

Medial Sphenoid Wing Meningiomas: Surgical Excision and Recurrence — A Comprehensive Review

Radwan Nouby Mahmoud¹, Ali R. Hamdan², Ahmed G. Tammam^{2*}, Ali Kotb Ali³

1: Neurosurgery Department, Faculty of Medicine, Assuit University, Assuit, Egypt.

2: Neurosurgery Department, Faculty of Medicine, Qena University, Qena, Egypt.

3: Neurosurgery Department, Faculty of Medicine, Ain Shams University, Cairo, Egypt.

*Corresponding Author: Ahmed G. Tammam, ORCID: 0000-0002-2508-7574

Abstract

Medial sphenoid wing (MSW) meningiomas are challenging skull-base tumors because their dural attachment is closely related to the optic apparatus, supraclinoid internal carotid artery (ICA) and its branches, anterior clinoid process, cavernous sinus, superior orbital fissure, and cranial nerves. Although most meningiomas are histologically benign and slow growing, MSW tumors may produce substantial visual, neurological, and functional morbidity, and their surgical management requires a balance between extent of resection and preservation of critical neurovascular structures. This review summarizes the relevant anatomy, epidemiology, pathology, clinical presentation, radiological assessment, surgical principles, complications, recurrence, and established or emerging prognostic factors relevant to MSW meningioma. Particular emphasis is placed on tumor size, location, vascular and cavernous sinus involvement, optic canal invasion, tumor shape, extent of resection, WHO grade, proliferative and molecular markers, and postoperative management. Contemporary evidence supports a shift from indiscriminate radical resection toward maximal safe resection tailored to tumor biology and neurovascular relationships, with adjuvant radiotherapy or surveillance selected according to residual disease, grade, and recurrence risk.

Keywords: Sphenoid Wing; Meningioma; Visual Outcome; Recurrence; Prognostic Factors.

Introduction

Meningiomas are predominantly slow-growing extra-axial tumors arising from arachnoid cap cells and represent one of the most common primary intracranial neoplasms. Epidemiological studies consistently demonstrate a female predominance and increasing incidence with age, while hormonal, genetic, and environmental factors have been investigated as possible contributors [1, 2]. wing meningiomas constitute an important subgroup of supratentorial meningiomas and are commonly classified according to their relationship to the sphenoid ridge into lateral, middle, and medial types [3].

MSW meningiomas arise from the medial sphenoid ridge and frequently extend toward the anterior clinoid, optic canal, parasellar region, cavernous sinus, and carotid cistern. Their defining surgical problem is not simply tumor size, but the intimate relationship between tumor, optic pathways, ICA, anterior cerebral and middle cerebral circulation, perforating vessels, cavernous sinus, and cranial nerves. Consequently, complete tumor removal may be technically possible in some patients but unsafe in others. Modern treatment therefore emphasizes individualized maximal safe resection rather than an absolute requirement for anatomical radicality [4, 5].

Historically, skull-base meningioma surgery was associated with substantial mortality and neurological morbidity. Improvements in microsurgical anatomy, skull-base drilling, neuroimaging, intraoperative visualization, and postoperative care have markedly improved outcomes. Nevertheless, recurrence and postoperative visual or vascular complications remain clinically important, particularly when the tumor encases arteries or invades the cavernous sinus [6, 7].

Anatomical Basis of Surgical Difficulty

The sphenoid bone forms a central component of the anterior and middle cranial fossae. Its lesser wing continues medially into the anterior clinoid process (ACP), while the optic canal lies between the roots of the lesser wing. The optic strut forms the inferolateral root of the ACP and separates the optic canal from the superior orbital fissure. The ACP may contain cancellous bone and, in some individuals, air cells communicating with the sphenoid sinus; therefore, anterior clinoidectomy requires detailed preoperative assessment of pneumatization and careful management of any opened air cell (Fig 1, 2) [8].

