Management of Benign Skull Base Meningiomas: A Review

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ABSTRACT

The optimal management of benign meningiomas of the skull base is reviewed. Elderly patients with small, asymptomatic tumors can be observed and treatment can be initiated if and when progression occurs. Patients with tumors that appear to be amenable to complete resection with an acceptable rate of morbidity are optimally treated with surgery. Decompression of more extensive tumors through conservative subtotal resection and preservation of the involved cranial nerves may result in improved neurological function. Either alone or after subtotal resection, radiosurgery is indicated for tumors that can be treated adequately with this modality. Larger, ill-defined tumors and those that abut radiosensitive structures such as the optic nerve(s) are optimally treated with radiotherapy. Extensive subtotal resections that sacrifice one or more cranial nerves are no more likely to enhance the probability of success of subsequent radiotherapy than more conservative procedures.

KEYWORDS: Neoplasm, skull base, treatment outcome, radiotherapy, radiosurgery, surgery

Primary brain tumors account for about 20% of all intracranial neoplasms; meningiomas constitute 15 to 20% of primary brain tumors.¹ The incidence of meningiomas is about 2.6 per 100,000 persons.² They occur most often in the sixth decade of life and are more likely to be found in women than in men.³⁻⁷ Most meningiomas are benign and exhibit an indolent growth pattern.^{8,9} Tumors that recur after treatment, whether surgical or radio-

therapeutic, are more likely to exhibit aggressive behavior.⁹ Some patients present with atypical or malignant meningiomas associated with a relatively unfavorable prognosis.^{7,9}

Lanzafame et al¹⁰ analyzed 69 patients who underwent complete resection of meningiomas at the University of Catania (Catania, Italy) between 1988 and 1994. Follow-up ranged from 4 to 10 years. MIB-1 labeling index (LI), was analyzed

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to assess the proliferative activity of the meningiomas, and was increased in World Health Organization (WHO) grade II (atypical) and grade III (malignant) tumors ($p = 0.0006$). Furthermore, within the subset of 54 patients with WHO grade I (benign) meningiomas, increased MIB-1 positivity correlated significantly ($p = 0.0006$) with the probability of recurrence.

Meningiomas occur in a variety of intracranial locations. Between 1964 and 1992, Condra et al⁷ treated 262 patients for meningiomas at the University of Florida, and observed the following site distribution: sphenoid ridge (16%), convexity (14%), cerebellopontine angle (13%), parasellar (12%), parasagittal (11%), posterior fossa (8%), olfactory groove (8%), falx (7%), foramen magnum (3%), orbit (3%), and other (6%).

Patients with small, asymptomatic meningiomas who are elderly, medically infirm, or both may be observed and treatment initiated if and when progression is documented. The disadvantage of observation is that a neurological deficit such as a cranial neuropathy may develop and may not resolve after definitive treatment. However, if the patient is observed closely and treatment is instituted as soon as tumor growth is appreciated, significant neurological deficits are unlikely to occur.

Meningiomas can be treated with either surgery, radiosurgery, or radiotherapy. *Radiosurgery*, which can be administered with either a linear accelerator or a Gamma knife, refers to the delivery of a single high dose of irradiation to the tumor. The specified dose is delivered at the radiographically defined edge of the lesion and very little dose is delivered to the surrounding normal tissue.^{11,12} *Radiotherapy* refers to a course of conventionally fractionated irradiation to the tumor and a 5 to 10 mm margin of surrounding normal tissue.

Many physicians regard surgery as the treatment of choice for patients with apparently resectable meningiomas. The likelihood of accomplishing a complete resection is related to the site and extent of the tumor. Skull base meningiomas can be particularly challenging because they often cannot be completely resected, and surgery can be associated

with significant complications. This article reviews the optimal treatment of patients with benign meningiomas involving the skull base.

MATERIALS AND METHODS

The efficacy of treatment can be measured by local control and complications. Survival is of interest but is a less useful end point because few patients with benign meningiomas die secondary to the tumor.

