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# Contemporary Endoscopic Treatment of Pituitary and Parasellar Lesions: From Diagnosis to Outcome Assessment

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## ABSTRACT

***Background*:** Pituitary and parasellar lesions constitute a diverse group of pathological entities that frequently involve critical neurovascular and endocrine structures within the sellar region. These lesions include pituitary neuroendocrine tumors (PitNETs), craniopharyngiomas, Rathke cleft cysts, tuberculum sellae meningiomas, and other suprasellar pathologies that may present with visual impairment, hormonal dysfunction, headaches, and symptoms related to mass effect. Over the last three decades, endoscopic endonasal surgery has revolutionized the management of these lesions, providing a minimally invasive route that offers superior visualization, improved illumination, and expanded access to the skull base compared with traditional microscopic approaches. Technological advances in endoscopic optics, neuronavigation, surgical instrumentation, and skull base reconstruction have further enhanced the safety and effectiveness of these procedures.

Accurate diagnosis and treatment planning require a comprehensive understanding of the biological behavior, radiological characteristics, and endocrine implications of pituitary and parasellar lesions. Recent developments, including the 2022 World Health Organization classification of pituitary neuroendocrine tumors, have improved the understanding of tumor heterogeneity and prognostic factors, facilitating more individualized treatment strategies. In parallel, increasing clinical experience with endoscopic surgery has generated substantial evidence regarding surgical outcomes, extent of resection, visual recovery, endocrine remission, complication rates, and long-term disease control.

This review provides a contemporary overview of the diagnosis, classification, surgical management, and outcome assessment of pituitary and parasellar lesions in the endoscopic era. Particular emphasis is placed on current concepts in PitNET classification, indications for surgery, lesion-specific treatment strategies, postoperative outcome evaluation, and management of complications. Furthermore, available evidence comparing endoscopic and microscopic approaches is critically examined, and emerging technologies that may influence future skull base surgery are discussed.

Current literature supports endoscopic endonasal surgery as an effective and safe treatment modality for a broad spectrum of pituitary and parasellar lesions when performed by experienced multidisciplinary teams. Continued advances in surgical technology, molecular pathology, and perioperative care are expected to further improve patient outcomes and expand the role of endoscopic approaches in contemporary skull base practice.

**Keywords: Contemporary Endoscopic, Treatment, of Pituitary , Parasellar Lesions:**

## INTRODUCTION

Pituitary and parasellar lesions represent a heterogeneous group of neoplastic and non-neoplastic disorders that arise within or adjacent to the sellar region and frequently involve critical endocrine, visual, and neurovascular structures. These lesions encompass pituitary neuroendocrine tumors (PitNETs), craniopharyngiomas, Rathke cleft cysts, meningiomas, hypothalamic tumors, and other less common pathologies. Owing to their strategic anatomical location, these lesions may result in significant morbidity through hormonal hypersecretion, hypopituitarism, visual field defects, cranial nerve dysfunction, and compression of adjacent neural structures. Advances in neuroimaging and endocrine diagnostics have substantially improved the early detection and characterization of these disorders, contributing to more individualized treatment strategies and improved clinical outcomes.[1,2]

Among sellar lesions, PitNETs represent the most frequently encountered pathology and account for a considerable proportion of intracranial neoplasms. Epidemiological studies have demonstrated that pituitary tumors are more common than previously appreciated, with many lesions identified incidentally through modern imaging techniques. While a substantial proportion remain clinically silent, functioning tumors may produce excessive hormonal secretion leading to syndromes such as acromegaly, Cushing disease, hyperprolactinemia, and thyrotropin excess. Conversely, non-functioning tumors often present with symptoms related to mass effect, including visual deterioration and pituitary insufficiency.[3,4]

Historically, the management of sellar and parasellar lesions was dominated by transcranial and microscopic transsphenoidal approaches. Although these techniques achieved satisfactory outcomes, limitations in visualization and restricted access to complex skull base regions stimulated the development of endoscopic endonasal surgery. Since its introduction, endoscopic surgery has evolved from an adjunctive visualization tool to a primary treatment modality for many sellar and parasellar pathologies. The panoramic view, enhanced illumination, and ability to use angled optics provide superior visualization of critical anatomical structures and facilitate the treatment of lesions extending beyond the confines of the sella turcica.[5,6]

Recent advances in pathology have also transformed the understanding of pituitary tumors. The 2022 World Health Organization classification introduced the concept of pituitary neuroendocrine tumors and emphasized cell lineage-based classification, transcription factor expression, and clinicopathological behavior. These developments have refined diagnostic criteria and improved recognition of aggressive tumor subtypes, thereby influencing prognostication and treatment planning. Simultaneously, growing evidence has highlighted the importance of multidisciplinary management involving neurosurgeons, endocrinologists, neuroradiologists, neuropathologists, and radiation oncologists to optimize patient outcomes.[7,8]

Despite substantial progress in endoscopic techniques and perioperative care, several challenges remain. Questions persist regarding optimal treatment strategies for invasive tumors, predictors of recurrence, preservation of endocrine function, management of residual disease, and long-term quality-of-life outcomes. Furthermore, the rapid evolution of surgical technologies, including intraoperative imaging, fluorescence-guided surgery, artificial intelligence, and augmented reality, continues to reshape contemporary skull base practice.[9]

Therefore, the aim of this review is to provide a comprehensive and contemporary overview of the diagnosis, classification, surgical management, and outcome assessment of pituitary and parasellar lesions in the endoscopic era. Particular emphasis is placed on recent advances in PitNET classification, lesion-specific treatment strategies, evidence-based surgical outcomes, and future directions in endoscopic skull base surgery.