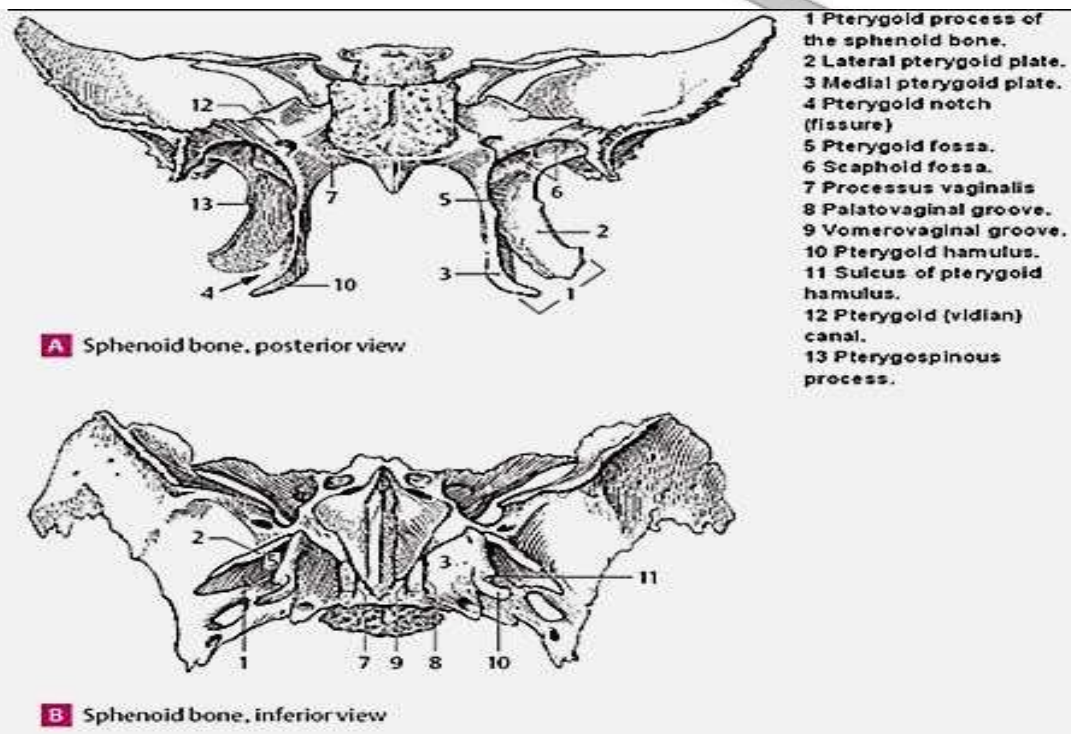


Figure 1: Sphenoid bone anatomy (Posterior and inferior views) [9].

