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CLINICAL ARTICLE

Outcomes of decompressive surgery for cavernous sinus meningiomas: long-term follow-up in 50 patients

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OBJECTIVE Cavernous sinus meningiomas are complex tumors that offer a perpetual challenge to skull base surgeons. The senior author has employed a management strategy for these lesions aimed at maximizing tumor control while minimizing neurological morbidity. This approach emphasizes combining "safe" tumor resection and direct decompression of the roof and lateral wall of the cavernous sinus as well as the optic nerve. Here, the authors review their experience with the application of this technique for the management of cavernous sinus meningiomas over the past 15 years.

METHODS A retrospective analysis was performed for patients with cavernous sinus meningiomas treated over a 15-year period (2002–2017) with this approach. Patient outcomes, including cranial nerve function, tumor control, and surgical complications were recorded.

RESULTS The authors identified 50 patients who underwent subtotal resection via frontotemporal craniotomy concurrently with decompression of the cavernous sinus and ipsilateral optic nerve. Of these, 25 (50%) underwent adjuvant radiation to the remaining tumor within the cavernous sinus. Patients most commonly presented with a cranial nerve (CN) palsy involving CN III–VI (70%), a visual deficit (62%), headaches (52%), or proptosis (44%). Thirty-five patients had cranial nerve deficits preoperatively. In 52% of these cases, the neuropathy improved postoperatively; it remained stable in 46%; and it worsened in only 2%. Similarly, 97% of preoperative visual deficits either improved or were stable postoperatively. Notably, 12 new cranial nerve deficits occurred postoperatively in 10 patients. Of these, half were transient and ultimately resolved. Finally, radiographic recurrence was noted in 5 patients (10%), with a median time to recurrence of 4.6 years.

CONCLUSIONS The treatment of cavernous sinus meningiomas using surgical decompression with or without adjuvant radiation is an effective oncological strategy, achieving excellent tumor control rates with low risk of neurological morbidity.

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KEYWORDS meningioma; cavernous sinus; skull base approach; cytoreduction; cranial nerve; oculoparesis; oncology

The cavernous sinus is a complex region characterized by a high density of intricate microanatomic structures. Historically, surgery in the cavernous sinus has challenged neurosurgeons because of the considerable morbidity associated with injury to its neural or vascular contents. In particular, surgery for cavernous sinus meningiomas, which account for 41% of all cavernous sinus tumors,[8] has undergone dramatic paradigm shifts over the decades.[23] Although these lesions were initially considered nonoperable, management evolved toward aggressive surgical extirpation in the 1980s and early 1990s, driven by advances in microsurgical techniques and improved understanding of cavernous sinus anatomy.[13] However, the excellent resection rates were often achieved at high functional cost, and recurrent tumor growth was consistently reported.[6,21] This was, in part, explained by histological evidence demonstrating tumor infiltration of both the cavernous carotid artery[14] and cranial nerves.[15] Subsequently, enthusiasm for aggressive intracavernous exploration waned in favor of nonoperative strategies employing advanced radiosurgical techniques.

In smaller tumors or those confined to the cavernous sinus proper, the use of stereotactic radiosurgery (SRS) has been associated with excellent tumor control rates with

ABBREVIATIONS CN = cranial nerve; KPS = Karnofsky Performance Status; SOF = superior orbital fissure; SRS = stereotactic radiosurgery; SRT = stereotactic radiotherapy.

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low periprocedural morbidity.[13] However, the application of single-fraction SRS is often limited for larger tumors with extracavernous extension or those that encroach upon the optic apparatus.[23] In fact, larger SRS treatment volumes have been associated with significantly greater risk of complications,[8] while the dose de-escalation required to protect the visual pathways often diminishes tumor control.[23] Moreover, despite a reported radiographic tumor response rate of 30%–70%,[13] there is relatively little post-treatment reduction in the mass effect imparted by the tumor after SRS.[16] Thus, in the last decade, there has been rising enthusiasm for the reapplication of microsurgical techniques in the management of cavernous sinus meningiomas. Couldwell et al.[4] first reported outcomes for 11 patients treated with a more conservative surgical strategy in which the cavernous sinus and optic nerve were decompressed and tumor was resected from areas where the risk of cranial nerve morbidity is low; the case series was updated with an additional 9 patients in 2009.[23] These reports demonstrated great potential for maximizing tumor control while providing an optimal milieu for neurological recovery. In the current study, we provide additional follow-up and further expand our cohort to 50 patients treated using this decompressive and cytoreductive approach.