### Spectrum of Pituitary and Parasellar Lesions

Pituitary and parasellar lesions comprise a broad spectrum of pathological entities that originate from the pituitary gland, surrounding meningeal structures, embryological remnants, cranial nerves, vascular components, and adjacent hypothalamic regions. Although these lesions share a common anatomical location, they differ considerably in their biological behavior, clinical presentation, radiological appearance, and therapeutic requirements. Accurate identification of the underlying pathology is therefore essential for selecting the most appropriate management strategy and predicting long-term outcomes.[10]

Pituitary neuroendocrine tumors (PitNETs) represent the most common lesions encountered within the sellar region and account for the majority of surgical interventions involving the pituitary gland. These tumors arise from adenohypophyseal cells and are

currently classified according to cellular lineage, transcription factor expression, and hormonal activity. Clinically, PitNETs may be functioning or non-functioning. Functioning tumors produce excess hormones that result in characteristic endocrine syndromes such as acromegaly, Cushing disease, hyperprolactinemia, and hyperthyroidism, whereas non-functioning tumors generally present because of tumor growth and compression of surrounding structures. Although most PitNETs exhibit benign behavior, some demonstrate invasive growth, recurrence, and resistance to conventional therapies, highlighting the importance of individualized management strategies.[11,12]

Craniopharyngiomas are epithelial tumors derived from remnants of Rathke's pouch and constitute one of the most challenging lesions encountered in the sellar and suprasellar regions. Despite their benign histological appearance, these tumors frequently adhere to critical structures including the optic apparatus, hypothalamus, pituitary stalk, and major cerebral vessels. Their complex anatomical relationships often result in visual impairment, endocrine dysfunction, hypothalamic disturbances, and significant long-term morbidity. Advances in endoscopic surgery have improved access to these lesions and expanded treatment options for carefully selected patients.[13]

Rathke cleft cysts are benign cystic lesions originating from remnants of the embryological Rathke pouch. These lesions are often discovered incidentally but may become symptomatic when enlargement causes compression of the optic apparatus or pituitary gland. Patients commonly present with headaches, visual disturbances, pituitary dysfunction, or a combination of these symptoms. Endoscopic transsphenoidal surgery has become the preferred treatment for symptomatic cysts because it provides effective decompression while minimizing injury to normal pituitary tissue.[14]

Meningiomas involving the tuberculum sellae, planum sphenoidale, and parasellar regions represent another important subgroup of lesions encountered during skull base surgery. These tumors arise from arachnoid cap cells and frequently present with progressive visual deterioration secondary to compression of the optic nerves and chiasm. Although transcranial surgery has traditionally been the standard treatment, advances in endoscopic endonasal techniques have enabled successful treatment of selected midline lesions through minimally invasive corridors, offering direct access to the site of dural attachment and early optic nerve decompression.[15,16]

Less common parasellar lesions include optic pathway gliomas, hypothalamic tumors, chordomas, metastatic lesions, inflammatory disorders, vascular abnormalities, and developmental cysts. Although these entities are encountered less frequently than PitNETs or meningiomas, they often require specialized diagnostic evaluation and individualized treatment strategies. Accurate differentiation among these lesions relies on integration of clinical findings, hormonal assessment, advanced neuroimaging, and histopathological examination.[17]

Given the diversity of pituitary and parasellar pathologies, a multidisciplinary diagnostic approach is essential for achieving optimal outcomes. Advances in molecular pathology, radiological characterization, and endoscopic surgical techniques continue to refine the management of these lesions and facilitate increasingly personalized treatment paradigms.[18]

**Contemporary Classification and Pathobiology of Pituitary Neuroendocrine Tumors**

**Evolution from Pituitary Adenoma to Pituitary Neuroendocrine Tumor**

Pituitary tumors have traditionally been classified as pituitary adenomas, reflecting their generally benign histological appearance and relatively indolent clinical behavior. However, accumulating evidence has demonstrated that a subset of these tumors exhibits invasive growth, local recurrence, resistance to treatment, and, in rare cases, metastatic potential. These observations challenged the traditional concept of pituitary adenomas as uniformly benign lesions and prompted efforts to develop a classification system that better reflects their biological diversity. Consequently, the term *pituitary neuroendocrine tumor (PitNET)* was introduced to emphasize their neuroendocrine origin and acknowledge the broad spectrum of clinical behavior observed among these lesions.[19,20]

The adoption of the PitNET terminology has generated considerable discussion within the neurosurgical and endocrine communities. Proponents argue that the new nomenclature more accurately reflects tumor biology and facilitates alignment with classification systems used for other neuroendocrine neoplasms. Conversely, concerns have been raised regarding the potential psychological impact of the term "tumor" on patients and the possibility of overestimating the malignant potential of lesions that often demonstrate benign clinical courses. Nevertheless, the PitNET concept has gained increasing acceptance and now forms the basis of contemporary pathological classification systems.[21]

