

Surgical treatment of patients with vestibular schwannomas after failed previous radiosurgery

Clinical article

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Object. An increasing number of patients with vestibular schwannomas (VSs) are being treated with radiosurgery. Treatment failure or secondary regrowth after radiosurgery, however, has been observed in 2%–9% of patients. In large tumors that compress the brainstem and in patients who experience rapid neurological deterioration, surgical removal is the only reasonable management option.

Methods. The authors evaluated the relevance of previous radiosurgery for the outcome of surgery in a series of 28 patients with VS. The cohort was further subdivided into Group A (radiosurgery prior to surgery) and Group B (partial tumor removal followed by radiosurgery prior to current surgery). The functional and general outcomes in these 2 groups were compared with those in a control group (no previous treatment, matched characteristics).

Results. There were 15 patients in Group A, 13 in Group B, and 30 in the control group. The indications for surgery were sustained tumor enlargement and progression of neurological symptoms in 12 patients, sustained tumor enlargement in 15 patients, and worsening of neurological symptoms without evidence of tumor growth in 1 patient. Total tumor removal was achieved in all patients in Groups A and B and in 96.7% of those in the control group. There were no deaths in any group. Although no significant differences in the neurological morbidity or complication rates after surgery were noted, the risk of new cranial nerve deficits and CSF leakage was highest in patients in Group B. Patients who underwent previous radiosurgical treatment (Groups A and B) tended to be at higher risk of developing postoperative hematomas in the tumor bed or cerebellum. The rate of facial nerve anatomical preservation was highest in those patients who were not treated previously (93.3%) and decreased to 86.7% in the patients in Group A and to 61.5% in those in Group B. Facial nerve function at follow-up was found to correlate to the previous treatment; excellent or good function was seen in 87% of the patients from the control group, 78% of those in Group A, and 68% of those in Group B.

Conclusions. Complete microsurgical removal of VSs after failed radiosurgery is possible with an acceptable morbidity rate. The functional outcome, however, tends to be worse than in nontreated patients. Surgery after previous partial tumor removal and radiosurgery is most challenging and related to worse outcome.

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KEY WORDS • facial nerve • radiosurgery • vestibular schwannoma

RADIOSURGERY is currently promoted either as a primary treatment option for VSs smaller than 3 cm or as a secondary treatment of tumor remnants or recurrences. The tumor growth control rate in recent series has been reported up to 91%–98%.^{14,15,21,22,28,30,39} Treatment failure or secondary regrowth after radiosurgery, however, has been observed in 2%–9% of patients.^{1–3,8,23} In large tumors that compress the brainstem and in patients who experience rapid neurological deterioration, surgical removal is the only reasonable management option. Given the increasing number of patients who undergo radiosurgery, it is obvious that this issue is becoming especially important.

Several studies published in the literature recently addressed the topic of surgery after failed radiosur-

gery.^{4,6,16–19,35,38} The general opinion is that such operations are technically more difficult and riskier than primary ones and that the outcome is worse.^{17,19,25,29,37} In regard to the surgical goal, recommendations vary from partial to complete tumor removal.^{17,19} Assuming that radical surgery is inevitably related to poor functional outcome, some authors have advocated tumor debulking or internal decompression.^{17,25,36} The small number of cases in most reports and the heterogeneity of the included patients, however, confound the reliability of the conclusions. Patients are surgically treated by different surgeons who use various operative techniques and have varying experience.^{11,17,19} Thus, the rates of preservation of cranial nerve function with this procedure vary widely. A recent popular trend in the management of large VSs is to perform tumor debulking followed by radiosurgery of the tumor remnant.^{5,10} The impact of tissue trauma caused by combined surgery and radiosurgery on the outcome of

Abbreviations used in this paper: CPA = cerebellopontine angle; VS = vestibular schwannoma.

surgery in cases of treatment failure has not been systematically evaluated.

In the current study, we evaluated the impact of previous radiosurgery on the outcome of surgery for VSs. We compared functional and general outcomes in such patients with those in a group of patients with VSs of similar size who did not undergo any previous treatment. Furthermore, we performed a correlative analysis of the outcome of surgery after failed radiosurgery and after failed combined surgery and radiosurgery.

Methods

Patient Population

We performed a retrospective analysis of patients with VS growth after previous radiosurgical treatment who underwent surgery at our institution during a 10-year period. All medical records, pre- and postoperative diagnostic images, pre- and postoperative audiograms, intraoperative findings, histological results, and follow-up examinations were reviewed. The main outcome measures were neurological status after surgery, in particular facial nerve function, hearing level, and development of new neurological deficits, as well as the complication rate.