Methods

After receiving institutional review board approval, we undertook a retrospective chart review of cases of cavernous sinus meningiomas treated at the University of Utah Hospital between 2002 and 2017. All patients included in the study had primary cavernous sinus involvement with significant encasement of the carotid artery (Hirsch grade 2 or 3),[10] and many had extracavernous extension. Patients uniformly underwent surgical treatment as described below, consisting of resection of the extracavernous portion of the tumor and direct decompression of the cavernous sinus (Fig. 1).[4]

Patient characteristics and clinical factors, such as age, sex, histology, history of previous treatments, and preoperative symptoms or neurological deficits, were examined. Patient outcomes were also recorded, including visual and cranial nerve function, tumor control, the use of adjuvant radiation, and surgical complications. Recurrence was defined as an increase of the contrast-enhancing lesion diameter by more than 2 mm or extracavernous extension of the lesion. Time to recurrence was calculated from the date of surgery to the date of the first MRI scan showing the change.

The patients from previously published series[8,23] are included in the current study with additional follow-up.

Statistical Analysis

Continuous variables, including patient age, time to recurrence, and duration of follow-up, were reported as median and range. Categorical variables, such as symptoms on presentation, were reported as number and percentage. The Kaplan-Meier method was used to calculate an actuarial tumor control rate using GraphPad Prism software version 6.01 (GraphPad Software).

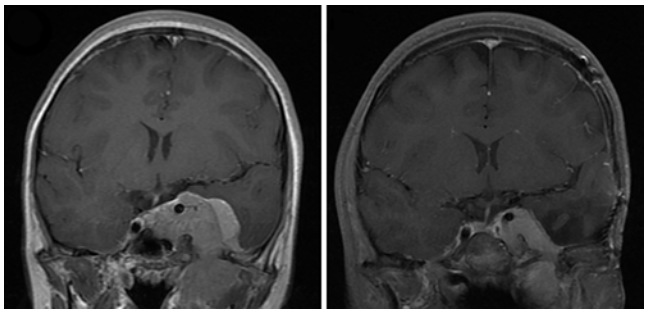

FIG. 1. Coronal contrast-enhanced T1-weighted MR images demonstrating preoperative tumor burden (**left**) and postoperative intracavernous residual (**right**) after frontotemporal craniotomy for subtotal resection and cavernous sinus decompression in 2 patients.

Surgical Technique

The operative technique employed in the treatment of all patients in the current study has been previously described by the senior author (W.T.C.) with the key elements described here.[4] The procedure is initiated with a standard frontotemporal craniotomy (Fig. 2, Video 1).

VIDEO 1. Video illustrating step-by-step decompression of the left cavernous sinus for meningioma. Copyright Department of Neurosurgery, University of Utah. Published with permission. Click here to view.

The lateral sphenoid wing is drilled to achieve complete bony decompression of the lateral orbit and superior orbital fissure (SOF).[7] Bone removal to completely unroof the foramen rotundum and foramen ovale ensures decompression of all 3 trigeminal branches. It requires elevation of the anterior middle fossa dura in a lateral-to-medial trajectory, a modification of the Kawase approach,[1] to access the nerve branches and their foramina. At this point, depending on the size of the tumor and the extent of optic nerve compression, the hyperostotic bone of the orbital roof may be removed and an extradural clinoidectomy performed. In cases where extradural manipulation of the lesion risks injury to the optic nerve because of constriction of the optic canal, it is recommended to first proceed with dural opening and tumor debulking. The final extradural step involves the elevation of the temporal lobe dura from the lateral dural wall of the cavernous sinus in the manner described by Hakuba et al.[9] This maneuver divides the intra- and extracavernous components of the tumor at the lateral margin of the sinus, decompresses the cranial nerves traversing the lateral cavernous sinus wall, and exposes tumor-involved medial temporal dura for subsequent resection.

The intradural portion of the procedure involves maximal tumor resection from "safe" areas least likely to produce neurovascular injury, removal of involved dura, and decompression of any other remaining neural elements in or near the cavernous sinus. After dural opening and bisection of the flap, accessible tumor can be debulked medially to free the optic nerve and suprasellar cistern. The sylvian fissure is divided as needed to accomplish exposure to the entire involved dura. The middle fossa component of the tumor can similarly be debulked; however, when possible, the plane between the tumor and temporal lobe is developed until normal dura is identified at the posterior edge of the tumor. A second cut extending from the normal dura

