Gamma Knife radiosurgery for hemangioma of the cavernous sinus

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OBJECTIVE Cavernous sinus hemangiomas (CSHs) are rare vascular tumors. A direct microsurgical approach usually results in massive hemorrhage and incomplete tumor resection. Although stereotactic radiosurgery (SRS) has emerged as a therapeutic alternative to microsurgery, outcome studies are few. Authors of the present study evaluated the role of SRS for CSH.

METHODS An international multicenter study was conducted to review outcome data in 31 patients with CSH. Eleven patients had initial microsurgery before SRS, and the other 20 patients (64.5%) underwent Gamma Knife SRS as the primary management for their CSH. Median age at the time of radiosurgery was 47 years, and 77.4% of patients had cranial nerve dysfunction before SRS. Patients received a median tumor margin dose of 12.6 Gy (range 12–19 Gy) at a median isodose of 55%.

RESULTS Tumor regression was confirmed by imaging in all 31 patients, and all patients had greater than 50% reduction in tumor volume at 6 months post-SRS. No patient had delayed tumor growth, new cranial neuropathy, visual function deterioration, adverse radiation effects, or hypopituitarism after SRS. Twenty-four patients had presented with cranial nerve disorders before SRS, and 6 (25%) of them had gradual improvement. Four (66.7%) of the 6 patients with orbital symptoms had symptomatic relief at the last follow-up.

CONCLUSIONS Stereotactic radiosurgery was effective in reducing the volume of CSH and attaining long-term tumor control in all patients at a median of 40 months. The authors' experience suggests that SRS is a reasonable primary and adjuvant treatment modality for patients in whom a CSH is diagnosed.

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KEY WORDS Gamma Knife; cavernous sinus hemangioma; stereotactic radiosurgery

CAVERNOUS sinus hemangioma (CSH) is a rare intracranial or intraorbital vascular neoplasm that accounts for approximately 2%–3% of all cavernous sinus (CS) tumors.¹³ This lesion differs from a cavernous malformation in the brain in that the CSH is a true vascular neoplasm and produces symptoms as a result of progressive tumor growth and local mass effect. Because of the CSH's highly vascular nature, a microsurgical approach can result in extensive and unanticipated bleeding culminating in even operative death.^{16,17,19,23,39} When total microsurgical tumor removal is attempted, usually in 30%–44% of patients,^{13,19,35} postoperative cranial neuropathies, espe-

cially sixth cranial nerve injury, occur frequently because the nerve often lies within the tumor substance.^{13,23,26}

In 1999, Iwai et al.⁶ reported on the first treatment of CSH with Gamma Knife radiosurgery (GKRS). The patient had previously undergone attempted microsurgical removal but had suffered major intraoperative bleeding. Gamma Knife radiosurgery was performed as adjuvant therapy for the patient, resulting in a dramatic decrease in tumor volume. Since then, 10 additional reports have been published, and all documented a similar response.^{2,4,5,8,9,18,21,27,35,37} The purpose of the present study was to further define the efficacy and safety of SRS for CSH. Imaging char-

ABBREVIATIONS CS = cavernous sinus; CSF = cerebrospinal fluid; CSH = cavernous sinus hemangioma; GKRS = Gamma Knife radiosurgery; ICA = internal carotid artery; IGKRF = International Gamma Knife Research Foundation; T1+c = T1-weighted MRI with contrast.

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acteristics of CSH on MRI, treatment parameters of SRS, indications for treatment options (primary or adjuvant), and results are factors reported in the current analysis.

Methods

Patient Population

Four academic medical centers, all participating members of the International Gamma Knife Research Foundation (IGKRF), received individual institutional review board approval to submit their retrospective clinical outcome data on patients with CSH. Among these medical centers in the years between 1989 and 2014, a total of 31 patients underwent GKRS. This study analyzed the results from 16 patients at Taipei Veterans General Hospital, 8 patients from the University of Pittsburgh Medical Center, 5 patients from the Ruber International Hospital of Madrid, Spain, and 2 patients from the University of Virginia Health System. The medical records of these patients were retrospectively reviewed at each center. A common EXCEL spreadsheet database with specific variables was established and used by all participating centers through the coordination of the IGKRF. The compiled data were de-identified, reviewed, and analyzed, and a report was then drafted by the authors.

