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Radiosurgery: an effective treatment for cavernous sinus meningiomas?

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Abstract Meningiomas involving the cavernous sinus present the neurosurgeon with different choices: observation, microsurgery, or radiosurgery. During the last decade, advances in microsurgical techniques have significantly lowered the treatment-related morbidity, and some neurosurgeons have reported long-term follow-up results. Recently, several radiosurgical series have reported excellent tumor control and good functional preservation for tumors in this area. Most of these series do not provide complete information about the patient's cranial nerve function, and objective and subjective outcome data. The follow-up provided has also been short, considering that meningiomas have a tendency to recur or regrow up to 20 years postoperatively. There is also the concern about those patients who fail radiosurgical treatment, since microsurgery does not yield good results in such cases. In this paper, several radiosurgical series are critically reviewed, with a discussion about the pros and cons of microsurgery versus radiosurgery. The authors suggest that a uniform reporting strategy be adopted by all surgeons treating tumors of this area, which will allow comparative studies to be conducted. Additionally, we suggest a treatment algorithm for cavernous sinus meningiomas, based on the patients age, occupation and preference, preoperative binocular function, and curability of the tumor.

Key words Stereotactic radiosurgery · Linear accelerator · Intracranial meningioma · Cavernous sinus meningioma

Introduction

The use of radiosurgery for deep-seated tumors, especially those that are located in the petroclival, cavernous sinus (CS) and orbital region, is preferred by several authors. After the pioneering efforts by Leksell to develop the gamma knife, radiosurgery with photons derived from a cobalt source (gamma knife) or the linear accelerator (LINAC KNIFE) has been in popular use for the treatment of arteriovenous malformations, brain and extra-axial basal tumors, and other neurosurgical problems (Tables 1, 2). This article will review and analyze articles concerning the radiosurgical treatment of meningiomas involving the CS.

Although the surgical removal of meningiomas involving the CS was considered impossible a decade ago, operations to remove tumors in this location have become common place, thanks to the pioneering efforts of many neurosurgical leaders. This surgery does have potential risks to the carotid artery, to cranial

Table 1 Summary of gamma knife series (*inc.* including, *PA* petrous apex, *CS* cavernous sinus, *Dec.* decrease, *Inc.* increase, *CN* cranial nerve)

	Patients (*n*)	Tumor location	Minimal/mean follow-up (months)	Tumor diameter (cm)	Tumor volume (cm^3)	Marginal dose (Gy)	Central dose (Gy)	Volume change (%)			Results and complications	History of recurrent tumor
								Dec.	Same	Inc.		
Subach et al. [1]	62	62 Petroclival (6 clivus, 34 inc. PA and upper 2/3 clivus, 22 CS extension)	12/37	2.96	13.7 (0.8–56.8)	15 (11–20)	30 (20–50)	23	68	8	5 (8%) New CN deficit; 1 (0.6%) hydrocephalus	5 Patients (13%)
Pendl et al. (1995) (Stereotact Funct Neurosurg 64 [Suppl]: 11–18)	48	21 Parasellar, 9 orbital 6 clivus, 2 sellar, 3 pyramidal apex, 3 sphenoid wing, 2 craniocervical, 1 sphenoid plane, 1 olfactory groove	2.3/12	2.7 cm (1.2–5.4)	13.7 (0.8–82)	15 (8–25)	35.6 (20–56.7)	24	68	8	13% Worsening	1 Patient (2%)
Leber et al. (1995) (Stereotact Funct Neurosurg 64 [Suppl]: 233–238)	29	13 Sphenoid wing, 2 CN II sheath (8 pituitary adenoma), 2 craniopharyngioma, 1 schwannoma, 1 low-grade glioma, 2 vascular malformation)	6/(6–24)	–	–	III, IV, VI 4.5–30 II: 7.5–15	III, V, VI: 30 II: 15	34.5	65.5	–	2 Transient swelling (of conjunctiva and optic tract)	–
Duma et al. [5]	34	34 CS	6/26	2.1	5 (0.5–20)	16 (10–20)	32 (20–40)	56	44	–	2 New CN deficit; 3 peritumoral edema; 2 seizure	–

