Stereotactic radiosurgery for acoustic nerve tumors in patients with useful preoperative hearing: results at 2-year follow-up examination


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Twenty patients with acoustic nerve tumors (mean diameter = 30 mm) and useful preoperative hearing were examined 2 years after stereotactic radiosurgery to determine the effectiveness of the surgery in the control of tumor growth and the preservation of cranial nerve function. Results showed tumor volume stabilization (12 cases) or reduction (seven cases) was achieved in a total of 19 patients (95%). Useful hearing (defined as Gardner and Robertson Class I or II) preservation was obtained in 100% of cases immediately postoperatively, 53% at 6 months, and 45% at both 1 and 2 years. Two years after stereotactic radiosurgery, facial nerve function was preserved in 90% of patients and 75% continued to have normal trigeminal nerve function. All patients returned to and maintained their preoperative functional status within 3 to 5 days after radiosurgery.

These findings indicate that stereotactic radiosurgery with multiple isocenters and narrow radiation beams is a safe and effective management strategy for progressive acoustic nerve tumors. Auditory, facial, and trigeminal nerve function can be preserved in most patients. Prevention of further growth and preservation of cranial nerve function appear to be satisfactory goals in the current management of patients with acoustic neuromas.

KEY WORDS • stereotactic radiosurgery • radiosurgery • acoustic nerve tumor • hearing preservation • cranial nerve

The microsurgical techniques currently employed in the management of acoustic nerve tumors are generally effective in achieving the primary goals of total tumor excision with no mortality, preservation of facial nerve function, prevention of major surgical complications, and prevention of delayed tumor recurrence during prolonged follow-up study. Preservation of cochlear nerve function in patients who have useful preoperative hearing is, however, a more difficult task. Hearing preservation has been reported in up to 50% of selected patients undergoing surgery via either a posterior fossa or a middle fossa approach at centers with experienced staff. Hearing preservation is usually attempted only when the tumors are small (average diameter = 2 cm).

Stereotactic radiosurgery is a safe and effective alternative to microsurgery for small to moderate-sized tumors. Hearing preservation after radiosurgery has been reported even in patients with tumors as large as 3 to 3.5 cm. Hearing preservation was more likely with tumors averaging less than 10 mm in diameter, such as intracanalicular tumors.

The present study was designed to assess the results of stereotactic radiosurgery in the management of acoustic nerve tumor patients who have useful preoperative hearing. A 2-year period was necessary to fully assess cranial nerve morbidity and to evaluate tumor control rates.

Clinical Material and Methods

Patient Selection

Between August, 1987, and December, 1990, 115 patients with newly diagnosed or recurrent unilateral acoustic nerve tumors underwent stereotactic radiosurgery at our institution. All patients were evaluated using high-resolution computerized tomography (CT) or magnetic resonance (MR) imaging. We identified 20 patients with useful preoperative hearing in the tumor-related ear (speech discrimination (SD) ≥ 50% and pure-tone average (PTA) ≤ 50 dB) and acoustic nerve tumors of 30 mm or less in average extracanalicular diameter.
Clinical Characteristics

Table 1 shows patient characteristics: nine patients (45%) were women and 11 (55%) were men. Their ages varied from 24 to 73 years (median 47 years). Eleven patients (55%) had left-sided acoustic nerve tumors, and nine (45%) had right-sided tumors. Patients with bilateral acoustic neurofibromatosis (NF2) were excluded from the study; results from those patients have been reported elsewhere.\(^26\) Previously, one patient had undergone gross total resection and another had undergone subtotal resection. No patient received fractionated external beam radiation.

Preoperative symptoms included partial loss of hearing in 16 patients (80%), imbalance and/or ataxia in 11 (55%), tinnitus in eight (40%), facial weakness in one (5%), and facial sensory loss in two (10%). Pre- and postoperative hearing were graded according to the Gardner-Robertson\(^13\) modification of the classification of Silverstein, et al.\(^10\) When PTA and SD scores fell into different classes, the poorer Gardner-Robertson classification was assigned. Facial strength was assessed in all patients and classified according to the grading system of House and Brackmann.\(^17\)