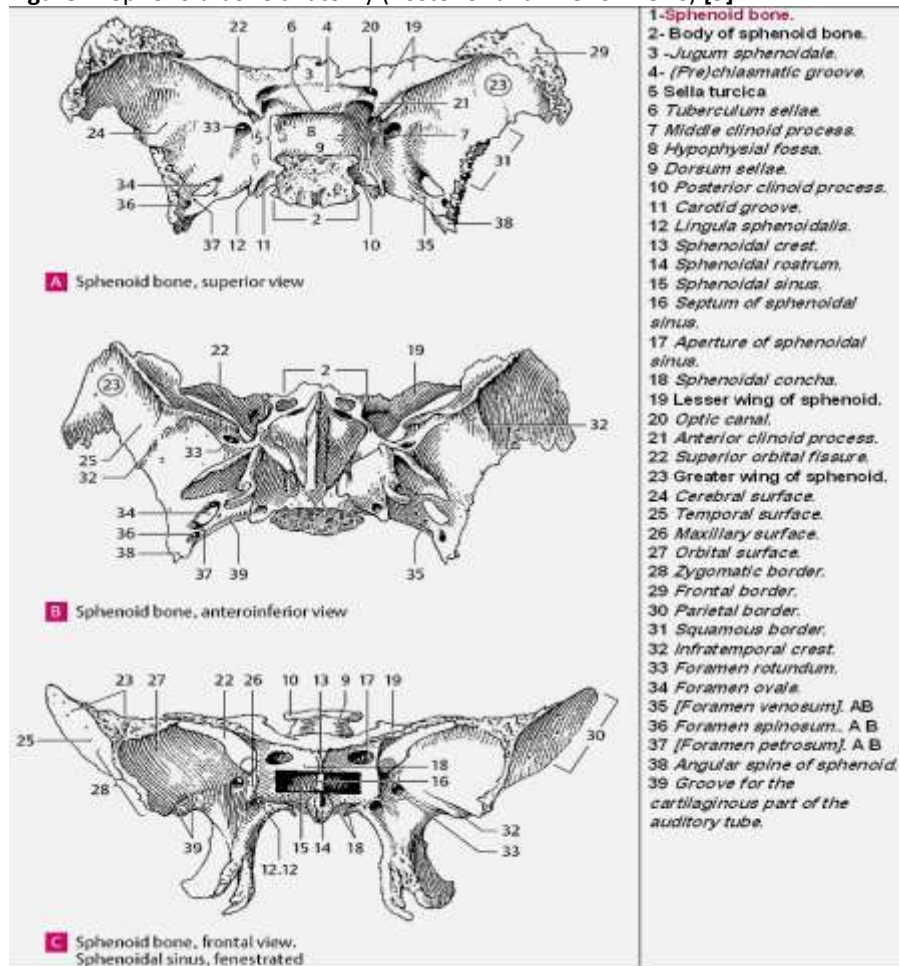


Figure 2: Anatomy of sphenoid bone [9].

The optic nerve, ophthalmic artery, and clinoidal ICA are central structures in MSW surgery. The optic nerve passes immediately medial to the ACP and above the optic strut. The ophthalmic artery commonly arises from the medial aspect of the ICA near the upper dural ring and travels beneath the optic nerve toward the optic canal. The clinoidal ICA is surrounded by the carotid collar and upper and lower dural rings, which create important surgical planes during clinoidectomy and tumor mobilization [8, 10].

The cavernous sinus is another critical structure. It contains the cavernous ICA and is closely related to cranial nerves III, IV, V1, V2, and VI. The superior orbital fissure contains cranial nerves III, IV, VI, and the ophthalmic division of the trigeminal nerve together with orbital venous structures. Small anatomical variations can substantially influence the safety of tumor dissection [11, 12].

The anterior basal cisterns and Sylvian fissure provide important arachnoid planes for skull-base surgery. The carotid and chiasmatic cisterns contain the supraclinoid ICA, ophthalmic artery, posterior communicating artery, anterior choroidal artery, optic nerves, chiasm, and small perforators. Preservation of these arachnoid planes permits cerebrospinal fluid release and facilitates brain relaxation without excessive retraction. The pterional approach exploits these natural corridors to access the medial sphenoid region [13, 14].

Epidemiology and Etiology

Meningiomas account for a substantial proportion of primary intracranial tumors, with population studies showing a predominance in women and increasing incidence with age. Many lesions are now detected incidentally because of the widespread use of MRI [1, 2]. Established risk factors include prior ionizing radiation, while associations with sex hormones have been extensively investigated. The biological basis of the female predominance is supported by frequent hormone receptor expression, although receptor positivity does not by itself establish causation [15].

Molecular studies have substantially changed the understanding of meningioma biology. Recurrent alterations include NF2-associated pathways as well as mutations involving AKT1, SMO, PIK3CA and other signaling pathways. Molecular subgroups can differ in their biological behavior and recurrence risk, and molecular classification is increasingly relevant to prognostication beyond conventional histopathology [16, 17]. In addition, TERT promoter alterations have been associated with adverse biological behavior, while molecular subgroup has been linked to recurrence independent of some conventional clinicopathological variables [18, 19].

Pathology and Biological Behavior

Most meningiomas are WHO grade 1 tumors with relatively indolent behavior, but atypical and anaplastic lesions demonstrate progressively greater proliferative activity and recurrence potential. Histological assessment considers cellularity, mitotic activity, architecture, necrosis, brain invasion, and specific morphological features. Brain invasion has particular prognostic relevance and has influenced modern grading concepts [20, 21].

The proliferative index Ki-67/MIB-1 is frequently investigated as an adjunctive prognostic marker. Higher Ki-67 values generally correlate with increased proliferative activity and recurrence risk, although the exact threshold and prognostic performance vary between studies and laboratories [22]. The combined assessment of Ki-67 with other markers, including p53, may improve recurrence prediction in selected populations [23].

Molecular biomarkers are increasingly important. TERT promoter mutations, specific molecular subgroups, and other genomic alterations can identify tumors with behavior that is not fully explained by anatomical extent or WHO grade alone [18, 19]. Therefore, future prognostic assessment of MSW meningiomas is likely to integrate clinical, radiological, histological, and molecular variables.

Anatomical Classification of Sphenoid Wing and Medial Sphenoid Wing

Meningiomas

Sphenoid wing meningiomas may be described as lateral, middle, or medial according to the site of dural attachment along the sphenoid ridge [24]. Medial lesions are closely related to the anterior clinoid and parasellar structures and may be further characterized by their extension into the optic canal, cavernous sinus, orbital apex, carotid cistern, or middle cranial fossa.