nerves (CNs) III–VI, to the brain, and of cerebrospinal fluid leak. However, continuous improvements are occurring in the microsurgical techniques to remove these tumors. It has also now been well documented that operations on previously irradiated tumors of this location cause a greater risk, with poorer outcomes. On the other hand, a number of recent articles in the literature have presented the results of treatment of CS meningiomas with radiosurgery, either as a primary treatment, or as an adjuvant to microsurgical resection. In this paper, we will review some of these articles and present a synthesis of our present approach to these lesions.

[1] Management of petroclival meningiomas by stereotactic radiosurgery

Neurosurgery (1998) 42: 437–445

Information. The authors report a retrospective review of 62 patients with petroclival meningiomas who underwent stereotactic radiosurgery. Six patients (10%) had tumors arising from the clivus, 34 (55%) had tumors involving the petrous apex and the upper two-thirds of the clivus, and 22 (35%) had petroclival tumors with extension into the CS. The tumor volumes varied from 0.8 to 56.8 cc (mean tumor volume was 13.7 cc). The calculated mean tumor diameter was 2.96 cm. Thirty-nine of the patients (63%) had previously undergone one or more attempts at surgical resection. Five patients (13%) had a history of tumor recurrence after microsurgery in this series. Gross total resection was thought to have been achieved in 5 patients (13%), whereas subtotal resection were achieved in 34 (87%). Seven patients (11%) had received previous fractionated radiation therapy (average 54 Gy). The mean dose delivered to the tumor center was 30 Gy (range 20–50). The mean dose delivered to the margin was 15 Gy (range 11–20). The median follow-up of this series was 37 months, with a minimum of 12 months. The neurolog-

Table 2 Summary of linear accelerator-based radiosurgery series (*CPA* cerebellopontile angle, *BS* brain stem, *RS* radiosurgery)

	Patients (*n*)	Tumor location	Minimal/mean follow-up (months)	Tumor diameter (cm)	Tumor volume (cm^3)	Marginal dose (Gy)	Central dose (Gy)	Volume changes (%)			Results and complications	History of recurrent tumor
								Dec.	Same	Inc.		
Hakim et al. [2]	127 (155 tumors)	31 Convexity, 39 parasagittal/falcine, 82 cranial base, 3 ventricle/pineal	12/31	1.98	4.1 (0.16–51.2)	15 (9–20)	18 (9.4–25)	–	84	16	1 Blindness; 1 unilateral hearing loss; 1 leg weakness, hypesthesia; 1 hemiparesis; 2 died	16 Patients (12.5%)
Chang and Adler [3]	55	25 CS, 5 CPA, 3 petrous apex, 4 tentorium, 2 clivus, 2 CN II, 6 sphenoid wing, 3 jugular foramen, 2 foramen magnum, 2 tuberculum sella, 1 petroclival	17/48.4	2.4	7.33 (0.45–27.6)	18.3	25	29	69	2	2 Radionecrosis; 2 edema; 12 CN deficit; 5% worse; 5% died	38 Patients (69%)
Valentino et al. [6]	72	72 Middle fossa	30/64	2.7	11.4 (0.588–76.346)	15	45	69.4	25	5.6	2 Regrowth after shrinkage; 2 hydrocephalus	21 Patients (29%)
Engenhardt et al. [7]	17	8 Sphenoid ridge, 3 parasellar region, 2 clivus and BS, 2 Falx, 1 CPA, 1 CN II sheath	1/40	4.0 (1.8–5.2)	33.5	23 (8–40)	29 (10–50)	11.7	64.7	11.7	1 (5.5%) Died as result of RS; 1 (5.5%) died as result of tumor, 2 (11%) died as result unrelated causes; 7 (41%) brain edema; 1 (5.5%) loss of vision	7 Patients (41%)