Diagnostic Criteria

All patients underwent brain MRI as the primary diagnostic tool. Cavernous sinus hemangioma was diagnosed when MRI showed characteristic imaging findings of low to isodense mass lesions on T1-weighted images, extremely high intensity on T2-weighted images (as bright as a cerebrospinal fluid [CSF] signal), and strong homogeneous or heterogeneous enhancement after Gd-DTPA injection.^{5,14,34,38} Typically, these tumors do not have a dural tail, and on T2 imaging they have a dark margin around the globular tumor border. As a CSH grows, the internal carotid artery (ICA) is usually encased without narrowing. For patients who undergo cerebral angiography, most of them will show a hypervascular neoplasm (Fig. 1).

Patients and Characteristics

The median age of the patients was 47 years, and 58% were women. The median tumor volume was 9.3 cm³ (range 1.5–42.1 cm³). Eleven patients had a histological diagnosis at the time of a prior resection, whereas the remaining patients were diagnosed on the basis of clinical and imaging evidence. Among the 11 patients who underwent resection, a cerebral angiogram was obtained in 8 of them, and all angiograms showed significant hypervascularity. The estimated volume of tumor resected in these 11 patients ranged from 10% to 73%. After attempted microsurgery, 8 patients suffered new neurological symptoms including abducens palsy, oculomotor palsy, or even optic nerve function deterioration. Blood loss volumes at the time of surgery ranged from 500 to 6000 ml.

All patients had tumors that primarily involved the cavernous sinus. Fifteen patients had right CSH, and the other 16 patients had a CSH on the left side. One patient had a CSH that extended into the intraorbital cavity, and 1 had some degree of suprasellar extension. All patients

FIG. 1. The typical imaging appearance of CSH includes low to isodense mass lesions on T1-weighted images (T1WI), extremely high intensity on T2-weighted images (T2WI; as bright as a CSF signal), and strong homogeneous or heterogeneous enhancement after Gd-DTPA injection (T1+c). There is no abnormal vascularity on the cerebral angiogram, although the CSH is a hypervascular lesion by nature.

had an encased ipsilateral ICA, which was compressed in none. Twenty-four patients (77.4%) had cranial nerve dysfunction before GKRS: 18 had oculomotor palsies, 7 had abducens palsies, 3 had trochlear nerve palsies, and 3 had trigeminal facial pain. Four patients (12.9%) had partial visual field defects before GKRS. Six patients (19.4%) had signs of orbital involvement, including chemosis, ptosis, and exophthalmos (Table 1).

Gamma Knife Radiosurgery Technique

Patients underwent stereotactic frame placement supplemented by local anesthesia and conscious sedation as needed. Stereotactic MRI was then performed for treatment planning. If the patient could not tolerate MRI due to incompatible implants, CT was used to define the target. For CSH, the goal of GKRS dose planning was to cover the solid component of the tumor with 1 or more isocenters while limiting irradiation of surrounding normal structure as much as possible, especially radiation-sensitive tissue such as the optic apparatus, hypothalamus, and brainstem (Fig. 2).

In delivering an optimal radiation dose to the CSH, exposing the ICA and cranial nerves within the CS to a moderate level of radiation is unavoidable (for example, cranial nerves III, IV, VI, and VI). Therefore, cranial nerve dysfunction and radiation-induced ICA stenosis are given close attention after GKRS. Importantly, radiation expo-