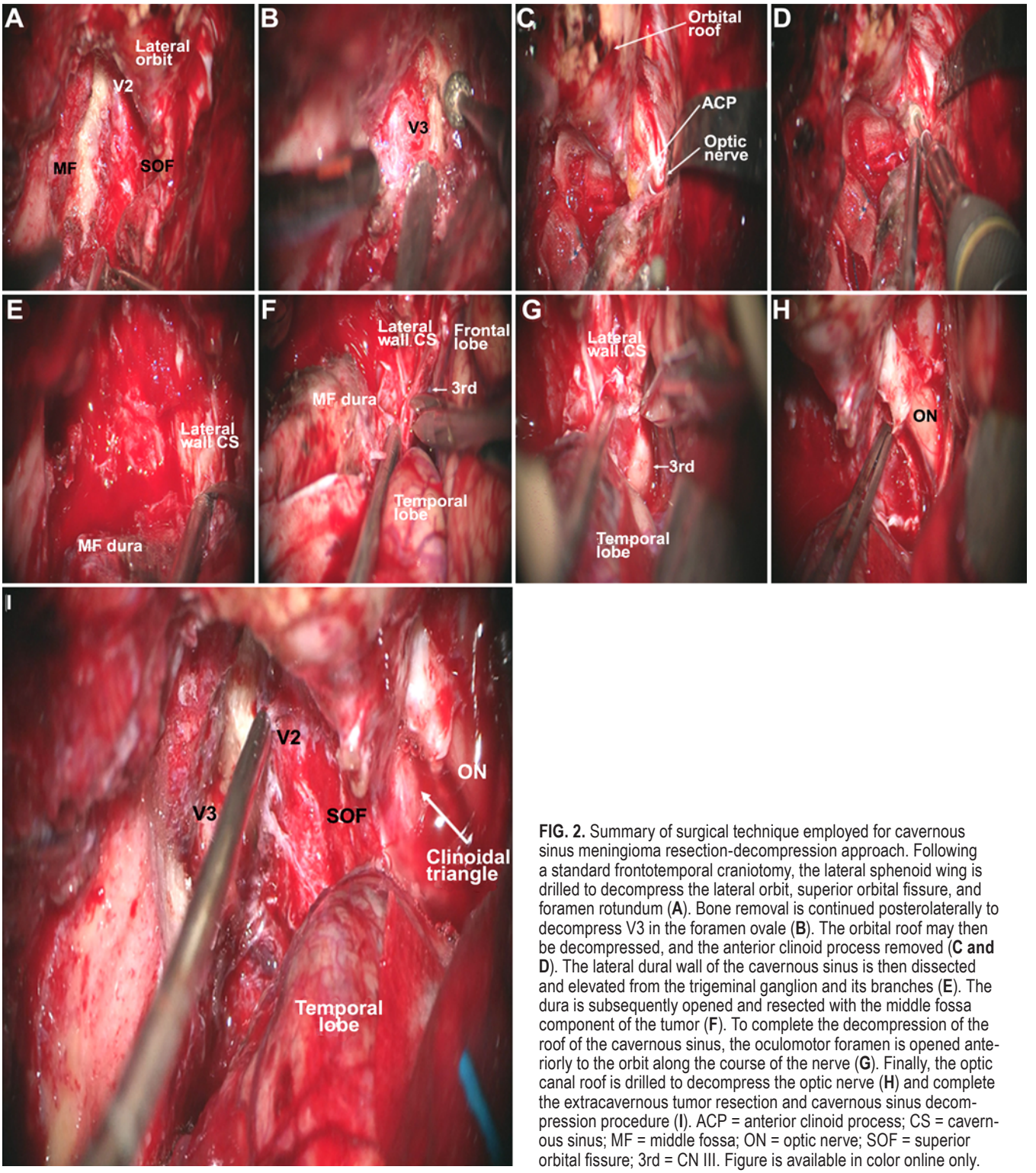

FIG. 2. Summary of surgical technique employed for cavernous sinus meningioma resection-decompression approach. Following a standard frontotemporal craniotomy, the lateral sphenoid wing is drilled to decompress the lateral orbit, superior orbital fissure, and foramen rotundum (**A**). Bone removal is continued posterolaterally to decompress V3 in the foramen ovale (**B**). The orbital roof may then be decompressed, and the anterior clinoid process removed (**C and D**). The lateral dural wall of the cavernous sinus is then dissected and elevated from the trigeminal ganglion and its branches (**E**). The dura is subsequently opened and resected with the middle fossa component of the tumor (**F**). To complete the decompression of the roof of the cavernous sinus, the oculomotor foramen is opened anteriorly to the orbit along the course of the nerve (**G**). Finally, the optic canal roof is drilled to decompress the optic nerve (**H**) and complete the extracavernous tumor resection and cavernous sinus decompression procedure (**I**). ACP = anterior clinoid process; CS = cavernous sinus; MF = middle fossa; ON = optic nerve; SOF = superior orbital fissure; 3rd = CN III. Figure is available in color online only.

