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Surgical Outcomes Using a Medial-to-Lateral Endonasal Endoscopic Approach to Pituitary Adenomas Invading the Cavernous Sinus

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Abstract

OBJECT—To detail the extent of resection and complications with endonasal endoscopic surgery for pituitary tumors invading the cavernous sinus (CS) using a moderately aggressive approach to maximize extent of resection through the medial cavernous sinus wall while minimizing the risk of cranial neuropathy and blood loss. Tumor in the medial cavernous sinus was aggressively pursued while tumor in the lateral cavernous sinus was debulked in preparation for radiosurgery.

METHODS—A prospective surgical database of consecutive endonasal pituitary surgeries with verified CS invasion on intraoperative visual inspection was reviewed. The extent of resection as a whole and within the CS was assessed by an independent neuroradiologist using pre- and post-operative Knosp-Steiner (KS) categorization and volumetrics of the respective magnetic resonance images. The extent of resection and clinical outcomes were compared for medial (KS1-2) and lateral (KS3-4) lesions.

RESULTS—Thirty-six consecutive patients with pituitary adenomas involving the CS who had surgery via an endonasal endoscopic approach were identified. The extent of resection was 84.6% for KS 1–2 and 66.6% for KS 3–4 ($p=.04$). Gross-total resection was 53.8% for KS 1–2 and 8.7% for KS 3–4 ($p=.0006$). Of six patients (16.8%) with pre-operative cranial neuropathies, all showed

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subjective improvement after surgery. Surgical complications included 2 transient post-operative cranial neuropathies (5.6%), 1 postoperative CSF leak (2.8%), 1 reoperation for mucocoele (2.8%) and 1 infection (2.8%).

CONCLUSIONS—The endoscopic endonasal “medial-to-lateral” approach permits safe debulking of tumors in the medial and lateral CS. Although GTR rates are moderate, particularly in the lateral CS, the risk of permanent cranial neuropathy is extremely low with a high chance of improvement of pre-existing deficits. This approach can also facilitate targeting for post-operative radiosurgery.

Keywords

Cavernous sinus; Endoscopic; endonasal; Knosp-Steiner; minimally-invasive; skull base; transphenoidal

Introduction

Lesions involving the cavernous sinus (CS) have proven to be surgically challenging due to the close proximity of critical neurovascular structures and the deep intracranial location. Visualization and dissection of the complex anatomy, including the carotid artery and its branches and numerous cranial nerves, is often hindered by robust blood flow in this space. Although technical advances have increased surgeons' ability to operate within the CS³⁰, the region remains treacherous even in the hands of experienced surgeons.¹¹

Traditional approaches to the CS have focused on transcranial “lateral-to-medial” routes, where cranial nerves (CN) III, IV, and V1 in the lateral wall significantly obstruct the surgical corridors. Deep to these structures lie the abducens nerve, carotid artery and its arterial branches to these intracavernous CNs, dorsal clivus, tentorium, pituitary gland, trigeminal ganglion, and foramen rotundum.³¹ While numerous surgical approaches have been described to limit damage to these structures^{21,22,40}, exposure and visualization, particularly to medially-situated lesions, is limited.

Endonasal endoscopic approaches, on the other hand, offer a “medial-to-lateral” route, which places the cranial nerves on the far side of the surgical corridor. We consider this approach a safer corridor when applied to soft tumors that arise medially and push the neurovascular structures laterally, thereby forming a safe passage into the medial, and sometimes even the lateral, CS. Further safety is afforded by angled endoscopes that allow direct visualization of tumor debulking in this area. Since the contents of the lateral CS are further from radiosensitive structures such as the pituitary gland and optic nerves, radical debulking of the medial CS in preparation for radiosurgery is a reasonable surgical goal, assuming it can be achieved safely. Likewise, decompression of the lateral CS can relieve pre-existing cranial neuropathies. In this study, we expand on prior studies that have discussed this technique by detailing our series utilizing an endoscopic endonasal “medial-to-lateral” route and evaluate the outcomes of this approach based on the Knosp-Steiner criteria.^{7,14,25,27,56}

