circumferential encasement of the supraclinoid ICA and the M1 and A1 segments as the "deadly triad," which represents a definite indication for STR to prevent postoperative ischemia. When these tumors lack the arachnoid plane between the tumor and associated vessel, resection becomes more difficult, thereby increasing the risk of vascular injury.[9] Encasement of the supraclinoidal ICA was present in 18 cases and 6 (33.3%) were GTR in our series. Encasement of MCA was present in 28 tumors and 12 (42.9%) underwent total resection, whereas ACA encasement was seen in 5 cases and 3 (60%) were totally resected. The rate of vascular injury in our series was 2.5%. Therefore, arterial encasement was implemented to our scoring system.

Bone Invasion/Hyperostosis. Roser et al.[21] showed that hyperostosis or intraosseous tumor masses can be present in all types of SWM, regardless of the morphology and location of the tumor. Osseous involvement was found to have an impact on the extent of resection. Optic canal, SOF, sphenoid body, and orbital extension of the tumor are also considered as a barrier to complete removal of SWM.[27,29,32,48] Considering the intricate relationship between the cranial nerves and the SOF, optic canal, and the orbit, invasion of these structures by tumor increases the risk of morbidity. Furthermore, extracranial extension of the tumor may limit the extent of resection and may be associated with morbidity as well. For this reason, tumoral invasion of bony structures such as the SOF, optic canal, and orbit is associated with higher risk. There were 17 tumors with SOF invasion and none (0%) were totally resected. Twenty-one tumors had optic canal invasion and (19%) were totally resected, and 31 tumors had orbital invasion, and 4 (12.9%) were totally resected.

Because of all these factors, these parameters should be included in the classification system to make a preoperative assessment for extent of resection. The literature and our experience support these limiting factors of resection.

Extent of Resection and Outcome

The total resection rates for medial SWM ranged from 42.5% to 86.7% in recent series.[9,14,15,18,20,40] Nakamura et al.[18] reported that the rate of complete resection depended on presence of cavernous infiltration in these tumors (92.3% vs. 14.5%).[18] This finding was confirmed by Russell and Benjamin.[12] Sughrue et al.[40] reviewed surgical results of globoid tumors and found similar GTR rates between the 3 groups (medial, middle, and lateral). However, Honig et al.[39] achieved the highest rate of complete resection in tumors with lateral location.

In our study, the overall GTR rate was 69.5%. The highest rate of GTR was observed in lateral tumors (100%), followed by middle tumors (94.3%). In contrast, most SOMs were resected subtotally (87.1%). SOMs were significantly associated with STR compared with other groups ($P < 0.05$). The orbital structures and the optic sheath are the major limitations of total resection of SOM. Especially in the earlier series, total resection was rarely possible.[3,19,20] However, modern series reported higher GTR rates ($\leq$83%) for SOM.[23,27-29] Our results are not comparable to these reports. With orbital involvement, it is difficult to achieve GTR because of strong attachment of the tumor to intraorbital structures. Our GTR rate in patients with SOM was 12.9%.

The mortality and morbidity of medial SWM have decreased over the last 3 decades as a result of advances in cranial base techniques, microsurgical approaches, neuroimaging, and neuroanesthesia.[12,14-16,18,20] Mortality varied between 0% and 43%. Postoperative mortality of SOM ranged from 0% to 14% in recent

series.[3,20-22,26,28] In our study, the mortality was 0.6% ($n = 1$), which was associated with massive pulmonary embolus on postoperative day 9; in addition, the patient had a medial tumor. Russell and Benjamin[12] found an overall 18% morbidity with medial SWM. The major morbidity with globoid tumors is cranial neuropathy, which mainly involves the third cranial nerve and is typically seen in medial tumors.[12,18,40] Sughrue et al.[40] reported no significant difference in neurosurgical complication rates between globoid tumors with respect to their location. However, medial location was predictive of a higher risk of new or worsened neurologic deficit (19%), which was attributed to the propensity of these tumors to invade the optic canal, encase major vessels, and invade the CS along the path of the cranial nerves.[40] Honig et al.[39] reported a higher risk of cranial nerve deficits in SOM in addition to medial tumors. In our series, supporting these findings, ophthalmoplegia associated with oculomotor or abducens palsy was observed only in the medial group of tumors. Morbidity associated with SOM included cranial nerve palsies (particularly of the third nerve) in up to 30% of patients.[3,26,29,31,32] In our study, no complications were observed for patients with SOM. Our conservative approach with these tumors is the main reason for our low complication rates.

Limitations

The interrater reliability was not calculated. In addition, a single neurosurgeon performed the operations. Therefore, it is not possible to know whether the surgical results are independent from the skills and experience of the surgeon.

CONCLUSIONS

SWMs comprise a large group, with subtypes having distinct characteristics. Lateral SWM can usually be approached like a convexity meningioma, whereas SOM may need skull base techniques.

The scoring system can be useful to predict extent of resection. It will be helpful for surgical decision making in SWM, which may guide for planning intentional STR and postoperative follow-up.

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