ical status improved in 13 patients (21%), remained stable in 41 patients (66%), and worsened in 8 patients (13%). Tumor volumes decreased in 14 patients (23%), remained stable in 42 patients (68%), and increased in 5 patients (8%). Complications related to radiosurgery were new cranial nerve deficits within 24 months of radiosurgery in 5 patients (8%). None of them had evidence of tumor regression. In 2 patients, these symptoms resolved within 6 months of onset. The authors conclude that stereotactic radiosurgery provides a safe and effective management strategy for petroclival meningiomas, both as a primary procedure and as an adjunct to incomplete resection.

Analysis. This is the experience of a series of 62 patients with a mean follow-up of 37 months using gamma knife radiosurgery. Almost all of these patients had benign meningiomas, and 22 of these tumors (35%) had CS extension. The authors report that the outcomes after primary radiosurgery are better than those after radiosurgery that is performed after incomplete resection. As the authors pointed out, the median clinical follow-up period is sufficient to assess complications, but is inadequate to assess the long-term tumor control rate for benign meningiomas. For tumors with diameters equal to or smaller than 3 cm (14 cm^3), they recommend radiosurgery as the primary modality of choice. For tumors larger than 3 cm, they recommend initial surgical resection followed by adjuvant radiosurgery because the peritumoral edema after primary radiosurgical treatment may result in a bad clinical outcome.

[2] Results of linear accelerator-based radiosurgery for intracranial meningiomas

Neurosurgery (1998) 42:446–454

Information. This is a series of 127 patients with 155 meningiomas treated with linear accelerator-based

radiosurgery (LINAC) over a period of 8 years. The tumor location was as follows: convexity, 31 tumors; parasagittal/falcine, 39 tumors; cranial base, 82 tumors; and ventricular/pineal, 3 tumors. The median follow-up period of this series was 31 months, with minimum 12 months. A median tumor volume of 4.1 cc was reported in this series, and the calculated median tumor diameter was 1.98 cm. The median marginal dose was 15 Gy, and the median central dose was 18 Gy. There were 106 benign, 26 atypical, and 18 malignant meningiomas and 5 cases of meningiomatosis. Stereotactic radiosurgery was performed on 48 lesions as the initial treatment and on 107 lesions as adjunctive therapy. Tumor did not progress in 107 (84.3%), at a median time of 2.9 months. Twenty patients had progression; 16 of them were marginal (12.6%) and 4 local (3.1%), with a median time of progression of 19.6 months. Six patients (4.7%) had permanent complications, with two deaths, one case of blindness, one of unilateral hearing loss, one of leg weakness with hypesthesia, and one of hemiparesis. Thirteen patients died as a result of causes related to the meningiomas. The 1- and 5-year survival rates for the entire group of patients were 90.3% and 68.2%; for the patients with benign meningiomas, excluding death resulting from intercurrent disease, the 1-year survival was 97.6% and the 5-year survival was 91.0%. The 1- and 4-year survival rates for the patients with atypical meningiomas were 91.7% and 83.3%; and for the patients with malignant meningiomas they were 92.3% and 21.5%, respectively. The authors conclude that even though complications from stereotactic surgery are expected more frequently with large tumors near critical structures, stereotactic surgery is a safe and effective means of treating selected meningiomas.

Analysis. This is the largest series of meningiomas treated with linear accelerator-based stereotactic radiosurgery. Benign meningiomas in this series had a tumor control rate of 89%, but the results for meningiomas of the CS are not separated. So they have shown that radiosurgery for benign meningiomas has a low risk, but with very short follow-up (median 2.9 months). Complications of treatment were significant in this series. Even though they had a complication rate of 4.7%, the mortality rate is significant at 24%. Two of them were related to radiosurgery. The overall survival was poor, 90.3% at 1 year, 68.2% at 5 years, with 30 patients dead at a median time of 15.2 months. This may be explained by the fact that many patients in this series had malignant meningiomas, atypical meningiomas, or meningotheliomatosis. As in several previous reports on radiosurgery, the postoperative follow-up period is still too short.