From a surgical perspective, the most useful classification is often based on relationships to critical structures rather than a single anatomical label. Important descriptors include tumor size, degree of ICA encasement, arterial narrowing or displacement, optic canal involvement, cavernous sinus extension, anterior clinoid involvement, hyperostosis, orbital extension, and the presence or absence of a preserved arachnoid plane. Three-dimensional multimodality imaging has

been used to construct predictive scoring systems for extent of resection, emphasizing that anatomical complexity can be quantified before surgery [25].

Clinical Presentation

The clinical presentation depends on tumor size, growth rate, and the structures compressed or invaded. Headache and visual impairment are among the most characteristic symptoms because of the close relationship to the optic nerve and optic canal. Visual deficits may include reduced visual acuity, visual-field loss, or both. Prolonged optic nerve compression can produce optic atrophy and limits the possibility of postoperative visual recovery [26].

Cranial neuropathies may occur when the tumor extends into the cavernous sinus or superior orbital fissure. Oculomotor, trochlear, ophthalmic trigeminal, and abducens dysfunction may result in diplopia, ophthalmoplegia, facial sensory symptoms, or corneal sensory impairment. Large tumors may compress the temporal or frontal lobes and cause seizures, cognitive or behavioral changes, dysphasia, or contralateral motor deficits. Hyperostosis or orbital involvement can produce proptosis, orbital pain, or cosmetic deformity [3, 27].

Preoperative functional status is relevant to prognosis. Performance scales such as the Karnofsky Performance Status can capture overall neurological and functional reserve and may influence postoperative recovery. Long-standing visual loss, advanced age, large tumor size, and severe preoperative neurological impairment may limit functional improvement even when technically successful resection is achieved [28, 29].

Radiological Evaluation

MRI with gadolinium is the principal imaging modality for diagnosis and surgical planning. Typical meningiomas are extra-axial, well-defined lesions with strong enhancement and may demonstrate a dural tail. T1- and T2-weighted signal characteristics are often relatively similar to gray matter, although calcification, cystic change, necrosis, and unusual histological variants may alter the appearance [3].

For MSW meningiomas, routine MRI should be supplemented by detailed assessment of the optic canal, cavernous sinus, orbital apex, ICA and its branches, and the relationship between tumor and brain. High-resolution imaging can demonstrate arterial encasement or narrowing, while CT is particularly useful for defining hyperostosis, calcification, bony destruction, and the anatomy of the sphenoid sinus and ACP. CT angiography or MR angiography can assist in evaluating vascular relationships, and catheter angiography remains useful in selected cases when vascular anatomy or preoperative embolization requires detailed assessment.

Tumor morphology may have prognostic relevance. Recent work has suggested that irregular tumor shape is associated with postoperative cranial nerve function, proliferative behavior, and progression-free survival, highlighting the value of quantitative radiological characterization beyond conventional tumor diameter [30]. Radiomic and shape-related features may also contribute to prediction of postoperative vision-related quality of life [31].

Principles of Surgical Management

Surgery remains the principal treatment for symptomatic or enlarging MSW meningiomas in patients who are appropriate surgical candidates. The central objective is maximal safe tumor control while preserving vision, arterial flow, cranial nerve function, and quality of life. The traditional goal of gross-total removal has therefore been modified by the recognition that a small residual tumor in a high-risk location may be preferable to injury to the optic nerve, ICA, or perforating arteries [5, 32].

The pterional approach provides broad access to the sphenoid ridge, Sylvian fissure, anterior cranial base, optic nerve, and parasellar region. Its effectiveness depends on appropriate positioning, low anterior and sphenoid drilling, adequate Sylvian fissure opening, and early identification of the optic nerve and carotid artery. Extended pterional and orbitopterional/orbitozygomatic variants may improve the surgical angle for large or giant lesions while reducing the need for fixed brain retraction (Fig 3) [33-35].



Figure 3: Endocranial surface of the anterior and middle cranial base [10].

Anterior Clinoidectomy and Optic Canal Decompression

Anterior clinoidectomy is a key component of many MSW operations. Removal of the ACP can expose the clinoidal ICA, increase the working corridor around the optic nerve, and permit mobilization of the tumor from the optic canal and parasellar dura. The technique may be intradural, extradural, or hybrid. A two-step hybrid strategy combines advantages of both techniques while allowing controlled bone removal and visualization of critical structures [36].