Tumor size was determined according to the system of Kanzaki et al.¹³ The tumors were classified according to the Hannover tumor extension system as follows:³³ Class T1, intrameatal tumor; Class T2, intra- and extrameatal tumor; Class T3a, lesion filling the cerebellopontine cistern; Class T3b, tumor reaching the brainstem; Class T4a, lesion compressing the brainstem; and Class T4b, tumor severely dislocating the brainstem and compressing the fourth ventricle. Facial nerve function was assessed using the House-Brackmann grading system.⁹ The New Hannover Hearing classification, based on audiogram and speech discrimination evaluation, was applied to categorize hearing before and after surgery.³⁴ Serviceable hearing was defined as a pure tone average of 40 dB or less and a speech discrimination score of 70% or more.

Indications for Surgery and Surgical Technique

The indications for surgery were sustained tumor growth on serial MR images and/or progression of neurological symptoms despite steroid therapy. In all cases, the primary goal was to remove the tumor completely because these VSs had already proven to be biologically highly active. All patients underwent surgery in the semi-sitting position via the retrosigmoid approach performed by 1 surgeon (M.S.). The intraoperative monitoring of somatosensory evoked potentials and auditory brainstem responses and facial nerve electromyography provided continuous feedback information. The technique for tumor removal has been described in detail previously.^{31–33}

Data Analysis

Patients were divided in 2 groups depending on the type of previous treatment. Group A comprised patients with VS regrowth after previous radiosurgical treatment. Group B included patients who had undergone radiosurgery after prior partial operative tumor removal. All pa-

tients underwent previous surgery at other neurosurgical facilities. The functional and general outcomes in these groups were compared with a matched group of 30 patients undergoing surgery for VS performed by the same surgeon; these patients had not been previously treated. Patients with neurofibromatosis Type 2 were excluded from the study.

Statistical Analysis

Univariate analysis was applied to evaluate the correlation between the type of previous treatment and the following variables: completeness of tumor resection, facial nerve function, hearing level, development of new neurological symptoms, and complication rate.

Subgroup analysis was performed using the Pearson chi-square test or the Fisher exact test for comparison of binary values and the paired t-test for comparison of 2 mean values. The results from the tests were considered statistically significant at $p < 0.05$.

Results

Patient Population and Indications for Surgery

Twenty-eight patients with VSs who were treated previously using radiosurgery underwent surgery during a 10-year period at our institution (Table 1). Their mean age was 47.6 years, and the male-to-female ratio was 1:1.8. Nineteen patients were treated using Gamma Knife surgery (twice in 1 patient), 5 were treated using the CyberKnife, and 4 were treated using fractionated stereotactic radiotherapy. In all cases, initial surgical and/or radiosurgical procedures were performed at various neurosurgical centers. Due to a lack of precise information regarding the treatment and its indications, we were not able to pursue this issue further. The mean interval between the radiosurgical treatment and surgery at our institution was 30.7 months (range 6–60 months). Tumor enlargement was documented on serial MR imaging examinations in 27 of the 28 patients. Thirteen patients presented with progressive neurological symptoms (intracranial hypertension in 5 patients, gait imbalance in 7 patients, and contralateral hemiparesis in 1 patient).

The indications for surgery were sustained tumor enlargement and progression of neurological symptoms in 12 patients, sustained tumor enlargement in 15 patients, and progression of neurological symptoms without evidence of tumor growth in 1 patient. The latter patient had a large VS (maximum extrameatal diameter 4.2 cm) and signs of intracranial hypertension with papilledema. Surgery was not performed in the early stages after radiosurgery, except in 1 patient who presented 6 months after radiosurgery with rapid neurological deterioration and a 4.7-cm VS that severely compressed the brainstem.