Methods

This study and the prospective database were approved for research by the Weill-Cornell Medical College institutional review board. We reviewed all endoscopic endonasal pituitary surgeries done by THS and VKA at Weill-Cornell Medical College to identify patients with lesions involving the cavernous sinus based on magnetic resonance imaging (MRI). Cases were only included if, at the time of surgery, the surgeon directly visualized that the tumor breached the medial wall of the CS and recorded that the dissection included this region. All pre- and post-operative images were retrospectively reviewed by an independent neuroradiologist (AJT), who calculated the volume of the tumor, degree of CS invasion [based on the Knosp-Steiner (KS) criteria], and extent of both total surgical resection and resection within each CS. The KS grading system includes 5 categories (Figure 1)²⁸: (0) no invasion with all of the lesion medial to the cavernous carotid artery (CCA), (1) invasion extending to but not past, the medial aspect of the CCA, (2) invasion extending to but not past, the lateral aspect of the CCA, (3) invasion past the lateral aspect of the CCA but not completely filling the CS, and (4) completely filling the CS both medial and lateral to the CCA. Only those cases with intraoperative confirmation of CS invasion were included in the study, regardless of the pre-operative KS grade. Based on this grading scheme and the comparison between the pre- and post-operative MRI scans, the patients were categorized by a neuro-radiologist using volumetric software as (1) Partial resection (<50% volume removed from the cavernous sinus), (2) Subtotal resection [STR] (50–80% volume removed from the cavernous sinus), (3) Near total resection [NTR] (80–99% volume removed from the cavernous sinus), and (4) Gross total resection [GTR] (100% volume removed from the cavernous sinus). For patients with bilateral involvement, each cavernous sinus was graded separately with regard to degree of invasion and extent of resection.

Endonasal endoscopic surgery was performed in a standard fashion as described in previous publications, using a 2 surgeon, binocular technique which enables microdissection with counter-traction.¹⁶ Electrophysiologic monitoring was not routinely used. Of note, intrathecal fluorescein was used in every case to enable clear visualization of cerebrospinal fluid (CSF) leaks.⁴¹ Once a panoramic view of the sphenoid sinus was achieved, CS invasion was addressed in the following manner. First, the bone was removed over the anterior wall of the CS from within the sphenoid sinus using a Kerrison punch and the Doppler was used to identify the exact location of the carotid artery (Figure 2). For tumors arising within the sella, the dura over the sella was opened as close to the carotid as safely possible and an angled endoscope was used to follow the tumor through the medial wall of the CS behind the carotid siphon using angled suctions and ring curettes (Figure 3). All soft tumor tissue that could be easily removed without traumatic dissection was removed in this fashion under direct vision. Since the bone is removed over the anterior wall of the sinus, the carotid artery can be gently pushed laterally to increase visualization. Any breach in the medial cavernous sinus wall was enlarged bluntly to facilitate further tumor removal. For tumors with a component that pushed the carotid medially, the dura was opened lateral to the carotid siphon to remove soft tumor with a ring curette. Lateral visualization was often obtained using a transpterygoid extension of the approach.¹⁸ Any firm tumor stuck to

neurovascular structures (Figure 4) was left in place to be addressed with post-operative radiosurgery or observation.

Clinical outcome and follow-up care were compared based on Knosp-Steiner grade. Cohort summary data were analyzed using mean $\pm$ SD, median [interquartile range (IQR)], and number (%) where appropriate. Categorical data were compared using the Chi-square or Fisher exact test where appropriate; parametric data were compared using the student's t-test, and non-parametric data were compared using the Wilcoxon rank sum test.

Results

Review of a prospective surgical database of over 400 endonasal endoscopic cases identified 36 patients with pituitary tumors with verified extension into the cavernous sinus on intraoperative visual inspection. The mean patient age was 47 years and 22 (61%) were female. The median follow-up was 13 months (mean: 15.5, range 1–49). The cohort data including presenting symptoms, lesion characteristics, and operative variables, are provided in Table 1.