posterior to the tumor to the oculomotor nerve releases the temporal dura and the extracavernous tumor in the middle fossa, allowing en bloc resection of this component of the tumor. In accordance with the Dolenc technique, the oculomotor foramen is opened superiorly along the axis of the nerve until just proximal to the SOF to avoid injury to the crossing trochlear nerve.[22] The opening of the oculomotor triangle, coupled with the previous clinoidectomy, completes the decompression of the cavernous sinus roof. Finally, optic nerve decompression may be performed to circumferentially release the optic nerve, and any tumor identified within the optic canal may then be readily removed.

Results

A total of 50 patients met criteria for inclusion in the study, having undergone maximal safe resection for cavernous sinus meningiomas with concomitant superolateral decompression of the sinus during the 15-year study period. Demographic characteristics for these patients are summarized in Table 1. The cohort comprised 33 women (66%) and 17 men (34%), reflecting the typical sex distribution. The patients' median age was 56 years (IQR 51–65 years). Of these 50 patients, 6 (12%) had undergone a separate resection prior to the index procedure, and 3 (6%) patients had prior radiation treatment. None had undergone a procedure to decompress the cavernous sinus or optic nerve. In all patients, the primary indication for surgical intervention was the onset of tumor-associated symptoms. The primary presenting symptoms were headaches (52%), worsening visual acuity (62%), diplopia secondary to oculoparesis (70%), proptosis (44%), and new-onset seizure (8%).

The mean duration of postoperative follow-up was 5.4 years (range 0.1–15.6 years), although 23 patients were lost to follow-up after an average of 5.2 years (range 0.6–13.0 years). Two patients died during the study period, one from a pulmonary embolus associated with an unrelated malignancy more than 4 years after surgery, and the second at the age of 75 years from an unclear cause more than a year after surgery. In the immediate postoperative period, the latter patient's functional status was acceptable (Karnofsky Performance Status [KPS] of 80) with documented improvement of his visual acuity from hand motion only to counting fingers at a distance of 3 feet. However, the histopathologic diagnosis was an atypical meningioma (WHO grade II) for which he underwent adjuvant stereotactic radiotherapy. Within several months, and after undergoing a thyroidectomy for newly diagnosed papillary thyroid carcinoma, the patient complained of progressive imbalance, fatigue, and depression. Moreover, his vision deteriorated without evidence of tumor recurrence. Ultimately, he became nonverbal, with a KPS of 30, leading to his elective admission to hospice care.

Tumor Control

Of the 50 patients included in the study, 25 (50%) underwent adjuvant radiation at a median of 67 days (IQR 47–118 days) postoperatively (Table 1). These included the only 2 patients diagnosed with WHO grade II lesions in this cohort. Thereafter, 39 patients had radiographic follow-up longer than 1 year from the time of initial treatment.

Overall, tumor progression was detected on surveillance MRI in 5 patients, with a median time to recurrence of 4.6 years (range 3.5–11.8 years). The tumor control rate was, therefore, 90% (5/50), with an actuarial control rate of 87.8% at 5 years (Fig. 3A). Among the patients who had tumor recurrence, 2 had received adjuvant radiation after the initial resection, resulting in an actuarial control rate of 90% at 5 years (Fig. 3B). Of these, 1 patient underwent repeat surgery for recurrence within the middle fossa adjacent to the residual cavernous component. The second required more extensive treatment, including fractionated stereotactic radiotherapy (SRT) to tumor extending into the contralateral cavernous sinus, repeat resection of a recurrence with intraorbital extension, and additional SRT to the orbital resection cavity. Of the remaining 3 patients who experienced tumor recurrence, 2 were treated with SRT and 1 was treated with repeat resection because of complaints of worsening visual acuity. Thus, the actuarial control rate for patients who did not undergo adjuvant radiation was 85.7% at 5 years (Fig. 3C).