LOCAL CONTROL

Local control after resection implies complete removal of the tumor without evidence of recurrence on follow-up evaluations. In contrast, local control after radiosurgery or radiotherapy implies stabilization of the tumor with no evidence of progression on follow-up evaluations. Benign tumors regress partially but rarely disappear completely after successful irradiation.^{13–15} However, as long as there is no evidence of disease progression, local control of the tumor is as effective as if it had been completely removed without a subsequent recurrence. Benign tumors can recur many years after treatment. Thus, patients must be followed for long periods, and local control must be calculated using the product-limit method to appreciate the efficacy of therapy.^{16–18}

Surgery

Between 1947 and 1982 at the Karolinska Hospital (Stockholm, Sweden), Mathiesen et al³ treated 338 patients with skull base meningiomas almost exclusively with surgery. Patients were followed until recurrence or death, or for a minimum of 10 years. Because most patients were treated before computed tomography (CT) and magnetic resonance imaging (MRI) were available, *recurrence* was defined as clinical evidence of disease progression. Of

Table 1 Simpson's Classification of Extent of Resection¹⁹

Grade	Extent of Resection
I	Gross total resection of tumor, dural attachments, and abnormal bone
II	Gross total resection of tumor, coagulation of dural attachments
III	Gross total resection of tumor, without resection or coagulation of dural attachments, or of its extradural extensions
IV	Partial resection of tumor
V	Simple decompression (biopsy)

From De Monte² (Table 3, p 86) with permission from Elsevier.

the 338 patients, 98% had benign meningiomas and the remainder had tumors thought to be atypical or malignant. Some patients were lost to follow-up after 10 years; therefore, local recurrence rates at 15 years were calculated as the percentage of recurrences observed (lower percentage) and also as the maximum number of potential recurrences accounting for patients lost to follow-up (higher percentage). Extent of resection was graded according to criteria described by Simpson¹⁹ (Table 1).² No patient with a Simpson grade IV or V resection who had follow-up for more than 20 years was free of symptomatic disease progression (Table 2).^{3,19} The local recurrence rate was highest in patients with central skull base tumors. It could be argued that surgical techniques have improved significantly over the past 20 years. The authors, however, point out that patients operated on many years ago must be evaluated to assess long-term outcomes.

Table 2 Skull Base Meningiomas: Local Recurrence versus Extent of Resection — Karolinska Hospital (Stockholm, Sweden)

Simpson Grade ¹⁹	5 Years (%)	15 Years (%)
I	3.5	7–10
II	4	11–15
III	25	37–43
IV	45	81–100
V	36	63–100

Adapted from Mathiesen et al³ (Table 1, p 4) with permission from Lippincott Williams & Wilkins.

De Jesús et al²⁰ described 119 patients with skull base meningiomas treated surgically by Sekhar and colleagues at the University of Pittsburgh between 1983 and 1993. Tumors were considered to be *confined* if their maximum diameter was less than 3 cm and involved the cavernous sinus and immediately adjacent areas (29%). In contrast, 71% of patients were defined as having *extensive* tumors (i.e., 3 cm or larger and involving multiple areas of the skull base). Forty-four percent of the patients had undergone prior surgery, and 7% had received prior radiotherapy. The mean follow-up was 34 months; 21% had been followed for 5 years or more. Gross total resection was achieved in 73 (61%) patients (confined, 72%; extensive, 58%). There was no relationship between the likelihood of gross total resection and whether the patient had received prior treatment. Local recurrence, progression, or both were observed in 7 (10%) of the 73 patients after gross total resection compared with 7 (15%) of the 46 patients after subtotal resection. The 5-year local control rate was 81% after complete resection compared with 62% after subtotal resection. Of the 46 patients who underwent incomplete resection, 17 (37%) subsequently received radiotherapy.

Between 1985 and 1992, Knosp et al²¹ (University of Vienna, Austria) treated 29 patients for meningiomas primarily arising in the cavernous sinus. Complete resection was achieved in 5 patients (17%); the long-term local control rate was not stated. De Monte et al²² reported 41 patients who underwent resection by Al-Mefty and colleagues for benign meningiomas involving the cavernous sinus between 1982 and 1992. Follow-up information was available for 38 patients (mean follow-up, 45 months; range, 2 months to 10 years). Complete resection was achieved in 31 (76%) patients. Improved function was observed in 14% of affected cranial nerves. After complete resection, local control was obtained in 25 (89%) of 28 patients for whom follow-up was available and in eight (80%) of 10 patients with a subtotal resection. However, the follow-up in eight patients who remained progression-free after subtotal resection was very short.

Of 33 patients treated by Bricolo et al⁵ at the University Hospital (Verona, Italy), 26 patients (79%) underwent complete and seven (21%) underwent subtotal resection of a petroclival meningioma. Three patients died postoperatively. The mean follow-up for the remaining 30 patients was 4.3 years. Three patients (10%) died from tumor progression. Karnofsky performance 1 month after surgery and at last follow-up, respectively, was as follows: unchanged, 60% and 70%; improved, 17% and 30%; and worse, 23% and 0%.