General Patient Characteristics

The general characteristics of the patients in all 3 groups, in particular sex distribution, age, tumor size, and extension, were similar (Table 2). There were 15 patients in Group A (radiosurgery prior to current surgery). Their mean age was 51 years (range 35–66 years), and

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TABLE 1: Demographics of the patients who underwent surgery after failed previous radiosurgery*

| Case No. | Age (yrs), Sex | Surgery Before RS | Type of RS | Interval to RS (mos) | Preop CN VII Function (HB grade) | Tumor Extension & Diameter in cm† | Anatomical Preservation of CN VII | Postop CN VII function (HB grade) | Op Complications/New Neurological Deficits |
|----------|----------------|-------------------|-------------|----------------------|----------------------------------|-----------------------------------|-----------------------------------|-----------------------------------|--|
| Group A | | | | | | | | | |
| 1 | 40, F | no | GKS | 60 | I | T4a, 3.5 | yes | I | |
| 2 | 66, M | no | GKS | 34 | I | T4b, 4.8 | no, reconstruction | V | |
| 3 | 38, M | no | GKS | 24 | I | T3b, 2.6 | yes | I | |
| 4 | 56, F | no | GKS | 14 | I | T4b, 3.8 | yes | III | pneumocephalus |
| 5 | 54, M | no | GKS | 41 | I | T3b, 2.6 | yes | II | |
| 6 | 35, M | no | GKS | 25 | I | T4b, 4 | yes | II | blood collection (tumor bed) |
| 7 | 65, M | no | GKS | 6 | II | T4b, 4.7 | no, reconstruction | IV | temporal lobe ischemic stroke, motor aphasia |
| 8 | 50, M | no | CK | 22 | I | T3a, 1.8 | yes | I | |
| 9 | 52, F | no | GKS | 60 | I | T3b, 2 | yes | I | |
| 10 | 59, F | no | FSR | 40 | I | T4a, 2 | yes | IV | |
| 11 | 63, F | no | FSR | 48 | II | T4a, 3.1 | yes | I | |
| 12 | 58, F | no | FSR | 14 | I | T3b, 2.5 | yes | III | |
| 13 | 40, F | no | CK | 20 | I | T4a, 2.1 | yes | III | |
| 14 | 50, F | no | CK | 36 | I | T3b, 3.1 | yes | II | |
| 15 | 45, F | no | CK | 18 | I | T4b, 3.5 | yes | NA | epileptic seizure |
| Group B | | | | | | | | | |
| 1 | 47, F | twice | GKS | 35 | III | T3a, 2.5 | yes | II | |
| 2 | 38, M | twice | GKS | 51 | I | T3a, 4.2 | yes | I | |
| 3 | 59, M | twice | GKS | 40 | II | T4a, 3.9 | yes | IV | |
| 4 | 41, M | once | GKS | 37 | II | T4a, 3 | yes | I | |
| 5 | 53, F | once | GKS | 25 | III | T4b, 4.2 | no, reconstruction | IV | |
| 6 | 33, F | once | GKS | 24 | I | T4a, 4 | yes | I | |
| 7 | 37, F | once | GKS | 26 | V | T4a, 3.4 | no, reconstruction | IV | |
| 8 | 38, F | once | GKS | 36 | IV | T4b, 4.5 | no, reconstruction | V | blood collection (cerebellum) |
| 9 | 46, F | once | GKS (twice) | 22 | II | T4a, 3.7 | yes | I | |
| 10 | 48, F | once | GKS | 25 | II | T4b, 3 | yes | II | trochlear nerve dysfunction |
| 11 | 58, M | once | GKS | 20 | I | T4a, 2.7 | yes | III | |
| 12 | 30, F | twice | FSR | 14 | VI | T4b, 3.8 | no, reconstruction | III | pneumocephalus, CSF leak |
| 13 | 35, F | once | CK | 42 | VI | T4a, 2.5 | no, reconstruction | NA | |

* CK = CyberKnife; CN = cranial nerve; GKS = Gamma Knife surgery; FSR = fractionated stereotactic radiotherapy; HB = House-Brackmann; NA = not available (follow-up period is < 2 months); RS = radiosurgery.

† Tumor extension is based on the Hannover tumor extension classification.³³

the male-to-female ratio was 1:1.5. The mean extrameatal tumor diameter was 3.2 cm (range 2–4.8 cm). Thirteen patients had normal facial nerve function (House-Brackmann Grade I), and 2 had slight facial nerve dysfunction (House-Brackmann Grade II). Only 1 patient had serviceable hearing at presentation.