There were 13 lesions that had bilateral CS involvement. Tumor characteristics include: 10 (27.8%) growth hormone secreting tumors, 7 (19.4%) prolactinomas, 3 (8.3%) ACTH-secreting tumors, and 2 (5.6%) gonadotrophin secreting tumors. Three patients had a previous operation.

The surgical approach was transsellar in 24 patients (66.7%) and either transsellar transplanum or transsellar ethmoidal in 12 (33.3%). The approach to the anterolateral corridor into the cavernous sinus including incisions lateral to the carotid artery, occurred in 23 patients. In these cases, the bone over the carotid protuberance along the posterior wall of the sphenoid sinus was completely removed to expose the dura lateral to the carotid artery. A vertical incision is then made parallel to the course of the carotid artery. A nasoseptal flap was used to create a multilayered closure of the skull base in 18 (50%) patients and a prophylactic lumbar drain was used in 11 (30.6%) of the cases. An intraoperative CSF leak was visualized in 19 (52.8%) patients, aided by intrathecal fluorescein injection at the start of the procedure, as described above. There was only one post-operative CSF leak (2.8%) that occurred prior to our use of vascularized mucosal flaps; this leak was successfully managed with a lumbar drain and the patient did not develop any signs or symptoms of meningitis.

Surgical outcomes are given in Table 2. Based on the preoperative imaging studies, 13 (36.1%) patients had lesions medial to the lateral aspect of the cavernous carotid artery (CCA) (KS grade 1–2) and 23 (63.9%) had lesions lateral to the CCA or completely filled the CS (KS grade 3–4). In evaluating degree of resection of tumor from within the CS, partial resection was reported in 2 (5.6%), STR in 21 (58.3%), NTR in 5 (13.9%), and GTR in 8 (22.2%) patients. Pre-operative cranial neuropathies were seen in 6 patients (16.8%), one of which was due to pituitary apoplexy. Subjective improvement occurred in all 6 (100%). New temporary post-operative cranial neuropathy (1 abducens nerve and 1 oculomotor nerve) occurred in 2 patients (5.6%), both of which had tumor in the lateral CS.

Both neuropathies resolved after 1 and 3 months. Pre-operative visual field defects were seen in 10 patients (27.8%). Nine patients (90%) improved post-operatively and 1 patient (10%) had no change. Pre-operative endocrine defects were found in 15 patients (41.6%). Six patients (40.0%) improved and nine patients (60.0%) had no change. Of the six patients who improved, the hormonal abnormalities were: elevated GH (2), elevated ACTH (2), elevated prolactin (1), and decreased FSH/LH (1).

There were differences in surgical outcomes between the KS categories: KS 1–2 (medial) and KS 3–4 (lateral) CS invasion (Table 3). The average degree of CS tumor resection (KS1-2: 84.6% vs. KS3-4: 66.6%, $p=.04$) and percentage with GTR (KS1-2: 53.8% vs. KS3-4: 8.7%, $p=.0006$) vs. STR (KS1-2: 15.4% vs. KS3-4: 82.6%, $p<.0001$) of the CS component of the tumor, varied significantly by KS category. A significantly higher degree of resection was achieved using the endonasal endoscopic approaches for medial compared to lateral CS lesions. Eleven (22.4%) patients went on to be treated with radiation either in the setting of tumor recurrence or as adjuvant therapy based on the tumor pathology. The remaining patients were followed closely for tumor recurrence or growth of residual. 39.1% of patients with KS3-4 tumors received post-operative radiation therapy compared to less than 15.4% of patients with K1-2 tumors.

At the time of last follow up (median follow-up 30.7 months), 1 patient (7.7%) with a medial KS 1–2 lesion had new growth by MRI compared to 1 patient (4.3%) with a KS 3–4 lesions. We divided complications into those that occurred attributable to CS surgery (eg. cranial neuropathy, infection) and those attributable to pituitary surgery (eg. hypopituitarism, DI, CSF leak, mucocoele). CS surgery resulted in an 8.4% transient morbidity (cranial neuropathy (2 cases) and infection (1 case)) and a 0% permanent morbidity. Pituitary surgery resulted in 19.2% transient morbidity from DI/hypopituitarism (5 cases), CSF leak (1 case), mucocoele (1 case), and an 8.3% permanent morbidity from DI/hypopituitarism (1 case), hypopituitarism without DI (2 cases).