### WHO 2022 Classification of Pituitary Neuroendocrine Tumors

The fifth edition of the World Health Organization (WHO) Classification of Endocrine and Neuroendocrine Tumors introduced a lineage-based framework for PitNET classification. Rather than relying solely on hormonal secretion patterns, the new system emphasizes cell differentiation pathways and transcription factor expression, thereby providing a more biologically meaningful approach to diagnosis. This classification recognizes that tumors with similar hormonal profiles may exhibit distinct molecular characteristics, clinical behaviors, and therapeutic responses.[22]

Under the WHO 2022 classification, PitNETs are categorized according to the transcription factors that govern pituitary cell differentiation. Three principal lineages are recognized: PIT1, TPIT, and SF1. PIT1-lineage tumors include somatotroph, lactotroph, mammosomatotroph, thyrotroph, and plurihormonal tumors. TPIT-lineage tumors correspond primarily to corticotroph neoplasms, whereas SF1-lineage tumors include gonadotroph tumors, which constitute the majority of clinically non-functioning PitNETs. This classification provides a standardized framework that improves diagnostic reproducibility and facilitates clinicopathological correlation.[22,23]

### Molecular and Histopathological Characteristics

Advances in molecular pathology have enhanced understanding of the biological mechanisms underlying PitNET development and progression. Immunohistochemical assessment of pituitary hormones and transcription factors now plays a central role in tumor classification and diagnosis. Additional molecular alterations involving signaling pathways, cell-cycle regulation, growth factor activity, and genetic susceptibility syndromes have also been identified. Although most PitNETs remain sporadic, familial conditions such as multiple endocrine neoplasia type 1 and familial isolated pituitary adenoma provide important insights into tumorigenesis and hereditary predisposition.[24,25]

Histopathological evaluation also contributes to risk stratification by identifying tumor subtypes associated with more aggressive behavior. Certain variants, including sparsely granulated somatotroph tumors, silent corticotroph tumors, Crooke cell tumors, and plurihormonal PIT1-positive tumors, have been linked to increased invasiveness, recurrence risk, and resistance to conventional therapies. Recognition of these high-risk subtypes has important implications for postoperative surveillance and long-term management.[26]

### Predictors of Tumor Behavior and Recurrence

Despite advances in classification, predicting the biological behavior of PitNETs remains a major clinical challenge. Tumor size, cavernous sinus invasion, suprasellar extension, proliferative activity, and histological subtype have all been associated with recurrence risk and long-term outcome. Radiological features such as Knosp grade and specific MRI signal characteristics may also provide valuable prognostic information before surgery.[27]

Recent studies have emphasized the importance of integrating clinical, radiological, pathological, and molecular parameters to achieve more accurate prognostication. Emerging predictive models incorporating artificial intelligence and machine learning algorithms may further improve risk stratification and facilitate personalized treatment planning in the future. Such approaches have the potential to identify patients at increased risk of recurrence and guide decisions regarding adjuvant therapy, surveillance intensity, and long-term follow-up strategies.[28]

## Clinical Presentation and Diagnostic Evaluation

### Endocrine Manifestations

The clinical presentation of pituitary and parasellar lesions is highly variable and depends on lesion size, anatomical extension, hormonal activity, and involvement of adjacent structures. Functioning PitNETs frequently present with symptoms related to hormone hypersecretion, often leading to earlier diagnosis than non-functioning lesions. Prolactin-secreting tumors commonly manifest with menstrual irregularities, galactorrhea, infertility, and hypogonadism, whereas growth hormone-secreting tumors produce the characteristic features of acromegaly, including acral enlargement, facial coarsening, metabolic dysfunction, and cardiovascular complications. Corticotroph tumors result in Cushing disease, which is associated with obesity, hypertension, diabetes mellitus, osteoporosis, and increased cardiovascular risk. Thyrotroph tumors are uncommon and typically present with clinical and biochemical evidence of hyperthyroidism.[29,30]

In contrast, non-functioning PitNETs generally remain clinically silent until they attain sufficient size to produce mass effect.

Patients may develop headaches, visual disturbances, hypopituitarism, or symptoms related to compression of surrounding neural structures. Hypopituitarism may involve one or multiple hormonal axes and can manifest as fatigue, sexual dysfunction, infertility, adrenal insufficiency, hypothyroidism, or growth hormone deficiency. Because endocrine dysfunction significantly influences both quality of life and long-term morbidity, comprehensive hormonal evaluation is essential in all patients presenting with sellar and parasellar lesions.[31,32]

**Neuro-Ophthalmological Presentation**

Visual disturbances represent one of the most common presenting manifestations of sellar and suprasellar lesions. Compression of the optic chiasm by enlarging tumors classically produces bitemporal hemianopia, although visual acuity loss, reduced color vision, visual field constriction, and other neuro-ophthalmological abnormalities may also occur. The severity of visual dysfunction often correlates with the degree and duration of optic pathway compression. Lesions involving the cavernous sinus or parasellar compartment may additionally affect cranial nerves III, IV, V, and VI, resulting in diplopia, ophthalmoplegia, facial sensory deficits, or ocular pain.[33]

Because visual deficits may be subtle during the early stages of disease, formal neuro-ophthalmological assessment is recommended for patients with radiological evidence of optic apparatus compression. Visual field testing, visual acuity assessment, and fundoscopic examination provide important baseline data that assist both surgical planning and postoperative outcome evaluation.[34]