There were 13 patients in Group B (partial tumor removal followed by radiosurgery prior to current surgery) with a mean age of 43.3 years and a male-to-female ratio of 2.2:1 (Table 2). The mean extrameatal tumor diameter was 3.5 cm (range 2.5–4.5 cm). Thirteen patients underwent surgery once and 4 patients underwent surgery twice prior to radiosurgery. Three patients (25%) had normal fa-

cial nerve function at presentation, 4 patients (33.3%) had slight facial weakness, 2 patients (16.7%) had moderate weakness, 1 patient (8.3%) had moderately severe weakness, and 1 patient (8.3%) had severe facial palsy. One patient presented with serviceable hearing (Class H2 according to the New Hannover classification). The control Group C consisted of a matched group of 30 patients with VSs larger than 2 cm that were not previously treated. These patients were selected randomly from a database comprising 400 patients who underwent surgery during the past 10 years performed by the senior author (M.S.) at the International Neuroscience Institute. The mean extrameatal tumor diameter in the group was 3.4 cm.

TABLE 2: General characteristics of the patients from the 3 groups*

| Variable | Value† | | | p Value |
|--------------------------------------|------------|------------|------------|---------|
| | Group A | Group B | Group C | |
| sex | | | | NS |
| male | 6 (40) | 4 (30.8) | 12 (40) | |
| female | 9 (60) | 9 (69.2) | 18 (60) | |
| mean age (yrs) | 51 ± 2.6 | 43.3 ± 2.6 | 47.5 ± 1.7 | |
| mean extrameatal tumor diameter (cm) | 3.2 ± 0.25 | 3.5 ± 0.19 | 3.4 ± 0.13 | NS |
| tumor extension | | | | |
| T1 | 0 | 0 | 0 | |
| T2 | 0 | 0 | 0 | |
| T3a | 1 (6.7) | 2 (15.4) | 5 (16.7) | |
| T3b | 5 (33.3) | 0 | 8 (26.7) | |
| T4a | 4 (26.7) | 7 (53.8) | 5 (16.7) | |
| T4b | 5 (33.3) | 4 (30.7) | 12 (40) | |

* Statistical analysis shows that the features of the patients in all 3 groups, in particular sex distribution, age, tumor size and extension, were similar. Abbreviation: NS = not significant.

† Mean values are presented as the mean ± SD. Other values are the number of patients with percentages in parentheses.

Comparison of the General Outcome of Surgery

Total tumor removal was achieved in all patients in Groups A and B and in 29 (96.7%) of 30 patients in Group C. Although significant differences in the neurological morbidity and complication rates after surgery were not found, the risk of new cranial nerve deficits and CSF leakage tended to be higher in patients who previously underwent surgery and radiosurgery (Group B). Patients who underwent previous radiosurgical treatment (Groups A and B) were at higher risk of developing postoperative hematomas in the tumor bed or cerebellum. Such blood collections were detected on routine CT scans in 2 patients (1 from Group A and 1 from Group B). Both cases were managed conservatively.

One patient (Case 7 in Group A) experienced a left-sided temporal lobe ischemic stroke with subsequent motor aphasia 7 days after surgery. Another patient had a generalized epileptic seizure on the 3rd postoperative day, but the electroencephalogram showed no focal electrical abnormality. Two patients had symptomatic pneumocephalus, which was managed conservatively. There were no deaths in the entire series.

Facial Nerve Function and Hearing

The rate of anatomical preservation of the facial nerve was highest in patients who were not treated previously (93.3%) and decreased to 86.7% in the patients in Group A. The preservation rate was lowest in patients in Group B who underwent both surgery and radiosurgery previously (61.5%), and the difference was statistically significant ($p = 0.037$) (Table 3).

In 2 patients in Group A, the facial nerve was atro-

TABLE 3: Surgical outcome in the 3 groups of patients

| Variable | No. of Patients (%) | | | p Value |
|---|---------------------|-----------|-----------|---------|
| | Group A | Group B | Group C | |
| complete tumor resection | 15 (100) | 13 (100) | 29 (96.7) | NS |
| anatomical preservation of facial nerve | 13 (86.7) | 8 (61.5)* | 28 (93.3) | 0.037 |
| new neurological deficit | 0 | 1 (7.7)† | 1 (3.3)‡ | NS |
| CSF leak | 0 | 1 (7.7) | 1 (3.3) | NS |
| blood collection cerebellum/tumor bed | 1 (6.7) | 1 (7.7) | 0 | NS |
| death | 0 | 0 | 0 | |

* Three patients presented with complete loss of function or severe facial nerve palsy before surgery, 1 had moderately severe palsy, and 1 had moderate function prior to surgery.

† Trochlear nerve dysfunction.