Optic canal unroofing is particularly important when the tumor extends into or compresses the canal. However, the decision to drill the optic canal should be individualized. Excessive drilling can expose the optic nerve and its vascular supply to thermal or mechanical injury, whereas insufficient decompression may leave the nerve compressed or prevent adequate tumor mobilization [37]. Recent surgical literature emphasizes early optic nerve decompression and preservation of its arachnoid and vascular planes as important strategies for visual function preservation [38].

Management of Vascular Encasement

ICA and arterial encasement are among the most important determinants of resectability. Large or giant MSW tumors may surround the ICA, anterior cerebral artery, middle cerebral artery, or their branches. When the artery is merely displaced and separated from the tumor by arachnoid, dissection can often be performed safely. In contrast, circumferential encasement, arterial narrowing, loss of the arachnoid plane, or adherence to perforators markedly increases the risk of vascular injury and ischemic complications [39].

The surgeon should distinguish tumor invasion from arterial encasement without true wall invasion. Sharp dissection under direct visualization and preservation of perforating vessels are essential. Iatrogenic ICA injury is rare but potentially catastrophic and may require temporary control, repair, trapping, or bypass depending on the circumstances and collateral circulation [40]. These considerations explain why a small residual tumor adherent to a major vessel can represent a deliberate and appropriate component of maximal safe resection.

Cavernous Sinus Involvement

Cavernous sinus invasion creates a distinct therapeutic dilemma because aggressive resection may expose the patient to cranial nerve deficits, venous bleeding, ICA injury, and carotid-cavernous complications. Contemporary strategies often favor conservative management of cavernous sinus tumor when complete removal would require unacceptable neurological risk. Residual disease can be observed or treated with focused radiation depending on tumor grade, growth, symptoms, and patient-specific factors [41].

The presence of cavernous sinus involvement should therefore be regarded as both an anatomical and prognostic variable. It can reduce the likelihood of gross-total resection and may influence postoperative cranial nerve outcomes. Importantly, the objective is not simply to remove every visible tumor fragment but to achieve durable disease control with acceptable morbidity.

Extent of Resection and the Concept of Maximal Safe Resection

Extent of resection remains one of the most important modifiable surgical variables. Simpson's classical grading system established the historical relationship between completeness of resection and recurrence [42]. However, skull-base meningiomas challenge the assumption that the most extensive resection is always the safest or most beneficial strategy.

Large series of sphenoid wing and MSW meningiomas demonstrate that tumor size, vascular encasement, cavernous sinus involvement, optic canal extension, and the quality of the arachnoid plane influence the feasibility of complete removal [6, 25]. Verma et al. [7] emphasized that modern microsurgical techniques can achieve favorable outcomes, but the risks of aggressive dissection must be balanced against neurological preservation.

Recent studies reinforce the concept of maximal safe resection. Seaman et al. [5] described the practical limits of resection in sphenoid wing tumors, while Sahu et al. [32] emphasized the relationship among extent of resection, visual outcome, and vascular injury. Thus, the meaningful surgical endpoint is individualized tumor control rather than a universal radiological definition of "total" resection.

Visual Outcomes

Visual function is one of the most important outcome measures in MSW surgery. The principal determinants of visual recovery include preoperative visual status, duration of visual symptoms, degree of optic nerve compression, optic canal invasion, tumor consistency and vascularity, and the preservation of the nerve's blood supply and arachnoid plane. Chaichana et al. [26] demonstrated that preoperative factors can predict postoperative visual outcome, supporting early diagnosis and treatment before irreversible optic neuropathy develops.

Visual deterioration may occur because of direct manipulation, thermal injury during drilling, interruption of small pial vessels, excessive optic nerve mobilization, or postoperative vascular compromise. Surgical techniques that provide early optic nerve decompression and avoid unnecessary manipulation may reduce these risks [38]. More recent work also recognizes vision-related quality of life as an outcome distinct from simple visual acuity or field measurements [31].

Other Postoperative Complications

Potential complications include neurological deterioration, cranial nerve palsy, vascular injury, ischemic stroke, hemorrhage, seizures, cerebrospinal fluid leakage, infection, venous injury, and cosmetic complications. Skull-base drilling can expose air cells or the frontal or sphenoid sinus, creating a potential pathway for CSF leakage or infection. Careful reconstruction is therefore important [43].