Discussion

In this study, we explore the relative merits of a moderately aggressive “medial to lateral” approach to pituitary tumors invading the CS. Pituitary tumors arise in the midline and generally push the contents of the CS in a medial to lateral direction. For this reason, the carotid artery and cranial nerves are at the lateral aspect of the approach and require minimal manipulation during tumor removal. Notably, there were no carotid artery injuries, only 1 post-operative CSF leak and two temporary cranial neuropathies, both in cases where tumor was resected from the lateral CS and neither resulted in permanent deficits. As one might expect, we observed that the degree of tumor resection from within the CS varies significantly based on Knosp-Steiner grade, where medially positioned lesions could be more completely removed compared to laterally positioned tumors.

These results support our overall philosophy, namely that radical debulking of the medial CS can be safely achieved whereas tumor in the lateral CS, although resectable, results in higher risk when pursued aggressively and a strategy of debulking may be a safer and equally effective alternative. This philosophy has been molded by the existence of the stereotactic

radiosurgical options available in the current era. Endoscope-assisted surgery has gained widespread usage during the last decade. Using certain approaches, visualization during endoscope-assisted surgery can be superior to microsurgery, as the endoscope permits improved visualization from a larger field of view achieved at the end of a narrow corridor since the lens and light source are close to the target. This provides excellent resolution of anatomic and pathologic details, particularly with the advent of 3D endoscopes.^{15,39,43} Moreover, the use of angled endoscopes and instruments enables the surgeon to visualize and remove structures around corners and avoid retraction. Disadvantages can include narrow working spaces causing reduced degrees of freedom with the dissecting instruments and proximity of the lens to debris and blood mandating frequent scope cleaning. As this technology has evolved, surgeons have explored the use of endonasal endoscopic approaches to remove lesions extending into the CS, particularly using the 2 surgeon, binarial technique which affords increased precision and safety. This deep, anatomically complex region offers unique challenges depending on the degree of invasion, consistency of the tumor, and angle of surgical approach.

Numerous anatomical studies have detailed the relevant surgical anatomy for these approaches from both a transcranial and transnasal perspective. Transcranial studies often describe various corridors between the CNs lying within the lateral wall of the CS. In one of the first landmark studies, Parkinson described surgical corridors to the cavernous carotid artery and detailed the anatomic triangle between CNs IV and V1, and the tentorium that now carries his name⁴⁰. Since then, other groups have advanced these concepts providing anatomical and technical nuances to aid in removing lesions from this area.^{2,21,22,30–32,46,47,55} Jho and Ha were some of the first to describe transnasal approaches to the CS; they included the paraseptal, middle meatal and middle turbinectomy corridors and detailed the relationships of key structures to the carotid siphon.²³ Numerous other groups have since illustrated the surgical anatomy and techniques important for successful endoscope-assisted access to the CS.^{3,4,8,17,18,24,25}

In the original publication by Knosp and Steiner in 1993 outlining the grading system for lesions invading the CS, they suggested that “the critical area where invasion of the cavernous sinus space becomes very likely and can be proven surgically is located between the intercarotid line and the lateral tangent, which is represented by [the] Grade 2”.²⁸ For this reason, we categorized our cases into Grade 1–2 and Grade 3–4 lesion for the purposes of this study. Our findings corroborate this key anatomic interface at the lateral aspect of the cavernous carotid segments in the determining the expected degree of resection and potential recurrence rate for a given lesion. In a later study by Frank and Pasquini, the endonasal endoscopic approach was used to treat 65 patients with pituitary adenomas invading the CS.¹⁴ The authors reported gross total resection in 60% for non-functional tumors and hormone remission in 67% of functional tumors. Complications included 3 (5%) CSF leaks, 2 (3%) patients with pituitary insufficiency, and 1 patient requiring craniotomy for hematoma evacuation. However, they did not differentiate these cases based on the relative degree of CS invasion. More recently, Ceylan and colleagues reported their series of 20 patients undergoing endonasal surgery for pituitary adenomas invading the CS and included Knosp-Steiner designations; in this series, 98% were KS grade 3–4. GTR was achieved in 65% and STR in 35%.⁷ For the secretory tumors (75%), hormone remission