**Radiological Assessment**

Magnetic resonance imaging (MRI) remains the cornerstone of diagnostic evaluation for pituitary and parasellar lesions. High-resolution contrast-enhanced MRI provides detailed information regarding lesion size, morphology, anatomical relationships, cavernous sinus invasion, suprasellar extension, and compression of surrounding neurovascular structures. MRI findings also contribute to differential diagnosis, as specific imaging characteristics may suggest particular pathological entities such as craniopharyngiomas, Rathke cleft cysts, meningiomas, or PitNET subtypes.[35]

Several radiological grading systems have been developed to facilitate preoperative assessment and outcome prediction. Among these, the Knosp classification is widely used to evaluate cavernous sinus invasion by PitNETs and serves as an important predictor of surgical resectability and recurrence risk. Additional imaging features, including tumor consistency, signal intensity characteristics, and relationship to the optic apparatus, may further influence operative planning and anticipated outcomes.[36]

**Hormonal Evaluation and Preoperative Risk Stratification**

A comprehensive endocrine assessment is mandatory before treatment. Baseline evaluation typically includes measurement of prolactin, growth hormone, insulin-like growth factor-1, adrenocorticotropic hormone, cortisol, thyroid hormones, gonadotropins, sex steroids, and other relevant biochemical markers according to the suspected diagnosis. Identification of hormonal hypersecretion syndromes not only confirms the diagnosis but also guides treatment selection and postoperative monitoring.[37]

Preoperative risk stratification requires integration of clinical findings, hormonal status, radiological characteristics, pathological considerations, and patient-specific factors. Tumor size, invasiveness, age, medical comorbidities, visual function, and endocrine reserve all influence treatment planning and expected outcomes. Advances in imaging analysis, molecular pathology, and predictive modeling have further improved the ability to identify patients at increased risk of recurrence, incomplete resection, or postoperative complications, supporting the growing trend toward personalized management strategies in contemporary pituitary surgery.[38]

**Indications for Endoscopic Surgical Management**

The decision to pursue surgical treatment for pituitary and parasellar lesions is based on a combination of clinical presentation, radiological findings, endocrine status, and anticipated disease progression. Although some lesions may be managed conservatively or with medical therapy, surgery remains the primary treatment modality for many symptomatic sellar and parasellar pathologies. The development of endoscopic endonasal techniques has expanded the range of lesions amenable to minimally invasive surgery while improving visualization and access to complex skull base regions.[39]

Visual compromise represents one of the most important indications for surgical intervention. Compression of the optic nerves,

optic chiasm, or visual pathways may result in visual field defects, reduced visual acuity, and progressive visual deterioration. Early surgical decompression is often recommended because prolonged compression may lead to irreversible neurological injury. Endoscopic surgery provides direct access to the lesion and allows effective decompression of the optic apparatus while minimizing manipulation of surrounding brain structures.[40]

Hormonal dysfunction is another major indication for treatment. Functioning PitNETs associated with excess hormone secretion frequently require surgical intervention when medical therapy is ineffective, contraindicated, or unlikely to achieve durable disease control. Surgical resection is commonly recommended for growth hormone-secreting tumors, adrenocorticotropic hormone-producing tumors, and selected thyrotroph adenomas. In contrast, prolactinomas are generally treated initially with dopamine agonists, with surgery reserved for patients who demonstrate medication intolerance, resistance, or tumor-related neurological complications.[41,42]

Non-functioning PitNETs often require surgery because of tumor growth and mass effect rather than hormonal hypersecretion. Progressive enlargement, suprasellar extension, cavernous sinus compression, headaches, visual impairment, and pituitary insufficiency frequently constitute indications for resection. Surgical treatment may also be considered in younger patients with enlarging incidentalomas to prevent future neurological and endocrine complications.[43]

Endoscopic surgery has also become an important treatment option for selected parasellar lesions. Craniopharyngiomas, Rathke cleft cysts, and tuberculum sellae meningiomas may be effectively managed through endoscopic approaches when anatomical characteristics are favorable. In these situations, the endoscopic corridor provides direct midline access, facilitates early identification of critical neurovascular structures, and may reduce surgical morbidity associated with traditional transcranial procedures. Nevertheless, careful patient selection remains essential because tumor size, vascular encasement, lateral extension, and hypothalamic involvement can significantly influence the suitability of an endoscopic approach.[44,45]

Ultimately, the decision to proceed with surgery should be individualized and guided by multidisciplinary evaluation. Consideration of patient age, comorbidities, endocrine function, radiological characteristics, anticipated extent of resection, and long-term quality-of-life outcomes is essential for optimizing treatment selection. Contemporary management increasingly emphasizes personalized care strategies that balance maximal disease control with preservation of neurological and endocrine function.[46]

**Endoscopic Treatment of Pituitary Neuroendocrine Tumors**

**Non-Functioning Pituitary Neuroendocrine Tumors**

Non-functioning pituitary neuroendocrine tumors (NF-PitNETs) represent the most common subtype of surgically treated pituitary tumors. Unlike functioning adenomas, these lesions do not produce clinically significant hormone hypersecretion and are therefore frequently diagnosed after enlargement causes compression of surrounding structures. Patients commonly present with visual impairment, headaches, hypopituitarism, or are diagnosed incidentally during neuroimaging performed for unrelated reasons. Given their tendency to remain asymptomatic until substantial growth has occurred, NF-PitNETs often present as macroadenomas with suprasellar extension at the time of diagnosis.[47,48]