‡ Lower nerve palsy, improved at follow-up.

phic and intensely adherent to the tumor and could not be preserved. Reconstruction in the CPA with a sural nerve interposition graft was feasible in one of them. In the second patient, a hypoglossal-to-facial nerve anastomosis was performed 2 weeks after tumor surgery. At follow-up, facial nerve function improved in both of them, to House-Brackmann Grade V in the one patient and Grade IV in the other. In the first patient, however, the follow-up period has been less than 12 months and further improvement could be expected. Two patients in Group B presented with complete facial nerve palsy. The nerve was probably destroyed previously, and during surgery it could not be identified. In the patient presenting with severe facial nerve dysfunction (House-Brackmann Grade V), only separate facial nerve fibers could be identified. In the patients in Cases 5 and 8, the facial nerve was atrophic and impossible to dissect due to intense scarring of the arachnoid plane. In these 5 patients, the facial nerve integrity was reconstructed using an interposition sural nerve graft (in 1 patient) and by a hypoglossal-to-facial nerve anastomosis (in 4 patients). At follow-up, the facial nerve function after the sural graft reconstruction improved to House-Brackmann Grade III. Two of the other patients had House-Brackmann Grade IV and 2 had House-Brackmann Grade V facial nerve function (at 12 and 14 months in the last 2 patients, respectively).

The facial nerve function at follow-up was generally better in patients who did not undergo previous treatment (Group C) than in previously treated patients (Groups A and B); 70% had excellent or slightly impaired function and 13.3% had poor function (Table 4). The rate of poor facial nerve function (House-Brackmann Grades IV and V) tended to correlate to previous radiosurgery. Patients in Group A tended to have better facial nerve outcome than those in Group B; excellent or slightly impaired function (House-Brackmann Grades I and II) was seen in 8 patients (57%) in Group A, and 6 (50%) in Group B. Patients in Group B had higher rates of poor facial nerve function (33%), although the difference did not reach significance.

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TABLE 4: Comparison of preoperative and postoperative facial nerve function and hearing level in the 3 groups of patients

| Variable | Group A* | | Group B* | | Group C | | p Value |
|---------------------|-----------|----------|----------|----------|-----------|-----------|---------|
| | Preop | Postop | Preop | Postop | Preop | Postop | |
| HB Grade | | | | | | | NS |
| I | 12 (85.7) | 5 (35.7) | 3 (25) | 4 (33.3) | 29 (96.7) | 16 (53.3) | |
| II | 2 (14.3) | 3 (21.4) | 4 (33.3) | 2 (16.7) | 1 (3.3) | 5 (16.7) | |
| III | 0 | 3 (21.4) | 2 (16.7) | 2 (16.7) | 0 | 5 (16.7) | |
| IV | 0 | 2 (14.3) | 1 (8.3) | 3 (25) | 0 | 3 (10) | |
| V | 0 | 1 (7.1) | 1 (8.3) | 1 (8.3) | 0 | 1 (3.3) | |
| VI | 0 | 0 | 1 (8.3) | 0 | 0 | 0 | |
| hearing level | | | | | | | |
| serviceable hearing | 2 | 1 | 1 | 0 | 9 | 2 | |

* House-Brackmann grades are not reported for 1 patient in both of these groups because the follow-up period was too short.

Most previously treated patients (89.3%) presented with severe or complete hearing loss. One of the 2 patients in Group A who presented with serviceable hearing maintained the hearing level after tumor removal. Although the cochlear nerve was preserved anatomically in the patient with serviceable hearing in Group B, hearing was completely lost. The rate of hearing preservation in the patients with serviceable hearing in Group C was 22.2%.

Discussion

Radiosurgery of VSs

Radiosurgery is increasingly widely used in patients with VS either as a primary or as a secondary treatment mode for tumor remnants and recurrences.^{15,21,27,28,39,40} In large published series, tumor growth control has been achieved in 91%–98% of the treated patients.^{14,21,26,28,41} Shrinkage of the tumor has been observed in 21%–75% of the cases, and tumor growth control (or absence of progressive growth) has been achieved in 18%–59%.