Between 1980 and 1992 at the University of Southern California School of Medicine (Los Angeles), Couldwell et al⁴ surgically treated 109 patients with petroclival meningiomas. Seventy-five patients (69%) underwent gross total resection. Follow-up ranged from 2.1 to 14 years (mean, 6.1 years). One hundred five patients had benign tumors, and 10% experienced local recurrence or progression.

radiosurgery

Between 1990 and 1998 at the Mayo Clinic (Rochester, MN), Stafford et al²³ treated 190 patients with 206 meningiomas with Gamma knife radiosurgery. Twenty-two patients (12%) had atypical or malignant tumors, and the remainder were benign. One hundred forty-seven tumors (77%) involved the skull base. The 5-year local control rate for benign tumors was 93%. Between 1988 and 1995 at Harvard Medical School (Boston, MA), Hakim et al²⁴ reported 127 patients with 155 meningiomas treated with linear accelerator-based radiosurgery who were followed for 1.2 to 79.8 months. Approximately half of the tumors involved the skull base, and 106 tumors (68%) were benign. The 5-year local control rate for benign tumors was 89%. Between 1989 and 1997 at the University of Florida, Shafron et al¹¹ described 70 patients with 76 benign meningiomas treated with linear accelerator-based radiosurgery. Follow-up ranged from 2 to 88 months (mean, 23 months). Thirty-four tumors (45%) involved the skull base. The local control rate was 100%.

Between 1987 and 1995 Subach et al²⁵ treated 62 patients with petroclival meningiomas with Gamma knife radiosurgery at the University of Pittsburgh Medical Center (Pittsburgh, PA). Follow-up ranged from 12 to 101 months (mean, 42 months). Thirty-nine patients (63%) had undergone one or more attempted resections, and seven patients (11%) had received prior external-beam radiotherapy. Neurological status improved in 21%, remained stable in 66%, and worsened in 13%. Overall local control was obtained in 92% of patients. The local control rate at 96 months was 92% for the subset of 54 patients with benign tumors who had not received prior radiotherapy. Lee et al²⁶ reported 176 patients with cavernous sinus meningiomas treated with Gamma knife radiosurgery at the same institution between 1987 and 2000. Follow-up ranged from 2 to 138 months (mean, 35 months). Seventeen patients were lost to follow-up and were excluded. Two patients had received prior radiotherapy, and four patients had atypical or malignant tumors. Seventy-six patients (48%) had received prior surgery, and 83 patients (52%) were treated with radiosurgery alone. Neurological status improved in 29%, remained stable in 62%, and worsened in 9%. The 10-year local control rate was 93% for patients with benign meningiomas.

Radiotherapy

Between 1985 and 1998 at the University of Heidelberg (Heidelberg, Germany), 189 patients were treated with stereotactic radiotherapy.²⁷ Follow-up ranged from 3 months to 12 years (median, 35 months). The skull base was involved in 155 patients (82%). The average dose was 56.8 Gy delivered at a median fraction size of 1.8 Gy. After treatment 45% of patients experienced neurological improvement. Local control was obtained in 177 (98%) of 180 patients with WHO grade 1 tumors. At the Royal Marsden Hospital (London) between 1962 and 1992, Nutting et al²⁸ treated 82 patients with benign skull base meningiomas with radiotherapy. Doses varied from 55 to 60 Gy in 33

fractions. The 10-year progression-free survival rate was 83%. Between 1980 and 1997 at the Timone Hospital (Marseille, France), Dufour et al²⁹ treated 31 patients with benign meningiomas with radiotherapy. Patients received 50 to 65 Gy (median, 52 Gy) at a median dose per fraction of 1.9 Gy. Median follow-up for living patients was 6.1 years (range, 2 to 16 years). The 10-year progression-free survival rate was 93%.

Between 1981 and 1996 at Harvard Medical School (Boston, MA), Wenkel et al³⁰ reported 46 patients with partially resected, unresectable, or recurrent benign meningiomas who were treated with combined proton and photon radiotherapy. The patients were followed for 12 to 207 months (median, 53 months; mean, 73 months). Forty-four tumors involved the skull base, and two tumors were orbital. Radiotherapy doses ranged from 53.1 to 74.1 cobalt gray equivalent (CGE) (median, 59 CGE) delivered at 1.8 to 1.9 CGE per fraction. The 10-year recurrence-free survival rate was 88%.