Radiosurgical Technique

On the morning of radiosurgery, a stereotactic coordinate head frame\(^*\) was applied to the patient’s head under local anesthesia. A high-resolution intravenously contrast-enhanced CT scan or MR image was obtained to define the target volume. Determination of stereotactic coordinates for individual irradiation isocenters was performed by the neurosurgeon. With the aid of a radiation physicist and a radiation oncologist, the appropriate conformal isodose configuration, total dosage, total number of isocenters, and treatment time were calculated using a computer workstation.\(^20\) Currently, we transfer the digitally acquired brain images to our computer workstation via a fiberoptic ethernet that connects the imaging site to our dose planning site. Dose planning was considered optimum if the entire tumor contour was enclosed within an isodose of 50% or greater (Fig. 1). Tumor irradiation was performed using a 201-source \(^{60}\)Co gamma unit.\(^1\)

In this study, average extracanalicular tumor diameters varied from 0 mm (for intracanalicular tumors) to 30 mm (median 16 mm). Tumor volumes varied from 100 to 14,300 cu mm (median 2300 cu mm). Maximum (central) tumor doses varied from 26.7 to 40 Gy (mean 34.37 Gy), and minimum tumor margin doses varied from 12 to 20 Gy (mean 17.35 Gy). Table 2 shows the dosimetry for the 20 patients.

Postoperative Evaluation

All patients had clinical examinations supplemented by repeat imaging studies (CT or MR imaging) at 6-month intervals for the first 2 years, then yearly for the next 2 years. Pure-tone audiograms and SD scores were requested at the same intervals as the imaging studies. The association between preserved useful hearing at 1 and 2 years and maximum dose of irradiation to the tumor, the tumor margin dose, the loss of central tumor enhancement, and the presence or absence of tumor growth were assessed for significance using the chi-squared test. The association between preserved hearing at 1 and 2 years and initial tumor volume and average diameter were assessed for significance using the two-tailed Fisher’s exact test.

Results

Functional Outcome

All patients were discharged within 18 to 24 hours after radiosurgery. Although many were elderly, all re-

* Leksell Model G head frame manufactured by Elekta Instruments, Atlanta, Georgia.

† Gamma unit manufactured by Elekta Instruments, Atlanta, Georgia.

Fig. 1. Drawing of the posterior fossa showing the radiosurgical dose (%) configuration around an acoustic nerve tumor. The intimate relationship between the tumor and the adjacent trigeminal, facial, and vestibulocochlear nerves, and the cochlea (within the lower isodose lines) is demonstrated.

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TABLE 1

Clinical characteristics in 20 patients with acoustic tumors

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>sex (M: F)</td>
<td>11:9</td>
</tr>
<tr>
<td>location</td>
<td></td>
</tr>
<tr>
<td>right</td>
<td>9</td>
</tr>
<tr>
<td>left</td>
<td>11</td>
</tr>
<tr>
<td>bilateral</td>
<td>0</td>
</tr>
<tr>
<td>prior resection</td>
<td>2</td>
</tr>
<tr>
<td>preop signs &amp; symptoms</td>
<td></td>
</tr>
<tr>
<td>hearing loss</td>
<td>16</td>
</tr>
<tr>
<td>imbalance/ataxia</td>
<td>11</td>
</tr>
<tr>
<td>tinnitus</td>
<td>8</td>
</tr>
<tr>
<td>trigeminal sensory loss</td>
<td>2</td>
</tr>
<tr>
<td>facial weakness</td>
<td>1</td>
</tr>
<tr>
<td>pons-petrous tumor dimensions</td>
<td></td>
</tr>
<tr>
<td>intracanalicular</td>
<td>1</td>
</tr>
<tr>
<td>≤ 10 mm</td>
<td>3</td>
</tr>
<tr>
<td>11-20 mm</td>
<td>13</td>
</tr>
<tr>
<td>21-30 mm</td>
<td>3</td>
</tr>
</tbody>
</table>

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Hearing preservation after acoustic tumor radiosurgery

**TABLE 2**
Dosimetry for 20 patients with acoustic tumors*

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Cases</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.†</td>
<td>Percent‡</td>
</tr>
<tr>
<td>collimator helmet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 mm</td>
<td>17</td>
<td>34.7</td>
</tr>
<tr>
<td>8 mm</td>
<td>19</td>
<td>38.8</td>
</tr>
<tr>
<td>14 mm</td>
<td>7</td>
<td>14.3</td>
</tr>
<tr>
<td>18 mm</td>
<td>6</td>
<td>12.2</td>
</tr>
<tr>
<td>isodose enclosing tumor margin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40%</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>45%</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>50%</td>
<td>18</td>
<td>90</td>
</tr>
<tr>
<td>55%</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>70%</td>
<td>1</td>
<td>5</td>
</tr>
</tbody>
</table>

* The central dose ranged from 26.7 to 40 Gy (mean 34.37 Gy), and the tumor margin dose ranged between 12 and 20 Gy (mean 17.35 Gy).
† In 20 patients, 40 isocenters were used (2.5 per patient).
‡ Percentage of 20 patients requiring this diameter isocenter alone or in combination with others.