TABLE 1. Demographic data in 31 patients who underwent GKRS for CSH

Characteristic	Value
Median age in yrs (range)	47 (12–83)
Sex (F:M)	18:13
Median tumor vol in cm ³ (range)	9.3 (1.5–42.1)
Patients w/ ICA compression	0
Patients w/ prior microsurgical treatment (%)	11 (35.5)
Patients w/ pre-GKRS cranial nerve dysfunction (%)	24 (77.4)
Patients w/ pre-GKRS visual deficits (%)	4 (12.9)
Patients w/ pre-GKRS orbital symptoms (%)	6 (19.4)
Median imaging FU in mos (range)	40 (6–199)
Median clinical FU in mos (range)	54 (6–200)
GKRS treatment parameter	
Median tumor margin radiation dose in Gy (range)	12.6 (12–19)
Median max radiation dose in Gy (range)	21.8 (20–38)
Median isodose level in % (range)	55 (50–60)
Median treatment vol in cm ³ (range)	9.4 (1.7–46.5)
Median optic chiasm radiation exposure in Gy (range)	7.6 (6.2–11.1)
Median optic nerve radiation exposure in Gy (range)	7.5 (6.1–11.2)
Median optic tract radiation exposure in Gy (range)	7.8 (6.3–11.2)

FU = follow-up.

sure of the optic apparatus, including the tract, chiasm, and nerve, was minimized. Because the CSH is a benign histology, we believed that a dose of 12 Gy was sufficient for the tumor. In this series, tumor margin radiosurgical doses varied from 12 to 19 Gy (median 12.6 Gy) at a median 55% isodose level (range 50%–60%). The median maximum radiation dose delivered to the optic apparatus was 7.6 Gy (optic chiasm), 7.5 Gy (optic nerve), and 7.8 Gy (optic tract; Table 1).

Imaging and Clinical Follow-Up

Tumor response was evaluated on T1-weighted MRI with contrast (T1+c). The tumor volume and its response to GKRS on MRI studies was classified into 3 categories: 1) decreased if the T1+c signal had reduced by more than 10% of its original size, 2) stable if the volume was $\pm 10\%$ of the original T1+c signal, and 3) increased if the volume progressed by more than 10% of its original size on T1+c sequences at the time of GKRS.

Tumor volumes were calculated from the sum of the areas contoured on each slice multiplied by the slice thickness. According to our previous work, the trapezoidal rule formula demonstrates that with accurate delineation on at least 5 slices, the calculated volume would have an expected error rate of 10% or less. Therefore, this kind of measurement generally has an uncertainty of 10% for the tomographic imaging used for radiosurgery of a structural target such as a tumor.³⁰

In addition, new-onset cranial nerve dysfunction, facial

FIG. 2. A 47-year-old female patient had major depression and hand tremor and underwent up-front GKRS for a CSH. Magnetic resonance imaging studies showed a T2-weighted high-signal tumor in the left CS. The tumor volume was 21.2 cm³. A radiation dose of 12 Gy was delivered to the tumor margin (at the 50% isodose line), and the mean dose was 16.4 Gy. An MRI series showed rapid shrinkage of the hemangioma during a 6-month time span post-GKRS. The patient had no complications during 10 years of follow-up. Figure is available in color online only.

numbness, vertigo, visual deterioration, hypopituitarism, radiation necrosis, and cerebrovascular stenosis within the radiation coverage after SRS were defined as complications of GKRS.

Statistical Analysis

Data are presented as the median or mean and range for continuous variables and as frequency and percentages for categorical variables. The tumor volume change was plotted to evaluate the effect of SRS from the time of GKRS to the last follow-up and the failure of treatment, if any. For statistical analysis, we used both IBM's SPSS (version 20.0) and Apple's Numbers (version 2009).

Results

Tumor Response

The median neuroimaging follow-up was 40 months (range 6–199 months). At the last follow-up, all tumors had decreased in volume shortly after GKRS (Table 2). Actuarial progression-free survival was 100% at both 5 and 10 years postradiosurgery. Figure 2 features images from a patient with excellent tumor response after GKRS.

The median clinical follow-up was 54 months (range 6–200 months). Tumor volume regression tended to occur within 6 months. Figure 3 demonstrates significant tumor regression in the early follow-up period. At the 6th month after GKRS, an average 61% tumor volume reduction was observed. Further volumetric regression was noted as follows: 64% volume reduction at 12 months, 73% at 24 months, 79% at 36 months, 82% at 48 months, and 84% at 60 months.