TABLE 1. Demographic and clinical variables of 50 patients with cavernous sinus meningiomas

Characteristic	Value
Male patients	17 (34)
Median age in yrs (IQR)	56.0 (50.9–64.5)
Presenting symptoms	
Headaches	26 (52)
Visual loss	31 (62)
Cranial nerve palsy, CN III–VI	35 (70)
Proptosis	22 (44)
Seizures	4 (8)
Prior surgery	6 (12)
Prior radiation	3 (6)
Pathology	
WHO grade I	45 (96)
WHO grade II	2 (4)
Adjuvant radiation	25 (50)
Median days to radiation (IQR)	67 (47–118)
Median radiographic FU in yrs (IQR)	4.3 (1.3–7.9)
Radiographic recurrence	5 (10)
Median time to recurrence in yrs (IQR)	4.6 (4.2–5.2)

FU = follow-up.
Values reported as n (%) unless otherwise indicated.

Cranial Neuropathies and Visual Loss

Preoperative cranial nerve (CN) deficits (CN III–VI) affected 35 patients (70%) (Table 2). The most common presenting cranial neuropathy was oculomotor palsy (36%), followed closely by abducens palsy (32%) and trigeminal dysfunction (30%). Dramatic improvement was documented postoperatively in patients with CN VI palsy, with 81% (13/16 patients) showing some measure of recovery. Similarly, 50% of the patients (9/18) with CN III dysfunction demonstrated improvement after surgical decompression of the cavernous sinus. Improvement was less pronounced in patients with CN V and CN IV palsies, with recovery noted in 33% (5/15 patients) and 0% (0/3), respectively. The remaining cranial neuropathies remained stable postoperatively, except in 1 patient whose facial numbness worsened in the V3 distribution and extended to involve V2. However, 12 new cranial neuropathies were documented postoperatively in 10 patients (20%). Half of the new neuropathies were seen in patients with preoperative dysfunction in other cranial nerves, and half occurred in patients whose cranial nerves III–VI were normal preoperatively. Although 50% (6/12) of the new cranial neuropathies involved the oculomotor nerve, 66% (4/6) of these subse-

quently resolved. The only patient with a new abducens palsy had a similarly transient course, but only 33% (1/3) of new trochlear nerve palsies and none (0/2) of the new trigeminal nerve injuries resolved. Ultimately, permanent new cranial neuropathies affected 5 patients (10%).

Visual outcomes tracked in the study cohort are reported in Table 3. Preoperative visual deficits were recorded in 31 patients (62%). Of these deficits, 42% improved (13/31) and 55% stabilized (17/31); only 1 patient (3%) experienced further visual loss. Notably, none of the patients presenting with normal vision experienced postoperative decrement in visual acuity.

Complications

In addition to the new cranial neuropathies reported above, perioperative morbidity of varying severity was observed (Table 4). Two patients experienced cerebral ischemic events documented on the immediate postoperative MRI. Of these, 1 patient was asymptomatic despite several small acute left cerebellar infarcts consistent with an embolic phenomenon without an identified source. The second patient, however, had a small lenticulostriate stroke affecting the internal capsule and correspondingly developed contralateral lower leg weakness. Two patients developed new postoperative pituitary dysfunction. Of these, 1 patient required readmission for management of hyponatremia, adrenal insufficiency, and central hypothyroidism. Additionally, 1 patient developed a symptomatic postoperative pulmonary embolus requiring therapeutic anticoagulation, and another complained of pulsatile exophthalmos that was managed nonoperatively. Finally, 1 patient, who had undergone previous resection attempts and radiation, re-presented 3 months after surgery with scalp wound breakdown and osteomyelitis. She required craniectomy and multiple scalp revisions over several months. Ultimately, her craniectomy defect was reconstructed with a custom bone flap and a latissimus dorsi free flap anastomosed to the facial artery.

Discussion

Meningiomas involving the cavernous sinus are complex tumors whose management continues to evolve. The espoused treatment philosophy, as is true in nearly all skull base lesions, remains to maximize tumor control while retaining, or in some cases restoring, neurological functionality. Considering the high operative risk involved in the resection of lesions within the cavernous sinus, we and others have previously proposed treatment algorithms that recommend observation or SRS alone for the management of asymptomatic tumors confined to the cavernous sinus.[8,13,20,23] Conversely, aggressive cavernous sinus exenteration with the goal of oncological cure is an option for young healthy patients with treatment-resistant tumors and concurrent monocular blindness and oculoplegia.[5] However, in patients with symptomatic lesions and extracavernous extension, the optimal management strategy remains unsettled. The driving force for this debate is the contrast between the safety of SRS and the reported surgical morbidity in the treatment of tumors with a generally benign natural history.[2,16,18,23] The current study represents our 15-year experience using a prescribed cytoreductive and decompressive surgical approach for the treatment of 50 such cavernous sinus meningiomas.