Between 1994 and 1999 at Baylor College of Medicine (Houston, TX), 40 patients had benign meningiomas treated with intensity-modulated radiotherapy (IMRT).³¹ Follow-up was 6 to 71 months (median, 30 months). Thirty-two tumors (80%) involved the skull base. Patients were treated with 40 to 56 Gy (median, 50.4 Gy) at 1.7 to 2 Gy per fraction. The 5-year local control rate was 93%.

At the University of Chicago Hospitals (Chicago, IL) between 1984 and 1995, Connell et al³² treated 54 patients with benign meningiomas with radiotherapy. Follow-up ranged from 7 to 124 months (median, 55 months). Primary site distribution was as follows: sphenoid wing (26%), convexity (20%), parasellar (17%), parasagittal (13%), and other (24%). The 5-year progression-free survival rate was 93% for tumors smaller than 5 cm compared with 40% for tumors 5 cm or larger ($p < 0.0001$). The overall 5-year progression-free survival rate was 76%.

Between 1967 and 1990 at the University of California at San Francisco, Goldsmith et al³³

treated 117 patients with benign and 23 patients with malignant meningiomas with radiotherapy (median dose, 54 Gy). The 5- and 10-year progression-free survival rates for the patients with benign tumors were 89% and 77%, respectively. In contrast to the data reported by Connell et al,³² progression-free survival was unrelated to tumor size. However, progression-free survival was better after 1980 when CT or MRI was available to define the extent of tumors and for patients who received doses larger than 52 Gy ($p = 0.04$).

SURVIVAL

Surgery

The 10-year survival rate was about 79% for 315 patients treated surgically for skull base meningiomas. Forty-six patients underwent surgery for central skull base tumors, and 13 of 46 received postoperative radiotherapy. Survival rates after treatment for those treated with surgery alone compared with surgery and radiotherapy were as follows: 10 years, 14 of 33 (42%) versus 10 of 13 (77%) ($p \leq 0.05$); and 20 years, 6 of 33 (18%) versus 5 of 13 (38%) (not statistically significant).³

For 262 patients treated with surgery alone (229), surgery and postoperative radiotherapy (21), radiotherapy alone (7), and radiosurgery (5), the 15-year cause-specific survival rates were as follows: total resection, 88%; subtotal resection and radiotherapy, 86%; and subtotal resection alone, 51% ($p = 0.0003$). Sixty percent of tumors involved the skull base, and 47 tumors in 46 patients (18%) were atypical.⁷

Radiosurgery

Survival data for patients treated with radiosurgery are limited. Stafford and coworkers²³ reported a 100% 5-year cause-specific survival rate for 178 patients treated at the Mayo Clinic.

Radiotherapy

Overall survival rates for 180 patients treated with stereotactic radiotherapy for WHO grade 1 meningiomas were as follows: 5 years, 97%, and 10 years, 96%.²⁷ Thirty-one patients treated with radiotherapy for cavernous sinus meningiomas had a 94% 10-year overall survival rate and a 100% 10-year cause-specific survival rate.²⁹ The 10-year survival rate for 117 patients treated with radiotherapy for benign meningiomas was 77%.³³ A 71% overall survival rate was reported for 82 patients treated with radiotherapy for benign skull base meningiomas.²⁸

COMPLICATIONS

Surgery

Of 29 patients treated surgically for meningiomas of the cavernous sinus, complete resection was accomplished in five patients (17%). Oculomotor nerve function deteriorated in 14% of patients. New cranial nerve deficits included the following: trochlear, 7%; ophthalmic, 3%; maxillary, 10%; mandibular, 17%; and abducens, 3%. There was no operative mortality. Two patients required a second operation for a pseudoaneurysm of the internal carotid artery (1) and a cerebrospinal fluid leak (1).²¹

O'Sullivan et al³⁴ reported 39 patients treated surgically at the University of Cincinnati (Cincinnati, OH) between 1985 and 1994 for meningiomas involving the cavernous sinus. Complete resection was performed in eight patients (20%). Permanent cranial nerve deficits were assessed 6 months after surgery. A new optic nerve deficit was observed in one patient, and new oculomotor nerve deficits occurred in seven patients (18%). There were no postoperative deaths.