Clinical Outcomes

Ten patients reported headaches prior to GKRS, and 4 (40.0%) of them had subjective improvement in their headaches at the last follow-up. Four patients had preexisting visual field deficits, and 1 (25.0%) of the 4 experienced objective visual improvement after GKRS. Twenty-four patients had pre-SRS cranial neuropathies including oculomotor, trochlear, or abducens palsies, and 6 (25%) of the 24 had gradual improvement. Four (66.7%) of the 6 patients with orbital symptoms had symptom relief at the last follow-up (Table 2).

Complications

A single patient without tumor enlargement developed new trigeminal sensory loss numbness 22 months after SRS (Table 2). Another patient reported nonspecific vertigo 18 months after radiosurgery. No additional complications such as adverse radiation effect, visual deterioration, stroke, or hypopituitarism were detected.

Discussion

The Role of Radiation and Radiosurgery

Fractionated radiation therapy has been used as adjuvant management after subtotal removal of CSH.^{15–17,24,29} In 1999, Iwai et al.⁶ described the first CSH patient treated with GKRS. Since then, there were only a few case reports

TABLE 2. Outcomes of 31 patients who underwent GKRS for CSH

Parameter	No. (%)
Tumor response	
Shrinkage	31 (100)
Stable	0
Enlarged	0
Clinical improvement	
Headache relief	4 (40)
Visual improvement	1 (25)
Cranial nerve dysfunction	6 (25)
Orbital symptoms	4 (66.7)
Complication	
Facial numbness	1 (3)*
Vertigo	1 (3)†
New cranial nerve palsy	0
Radiation necrosis	0
Visual deterioration	0
Cerebrovascular accident	0
Hypopituitarism	0

* Months to occur: 22.

† Months to occur: 18.

(27 patients in 8 reports) up to 2009 (Table 3).^{5,6,8,9,18,21,27,35} Thompson et al.³⁵ reported on 4 CSH patients treated with GKRS in 2000. In the follow-up period of 6 months–2 years, there was a mean 54% tumor reduction rate (range 0%–86%). In 2001, Kida et al.⁹ documented 3 CSHs treated using GKRS with a mean follow-up time of 27 months. The mean tumor volume reduction was 57% (57%, 59%, and 54%, respectively). In 2010, 2 series,^{2,37} comprising a total of 37 patients, provided general features of the radiosurgical results. Yamamoto et al.³⁷ published the largest series in 2010, collecting 30 patients from 7 facilities in Japan. The Taipei Veterans General Hospital also reported a series of 7 patients in 2010.² In these studies, the effect of radiosurgery was excellent. Most tumors regressed (97.3%), and only 1 patient (2.7%) had a stable tumor volume at the 1-year follow-up. A 72% volume reduction at 6 months of follow-up and an 80% reduction at 12 months of follow-up were also noted in the Taipei series. The current study represents the largest series of CSH patients treated with SRS. We demonstrate that SRS affords excellent tumor control as well as symptomatic and neurological improvement in most patients. Moreover, it does so in a durable and low-risk fashion.

Song et al.³² attempted to explain the favorable SRS response of these hypervascular intracranial lesions. They believed that SRS, which delivers hypofractionated irradiation at a high dose per fraction, provided indirect cell death due to vascular damage. Authors of this study also implied that the characteristics of CSH were suitable for GKRS.