[3] Treatment of cranial base meningiomas with linear accelerator radiosurgery

Neurosurgery (1997) 41:1019–1027

Information. This is a report of 55 patients with cranial base meningiomas who were treated with LINAC. In 25, the location or extension was in or into the CS. The mean patient age was 55.1. The mean tumor volume was 7.33 cc (range 0.16–27.6 cm^3), and the average radiation dose was 18.3 Gy (range 12–25). The mean central dose was 25 Gy. The calculated mean tumor diameter was 2.4 cm (all tumors were less than 3 cm). With a mean follow-up period of 48.4 months (range 17–81), the patients were evaluated retrospectively through clinical notes, and residual tumor volume was also measured. Tumor stabilization after radiosurgery was noted in 38 patients (69%), shrinkage in 16 patients (29%), and enlargement in only 1 patient (2%). Eleven meningiomas (55%) had decreased central contrast uptake, possibly indicating evidence of central tumor necrosis or tumor vessel obliteration. Neurological status was improved in 15 patients (27%) and unchanged in 34 patients (62%). In this series, 38 (69%) patients had recurrent tumors. Three patients (5%) died during follow-up period, all as a result of causes other than tumor progression. Three patients (5%) developed new permanent symptoms (1 patient with seizures, 1 patient with mild right hemiparesis, and 1 patient with both vagal and hypoglossal nerve palsy). All other complications were transient, including partial trigeminal nerve palsy in 7 patients and diplopia in 3 patients. The 2-year actuarial tumor control rate was 98%. The authors conclude that although their follow-up period is short, this experience corroborates previous reports that radiosurgery can be used to ablate selected small cranial base meningiomas, with good clinical results and modest morbidity.

Analysis. This analysis with LINAC in 55 benign cranial base meningiomas has a relatively short follow-up (mean 48.4 months), but is one of the longer followed series. For meningiomas, 5-year, 10-year, and 20-year follow-up are important to assess recurrence. From 18 patients with several cranial deficits, 8 of them had com-

plete resolution after radiosurgery, and 5 of them had improvement in different degrees. On the other hand, 22% of patients in this series developed new cranial deficits over a period of 1 year. Most of them were temporary. Patients in whom permanent CN deficits occurred had similar mean doses of irradiation to those who did not. This result may be explained by the increased radiosensitivity of cranial nerves in some patients. The authors selected patients with small cranial base meningiomas. However, the marginal doses in this series were between 16 and 20 Gy and were higher than those currently used by other surgeons. The higher complication rate in this series may be explained by that fact.

[4] Contemporary management of meningiomas: radiation therapy as adjuvant and radiosurgery as an alternative to surgical removal?