Endoscopic endonasal surgery is considered the primary treatment for symptomatic NF-PitNETs. The principal objectives of surgery include decompression of the optic apparatus, preservation of pituitary function, and maximal safe tumor resection. Advances in endoscopic visualization have improved the surgeon's ability to identify tumor boundaries and inspect hidden anatomical recesses, particularly in lesions with suprasellar extension. Gross-total resection is frequently achievable in non-invasive tumors; however, cavernous sinus invasion remains a major determinant of residual disease and long-term recurrence risk.[49,50]

Long-term outcomes following endoscopic resection are generally favorable. Significant visual improvement is observed in the majority of patients, while endocrine recovery may occur in selected cases depending on the duration and severity of preoperative pituitary dysfunction. Residual or recurrent tumors may require repeat surgery, stereotactic radiosurgery, or fractionated radiotherapy as part of a multidisciplinary treatment strategy.[51]

**Prolactin-Secreting Tumors**

Prolactinomas are the most common functioning PitNETs and are characterized by excessive prolactin secretion leading to

hypogonadism, infertility, galactorrhea, menstrual disturbances, and sexual dysfunction. Dopamine agonists remain the first-line treatment because they effectively normalize prolactin levels and reduce tumor volume in most patients. Consequently, surgery is typically reserved for individuals who are resistant or intolerant to medical therapy, experience medication-related adverse effects, or present with significant neurological compromise caused by tumor growth.[52,53]

When surgery is indicated, endoscopic endonasal resection provides excellent access to the lesion while preserving surrounding pituitary tissue. Outcomes are generally most favorable in microprolactinomas and well-circumscribed macroprolactinomas without cavernous sinus invasion. Successful surgery may result in normalization of prolactin levels, symptom resolution, and reduced dependence on long-term pharmacological therapy. Nevertheless, careful patient selection remains critical because remission rates decline in larger and invasive tumors.[54]

**Growth Hormone-Secreting Tumors**

Growth hormone-secreting PitNETs are responsible for acromegaly, a chronic disorder associated with significant cardiovascular, metabolic, musculoskeletal, and respiratory morbidity. Surgical resection remains the preferred first-line treatment for most patients because it offers the possibility of immediate biochemical remission and relief of mass effect. The success of surgery depends largely on tumor size, extent of invasion, and preoperative hormone levels.[55]

Endoscopic surgery has demonstrated favorable outcomes in the treatment of acromegaly, particularly in patients with microadenomas and non-invasive macroadenomas. Improved visualization facilitates selective tumor removal while preserving normal pituitary tissue. Biochemical remission is associated with substantial reductions in long-term morbidity and mortality, emphasizing the importance of achieving effective surgical control whenever feasible. Adjuvant medical therapy and radiotherapy may be required in patients with persistent or recurrent disease.[56,57]

**Adrenocorticotropic Hormone-Secreting Tumors**

ACTH-secreting PitNETs are responsible for Cushing disease, a condition characterized by chronic cortisol excess and associated with significant metabolic, cardiovascular, and immunological complications. Surgical removal of the causative tumor remains the treatment of choice because successful resection can rapidly normalize cortisol levels and improve long-term outcomes. However, these tumors are frequently small and may be difficult to identify radiologically, making surgical expertise particularly important.[58]

The endoscopic approach provides enhanced visualization of the sellar compartment and may improve identification of microadenomas compared with traditional microscopic techniques. Modern surgical series have reported favorable remission rates, although recurrence remains an important long-term concern. Consequently, lifelong endocrinological surveillance is recommended even after apparent biochemical cure.[59]

**Thyrotroph-Secreting Tumors**

Thyrotroph PitNETs are rare tumors that produce inappropriate secretion of thyroid-stimulating hormone, resulting in secondary hyperthyroidism. Patients may present with weight loss, palpitations, tremor, heat intolerance, and diffuse thyroid enlargement. Because of their rarity and variable clinical presentation, diagnosis is often delayed and requires careful biochemical and radiological assessment.[60]

Endoscopic endonasal surgery represents the primary treatment modality for most thyrotroph tumors. Surgical resection frequently results in normalization of thyroid function and relief of mass effect. In cases of residual or recurrent disease, adjunctive medical therapy and radiotherapy may be considered. Although outcomes are generally favorable, long-term follow-up remains necessary because delayed recurrence has been reported.[61]

**Endoscopic Management of Parasellar Lesions**

**Craniopharyngiomas**

Craniopharyngiomas are benign epithelial tumors arising from remnants of Rathke’s pouch and account for a significant proportion of sellar and suprasellar lesions encountered in both pediatric and adult populations. Despite their benign histological classification, these tumors are associated with considerable morbidity because of their intimate relationship with the optic apparatus, hypothalamus, pituitary stalk, and major cerebral vessels. Clinical manifestations commonly include visual deterioration, endocrine dysfunction, hypothalamic disturbances, headache, and cognitive impairment. The primary goals of

treatment are durable tumor control, preservation of neurological function, and maintenance of endocrine and hypothalamic integrity.[62,63]

The endoscopic endonasal approach has emerged as an important surgical option for selected craniopharyngiomas, particularly those located in the midline and inferior to the optic chiasm. This approach provides a direct ventral route to the tumor, allowing early identification of the pituitary stalk, optic apparatus, and major vascular structures. Compared with traditional transcranial approaches, endoscopic surgery may offer improved visualization of the tumor–hypothalamic interface and facilitate more effective decompression of the visual pathways. Nevertheless, complete tumor removal must be balanced against the risk of hypothalamic injury and permanent endocrine dysfunction, especially in lesions demonstrating dense adhesions to surrounding structures.[64]