Defining CSH by Current Imaging Modalities

In the current study, MRI, given its ability to demonstrate versatile tissue contrast, anatomical details, and

FIG. 3. Significant tumor regression was found in the early follow-up period. At the 6-month follow-up, an average of 61% tumor shrinkage was found in the current study. The average tumor reduction at 12 months was 64%; at 24 months, 73%; at 36 months, 79%; at 48 months, 82%; and at 60 months, 84%. No recurrence was found. Figure is available in color online only.

major vasculatures, became the primary diagnostic tool for detecting CS tumors. Cavernous sinus hemangiomas usually appear on MRI as a well-circumscribed, lobulated mass with hypointense or isointense signals on T1-weighted sequences, markedly hyperintense signals on T2-weighted sequences, and strongly homogeneous

enhancement on delayed contrast images. These characteristic MRI features are due to the abundant amount of blood filling the sinusoid spaces, the soft tissue contents, and the presence of a fibrous pseudocapsule.^{13,31} The high T2-weighted signal intensity of the CSH can be as bright as the surrounding CSF and is readily differentiated from

TABLE 3. Literature review of SRS treatment for hemangiomas of CS*

Authors & Year	No. of Cases	Age, Average &/or Range (yrs)	Sex (M:F)	No. of Patients w/ CN Symptoms Pre-GKRS	Tumor Vol, Average &/or Range (cm ³)	Tumor Margin Dose (Gy)	Length of FU, Average &/or Range	Tumor Vol Reduction	No. of Cases w/ Histological Diagnosis
Iwai et al., 1999	1	40	1:0	1	5.3	12	20	Significant	1
Thompson et al., 2000	4	28	1:2	3	5.2–10.8	14–19	12–24	14%–100%	2
Seo et al., 2000	1	79	0:1	1	8.5	15	24	Significant	1
Kida et al., 2001	3	38–66	0:3	3	1.5–11.1	14–17	12–33	41%–47%	2
Nakamura et al., 2002	3	55–75	0:3	2	3.3–9.5	12–14	24–60	45%–91%	1
Peker et al., 2004	5	37–60	3:2	4	3.8–6.2	14–16	32 (6–52)	21%–39%	4
Ivanov et al., 2008	3	NA	NA	3	NA	10–13	12	60% (45%–75%)	NA
Khan et al., 2009	7	44 (14–72)	3:4	5	7.8 (2.5–18)	14.5	80 (40–127)	69% (0%–100%)	4
Hori et al., 2010	1	77	0:1	1	NA	Cyberknife	NA	Significant	1
Chou et al., 2010	7	47 (26–77)	2:5	6	7.6 (2.9–23.1)	12.5	6 12 60	72% (56%–83%) 80% (69%–90%) 90%	3
Yamamoto et al., 2010	30	19–78	11:19	22	11.5 (1.5–51.4)	13.8 (10–17)	53 (12–138)	Significant	17
Current study	31	47 (12–83)	13:18	24	9.3 (1.5–42.1)	12.6	40 (6–199)	All >50%	11

CN = cranial nerve; NA = not available.

* No complications occurred in any of the studies.

TABLE 4. Different radiological features of various CS tumors

Parameter	CSH	CS Meningioma	Pituitary Adenoma	Neuroma in CS
T1W MRI	Isointense	Isointense or hypointense	Isointense	Isodense
T2W MRI	Marked hyperintense (as CSF)	Isointense (70%) or hyperintense (30%; like gray matter)	Isointense to slightly hyperintense	Hyperintense
T1+c	Not homogeneous	Homogeneous	Not homogeneous	Not homogeneous
ICA encasement	w/o stenosis	w/ stenosis	w/o stenosis	w/o stenosis
Relationship w/ optic nerve	From CS, less chance to abut CN II	From CS, less chance to abut CN II	From suprasellar region, more chance to abut CN II	From CS, less chance to abut CN II
Relationship w/ tentorium	Not cross tentorium	w/ dural tail, may cross tentorium	Not cross tentorium	Cross tentorium (dumbbell shape)
Calcification	Rare	Sometimes	Rare	Rare
Adjacent bone	Erosion or remodeling	Hyperostosis w/ dural tail	Erosion or remodeling	Erosion or remodeling
6 mos FU after GKRS	Prompt regression (usually >50%)	Slow regression (usually <50%)	Slow regression (usually <50%)	Loss of central enhancement, may mildly increase in tumor vol

T1W = T1-weighted; T2W = T2-weighted.