occurred in 10/15 (67%). Reported complications included DI in 3 (15%) and CSF leak in 3 (15%). Although our rates of resection are lower, our complications are also lower, indicating that perhaps a more conservative approach, particularly with respect to lateral CS invasion, may reduce complications. Operative time and complications, particularly CSF leaks, are major considerations for these cases. Of note, our low CSF leak rate in this series is the result of a systemic effort to create a multi-layer closure construct which begins with the planning of the bony opening and continues with nasoseptal flap harvesting at the beginning of the case for larger (> 2.5 cm) tumors.

Comparisons of the outcomes and complication rates between the transnasal and transcranial approaches are difficult as it is not possible to gauge the important contributions of patient selection bias and surgeon familiarity with these challenging techniques. However, the major publications include varying pathologies and report a 60–80% degree of resection, transient morbidity in 20–80%, permanent morbidity in 5–15%, and recurrence in 10–25% following transcranial approaches. (Table 4) In this series we divide patients based on CS invasion and offer such radical resection rates only when the medial CS is involved and tumor can be removed safely. Hence, our extent of resection rate is lower than in other series as are our morbidity rates. Morbidity rates for tumors only positioned within the medial CS are even lower.

While there are no studies directly comparing the clinical outcomes of the transcranial microsurgical approach to the CS with the endonasal endoscopic technique, direct comparisons of the relevant surgical anatomy have been more common, in particular detailing the relative courses of the cavernous CNs.^{6,19,20} Ultimately, tumors that invade into the medial CS (medial to the lateral carotid tangent) can be approached endonasally with acceptably low morbidity and reasonably high degrees of resection, particularly if the tumor arises in the midline, likely has a soft consistency and invades in a medial to lateral trajectory pushing the CS contents laterally. Tumors that extend into the lateral CS can be removed at least partially through a medial to lateral route, particularly if they are soft. More firm tumors primarily in the lateral CS, in particular meningiomas, may require a lateral, transcranial approach to achieve a greater degree of resection to effectively decompress neurovascular structures and create space for adjuvant radiation treatment. Consideration of less invasive treatments such as stereotactic radiosurgery or fractionated radiotherapy should be strongly considered depending on the therapeutic goals and the overall treatment plan.

Radiation Therapy

The utility of radiosurgery for lesions in the CS should be carefully considered prior to discussing the goals of surgery: biopsy versus lesion debulking versus gross total resection. Numerous studies have explored the role of conventional fractionated radiation and stereotactic radiosurgery in the treatment of benign and malignant cavernous sinus lesions. Rates of tumor control vary from 50–100% and tumor reduction from 30–70%, depending on the lesion size and histopathology.^{5,26,29,33–35,37,42,45,48,49} Important in evaluating these studies, the tumor growth rates *prior* to treatment, should be closely considered when determining the tumor control (often set as no new growth) rates following radiation-based therapies. For secretory pituitary adenomas, hormone remission rates have been suggested to

be upwards of 40–50% regardless of the type.^{26,36,38,44,50,51,53} In addition, the risk of transient and permanent procedure-associated morbidity ranges from 0–25% and 0–6% respectively.^{26,33,34,42,48} Radiation injury to the optic apparatus and the pituitary gland are particular concerns - reported to be as high as 6% and 35% respectively.^{1,50} To enable higher radiation doses and limit this damage, pituitary transposition has been suggested as a useful and effective technique.^{9,52} The decision to aggressively debulk the medical CS offers an additional measure, like pituitary transposition, to render post-operative radiosurgery more safe and increase the radiobiological margin for critical structures.