Contemporary studies have demonstrated favorable visual outcomes and acceptable tumor control rates following endoscopic surgery for appropriately selected craniopharyngiomas. However, recurrence remains a significant challenge, particularly after subtotal resection. Consequently, multimodal management strategies incorporating surgery, radiotherapy, and long-term endocrinological follow-up are frequently required to optimize outcomes and minimize treatment-related morbidity.[65]

**Rathke Cleft Cysts**

Rathke cleft cysts are benign developmental lesions derived from embryological remnants of Rathke's pouch. Although many remain asymptomatic throughout life, enlargement may result in headaches, visual impairment, pituitary dysfunction, and occasionally pituitary apoplexy-like presentations. Magnetic resonance imaging typically reveals a well-circumscribed cystic lesion within the sellar or sellar-suprasellar region, often facilitating differentiation from other pituitary pathologies.[66]

Endoscopic transsphenoidal surgery has become the preferred treatment for symptomatic Rathke cleft cysts because it allows effective cyst drainage and decompression while preserving surrounding pituitary tissue. The primary surgical objective is restoration of normal anatomical relationships and symptom relief rather than aggressive excision of the entire cyst wall. This conservative strategy minimizes the risk of pituitary injury and postoperative endocrinological deficits while maintaining favorable long-term outcomes.[67]

Most patients experience significant improvement in visual symptoms and headaches following surgical decompression. Nevertheless, recurrence remains a recognized limitation of treatment and may necessitate repeat intervention in selected cases. Careful radiological and endocrinological follow-up is therefore recommended, particularly in patients with residual cyst components or recurrent symptoms.[68]

**Tuberculum Sellae Meningiomas**

Tuberculum sellae meningiomas arise from the dura of the tuberculum sellae, planum sphenoidale, and adjacent skull base structures. Because of their proximity to the optic nerves and optic chiasm, progressive visual deterioration is often the predominant presenting symptom. Historically, these tumors were managed through transcranial approaches; however, advances in endoscopic skull base surgery have expanded the role of endonasal techniques for selected lesions.[69]

The endoscopic endonasal approach offers several theoretical advantages, including direct access to the tumor attachment site, early optic nerve decompression, and avoidance of brain retraction. Midline lesions with limited lateral extension are generally considered the most suitable candidates for endoscopic treatment. Careful preoperative assessment of tumor size, vascular encasement, optic canal involvement, and extension beyond the carotid arteries is essential when selecting the optimal surgical approach.[70]

Clinical series have reported encouraging outcomes with respect to visual improvement and extent of resection in appropriately selected patients. However, large tumors with extensive lateral extension or complex vascular relationships may remain better suited to transcranial approaches. Consequently, individualized treatment planning remains fundamental to achieving optimal surgical outcomes while minimizing morbidity.[71]

**Selected Suprasellar and Parasellar Tumors**

Advances in endoscopic skull base surgery have also facilitated treatment of selected suprasellar and parasellar lesions beyond PitNETs, craniopharyngiomas, and meningiomas. These include optic pathway gliomas, hypothalamic tumors, chordomas, metastatic lesions, and other uncommon skull base neoplasms. The suitability of endoscopic treatment depends on lesion

location, growth pattern, vascular relationships, and anticipated surgical objectives.[72]

For many of these tumors, endoscopic surgery serves not only as a therapeutic modality but also as a means of obtaining tissue diagnosis while minimizing surgical morbidity. Continued refinement of surgical techniques, reconstruction methods, and intraoperative visualization technologies has expanded the indications for endoscopic management and improved outcomes in carefully selected cases. Nevertheless, multidisciplinary evaluation remains essential because many parasellar lesions require combined surgical, endocrinological, oncological, and radiotherapeutic management strategies.[73]

**Outcome Assessment Following Endoscopic Surgery**

**Extent of Resection**

The extent of tumor resection remains one of the most important indicators of surgical success in the management of pituitary and parasellar lesions. Advances in endoscopic visualization, angled optics, and specialized instrumentation have significantly improved the surgeon's ability to identify tumor boundaries and inspect anatomical regions that are difficult to visualize using conventional microscopic techniques. Consequently, endoscopic surgery has been associated with high rates of gross-total resection in appropriately selected lesions, particularly for non-invasive PitNETs and midline suprasellar tumors. Nevertheless, the extent of resection is influenced by multiple factors including tumor size, consistency, cavernous sinus invasion, suprasellar extension, and proximity to critical neurovascular structures.[74,75]

For invasive lesions, particularly those involving the cavernous sinus, complete removal may not be feasible without unacceptable neurological risk. In such cases, the surgical objective shifts from radical excision to maximal safe resection, prioritizing preservation of visual, endocrine, and neurological function. Contemporary treatment strategies increasingly recognize that long-term disease control may be achieved through a combination of surgery, radiotherapy, and medical therapy rather than aggressive attempts at complete resection in anatomically complex tumors.[76]

**Visual Outcomes**

Improvement of visual function is among the most important goals of surgery for sellar and parasellar lesions. Compression of the optic nerves and optic chiasm frequently results in visual field defects, reduced visual acuity, impaired color vision, and other neuro-ophthalmological abnormalities. Numerous studies have demonstrated substantial visual improvement following endoscopic decompression, particularly when intervention occurs before irreversible optic nerve damage develops. Recovery rates are influenced by the duration and severity of preoperative visual impairment, patient age, and the extent of optic apparatus compression.[77]