J Neurosurg (1994) 80: 187–190

Information. As the author points out, complete surgical resection is a logical treatment choice for meningiomas. Despite complete resection, patients have a continuing risk of relapse up to 25 years after surgery. This comment emphasizes the importance of long-term analysis of the results of meningioma surgery. Postoperative high-resolution magnetic resonance (MR) imaging often reveals residual tumor margins despite the operative surgeon's opinion that complete surgical resection was performed. Advances in modern skull-base surgery allow a number of meningiomas to be completely resected; some of these patients suffer major neurological morbidity. When followed by adjuvant radiation techniques, subtotal surgical removal is one method to obtain tumor control while preserving neurological function. After review of the neuroimaging and analysis of the likelihood of undesirable side effects, the treatment strategy should be determined in advance of the surgical procedure itself, especially in patients with meningiomas located in the CS and petroclival region. Even if the preoperative plan is to attempt surgical excision, the goal can be modified appropriately if intraoperative findings such as unanticipated cranial nerve adherence or vascular involvement preclude safe resection. Tumor control rates for meningiomas treated by conventional external beam fractionated radiation therapy vary from 50 to 90%, of which some may be affected by several factors. The timing of radiation therapy is important to prevent tumor progression. The risks of fractionated radiation therapy are loss of vision, pituitary dysfunction, delayed radiation-induced injury of the brain, and the development of secondary neoplasm. The last one was reduced with modern technology. Stereotactic radiosurgery is a potentially effective alternative for surgical removal of a wide variety of small to moderate-sized meningiomas. The author reports a series of 115 patients who were treated with radiosurgery using the Co-source gamma knife over a period of 7 years. Radiosurgery was performed if the tumor had an average diameter of 35 mm or less, if the tumor was not considered amenable to initial or repeat surgical resection (with risks acceptable to both surgeon and patient), and if the tumor was at least 3–5 mm distant from the optic nerve or chiasm. The 4-year actuarial tumor control rate for the 94 benign meningiomas undergoing gamma knife radiosurgery was 92%. The author evaluated the efficacy and safety of stereotactic radiosurgery in a series of 34 patients with growing or recurrent CS meningiomas. The median clinical follow-up period was 26 months, and a 100% tumor control rate was encountered. No patient had evidence of tumor growth after surgery, and 19 (56%) of the 34 tumors regressed. Two patients (6%) developed delayed onset of cranial nerve complications. The author suggested that these results after gamma knife radiosurgery compare favorably with those reported from skilled microsurgical centers. For him radiosurgery also had additional short- and long-term benefits: (1) reduced length of hospital stay (<36 h); (2) reduced patient cost; and (3) rapid return to preoperative functional status (within days). Radiosurgery can be anticipated in advance as an adjunct to microsurgical subtotal removal. For example, for larger tumors at the skull base, judicious removal of the main mass (leaving a smaller portion of the tumor within the CS or petrous apex) can be followed by delayed radiosurgery of the residual tumor. This reduces the patient's morbidity and enhances tumor control rates. The author concludes that the goals of radiosurgery should be preservation of neurological function and prevention of further tumor growth. Surgery, fractionated radiation therapy, and radiosurgery used alone or in combination are effective techniques to reach these goals.

Analysis. In this paper, the author considers how often total removal of a meningioma is possible and the alternative treatment should be applied. As the author mentions, the recurrence rates of various series show different values, but all authors emphasize the importance of

long-term follow-up. The author points out that subtotal removal with adjuvant radiotherapy may preserve neurological function. The problem is when the tumors recur – microsurgical resection becomes more difficult, with worse results. The author proposes a good strategy for the adjustment of fractionated dose rate. Patients who undergo subtotal resection followed by radiation therapy will have a lower recurrence rate than patients who only undergo subtotal resection. On the other hand, patients who have previously undergone subtotal removal followed by radiation therapy will have a more difficult surgery and poorer outcome, in the event of recurrence.

[5] Stereotactic radiosurgery of cavernous sinus meningiomas as an addition or alternative to microsurgery