...continued to their preoperative level of function or employment within 3 to 5 days after radiosurgery. This functional level was maintained in all patients during the average follow-up interval of 30 months (range 26 to 53 months).

**Hearing Preservation**

Table 3 demonstrates the results of audiological studies in these patients 24 months after radiosurgery. Graphs of the hearing results for the 20 patients pre- and postoperatively are presented in Figs. 2 and 3. Useful hearing was found in all 20 patients (100%) in the immediate postoperative period, but the incidence of useful hearing preservation decreased to 50% of patients at 6 months and to 45% at both 1 and 2 years after radiosurgery (Fig. 3). Loss or preservation of useful hearing in this study was not significantly associated with the maximum dose to the tumor, the tumor margin dose, tumor margin isodose, control of tumor growth, or loss of central contrast enhancement of the tumor (p = 0.62). An additional four patients (20%) retained some hearing.

A trend toward preservation of useful hearing was noted but did not correlate significantly with initial average tumor diameter (p = 0.12) or initial tumor volume (p = 0.06). Patients with purely intracanalicular tumors tended to have a greater chance of useful hearing preservation. Deterioration of hearing occurred between 1 week and 12 months (median 6 months) postoperatively, was most prominent during the first postradiosurgical year, and did not progress after 2 years.

**Facial Nerve Function**

The preoperative and 24-month postoperative House-Brackmann facial nerve function scores are shown in Table 4. Of the 19 patients with normal preoperative facial function, delayed facial neuropathy occurred in two (10.5%). One patient with mild preoperative facial nerve dysfunction showed delayed worsening of function that improved over time. Overall, the incidence of residual facial nerve dysfunction was 10% at 2 years after radiosurgery.

**Trigeminal Nerve Function**

Trigeminal nerve sensory loss or paresthesia reported by a patient was counted as an incidence of trigeminal neuropathy regardless of whether decreased sensation was demonstrated during the neurological examination. Five (27.8%) of 18 patients who had normal preoperative trigeminal nerve function reported delayed onset of trigeminal nerve sensory dysfunction. One of two patients with pre-existing trigeminal nerve dysfunction suffered deterioration, and one had improved function. The onset of new trigeminal nerve symptoms varied from 5 to 18 months (median 6 months).

**TABLE 3**
Hearing classification in 20 patients before and 24 months after radiosurgery

<table>
<thead>
<tr>
<th>Hearing Classification*</th>
<th>Clinical Description</th>
<th>Minimum SD Score† (%)</th>
<th>Maximum PTA (dB)</th>
<th>Preradiosurgery</th>
<th>24 Months Postradiosurgery</th>
</tr>
</thead>
<tbody>
<tr>
<td>class I</td>
<td>good</td>
<td>70–100</td>
<td>0–30</td>
<td>11 (55%)</td>
<td>5 (25%)</td>
</tr>
<tr>
<td>class II</td>
<td>serviceable</td>
<td>50–69</td>
<td>31–50</td>
<td>9 (45%)</td>
<td>4 (20%)</td>
</tr>
<tr>
<td>class III</td>
<td>non-serviceable</td>
<td>4–49</td>
<td>51–90</td>
<td>0 (0%)</td>
<td>4 (20%)</td>
</tr>
<tr>
<td>class IV</td>
<td>poor</td>
<td>1–4</td>
<td>91–maximum</td>
<td>0 (0%)</td>
<td>0 (0%)</td>
</tr>
<tr>
<td>class V</td>
<td>none</td>
<td>0</td>
<td>not testable</td>
<td>0 (0%)</td>
<td>7 (35%)</td>
</tr>
</tbody>
</table>

* Categorized according to modification by Gardner and Robertson13 of the classification of Silverstein, et al.13
† If the speech discrimination (SD) scores and pure-tone average (PTA) did not qualify for the same class, the lower class was used.
months) after treatment. Two years after radiosurgery, five patients (25%) still had mild residual trigeminal nerve sensory symptoms. No patient in this series developed either trigeminal motor neuropathy or deafferentation pain.