The panoramic visualization provided by endoscopic surgery facilitates direct inspection of the optic pathways and allows effective decompression with minimal manipulation of surrounding structures. Favorable visual outcomes have been consistently reported for PitNETs, craniopharyngiomas, Rathke cleft cysts, and tuberculum sellae meningiomas. Early diagnosis and timely surgical intervention remain critical factors in maximizing the likelihood of postoperative visual recovery.[78]

**Endocrine Outcomes**

Preservation or restoration of endocrine function represents another key measure of treatment success. Surgical outcomes vary according to tumor type, hormonal activity, and preoperative pituitary status. In functioning PitNETs, effective surgery may achieve biochemical remission, eliminate hormone hypersecretion, and substantially reduce disease-related morbidity. Patients with acromegaly, Cushing disease, and thyrotroph tumors frequently experience significant clinical improvement following successful tumor removal.[79]

For non-functioning lesions, endocrine outcomes are primarily related to preservation of normal pituitary tissue and vascular supply. Although postoperative hormonal recovery may occur in some patients, endocrine deficits may persist or develop following surgery, particularly in large tumors requiring extensive dissection. Careful surgical technique and preservation of the pituitary stalk remain essential for minimizing postoperative hypopituitarism and maintaining long-term endocrine function.[80]

**Quality of Life Outcomes**

Beyond traditional surgical endpoints, quality of life has emerged as an increasingly important outcome measure in contemporary pituitary surgery. Successful treatment often results in improvement of visual symptoms, endocrine abnormalities, headache burden, cognitive performance, and psychosocial well-being. Patients with functioning PitNETs may experience particularly

significant benefits following normalization of hormone secretion, including improvements in cardiovascular health, metabolic function, and overall daily functioning.[81]

Nevertheless, some patients continue to experience persistent symptoms despite technically successful surgery. Residual endocrine dysfunction, hypothalamic injury, visual impairment, and psychological effects may negatively influence long-term quality of life. These observations highlight the importance of multidisciplinary postoperative care and long-term follow-up extending beyond radiological assessment alone.[82]

**Recurrence and Long-Term Follow-Up**

Long-term surveillance remains an essential component of management because recurrence may occur even after apparently successful treatment. The risk of recurrence varies according to tumor subtype, extent of resection, biological behavior, and pathological characteristics. Residual tumor, cavernous sinus invasion, aggressive histological features, and specific molecular profiles have all been associated with increased recurrence risk.[83]

Postoperative follow-up typically includes serial magnetic resonance imaging, endocrinological assessment, and neuro-ophthalmological evaluation. Early identification of recurrent or progressive disease facilitates timely intervention through repeat surgery, medical therapy, stereotactic radiosurgery, or conventional radiotherapy when appropriate. As understanding of tumor biology continues to evolve, integration of molecular markers and predictive models may further refine long-term surveillance strategies and improve individualized patient care.[84,85]

**Complications and Their Management**

Although endoscopic surgery has significantly improved the treatment of pituitary and parasellar lesions, complications remain an important consideration in clinical practice. The close anatomical relationship between sellar lesions and critical neurovascular and endocrine structures creates potential risks during both surgery and the postoperative period. Fortunately, advances in surgical technique, anatomical understanding, intraoperative navigation, and skull base reconstruction have substantially reduced complication rates over the last two decades. Early recognition and prompt management remain essential for optimizing patient outcomes and minimizing long-term morbidity.[86]

**Cerebrospinal Fluid Leakage**

Postoperative cerebrospinal fluid (CSF) leakage is among the most frequently reported complications of endoscopic skull base surgery. The risk is particularly elevated in extended endoscopic approaches involving large dural defects and direct communication with the subarachnoid space. Persistent CSF leakage may result in meningitis, pneumocephalus, prolonged hospitalization, and the need for revision surgery. The introduction of multilayer reconstruction techniques and vascularized nasoseptal flaps has dramatically reduced postoperative leak rates and transformed the safety profile of endoscopic skull base procedures.[87,88]

Successful management depends on accurate intraoperative identification of the leak source, meticulous reconstruction, and appropriate postoperative monitoring. In selected cases involving high-flow leaks or complex skull base defects, temporary lumbar drainage may be considered as an adjunct to reconstruction. Contemporary studies demonstrate that most CSF leaks can be effectively prevented through standardized reconstruction protocols and experienced multidisciplinary care.[89]

**Endocrine Complications**

Endocrine disturbances remain common after surgery involving the pituitary gland and surrounding structures. Transient diabetes insipidus is one of the most frequently encountered postoperative complications and typically results from manipulation of the pituitary stalk or posterior pituitary gland. Although most cases resolve spontaneously, permanent diabetes insipidus may occur in a minority of patients, particularly following surgery for large suprasellar lesions or craniopharyngiomas.[90]

Additional endocrine complications include adrenal insufficiency, hypothyroidism, hypogonadism, growth hormone deficiency, and panhypopituitarism. Comprehensive postoperative hormonal assessment is therefore mandatory to ensure timely recognition and treatment of endocrine deficits. Long-term endocrinological follow-up remains an essential component of patient care because hormonal abnormalities may evolve months or even years after surgery.[91]