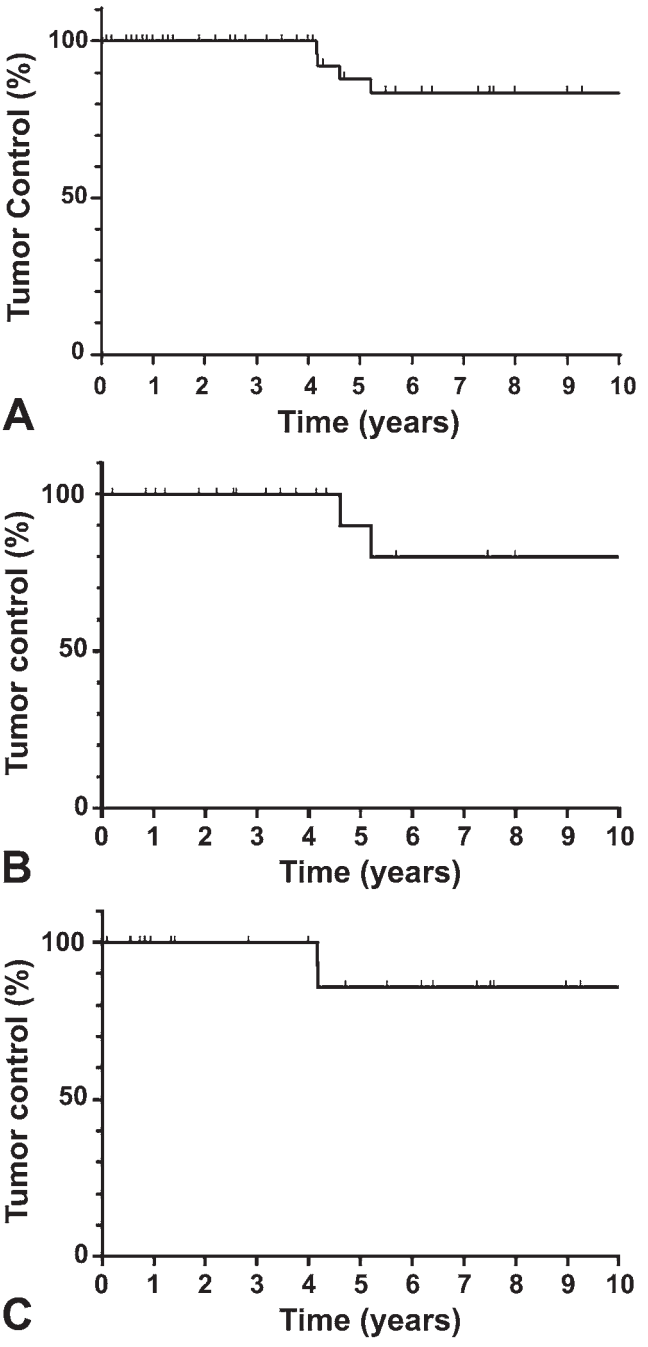

FIG. 3. Kaplan-Meier curve depicting tumor control rate in patients following subtotal resection and cavernous sinus decompression. **A:** All patients. **B:** Patients who had adjuvant radiation. **C:** Patients who did not have adjuvant radiation.

Subtotal Resection Strategy

The surgical strategy of planned subtotal resection from "safe" extracavernous zones and concomitant neural element decompression has been examined for the past 2

TABLE 2. Preoperative and postoperative cranial neuropathy

Pt Group & Cranial Nerve	No. of Pts w/ Preop Deficit	Postop Function			
		Improved	Unchanged	Worsened	New Deficit
Pts w/ preop deficits (n = 35)					
CN III	18	9	9	0	3
CN IV	3	0	3	0	1
CN V	15	5	9	1	1
CN VI	16	13	3	0	1
Pts w/o preop deficits (n = 15)					
CN III	0	NA	NA	NA	3
CN IV	0	NA	NA	NA	2
CN V	0	NA	NA	NA	1
CN VI	0	NA	NA	NA	0

NA = not applicable; pt = patient.
Data are numbers of patients. Some patients had deficits involving more than 1 cranial nerve.

decades. The specific approach used herein was formally reported in 2006; it employs a frontotemporal corridor coupled with elements from the techniques described by Dolenc, Hakuba, and Kawase to access the roof and lateral wall of the cavernous sinus.[1,4] The initial study group, in which all patients had symptomatic tumors categorized at least as Hirsch grade 2, was subsequently updated in 2009 to 20 patients who were monitored for an average of 27.6 months.[23] In this population, the results of decompressive surgery were promising, with half of the patients demonstrating improvement in preoperative oculoparesis and 55% experiencing improvement in vision postoperatively. Only 3 patients (15%) developed new, mostly transient, cranial neuropathies, and radiographic tumor control was excellent (95%). In expanding the study population to 50 patients in the current analysis, our outcomes generally remained consistent, suggesting that the described surgical procedure and consequent functional recovery can be reproducibly attained. Overall, improvement was recorded in 52% of patients with preoperative CN III–VI deficits and 42% of patients presenting with visual loss. Similarly, the tumor control rate remained excellent, with recurrence recorded in only 10% of patients despite more than doubling the mean follow-up interval to 64.6 months.