In 119 patients who were treated surgically for skull base meningiomas at the University of Pittsburgh, complete resection was performed in 61% of patients. Complications included cerebrospinal fluid leakage (21%), pituitary dysfunction

(14%), cerebrovascular accident (5%), infection (4%), and brain hematoma or contusion (3%).²⁰ Of 109 patients operated on for petroclival meningiomas, 69% underwent a gross total resection. Four patients (4%) died postoperatively because of complications. Permanent cranial neuropathies were observed in 36 patients (33%).⁴

Forty-one patients were treated surgically for benign meningiomas involving the cavernous sinus; 76% underwent a complete resection. Seven patients (18%) had new cranial neuropathies, usually involving the oculomotor and trigeminal nerves. Two patients experienced a cerebrovascular accident with a permanent deficit of the dominant hemisphere, two patients had a cerebrospinal fluid leak, and three patients (7%) died postoperatively.²²

Thirty-three patients were treated surgically for a petroclival meningioma; 79% underwent a complete resection. Twenty-five patients (76%) had at least one new cranial nerve deficit, and 12 patients (36%) experienced worsening of a pre-existing deficit. Cranial nerve deficits per patient averaged 2.2 preoperatively, 3.6 perioperatively, and 2.7 at last follow-up. Three patients (9%) died perioperatively.⁵

Radiosurgery

Of 190 patients treated with radiosurgery for 206 meningiomas, 24 patients (13%) experienced complications including cranial nerve deficits (8%), symptomatic parenchymal changes (3%), internal carotid artery stenosis (1%), and symptomatic cyst formation (1%). Three percent of patients exhibited decreased functional status because of radiosurgery.²³ In a report of 127 patients with 155 meningiomas who were treated with radiosurgery, six patients (5%) experienced severe complications including unilateral blindness (1), unilateral deafness (1), leg weakness (1), hemiparesis (1), and death (2).²⁴

Of 62 patients treated with radiosurgery for petroclival meningiomas, three patients (5%) experienced new, persistent cranial nerve deficits

without evidence of disease progression.²⁵ Of 159 patients treated with radiosurgery for cavernous sinus meningiomas, 11 patients (7%) experienced complications including visual deterioration (3), new trigeminal nerve dysfunction (5), medically controlled partial complex seizures (2), and cognitive deterioration (1).²⁶

Radiotherapy

Of 82 patients with benign skull base meningiomas who were treated with radiotherapy, six patients (7%) experienced diminished vision (cataract, 5; retinopathy, 1). Four patients had decreased short-term memory, and hypopituitarism developed in three patients.²⁸ In another report, 40 patients were treated with IMRT for benign meningiomas. Three patients (8%) experienced significant toxicity including memory loss and personality changes (2) and fatal brainstem necrosis (1).³¹ In a third report, significant late toxicity was observed in four (2%) of 189 patients treated with stereotactic radiotherapy; there were no fatal complications.²⁷

In a report of 31 patients with cavernous sinus meningiomas treated with radiotherapy, one patient experienced short-term memory loss.²⁹ Maguire et al³⁵ described 28 patients with cavernous sinus meningiomas who were treated with radiotherapy at Duke University Medical Center (Durham, NC) between 1985 and 1998. Two patients (7%) experienced late toxicity including decreased cognitive function (1) and orbital fibrosis (1). The latter patient had received radiotherapy 35 years previously for a retinoblastoma.

CONCLUSION

The treatment of benign skull base meningiomas presents a challenge. Although a significant subset of patients will remain locally controlled after surgery or radiotherapy, the probability of progression-free survival decreases with longer follow-up. The rates of long-term local control and survival are

similar after complete resection, radiosurgery, and radiotherapy. Therefore, the choice of treatment depends on the risk of complications.

The likelihood of complete resection depends on the location and extent of the tumor. Complete resection of extensive tumors, or even limited lesions in critical sites, results in permanent neurological deficits in a significant subset of patients. Although such deficits may be "acceptable" to the attending physician, a permanent "minor" deficit is often one experienced by someone else. On the other hand, radiosurgery and radiotherapy are not risk-free; a smaller, but no less significant, subset of patients will suffer radiotherapy complications.