Treatment failure is defined as progressive tumor enlargement demonstrated on 2 or more imaging studies.²⁵ It has been estimated that 2.5%–9% of the tumors continue to progress despite treatment.^{7,14,21} The unresponsiveness to radiotherapy of some VSs may be related to their inherently low proliferation index and the radioresistance of the tumor bulk.^{20,42} Such treatment failure should be differentiated from the temporary increase in tumor volume during the 1st year after therapy, occurring in 17%–74% of patients.^{7,24,28}

Radiosurgery Failure

Patients in whom radiosurgery has failed are managed surgically or with additional radiosurgery.^{12,43} In cases of large VSs that compress the brainstem and in patients with rapid neurological deterioration or major neurological symptoms, such as significant cerebellar ataxia, pyramidal tract signs, or intracranial hypertension, surgical removal is the only reasonable management option. Tumor enlargement or development of new neuro-

logical symptoms per se is not an indication for immediate surgery. A common observation during the 1st year after radiosurgery is an initial increase in tumor volume, possibly with neurological worsening that precedes its shrinkage.²⁸ Furthermore, neurological deficits could be a delayed consequence of radiation therapy, and a trial with steroids should be undertaken. In cases of sustained tumor growth, we propose undertaking surgery in patients with large tumors compressing the brainstem, which are documented on serial MR imaging examinations, or in cases of progression of symptoms that could be definitively related to tumor enlargement and do not respond to steroid therapy. In approximately 4% of patients, significant tumor swelling occurs that may persist more than 2 years after treatment.⁴⁴ In such cases, we consider earlier surgical removal with the goal of brainstem decompression as the only safe option.

Another subgroup of patients who are potential candidates for surgery are those who experience clinical deterioration, such as intractable dizziness, trigeminal neuralgia, or severe facial nerve dysfunction, despite radiological evidence of tumor shrinkage. Microsurgical removal of the tumor and neurolysis of the cranial nerves may lead to resolution of the neuralgia or improvement of the facial function. Patients who experience dizziness profit from sectioning of the affected vestibular nerve. If the facial nerve dysfunction is due to radiation-induced axonal or nuclear damage, the only option to reanimate the face is to perform a hypoglossal-to-facial nerve anastomosis. Primary reconstruction within the CPA is not recommended because the extent of nerve damage cannot be assessed macroscopically. The outcome of surgery in this subgroup will be reported separately.

Operative Considerations

Microsurgical removal of previously irradiated VSs is complicated by the development of extensive post-radiation changes,^{35,38} which are regarded as a typical reaction of the peripheral nerve to irradiation. The main difficulty is encountered during dissection of the tumor from the cranial nerves or brainstem and is caused by the tight ad-

herence of cranial nerves to the tumor capsule or lack of a clear arachnoid plane. Authors asserting that no clear relationship exists between the performed radiosurgery and the subsequent ease or difficulty of microsurgery actually refer only to the initial stage of tumor removal, that is, internal debulking.^{11,17,25} In these series, the goal of surgery was subtotal VS removal and decompression of the neural structure. Dissection of the tumor from the cranial nerves or from the brainstem was not attempted.

In our series all surgeries in previously radiation-treated patients were assessed as more difficult than those in untreated patients, mainly due to the extensive arachnoid scarring that obliterated the normal arachnoid plane. Nonetheless, the surgical concept and technique used did not differ from those used for the treatment of other VSs of the same size.^{32,33} Some steps of the tumor removal were particularly important. The normal relationships of the tumor to CPA structures after previous radiosurgery and/or surgery might be changed and the neural structures are more sensitive to surgical trauma. The initial CSF drainage, achieved by opening of the lateral cerebellomedullary cistern, prevents additional retraction injury to the cerebellum. During surgery, delicate dissection in the arachnoid plane is especially important. Although it might be extremely difficult to find it, such a plane always exists. The 2-hand technique for tumor dissection is especially helpful in this regard. Bipolar coagulation should be avoided in close vicinity to the vulnerable cranial nerves. Furthermore, the blood supply to normal structures might be at risk after radiosurgery, and all efforts should be made to preserve both the arteries and the veins. The blood vessels frequently are more fragile due to radiation-induced changes, and thorough hemostasis at the end of surgery is mandatory.

Outcome Analysis

Most authors consider the preservation of neural functions during microsurgical removal of irradiated VSs especially challenging.^{17,19,29,37} The reported functional outcome is relatively poor, unless tumor debulking alone was performed.^{4,19,29,37} In the series by Lee et al.,¹⁸ which included VSs with a mean size of 19 cm, significant facial nerve and lower cranial nerve dysfunction were observed in half of the cases. Complete facial palsy after more than 1 year follow-up was seen in 4 of 5 surgically treated patients in the study by Slaterry and Brackmann.³⁸ These results are in contrast to their general VS series, and the authors' conclusion was that the operative morbidity in such patients is significantly increased. Roche et al.²⁹ evaluated 20 patients who underwent surgery performed by different surgeons after failed radiosurgery. Facial nerve preservation was found to be impaired by radiosurgery in half of the cases.