The high rates of functional recovery and tumor control observed in the current study are well supported by other published reports employing a similar strategy of tumor containment. In 2004, Abdel-Aziz et al.[1] described a related approach for the resection of the lateral tumor component in large sphenoid wing meningiomas with secondary cavernous extension. Only 14 of 38 patients had tumors with cavernous sinus involvement categorized as at least Hirsch grade 2, but the rate of CN III–VI dysfunction decreased postoperatively by nearly 70%. Visual loss, initially reported in 55% of patients, was recorded in only 16% of patients at 12 months postoperatively. Interestingly, 53% of patients underwent some form of adjuvant radiation, and tumor recurrence was noted in 4 patients (10.5%) with a mean clinical follow-up period of 96 months. Subsequently, Pamir and colleagues[19] reported outcomes for 12 patients treated with extracavernous cytoreductive surgery followed by SRS to the residual intracavernous component. In their patients, none of whom underwent dedicated cavernous neural decompression, no improvement was noted in the immediate postoperative period in either oculoparesis or in the 1 patient presenting with visual loss. New, mostly transient, cranial neuropathies involving CN III, IV, and VI developed in 33%, 42%, and 75% of patients, respectively. In 2009, Pichierri et al.[20] published their results of 123 cases with meningiomas involving the cavernous sinus treated with subtotal resection of the extracavernous portion via a variety of surgical approaches. Their outcomes similarly revealed 54% improvement in CN III–VI deficits and visual improvement in 11 of 22 patients presenting with visual loss. However, 26.1% of their patients developed tumor recurrence, with an average progression-free survival of 4.7 years. In 2016, Nanda et al.[18] demonstrated improvement in 75% of patients with CN III–VI dysfunction and 54% of patients with visual deficits in a heterogeneous population of 65 patients treated with varying degrees of surgical removal. New cranial nerve deficits were seen postoperatively in 54% of patients, ultimately resolving in 62.5% of those cases. Tumor recurrence was observed in 19% of patients over a mean follow-up time of 60.8 months. Finally, Morisako and colleagues[17] recently published their experience with subtotal resection of cavernous sinus meningiomas via a combined transpetrosal approach to the posterolateral aspect of the cavernous sinus. In their 9 patients, 21% of CN III–VI deficits improved postoperatively, with 1 patient developing a new transient oculomotor nerve deficit and no patient exhibiting visual improvement. In all, these studies validate the safety and, generally, the efficacy of a more conservative microsurgical approach to meningiomas involving the cavernous sinus. Moreover, they substantiate the functional importance of concurrently decompressing the cavernous sinus and optic nerve. The current study represents, to our knowledge, the largest homogeneous population of patients with surgically treated cavernous sinus meningiomas studied to date, both in terms of intracavernous tumor extension and surgical technique employed.

Radiation Treatment

The use of SRS and other stereotactic radiation delivery

TABLE 3. Postoperative outcomes after cavernous sinus decompression

Preop Visual Status & Outcome	No. of Pts (%)
Pts w/ preop visual deficit	31
Improvement	13 (42)
No change	17 (55)
Postop worsening	1 (3)
Pts w/ normal preop vision	19
No change	19 (100)
New deficit	0 (0)

TABLE 4. Complications in patients after cavernous sinus decompression

Complication	No. of Pts (%)
Headaches	3 (6)
Worsened vision	1 (2)
Pituitary dysfunction	2 (4)
Stroke	
Cerebellar (asymptomatic)	1 (2)
Internal capsule (left hemiparesis)	1 (2)
Frontalis branch palsy	1 (2)
New cranial nerve deficit	
CN III	6 (12)
CN IV	3 (6)
CN V	2 (4)
CN VI	1 (2)
CSF leak	1 (2)
Wound dehiscence/infection	1 (2)
Cerebral edema/encephalopathy	1 (2)
Pulsatile exophthalmos	1 (2)
Pulmonary embolus	1 (2)