Therefore, it seems reasonable to attempt complete resection in cases where the tumor is limited and the long-term morbidity associated with resection is minimal. More extensive lesions may be surgically decompressed if it is thought that decompression will ameliorate existing neuropathies. Most preexisting neuropathies will not improve after subtotal resection.^{21,22,34} If the lesion can be adequately encompassed within the treatment fields, radiosurgery is indicated after decompression or may be used alone if surgery is deemed unnecessary. There is no difference in outcomes comparing patients treated with Gamma knife versus linear accelerator-based systems.^{11,23-26} Radiotherapy is indicated if the tumor is irregular, too large to be treated with radiosurgery, or both. An additional subset of patients with tumors abutting radiosensitive structures, such as the optic nerves, is better treated with radiotherapy. It is critical to minimize the volume of normal tissue included in the radiotherapy fields to minimize the risk of long-term complications. The optimal dose fractionation schedule is approximately 50 to 55 Gy at 1.7 to 1.8 Gy per fraction, administered once daily, 5 days a week, in a continuous course.

REFERENCES

1. Wara WM, Bauman GS, Sneed PK, et al. Brain, brain stem, and cerebellum. In: Perez CA, Brady LW, eds.

- Principles and Practice of Radiation Oncology. 3rd ed. Philadelphia: Lippincott-Raven; 1997:777-828
2. De Monte F. Current management of meningiomas. *Oncology* 1995;9:83-96
3. Mathiesen T, Lindquist C, Kihlström L, Karlsson B. Recurrence of cranial base meningiomas. *Neurosurgery* 1996;39: 2-9
4. Couldwell WT, Fukushima T, Giannotta SL, et al. Petroclival meningiomas: surgical experience in 109 cases. *J Neurosurg* 1996;84:20-28
5. Bricolo AP, Turazzi S, Talacchi A, et al. Microsurgical removal of petroclival meningiomas: a report of 33 patients. *Neurosurgery* 1992;31:813-828
6. Mirimanoff RO, Dosoretz DE, Linggood RM, et al. Meningioma: analysis of recurrence and progression following neurosurgical resection. *J Neurosurg* 1985;62:18-24
7. Condra KS, Buatti JM, Mendenhall WM, et al. Benign meningiomas: primary treatment selection affects survival. *Int J Radiat Oncol Biol Physiol* 1997;39:427-436
8. Jaaskelainen J, Haltia M, Servo A. Atypical and anaplastic meningiomas: radiology, surgery, radiotherapy and outcome. *Surg Neurol* 1986;25:233-242
9. Wilson CB. Meningiomas: genetics, malignancy, and the role of radiation in induction and treatment. The Richard C. Schneider Lecture. *J Neurosurg* 1994;81:666-675
10. Lanzafame S, Torrisi A, Barbagallo G, et al. Correlation between histological grade, MIB-1, p53, and recurrence in 69 completely resected primary intracranial meningiomas with a 6-year mean follow-up. *Pathol Res Pract* 2000; 196:483-488
11. Shafron DH, Friedman WA, Buatti JM, et al. Linac radiosurgery for benign meningiomas. *Int J Radiat Oncol Biol Physiol* 1999;43:321-327
12. Friedman WA, Buatti JM, Bova FJ, et al. Linac Radiosurgery: A Practical Guide. New York: Springer-Verlag; 1998:1-176
13. Hinerman RW, Mendenhall WM, Amdur RJ, et al. Definitive radiotherapy in the management of chemodectomas arising in the temporal bone, carotid body, and glomus vagale. *Head Neck* 2001;23:363-371
14. Mendenhall WM, Friedman WA, Buatti JM, et al. Preliminary results of linear accelerator radiosurgery for acoustic schwannomas. *J Neurosurg* 1996;85:1013-1019
15. Mendenhall WM, Amdur RJ, Hinerman RW, et al. Radiotherapy and radiosurgery for skull base tumors. *Otolaryngol Clin North Am* 2001;34:1065-1077
16. Parsons JT, McCarty PJ, Rao PV, et al. On the definition of local control (Editorial). *Int J Radiat Oncol Biol Physiol* 1990;18:705-706
17. Kaplan EL, Meier P. Nonparametric estimation from incomplete observations. *J Am Stat Assoc* 1958;53:457-481
18. SAS Institute Inc. SAS OnlineDoc®, Version 8. Cary, NC: SAS Institute Inc.; 1999
19. Simpson D. The recurrence of intracranial meningiomas after surgical treatment. *J Neurol Neurosurg Psychiatry* 1957;20:22-39
20. De Jesús O, Sekhar LN, Parikh HK, et al. Long-term follow-up of patients with meningiomas involving the cavernous sinus: recurrence, progression, and quality of life. *Neurosurgery* 1996;39:915-920