Neurosurgery (1993) 32: 699–704, discussion 704–705

Information. To evaluate the response of CS meningiomas to stereotactic radiosurgery, the authors reviewed their 54-month experience with 34 patients. Radiosurgery with a 201-source cobalt-60 gamma unit was used in all patients. Twenty-eight patients (82%) had previous histological confirmation of a meningioma (1–5 cranial base craniotomies per patient); 6 (18%) were treated on the basis of neuroimaging criteria alone. The mean tumor diameter was 2.1 cm, and the mean tumor volume was 5 cc (range 0.5–20). The mean single-fraction tumor margin dose 16 Gy (range 10–20) was designed to conform to the irregular tumor volumes in all patients. The mean central dose was 32 Gy (range 20–40). The maximum radiation dose to the optic nerve or tract was reduced to 9 Gy in 31 patients. During a median follow-up interval of 26 months, with minimum 6 months, no patient had tumor growth. Tumor regression was observed in 56% of patients, who had an average of 18 months. Clinical improvement was encountered in 8 patients (24%) at follow-up examinations. Four patients developed new or worsened cranial nerve deficits, 2 of them had subsequent full improvement. An additional endocrinopathy or new extraocular muscle paresis was not encountered in any of the patients. All patients returned to their preoperative employment status within 3–5 days, after a maximum length of hospital stay of 36 h. The authors conclude that stereotactic radiosurgery with multiple isocenter dosimetry facilitated by the gamma knife unit is an accurate, safe, and effective technique to prevent the growth of the tumor involving the CS. They also point out that this technique has a low-morbidity alternative to aggressive microsurgical removal of small to moderate-sized tumors of the CS.

Analysis. This series has a median follow-up of 2.2 years; quite short, as previously pointed out. The authors reported a 100% progression-free survival. Fifty-six percent of patients have a reduction in the size of the tumor in this series. Tumor necrosis was found in 24% of patients, clinical improvement in 24%, and clinical complications in 12%. The results presented here are excellent, but much longer follow-up is needed.

[6] The results of radiosurgical management of 72 middle fossa meningiomas

Acta Neurochir (Wien) (1993) 122: 60–70

Information. Of 129 patients with intracranial meningiomas treated by radiosurgery over a period of 7 years, 72 had middle fossa meningiomas. Whenever the site of origin of the tumors in the middle fossa could not be determined precisely, it was classified on the basis of the structures appearing to be predominantly involved. In 17 patients, radiosurgery was performed post-operatively following incomplete resection, and in 21 patients the treatment was for regrowth of tumor after (apparently) total surgical removal. Eleven of these 38 patients had undergone two previous operations, and 1 had been operated on three times. In 34 patients, radiosurgery was the primary treatment modality. The mean tumor volume in this series was 11.4 cm^3. The calculated mean tumor diameter is 2.7 cm. Dynamic irradiation was performed with linear accelerator. The total tumor dose for each patient ranged from 15 to 45 Gy. The minimum follow-up period was 30 months, and the maximum 96 months (mean 64). In 50 (69.4%) patients there was tumor shrinkage ranging from 24 to 91% of the initial tumor volume. Shrinkage was associated with central tumor necrosis in 11 of these 50 patients. In 18 (25%) patients, the tumor volume remained stable. In 2 (2.8%) patients there was tumor progression and in 2 (2.8%) regrowth after initial reduction in tumor volume. Twenty-one (29%) patients in this series had the history of recurrent tumor. There was no significant treatment-related complication. The authors conclude that

radiosurgery is preferable to re-operation in recurrent meningiomas and indicated after incomplete surgical removal. In high-risk patients, as well as in "unresectable" meningiomas, it is an obvious alternative to microsurgery.

Analysis. This large series with LINAC has one of the longest mean follow-up periods (5.3 years) compared with other radiosurgery series in the literature. Seventeen of 72 patients had incomplete surgical resection before radiosurgery, and 21 had experienced tumor regrowth. Interestingly, with a longer mean follow-up period, they reported the highest rates of decreased tumor volume in the literature (68%). However, the marginal dose used was also high at 37 Gy. The authors point out that there were no significant treatment complications in their series. They reported two cases of hydrocephalus, and they mentioned that it was also uncertain whether this situation was related to previous radiosurgery. However, the results of this series conflict with the results of another series of patients treated with high-dose LINAC (see Engenhart et al. [7]). The majority of radiosurgical centers do not use such a large dose, because of the high complication rate.