**Vascular and Neurological Complications**

Vascular injury is a rare but potentially catastrophic complication of endoscopic skull base surgery. Damage to the internal carotid artery may result in massive hemorrhage, ischemic stroke, pseudoaneurysm formation, or death. Preoperative imaging analysis, identification of anatomical variations, careful bone removal, and adherence to established surgical landmarks are critical for reducing vascular risk. When vascular injury occurs, immediate multidisciplinary intervention involving neurosurgeons, otolaryngologists, and endovascular specialists is often required.[92]

Neurological complications may include visual deterioration, cranial nerve deficits, hypothalamic injury, postoperative hematoma, and cerebrovascular events. Visual worsening is uncommon but may occur because of direct neural injury, vascular compromise, excessive manipulation, or postoperative compression. Prompt recognition and intervention are essential because early treatment may improve neurological recovery and reduce permanent deficits.[93]

**Sinonasal Morbidity**

Because endoscopic surgery utilizes the nasal corridor as the primary surgical route, postoperative sinonasal symptoms are relatively common. Patients may experience nasal congestion, crusting, diminished olfaction, epistaxis, or temporary discomfort during the healing period. Most symptoms improve with appropriate postoperative care, including saline irrigations, endoscopic debridement, and routine rhinological follow-up. Long-term sinonasal morbidity is generally limited, and overall patient satisfaction remains high following modern endoscopic procedures.[94]

Despite the potential for complications, contemporary evidence demonstrates that endoscopic surgery maintains an excellent safety profile when performed in experienced centers. Continuous refinement of surgical techniques, perioperative management strategies, and reconstructive methods has contributed to progressively lower complication rates and improved overall outcomes for patients with pituitary and parasellar lesions.[95]

**Endoscopic Versus Microscopic Surgery: Current Evidence and Comparative Outcomes**

The transition from microscopic to endoscopic transsphenoidal surgery represents one of the most significant advances in the management of pituitary and parasellar lesions. For decades, microscopic transsphenoidal surgery was considered the standard surgical approach because it provided a minimally invasive route to the sellar region while avoiding craniotomy. Despite its effectiveness, microscopic surgery is inherently limited by a restricted field of view and a straight-line visualization corridor. The introduction of endoscopic technology addressed many of these limitations by providing panoramic visualization, superior illumination, and the ability to inspect anatomical regions beyond the direct line of sight through the use of angled optics.[96,97]

One of the principal advantages of endoscopic surgery is enhanced visualization of the sellar, suprasellar, and parasellar compartments. The panoramic endoscopic view allows improved identification of critical neurovascular structures, including the optic apparatus, pituitary stalk, cavernous sinus, and internal carotid arteries. This expanded visualization facilitates more precise tumor dissection and may improve the extent of resection, particularly in lesions demonstrating suprasellar extension or complex anatomical relationships. Angled endoscopes additionally permit inspection of hidden recesses that may harbor residual tumor tissue and are difficult to visualize using traditional microscopic techniques.[98]

Comparative studies have demonstrated favorable surgical outcomes associated with endoscopic approaches. Several investigations have reported higher rates of gross-total resection, improved visualization of residual disease, shorter hospital stays, and reduced postoperative discomfort when compared with microscopic surgery. Endoscopic techniques have also shown particular advantages in revision procedures and tumors with suprasellar or parasellar extension, where the wider field of view facilitates surgical orientation and lesion removal. These findings have contributed to the widespread adoption of endoscopic surgery in specialized skull base centers worldwide.[99,100]

Visual outcomes and endocrine results appear to be at least comparable, and in some studies superior, following endoscopic surgery. Enhanced visualization allows direct decompression of the optic apparatus while minimizing manipulation of surrounding neural structures. Similarly, improved identification of normal pituitary tissue may contribute to preservation of endocrine function. However, the magnitude of these benefits varies across studies and is influenced by tumor characteristics, patient selection, and surgeon experience.[101]

Despite the growing popularity of endoscopic surgery, microscopic transsphenoidal surgery continues to achieve excellent outcomes in experienced hands. Current evidence suggests that surgical expertise, multidisciplinary collaboration, and institutional experience may exert a greater influence on outcomes than the choice of visualization technique alone.

Consequently, both approaches remain valuable treatment options, and surgical strategy should be individualized according to lesion characteristics, anatomical considerations, and surgeon proficiency. Nevertheless, the accumulated literature increasingly supports endoscopic endonasal surgery as the preferred approach for the majority of pituitary and selected parasellar lesions in contemporary practice.[102,103]

**Conclusion**

The contemporary management of pituitary and parasellar lesions has been fundamentally transformed by the widespread adoption of endoscopic endonasal surgery. Enhanced visualization, improved access to the sellar and parasellar regions, and ongoing advances in surgical technology have enabled safe and effective treatment of a broad spectrum of pathologies, including PitNETs, craniopharyngiomas, Rathke cleft cysts, and selected meningiomas. Successful management relies on accurate diagnosis, comprehensive endocrine and radiological evaluation, careful patient selection, and multidisciplinary collaboration. Current evidence demonstrates favorable outcomes in terms of tumor control, visual recovery, endocrine remission, and quality of life, while maintaining acceptable complication rates. As understanding of tumor biology continues to evolve and emerging technologies become increasingly integrated into clinical practice, endoscopic surgery is expected to further advance personalized treatment strategies and improve long-term outcomes for patients with pituitary and parasellar lesions.

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