In this study, we aimed to identify some of the limitations and considerations in designing treatment strategies for patient with pituitary tumors involving the cavernous sinus. This retrospective analysis provides useful insight into the use of endonasal endoscopic techniques for a medial-to-lateral approach to these lesions. However, our findings cannot account for treatment and patient-selection biases that may play a role in the outcomes reported here. Furthermore, this study does not address the efficacy of our approach for the long-term control of these lesions due to the relatively short follow up. To limit the interpretation bias associated with the Knosp-Steiner and resection grading, we used an independent, outcome-blinded neuroradiologist to evaluate the pre- and post-operative imaging. Taken together, we feel this study offers useful information to guide the clinical decision-making for these patients.

Conclusion

The endoscopic endonasal approach provides a useful and safe medial-to-lateral approach to the CS. Radical debulking of the medial CS can be performed safely and may create a suitable distance between radiosensitive structures and the residual tumor. In certain situations, the lateral CS can be debulked as well, but with slightly higher risk to the cranial nerves. One must carefully weigh surgical goals with the risks of surgery and the availability of adjuvant treatment options.

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Adapted from E. Knosp et al. / *Neurosurgery* 33(4), 1993

Figure 1.

Knosp-Steiner classification scheme: (0) no invasion, the lesion does not reach the medial aspect of the CCA, (1) invasion extending to but not past, the intercarotid line, (2) invasion extending to but not past, the lateral aspect of the CCA, (3) invasion past the lateral aspect of the CCA but not completely filling the CS, and (4) completely filling the CS both medial and lateral to the CCA.

Figure 2.

Exposure of the region of the cavernous carotid artery (A), removal of the overlying bone (B), and location confirmation using the micro-doppler (C). [CS (cavernous sinus); S (sella); Cl (clivus); C (carotid artery)]

Figure 3.

Angled endoscopes are used to follow the tumor through the medial wall of the cavernous sinus behind the carotid siphon using angled suctions (A) and ring curettes (B). [P (pituitary gland); MW (medial wall of CS)]

Figure 4.

(A) Pre-operative MRI demonstrating a large expansive lesion in the right CS. (B) Following endonasal endoscopic surgery the majority of the tumor was removed. Any firm tumor stuck to neurovascular structures was left in place to be addressed with post-operative radiosurgery or observation as indicated by the pathology and the age of the patient. In this case, the small residual from this low grade lesion was observed.

Table 1

Summary data for 36 patients with 49 invasive cavernous sinus pituitary adenoma lesions undergoing endonasal endoscopic surgery.

Variable	Summary Statistic N = 36 Patients
Age, years	47.3 (16.4)
Female	22 (61)
Presenting symptoms	
Headache	9 (25.0)
Vision	8 (22.2)
Endocrine	16 (44.4)
Cranial neuropathy	6 (16.8)
Lesion Characteristics	
Bilateral	13 (33.3)
Non-secretory	16 (44.4)
Growth Hormone-Secreting	10 (27.8)
Prolactinoma	7 (19.4)
ACTH-Secreting	3 (8.3)
Gonadotrophin-Secreting	2 (5.6)
Operative Variables	
Re-operation	3 (8.3)
Approach	
■Transsellar	24 (66.7)
■Transsellar transplanum	9 (25.0)
■Transsellar transtethmoidal	3 (8.3)
Lumbar drain	11 (30.6)
Nasoseptal Flap	18 (50.0)
Follow-up, median (IQR)	13 (9.5–16.5)

* Data given as Number (%), Median (interquartile range), Mean (Standard Deviation)

Table 2

Outcome data from patients undergoing expanded endonasal surgery for invasive pituitary adenomas. [KS: Knosp-Steiner, CN: cranial nerve, PI: pituitary insufficiency]

Summary Statistic N = 36 patients		
<i>Degree of Invasion</i>		
KS Grade 1–2		13 (36.1)
KS Grade 3–4		23 (63.9)
<i>Degree of CS Resection (%)</i>		
Partial (<50%)		2 (5.6)
Subtotal (50–80%)		21 (58.3)
Near total (80–95%)		5 (13.9)
Gross total (>95%)		8 (22.2)
<i>Post-operative findings:</i>		
Visual (n=10)*	no change	1 (10.0)
	better	9 (90.0)
CN (n=6)*	no change	0 (0)
	better	6 (100)
Endocrine (n=15)*	no change	9 (60.0)
	better	6 (40.0)
<i>Follow-up:</i>		
Radiation therapy		11 (30.6)
Medical therapy		10 (27.8)
Repeat Surgery		1 (2.8)
Recurrence		2 (5.6)