platforms for the primary treatment of cavernous sinus meningiomas gained prominence as a reactionary response to the extensive morbidity associated with attempted radical resection of these lesions.[23] For slowly progressive small tumors confined to the cavernous sinus, SRS has emerged as the first-line therapy because of its consistently excellent tumor control rates and correspondingly low risk of complications.[8] Additional evidence published by Kano et al.[11] demonstrated dramatically superior rates of cranial nerve response after primary SRS versus adjuvant SRS after microsurgical resection for cavernous sinus meningiomas of similar tumor volume profiles. Specifically, cranial nerve dysfunction improved in 31% of 173 patients undergoing primary SRS but just 13% of 99 patients who underwent microsurgery before SRS. These data helped to further broaden the range of indications for SRS in the treatment of these lesions, despite the fact that the study took into account neither the specific microsurgical approach employed nor the degree of extracavernous extension. In 2017, Azar and colleagues[3] reported outcomes for 166 patients treated with SRS, 74% of whom had tumor extension beyond the cavernous sinus. Of these, 28% demonstrated improvement in CN III–VI dysfunction and 13% had improvement of visual deficits after SRS, significantly less than the functional recovery rate reported in the current study after microsurgical decompression. Interestingly, in both studies, improvement was seen in half of the patients presenting with oculomotor nerve palsy, whereas recovery of abducens or trigeminal-induced symptoms was rare after SRS but common after decompressive microsurgery (CN VI: 12% vs 81%; CN V: 5% vs 33%). The mechanism underlying differential recovery of cranial nerves after treatment, however, is unclear and requires further study. Finally, it is worthwhile to note that while SRS is often cited for its low morbidity, the procedure is not entirely benign. The observed complication rate in the series by Azar et al.[3] was 10.8%, including new or worsened cranial nerve deficits in 6.6% of patients. Although this was less than the 10% rate of new neurological deficit seen in the current study, rates of new cranial nerve dysfunction as high as 12.5%–20% have been reported following SRS.[3,16]

The application of adjuvant radiation after subtotal resection of cavernous sinus meningiomas has been well described.[18,23] In the current study, patients treated with and without adjuvant radiation demonstrated similar actuarial tumor control rates at 5 years, specifically 90% and 85.7%, respectively. The senior author currently considers early postoperative adjuvant radiation in patients with 1) active, growing tumor noted on serial MRI studies prior to surgery, and 2) WHO grade II or III meningiomas. If progression of residual tumor is evident on serial postoperative MRI, then radiation therapy is recommended. We acknowledge that freedom from progression may be slightly improved with early radiation as compared with delayed radiation at progression in all cases of subtotal resection. This advantage must be weighed against the risk of radiation therapy with respect to cranial nerve function.[12] Close radiographic surveillance of the intracavernous residual is initiated and patients are treated on first evidence of tumor growth. As our overall gross tumor recurrence rate is 10%, the current study is not sufficiently powered to formally evaluate the efficacy of this strategy and requires further validation.

Study Limitations

The principal limitation to this study is its design as a retrospective, single-institution series. Although it is one of the largest studies of its kind, we encourage and anticipate experience from other centers using this technique for further validation.

Conclusions

The past 2 decades have seen a trend toward more conservative strategies in the management of cavernous sinus meningiomas; however, for symptomatic meningiomas with extracavernous extension, the ideal treatment strategy is not clearly elucidated. The concept of cytoreductive "separation" surgery with cavernous neural element decompression has progressively gained recognition[8,20] but has yet to be generally accepted. Herein, we provide evidence for the safe application of this strategy, resulting in

excellent tumor control rates with low surgical morbidity. In addition to distancing radiation-intolerant structures, such as the optic apparatus, and thus increasing the likelihood of adequate radiosurgical tumor coverage in patients requiring adjuvant SRS, our approach also maximizes potential neurological recovery, both by eliminating mass effect on the adjacent parenchyma and by improving cranial nerve dysfunction in comparison with published rates following SRS.[3] We believe that the approach employed in the current study is emblematic of the emphasis placed within the field of skull base surgery on retaining functionality and should be primarily considered for patients with suitable cavernous sinus lesions.

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Disclosures

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Author Contributions

Conception and design: Couldwell, Gozal. Acquisition of data: Gozal, Alzhrani, Abou-Al-Shaar, Azab, Walsh. Analysis and interpretation of data: all authors. Drafting the article: Couldwell, Gozal. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Couldwell. Statistical analysis: Couldwell, Gozal. Study supervision: Couldwell.

Supplemental Information

Videos

Video 1. https://vimeo.com/301603774.

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