21. Knosp E, Perneczky A, Koos WT, et al. Meningiomas of the space of the cavernous sinus. *Neurosurgery* 1996;38: 434-444
22. DeMonte F, Smith HK, Al-Mefty O. Outcome of aggressive removal of cavernous sinus meningiomas. *J Neurosurg* 1994;81:245-251
23. Stafford SL, Pollock BE, Foote RL, et al. Meningioma radiosurgery: tumor control, outcomes, and complications among 190 consecutive patients. *Neurosurgery* 2001;49: 1029-1038
24. Hakim R, Alexander E III, Loeffler JS, et al. Results of linear accelerator-based radiosurgery for intracranial meningiomas. *Neurosurgery* 1998;42:446-454
25. Subach BR, Lunsford LD, Kondziolka D, et al. Management of petroclival meningiomas by stereotactic radiosurgery. *Neurosurgery* 1998;42:437-445
26. Lee JYK, Niranjan A, McNerney J, et al. Stereotactic radiosurgery providing long-term tumor control of cavernous sinus meningiomas. *J Neurosurg* 2002;97:65-72
27. Debus J, Wuendrich M, Prizkall A, et al. High efficacy of fractionated stereotactic radiotherapy of large base-of-skull meningiomas: long-term results. *J Clin Oncol* 2001;19: 3547-3553
28. Nutting C, Brada M, Brazil L, et al. Radiotherapy in the treatment of benign meningioma of the skull base. *J Neurosurg* 1999;90:823-827
29. Dufour H, Muracciole X, Metellus P, et al. Long-term tumor control and functional outcome in patients with cavernous sinus meningiomas treated by radiotherapy with or without previous surgery: is there an alternative to aggressive tumor removal? *Neurosurgery* 2001;48:285-294
30. Wenkel E, Thornton AF, Finkelstein D, et al. Benign meningioma: partially resected, biopsied, and recurrent intracranial tumors treated with combined proton and photon radiotherapy. *Int J Radiat Oncol Biol Physiol* 2000; 48:1363-1370
31. Uy NW, Woo SY, Teh BS, et al. Intensity-modulated radiation therapy (IMRT) for meningioma. *Int J Radiat Oncol Biol Physiol* 2002;53:1265-1270
32. Connell PP, Macdonald RL, Mansur DB, et al. Tumor size predicts control of benign meningiomas treated with radiotherapy. *Neurosurgery* 1999;44:1194-1200
33. Goldsmith BJ, Wara WM, Wilson CB, et al. Postoperative irradiation for subtotally resected meningiomas: a retrospective analysis of 140 patients treated from 1967 to 1990. *J Neurosurg* 1994;80:195-201
34. O'Sullivan MG, van Loveren HR, Tew JM Jr. The surgical resectability of meningiomas of the cavernous sinus. *Neurosurgery* 1997;40:238-247
35. Maguire PD, Clough R, Friedman AH, et al. Fractionated external-beam radiation therapy for meningiomas of the cavernous sinus. *Int J Radiat Oncol Biol Physiol* 1999;44: 75-79

Commentary

Mendenhall et al provide a concise, comprehensive review of the changing trends that have occurred in the past 2 decades in the management strategies for skull base meningiomas. The morbidity rate associated with surgical resection of various skull base meningiomas has decreased significantly with improved neuroimaging, better understanding of the anatomy, and the introduction of intraoperative neuronavigational techniques.

However, as we move into the third decade of modern skull base surgery, the emphasis has shifted from designing new approaches to establishing approaches that aim to preserve neural function. Skull base surgery in particular has evolved through certain phases of development: early skepticism, enthusiastic application, reconciliation with reports of morbidity and recurrences, and maturation in which goals and expectations translate into reason-

able application. The authors succeed in making this point by citing large series from specialized skull base surgery centers and quoting their control, mortality, and morbidity rates.

In the past few years, radiosurgery has rapidly gained popularity as a treatment option for benign skull base tumors. Many series have described both early and long-term outcomes associated with the treatment of various benign intracranial neoplasms, including meningiomas. Again, however, as the authors note, the definition of tumor control for radiation and radiosurgery is much more accommodating compared with the definition of control after resection (which mandates complete resection of the tumor and its dural attachment). This controversy will continue to be a topic of debate between microsurgeons and radiosurgeons in the near future.

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