the isointense or low signal intensity caused by soft tissue components in other CS tumors. When the CSH enlarges, it will encase the cavernous segment of the ICA. However, the caliber of the artery usually remains normal because of the soft and vascular consistency of the tumor. Similar to cavernous hemangiomas in other extracranial organs, CSHs may demonstrate a characteristic enhancing pattern of progressive “filling in” of the contrast material on sequential or dynamic MRI.^{7,25}

The imaging diagnosis must differentiate CSH from other more common tumors involving the CS, mainly meningiomas, pituitary adenomas, and neuromas (Table 4). Meningioma usually appears as a well-demarcated soft tissue mass in the CS with an isointense or mildly hyperintense signal (as the signal of gray matter of the brain) on T2-weighted images. In meningiomas, adjacent hyperostosis, dural tail signs, or encasement and constriction of the cavernous segment of the ICA are common. Neuromas involving the CS usually show heterogeneous signal intensity and contrast enhancement on MRI because of their heterogeneous distribution of tissue components of Antoni type A and type B, with the appearance of focal cystic degeneration, hemorrhage, or calcification inside the tumor. The main part of a pituitary adenoma is usually located in the pituitary fossa instead of the CS. The CS is rarely the tumor origin.

After GKRS, the tumor responses were different and were valuable for diagnosis. Rapid tumor regression was found in CSH. Significant tumor shrinkage (> 50%) can usually be found at the first imaging follow-up. In the present study, a tumor volume reduction of 61% was found 6 months after GKRS. Nevertheless, the volume of a CS meningioma after GKRS is quite stable, and these lesions rarely regress within 2–3 years. Furthermore, the volume change of a CS neuroma such as trigeminal neuroma is even more dramatic: a radiated neuroma is usually swollen for a period of time (for example, the first 1–2 years after GKRS), and then noticeable shrinkage can be seen if the follow-up persists for > 2 years. Tumor response to radiation is also a crucial point to reconfirm the diagnosis of a CS tumor. Once the unexpected tumor response is found,

we suggest reexamining the imaging features, clinical symptoms, and signs and reestablishing the diagnosis, if necessary.

Potential Complications Associated With Radiation Delivery to the CS

The proximity of the CSH to the optic nerves, cranial nerves of the CS, and ICAs requires special care when prescribing single and high radiation doses (such as in GKRS) to the tumor. Knowledge of radiation dose-response features of these neurovascular structures is important during rational dose planning.¹¹ Nevertheless, the tolerance dose in GKRS for such delicate neurovascular structures is still unclear and debated. Tishler et al.³⁶ found the dose was 8 Gy or less, and none of their 35 patients developed radiation-related optic neuropathy. In the same study, in a similar comparison of other cranial nerves of the CS, the use of high doses up to 40 Gy appears to be relatively safe when treating lesions within or near cranial nerves III–VI of the CS. More recent studies have reported that radiation doses of 10–14 Gy were well tolerated and had a low risk of radiation-related optic neuropathy.^{3,10,11,20,22,33} Therefore, selecting an optimal radiosurgical dose for CSH requires careful consideration. When prescribing a dose for a CSH, one should be careful of the optic apparatus and keep the maximal radiation exposure to 10 Gy or less, although the volume of the optic nerve receiving a specific dose is probably a more important issue. The other cranial nerves of the CS seem to have greater tolerance for radiation, and the radiation volume could include the whole CS, but we believe that 12.5 Gy is sufficient for most CSHs.

For the ICA, the radiation tolerance remains controversial. A few case reports have described ICA stenosis after GKRS for parasellar, suprasellar, and CS lesions.^{1,12} However, in a review of 150 cases of CS dural arteriovenous fistulas and 26 cases of CS tumors treated with GKRS, the volume of the ICA within the CS was not significantly changed, even though the radiation exposure was 16 Gy on average. In some cases, the caliber of the ICA was increased due to lesion shrinkage (Guo, unpublished data, 2016). Therefore, to obtain better tumor control, we be-

lieve that the radiation volume can safely cover the cavernous portion of the ICA.