Although this series is small for statistical analysis, some general trends can be determined. The surgery-related complication rate and the neurological morbidity do not differ significantly from the results of surgeries in untreated VSs of similar size. The outcome regarding facial nerve function was worse but was related mainly to the preoperative functional status. The low rate of hearing preservation in both groups is related to the poor

preoperative hearing level and the large tumor size. The rate of anatomical preservation of the facial nerve was slightly lower in Groups A and B (82%) than in Group C (93.3%). The rate of excellent and good facial function at follow-up, however, was similar. Regarding cranial nerve dysfunction and the CSF leakage rates, no significant difference between the groups was noted. Hemorrhagic complications tended to occur more frequently in cases of previous radiosurgery, but the difference was not statistically significant.

Goal of Surgery and Management of Failures

In an attempt to decrease the complication and morbidity rates and to improve the chances of preservation of cranial nerve function, some authors favor planned incomplete tumor removal as the preferred management strategy for patients after radiosurgery failure.^{11,17,27} Subtotal removal may indeed allow for preservation of neurological function in some cases but it is a short-term solution. It is difficult to assume that a remnant of a VS that expanded despite the previous therapy will change its biological behavior and stop growing. The follow-up period in the series of authors favoring incomplete removal is too short (between 21 and 36 months) to allow any definitive conclusions.^{11,36}

Furthermore, even subtotal tumor removal does not guarantee high rates of functional preservation. In a series in which only 15% of the tumors were larger than 3 cm, Pollock et al.²⁷ removed the tumors completely in 54%. Nevertheless, 4 patients developed new or worsened trigeminal nerve dysfunction, 7 had poor facial nerve function, and 2 had caudal cranial nerve palsy. At follow-up, 3 patients were incapable of caring for themselves. A conservative approach with partial tumor extirpation without removal of tumor parts close to the brainstem and in the internal auditory canal has been suggested by Iwai et al.¹¹ and was used in a series of 6 patients. Although in 4 patients the tumor was removed subtotally and in 2 it was partially removed, 1 patient experienced new facial nerve palsy (House-Brackmann Grade V), and in 1 patient the preexisting facial palsy deteriorated from House-Brackmann Grade II to Grade V.

According to our experience, the goal of every VS surgery, especially in cases of failed previous surgical and/or radiosurgical treatment, should be total tumor removal, as it is the only option that may provide a cure for the patient. Analysis of our results shows that total removal can be achieved without mortality and major morbidity. Although facial nerve function is worse than that in untreated VSs of similar size, its function is correlated mainly to the preoperative functional level of the nerve.

Management of Patients Who Underwent Previous Surgery and Radiotherapy

Surgery in patients who have undergone radiosurgery after prior incomplete operative tumor removal are most challenging, probably due to the cumulative effect of 2 different types of tissue injury. The initial surgery renders orientation within the CPA and identification of main structures very difficult. Since the goal of initial surgery in all cases was only subtotal tumor removal and

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extensive dissection of the tumor capsule from the cranial nerves or from the brainstem had not been performed, the arachnoid scarring and lack of dissection plane at the salvage surgery could be largely attributed to the radiation exposure.

One limitation to the current study, beyond the small number of cases in each analyzed group, is the lack of detailed information regarding the initial surgery, in particular in regard to the experience of the surgeon, intraoperative findings, and complications. Nevertheless, we found that the outcome of surgery in patients treated with surgery and radiotherapy is certainly worse than that in patients treated with radiosurgery alone. The rate of functional preservation of the facial nerve was significantly lower and the risk of new neurological deficits or CSF leakage tended to be higher.

Conclusions

Complete microsurgical removal of VSs after failed radiosurgery is possible with acceptable morbidity rates. The functional outcome, however, tends to be worse than in untreated patients. Surgery after previous partial tumor removal and radiosurgery is the most challenging and related to worse outcomes.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Gerganov. Acquisition of data: Gerganov. Analysis and interpretation of data: Giordano, Gerganov. Drafting the article: Gerganov. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Giordano. Statistical analysis: Giordano. Study supervision: AA Samii, M Samii.

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