Preoperative embolization may reduce tumor vascularity and intraoperative blood loss in selected highly vascular skull-base meningiomas. However, embolization itself carries risks, including ischemic complications and cranial nerve injury, and should therefore be reserved for carefully selected lesions in experienced centers [44, 45].

Prognostic Factors

Prognostic factors in MSW meningioma can be divided into patient-related, tumor-related, surgical, histopathological, and molecular factors.

Patient-related factors include age, preoperative functional status, comorbidity, and duration or severity of neurological and visual symptoms. Older age and poor baseline function may be associated with less favorable postoperative recovery, although their influence must be interpreted alongside tumor anatomy and biological behavior [28].

Tumor-related factors include size, location, shape, hyperostosis, optic canal invasion, cavernous sinus extension, vascular encasement, arterial narrowing, and loss of the arachnoid plane. Large and giant tumors with vascular involvement are particularly challenging and are associated with greater surgical complexity [39]. Irregular shape has also emerged as a potentially relevant marker of cranial nerve outcome and progression-free survival [30].

Surgical factors include extent of resection, preservation of the optic apparatus, vascular preservation, and management of residual tumor. Extent of resection remains strongly related to recurrence, but its interpretation must account for anatomical constraints. A subtotal resection performed deliberately to avoid major neurovascular injury may represent a favorable functional strategy even if it is not a Simpson grade I resection [5, 6].

Histopathological factors include WHO grade, mitotic activity, brain invasion, necrosis, and proliferative index. Ki-67/MIB-1 has demonstrated prognostic value in multiple studies, while combined biomarker approaches may improve risk stratification [22, 23]. Molecular variables, including TERT promoter mutation and molecular subgroup, may further identify tumors with increased recurrence risk [18, 19].

Recurrence and Its Predictors

Recurrence is a central long-term concern after meningioma surgery. Simpson's classic observations established the importance of residual tumor, but recurrence is now recognized as a multifactorial process involving residual volume, biological grade, tumor location, proliferative activity, and molecular characteristics [42].

MSW tumors are particularly susceptible to residual disease because tumor may remain intentionally around the ICA, optic apparatus, cavernous sinus, or cranial nerves. Nakamura et al. [46] reported that MSW meningiomas can achieve favorable clinical outcomes but remain associated with a clinically relevant recurrence risk. Güdük et al. [6] further demonstrated that anatomical factors influence the ability to achieve complete resection and consequently affect long-term control.

Radiological and histological variables may interact. Hwang et al. [47] suggested that imaging and extent of surgical resection can predict recurrence better than WHO grade alone in some meningioma populations. This supports a multidimensional model in which postoperative residual tumor volume and anatomical location are integrated with pathological and molecular risk.

Vascular endothelial growth factor expression has also been associated with meningioma recurrence and tumor vascularity [48]. More recent molecular research indicates that molecular subgroup can provide additional information regarding recurrence beyond conventional classification [19]. Accordingly, recurrence surveillance should be individualized and long-term, especially in patients with residual tumor, higher-grade histology, high proliferative indices, or adverse molecular findings.

Adjuvant and Salvage Treatment

Observation is appropriate for selected small, asymptomatic, stable, or intentionally residual tumors, particularly when the risk of reoperation is high. Serial MRI provides the principal method of surveillance. When residual or recurrent tumor demonstrates progression, treatment options include repeat surgery, stereotactic radiosurgery, fractionated radiotherapy, or systemic approaches in selected high-grade or refractory cases.

Radiation is particularly relevant for residual or recurrent higher-grade disease and for skull-base remnants that are surgically inaccessible or associated with high morbidity. The decision should incorporate tumor grade, growth rate, residual volume, previous treatment, and proximity to radiosensitive structures such as the optic apparatus.

Systemic therapy has historically had a limited role in benign meningioma. Agents such as hydroxyurea have been explored for recurrent or radiation-refractory tumors, although their efficacy is variable and they are generally considered salvage rather than primary therapy [49].

Current Concept of Prognostic Assessment

The prognostic assessment of MSW meningioma should not rely on a single variable. A clinically useful framework integrates: (1) patient age and baseline function; (2) preoperative visual and neurological status; (3) tumor size and morphology; (4) optic canal, orbital, and cavernous sinus extension; (5) ICA and branch encasement or narrowing; (6) presence of a preserved arachnoid plane; (7) extent of resection; (8) WHO grade and histopathological features; (9) Ki-67 and selected immunohistochemical markers; and (10) molecular alterations when available.