[7] Stereotactic single high dose radiation therapy of benign intracranial meningiomas

Int J Radiat Oncol Biol Phys (1990) 19: 1021–1026

Information. In this series, 17 patients were treated with single high-dose radiation using the LINAC knife. Indications for radiosurgery included unoperated tumors, residual tumors after surgical excision, and recurrent tumors (with 7 patients, 41%). The mean tumor diameter was 4.0 cm (range 1.8–5.2). The calculated mean tumor volume is 33.5 cm^3. The single irradiation dose ranged from 10 to 50 Gy (mean 29 Gy). The median follow-up period was 40 months, with minimum of 1 month. There was no evidence of tumor regrowth in 13 patients (76.5%). Eleven patients had arrest of tumor growth, and 2 had gradual decrease in tumor size. The location and size of the tumor and the high radiation dose likely had a relationship with the high complication rate. Eleven of these 17 large meningiomas originated from the sphenoid ridge and parasellar region. Four of 17 patients (23.1%) died. One death was tumor-related, one was treatment-related, and 2 other patients died of intercurrent disease. Late severe side effects were seen in 5 patients, consisting of a large area of brain edema, which was concurrent with tumor necrosis in 3 cases. The authors conclude that single doses of irradiation concentrated to the tumor volume by stereotactic methods can achieve local tumor control, but the effective therapeutic dose range must be better defined.

Analysis. This is the first reported LINAC series with meningiomas and has a high complication rate. The patients in this series had large meningiomas, and also high radiosurgical doses were used, although lower than the doses used by Valentino et al. [6].

[8] The long term side effects of radiation therapy for benign brain tumors in adults

J Neurosurg (1990) 73: 502–512

Information. The authors reported the long-term side effects of 58 benign brain tumors in adults who were treated with radiation therapy. This consecutive series consisted of 46 pituitary adenomas, 5 meningiomas, 4 glomus jugulare tumors, 2 pineal area tumors, and 1 craniopharyngioma. The average dose was 4984 cGy (range 3100–7012) given in an average of 27.2 fractions (range 15–45). The mean follow-up period was 8.1 years. Twenty-two patients had complications considered to be delayed side effects of radiosurgery: 2 cases of visual deterioration; 6 of pituitary dysfunction; 17 with varying degrees of parenchymal changes of the brain, occurring mostly in the temporal lobes and relating to the frequent presentation of pituitary tumors (2 of these also had pituitary dysfunction). One clival tumor with the radiographic appearance of a meningioma developed 30 years postirradiation for acromegaly. Parenchymal changes were mild in 5 patients, moderate in 6 patients, and severe in 4 patients, and diffuse brain atrophy was observed in 3 patients. Two of the patients in this study were discovered to have new tumors. Radiation therapy was likely the cause of one, while the second was probably coincidental. Visual changes after radiation therapy occurred between 5 months and 7 years, with a mean of 16.8 months. In the literature, many cases with visual impairment received an excessive total dose of >6000 cGy. When radiation-induced visual loss occurred despite an appropriate total dose of 5000 cGy, a fraction size in excess of 200 cGy caused optic pathway damage. Neither 2 of the authors'

patients with visual impairment had received total doses higher than 5000 cGy nor a fraction size larger than 200 cGy.

Analysis. The authors summarize the long-term side effects of radiation therapy very well, with an additional extended documentation of the literature. Even though there were five meningiomas in their series (there is no information in the paper about whether this series also included some CS meningiomas), the overall view of these several complications demonstrates how carefully radiation therapy should be used in selected cases, and how important long follow-up is in such cases. The authors also pointed out the possibility of the development of a second neoplasm in a long period, and they also had one case in their series with a latency period of 12.25 years. In another patient with a second neoplasm after a long period, probably coincidental, they reported the development of postirradiation gliosis of the hypothalamus of optic nerves.