* n= number of pre-operative complaints

Table 3

Lesion types and outcome data stratified by Knosp-Steiner grade (See also Figure 1.) [CN: cranial nerve, PI; pituitary insufficiency]

Variable	Knosp-Steiner Classification		p-value
	Grade 1–2 (n=13) Medial to Cavernous Carotid	Grade 3–4 (n=23) Lateral to Cavernous Carotid	
Degree of CS Resection (%)			
Partial (<50%)	1 (7.7)	1 (4.3)	0.67
Subtotal (50–80%)	2 (15.4)	19 (82.6)	<0.01
Near total (80–95%)	3 (23.1)	2 (8.7)	0.23
Gross total (>95%)	7 (53.8)	1 (8.7)	<0.01
Average	84.6%	66.6%	0.04
Follow-up:			
CSF leak	0 (0)	0 (0)	N/A
Radiation therapy	2 (15.4)	9 (39.1)	.14
Medical therapy	2 (15.4)	8 (34.8)	.21
Repeat Surgery	0 (0)	1 (4.3)	N/A
Recurrence	1 (7.7)	1 (4.3)	N/A
Post-operative findings:			
Visual – no change	0 (0.0)	1 (14.3)	0.46
better	3 (83.3)	6 (85.7)	0.84
CN – no change	0 (0)	0 (0)	N/A
better	2 (100)	4 (100)	N/A
Endocrine** – no change	0 (0.0)	9 (81.8)	<0.01
better	4 (100)	2 (18.2)	.09

* Data given as Number (%)

** Only includes permanent endocrinopathies

Table 4

Summary of studies exploring treatments for invasive cavernous sinus tumors: Transcranial-, Stereotactic Radio-, and Endonasal surgery. [TC (transcranial); SRS (stereotactic radio-surgery); TN (transnasal); trans. (transient); perm. (permanent); n/a (not available)] Gross total resection (GTR) is given based on the total tumor volume, as opposed to the cavernous sinus specific components.^{7,10,12–14,26,27,33,54,56}

Study	# Pts.	Approach	Pathology	Location	Tumor control/degree of resection *	% morbidity (trans./perm.)	% recurrence	Mean Follow-up (mo.)
Van Lindert <i>et al.</i> , 1991	53	TC	PA	CS	68% GTR	22% / 6%	36%	76
Cusimano <i>et al.</i> , 1995	124	TC	Mixed	CS	66% GTR	80% / 15%	10%	29
Dolenc <i>et al.</i> , 1997	210	TC	PA	CS	77% GTR	25% / 10%	n/a	n/a
Eisenberg <i>et al.</i> , 1999	40	TC	Mixed	CS	83% GTR	35% / 10%	15%	48
Kuo <i>et al.</i> , 2004	139	SRS	Mixed	CS	41% decrease	6% / 2%	7%	42
Kim <i>et al.</i> , 2006	67	SRS	PA	CS	72% decrease	0% / 2%	4%	33
Frank <i>et al.</i> , 2006	65	TN	PA	CS	60% GTR	6% / 3%	n/a	51
Kitano <i>et al.</i> , 2008	36	TN	PA	CS	72% GTR	40% / 5%	6%	40
Zhao <i>et al.</i> , 2010	126	TN	PA	CS	62% GTR	11% / 6%	n/a/	n/a
Ceylan <i>et al.</i> , 2010	20	TN	PA	CS	65% GTR	30% / 5%	n/a	n/a
Present study	36	TN	PA	CS	20% GTR	8.4% / 0% **	3%	13

* This number represents the degree of resection of the cavernous sinus component of the tumor

** this number includes only morbidity related to surgery in the cavernous sinus