This integrated approach is especially important because the same anatomical extent can have different prognostic implications depending on tumor biology and surgical planes. Conversely, a biologically indolent tumor may be difficult to remove completely because of its relationship to the ICA or cavernous sinus. The most clinically meaningful outcome is therefore a combination of durable tumor control, preservation or improvement of vision, avoidance of major neurological morbidity, and maintenance of quality of life.

Implications for the Present Thesis

The thesis objective—to identify and evaluate prognostic factors associated with surgical excision of MSW meningioma and recurrence—is strongly supported by the contemporary literature. The anatomical and clinical literature indicates that MSW meningiomas are particularly suitable for a prognostic model because their outcomes are influenced by both measurable preoperative variables and surgical decisions. Important variables for evaluation include age, sex, presenting symptoms, duration of visual impairment, tumor size, side, radiological characteristics, optic canal involvement, cavernous sinus extension, vascular encasement, preoperative neurological and functional status, extent of resection, postoperative neurological and visual outcome, histopathological grade, and recurrence during follow-up.

The literature also suggests that recurrence should not be interpreted solely as a consequence of incomplete surgery. Residual disease is often intentionally left when the tumor is densely adherent to critical neurovascular structures. Consequently, recurrence analysis should consider the reason for subtotal resection, residual location and volume, histological grade, proliferative index, and molecular or immunohistochemical markers when available. Such an approach can distinguish technically unavoidable residual disease from biologically aggressive recurrence.

Critical Synthesis: What Determines Outcome?

The most important lesson from the modern literature is that outcome in medial sphenoid wing (MSW) meningioma is not determined by tumor size, Simpson grade, or WHO grade in isolation. Surgical risk and long-term control arise from the interaction between tumor anatomy, neurovascular relationships, tumor biology, and the strategy selected to balance resection against neurological preservation. Large tumors are more likely to distort the optic apparatus, encase the internal carotid artery (ICA), involve the cavernous sinus, and obscure normal arachnoid planes, but two tumors of similar diameter may have very different resectability depending on these relationships [6, 25, 39].

Integrated Prognostic Framework

A clinically useful prognostic model should integrate seven domains: patient reserve, clinical status, tumor anatomy, vascular relationships, surgical treatment, pathological behavior, and molecular biology. This approach is more informative than relying on a single variable because it separates the probability of safe resection from the probability of functional recovery and the probability of future tumor progression.

Domain	Key variables	Main prognostic meaning	Clinical consequence
Patient	Age, KPS, comorbidity	Functional reserve	Tolerance of surgery and recovery
Clinical	Visual function, cranial neuropathy, symptom duration	Chronicity/severity of neural injury	Potential for postoperative recovery
Tumor anatomy	Size, shape, optic canal, cavernous sinus, orbital extension	Technical complexity	Resectability and morbidity
Vascular	ICA encasement/narrowing, branch or perforator involvement	Risk of ischemic injury	Safe extent of resection
Surgical	Extent of safe resection, optic decompression, residual site/volume	Residual tumor burden	Tumor control and functional outcome
Pathology	WHO grade, mitoses, brain invasion, Ki-67	Biological aggressiveness	Progression/recurrence risk
Molecular	TERT, methylation, molecular subgroup	Risk beyond conventional histology	Long-term recurrence stratification

The Visual Prognostic Axis

Visual outcome deserves separate consideration because preservation of vision is often more clinically important than radiological completeness. Preoperative visual loss, duration of symptoms, optic canal invasion, optic nerve atrophy, and the relationship of the tumor to the ophthalmic artery and small pial vessels influence the likelihood of postoperative recovery. Early decompression before irreversible optic neuropathy develops is therefore a major therapeutic principle [26, 38].

Optic canal decompression and anterior clinoidectomy can improve the working corridor and reduce fixed compression, but drilling itself introduces potential thermal or mechanical injury. The operative objective is consequently not simply to remove bone, but to create sufficient exposure while protecting the optic nerve, its vascular supply, and surrounding arachnoid planes [36, 37].

Visual quality of life should also be distinguished from visual acuity alone. A patient may retain measurable acuity yet experience substantial functional impairment because of field loss or binocular visual dysfunction. Contemporary outcome assessment should therefore consider both objective visual measures and patient-centered functional consequences [31].

Vascular Encasement: The Major Surgical Boundary

ICA encasement is one of the clearest markers of surgical complexity. Circumferential encasement, arterial narrowing, branch involvement, or disappearance of the arachnoid plane may indicate a substantially higher risk of arterial injury than simple vessel displacement. The distinction is important because displacement often permits safe dissection, whereas true adherence or invasion may make radical removal hazardous [39].