Synthesis

Our 15-year experience in removal of CS meningiomas prompted us to review and discuss the results of surgical removal with its alternative treatments. Between the years 1984 and 1993, 119 patients with benign CS meningiomas were operated on at the University of Pittsburg Medical Center (UPMC). A gross total removal was obtained in 61% of all patients. Seventy-two percent of patients with total removal had a tumor size smaller than 3 cm compared with patients with larger tumors (58%). A median follow-up period of 33.8 months was obtained. Seven patients had recurrence, and another 7 experienced regrowth after incomplete resection. The 5-year recurrence rate was 19% for completely resected tumors and 38% for incompletely resected tumors (P = 0.05). Seventeen patients received postoperative radiotherapy, 7 of them had recurrence (41%); 1 after gamma knife, 2 after LINAC, and 4 after fractionated radiotherapy. The series from George Washington University Medical Center (GWUMC) includes 120 patients with meningiomas involving the CS operated on between the years 1993 and 1997. Gross total removal was performed in 49% of all patients. This group had a mean follow-up period of 19 months. Seven patients (5.7%) had recurrence. A group of 13 patients who had prior surgery and radiotherapy fared considerably worse and had a mean Karnofsky change of –2.76 compared with –1.14 for patients with no prior treatment and –0.68 for patients with prior surgery. A statistical significance of $P<0.05$ for Karnofsky change between the group having prior radiotherapy and those with either surgery or no treatment was encountered. In the group with prior radiotherapy, the complication rates were twice those of the remaining patients [1].

The ultimate goal of treatment of meningiomas is tumor control without recurrence, and excellent functional results. Both microsurgery and radiosurgery should be evaluated according to these criteria, and the patient should receive whichever treatment is appropriate.

Large series [2, 3] document results after microsurgical removal of meningiomas of the CS along with complications and recurrence rates. Objective patient outcomes according to Karnofsky scores have been reported, but subjective outcomes according to the SF-36 scale were not reported. It is hard to compare these series exactly with radiosurgical series since these tumors were not evaluated prospectively for possibility of radiosurgery. Only one series [2] reported a long-term follow-up of recurrence rates after microsurgical removal of CS meningiomas, although a considerable body of literature exists for intracranial meningiomas treated by surgery.

Radiosurgical series are reporting very promising results for the treatment of basal meningiomas, but three concerns remain. None of them report cranial nerve results, objective functional patient data (Karnofsky scores), and subjective patient outcome (SF-36) in a standardized fashion. The information reported is usually inadequate. Second, follow-up is too short in most series, since meningiomas require a follow-up of at least 2 years after radiosurgery to evaluate the occurrence of complications, and a follow-up of at least 5 years (and preferably 10–20 years) to evaluate recurrence. The third concern is about the fate of patients who require microsurgery after radiosurgery. Preliminary information suggests that the outcome is much worse because of scarring, and perhaps because of microvascular damage that is caused by the radiation. This radiation should be factored into the results of radiosurgery,

since treatment failure leads to microsurgery, which may produce a poor outcome.

Our current approach is give patients information and a choice. An algorithm for meningiomas involving the CS including the patient's occupation and preference, preoperative binocular function, and curability of the tumor is necessary. We believe that because of a potential longevity of 20+ years, patients aged 55 years and under must be given the choice of complete microsurgical resection versus partial/subtotal removal and radiosurgery. On the other hand, in patients older than 55 years, it seems reasonable to perform partial/subtotal resection microsurgically, followed by radiosurgery. The rationale for this approach must be discussed with the patient and the family. Attention must be paid to the patients' existing neurological deficits, their occupation, and their feelings about diplopia. Since the complications of radiosurgery appear to be dependent upon tumor size and proximity to structures such as the optic nerve or the brain stem, partial tumor resection has a role in the majority of patients, even when radiosurgery is selected.

Since randomized, controlled studies are unlikely, both microsurgeons and radiosurgeons must agree on and abide by a uniform reporting strategy, in order to enable better comparison of treatment results. A task force should be established by the WFNS to make appropriate recommendations in this regard. A cooperative study could be designed wherein patients and their tumors are evaluated and reported in a standardized fashion, for both patients treated by radiosurgery and microsurgery.

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