Role of Up-Front GKRS in the Management of CSH

In most reports, radiosurgery was used as adjuvant therapy for partially removed tumors,^{2,5,6,9,27,35,39} although it has been used as the primary treatment modality with good results in several patients.^{2,5,9,35} Before radiosurgery, CSHs can be readily differentiated from other CS tumors based on their distinctive MRI appearance of hyperintensity on T2-weighted images. During radiosurgery, highly selective treatment planning with conformal radiation to the tumor can be achieved under stereotactic MRI guidance. Optic nerves and surrounding vital structures are well protected and far away from the high-dose radiation. In 2008, Ivanov et al.⁵ described 3 cases of CSH treated with GKRS. One of the patients underwent radiosurgery without resection of the tumor. In 2010, Chou et al.² documented 7 cases of CSH treated with GKRS and emphasized the possibility of up-front GKRS using MRI diagnosis of CSH. Two commentators, Pollock and Regis, both agreed that craniotomy and biopsy are generally not necessary for the majority of patients with CSH because of the lesion's distinctive imaging characteristics.²

Considering the anatomical complexity involved and their bleeding tendency, these deep tumors have been shown to be a challenge for complete resection. For tumors located in the CS, partial resection means a higher rate of recurrence and the need for further adjuvant therapy such as SRS. Radiosurgery, unlike microsurgery, can extend the radiation volume within the CS with relative ease. Stereotactic radiosurgery is often used to treat CSHs within the CS as well as CSHs invading the parasellar region in one approach and conveys a low risk of cranial neuropathy. In a recent series by our coordinating group, the risk of cranial neuropathy after GKRS for a CS lesion such as a nonfunctioning pituitary adenoma was quite low, even in those with CS invasion.²⁸ Thus, up-front radiosurgery for a CSH residing primarily or exclusively in the CS may be an appealing approach.

Study Limitations

The main limitation of this study is its retrospective nature and relatively small patient population, which undoubtedly limited the statistical power of some of our analyses. In addition, all 4 of the contributing centers are tertiary care referral centers. Therefore, referral biases from doctors within the community may have affected the composition of the series. Selection biases and differences in radiosurgical technique also existed to some degree between the centers. We also recognized the bias caused by the different measurement tools between treatment (measured in GammaPlan) and follow-up (measured in each slice and then multiplied by the slice thickness). Fortunately, regression of the CSH was significant, and the average tumor regression was > 60% within 1 year. We believe that more cases and a longer follow-up will validate the results of the current study. However, CSHs are relatively rare, making a prospective trial difficult to conduct.

Conclusions

For patients with a CSH, up-front GKRS afforded prompt tumor shrinkage, a high rate of tumor control, and preservation of or even improvement in neurological function. Cranial nerve dysfunctions and ICA stenosis were rare. In the future, the application of up-front SRS for radiographically identified CSH seems reasonable. Further study is warranted to better define the role of SRS as compared with the standard approach of CSH resection for patients without the need for immediate relief of mass effect.

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Disclosures

Dr. Lunsford is a consultant for and stockholder in Elekta AB.

Author Contributions

Conception and design: Liu, Lee, Sheehan, Kano, Martinez-Alvarez, Martinez-Moreno, Lunsford. Acquisition of data: Liu, Lee, Sheehan, Kano, Akpınar, Martinez-Alvarez, Martinez-Moreno, Lunsford. Analysis and interpretation of data: Lee, Martinez-Moreno, Lunsford. Drafting the article: Lee, Martinez-Moreno. Critically revising the article: Liu, Lee, Sheehan, Kano, Martinez-Alvarez, Guo, Lunsford. Reviewed submitted version of manuscript: Liu, Lee, Sheehan, Kano, Akpınar, Martinez-Alvarez, Lunsford. Approved the final version of the manuscript on behalf of all authors: Liu. Statistical analysis: Liu, Lee, Martinez-Alvarez, Lunsford. Administrative/technical/material support: Liu, Lee, Sheehan, Kano, Martinez-Alvarez, Guo, Lunsford. Study supervision: Liu, Sheehan, Kano, Guo, Lunsford.

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