Perforating arteries deserve particular attention because their injury can cause small but strategically devastating infarctions. The surgeon must therefore prioritize preservation of arterial flow over removal of adherent tumor whenever further dissection threatens the parent artery or perforators. In selected cases, residual disease along the vessel can subsequently be monitored or treated with radiation [5, 40].

Cavernous Sinus Disease: Control Without Unnecessary Morbidity

Cavernous sinus involvement creates a characteristic trade-off between radicality and cranial nerve preservation. The cavernous sinus contains the ICA and cranial nerves III, IV, V1, V2, and VI; therefore, aggressive dissection may convert anatomically limited residual disease into permanent ophthalmoplegia, sensory loss, or vascular complications. Contemporary management frequently favors maximal safe extracavernous resection followed by surveillance or focused radiotherapy when residual tumor is progressive or clinically significant [41, 46].

The prognostic implication of cavernous sinus invasion is consequently twofold: it reduces the probability of complete resection and can increase postoperative morbidity. Its presence should be recorded as a major anatomical variable in prognostic studies rather than simply being incorporated into a generic location category.

Recurrence: A Multifactorial Biological and Surgical Endpoint

Recurrence after MSW meningioma surgery reflects both residual tumor and intrinsic biological behavior. Simpson's original observations established the relationship between extent of resection and recurrence, but modern evidence shows that residual volume, residual location, histological grade, proliferative activity, and molecular profile all contribute [42, 47].

Residual tumor is particularly common when MSW lesions involve the cavernous sinus, ICA, optic apparatus, or cranial nerves. For this reason, recurrence analysis should distinguish unavoidable residual disease from incomplete resection that could have been safely avoided. Residual location and volume should be reported whenever possible because a small remnant in a high-risk skull-base compartment has a different clinical meaning from a larger, surgically accessible remnant [6, 19].

Biological markers add another dimension. Ki-67/MIB-1 correlates with proliferative activity and has been associated with recurrence in multiple series, while TERT promoter alterations and molecular subgroups may identify tumors with unexpectedly aggressive behavior despite conventional histological classification [18, 19, 22].

Controversies and Areas Where Evidence Remains Incomplete

Whether every MSW meningioma should undergo gross-total resection remains unresolved. The contemporary trend is toward maximal safe resection, but the exact boundary between beneficial residual tumor and undertreatment is individualized and depends on anatomy, biology, patient age, symptoms, and available postoperative treatment options [5, 32].

The optimal management of stable residual WHO grade I tumor is also not uniform. Observation avoids radiation exposure and additional treatment, whereas early radiation may be considered in selected high-risk or progressive remnants. Evidence does not support treating all residual tumors identically; growth kinetics and anatomical risk should influence the decision [41].

Future Direction: From Anatomical Classification to Precision Prognostication

The next generation of MSW meningioma research is likely to combine high-resolution anatomical imaging with quantitative tumor shape, vascular relationships, pathological proliferation, and molecular classification. Shape-related imaging variables may provide additional information regarding cranial nerve outcomes and progression, while molecular profiling can reveal biological risk not captured by conventional microscopy [17, 25, 30].

Conclusion

Medial sphenoid wing meningiomas remain among the most demanding skull-base tumors because they develop in a region where the optic nerves, ICA and its branches, cavernous sinus, superior orbital fissure, and cranial nerves converge within a narrow anatomical space. Advances in microsurgical anatomy, skull-base approaches, anterior clinoidectomy, optic canal decompression, vascular imaging, and postoperative management have substantially improved safety and functional outcomes. Nevertheless, the risk of visual deterioration, vascular injury, cranial neuropathy, residual tumor, and recurrence remains significant.

Current evidence supports individualized maximal safe resection rather than routine pursuit of anatomical radicality at the expense of neurological function. Prognosis is determined by an interaction among patient characteristics, preoperative visual and neurological status, tumor size and morphology, vascular and cavernous sinus involvement, extent of resection, pathological grade, proliferative activity, and molecular biology. Long-term surveillance is essential, particularly when residual tumor is intentionally retained or adverse pathological or molecular features are present. A

comprehensive prognostic model incorporating these variables may improve patient counseling, surgical planning, postoperative surveillance, and selection of patients who may benefit from adjuvant treatment.

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