**Tumor Control Assessment**

The results of serial postoperative imaging studies for these 20 patients are shown in Table 5. Intracanalicular and extracanalicular tumor measurements and calculations of average tumor diameters and tumor volumes were made as described previously. Tumor size decreased in seven patients (35%) and remained unchanged in 12 (60%). Two examples of tumor regression are shown in Fig. 4. One patient (5%) underwent microsurgical tumor excision at another institution for delayed tumor growth 23 months after radiosurgery. The presence or absence of tumor growth was not significantly associated with useful hearing preservation.

Central tumor contrast enhancement decreased in 12 (60%) of the 20 patients (Table 5) between 4 and 12 months after radiosurgery (median 6 months) but was not significantly associated with useful hearing preservation. No patient developed hydrocephalus.

**Discussion**

*Goals in Acoustic Tumor Management*

During the 24-year interval since stereotactic radiosurgery was first performed for an acoustic nerve tumor, the role and results have been refined continuously. By March, 1993, more than 1500 patients worldwide had selected this therapeutic option either instead of or following surgical removal. Radiosurgery does not remove an acoustic tumor; instead, the goal is long-term prevention of tumor growth accompanied by a low surgical risk.

In previous publications we have defined various factors that help predict the risks associated with acoustic tumor radiosurgery. These factors include the length of cranial nerve exposed to irradiation, which in turn is correlated with the tumor volume. Whether microsurgery or radiosurgery is selected as the management option, results are best when the tumor is identified while it is still small and before neurological deficits become significant. Fortunately, with the advent of MR imaging and sophisticated hearing measurement, patients are increasingly diagnosed when their tumors are small.

**Hearing Preservation**

Analysis of the results of hearing preservation are hampered by the lack of a uniformly accepted definition or grading system. Most authors use a combination of audiometric tests, especially the PTA and SD scores, to identify patients with "serviceable" or "useful" hearing. In the Gardner-Robertson modification of the classification of Silverstein, et al., good hearing (Class I) requires an SD score of greater than 70% and a PTA of between 0 and 30 dB. Serviceable hearing suggests an SD score of greater than 50% to 69% and a PTA of between 31 and 50 dB. Patients with Class I or II hearing are generally believed to have useful hearing and may be candidates for surgery with attempted hearing preservation.

The preservation of useful hearing is possible using microsurgical middle fossa or posterior fossa retrosigmoid or retromastoid approaches; translabyrinthine surgery results in ipsilateral deafness. Using strict criteria, two recent studies analyzed the success rates of microsurgery with attempted hearing preservation per-
Hearing preservation after acoustic tumor radiosurgery

Fig. 4. A and B: Axial plane contrast-enhanced magnetic resonance (MR) images obtained in a 69-year-old woman with a left-sided acoustic nerve tumor who underwent stereotactic radiosurgery (17 Gy at margin, 50% isodose). In comparison to the size before radiosurgery (A), tumor regression was seen 10 months after treatment (B). C and D: Coronal plane contrast-enhanced MR images obtained in a 61-year-old woman with a right-sided acoustic nerve tumor (C) who underwent stereotactic radiosurgery (20 Gy at margin, 60% isodose). Tumor regression was noted 37 months later (D).

formed at centers with experienced staff. Hearing can be maintained in 10% to 33% of patients immediately after skilled removal via microsurgery. Subsequent studies have documented that delayed deterioration in hearing occurred years after initially successful hearing preservation in 15% to 56% of patients. The reasons for this later hearing deterioration are unknown but may represent neural fibrosis or scarring.

In the present study, we examined the 2-year follow-up results in 20 patients who had useful hearing before surgical intervention performed using gamma knife stereotactic radiosurgery. At the 2-year follow-up examination, nine patients (45%) had retained useful hearing and four (20%) had some hearing. Further delayed hearing loss (beyond 24 months) has not been observed to date. Our results compare favorably with those of Norén, et al., who reported useful hearing preservation rates of 24% at both 1 and 2 years after radiosurgery. Our radiosurgical results also compare favorably with current microsurgical outcomes obtained by experienced surgeons. Most patients who have tumors greater than 20 mm in intracanalicular average dimension are not considered candidates for attempted hearing preservation during microsurgery.

Any comparison of results between microsurgical and radiosurgical series must examine several stratification variables. The interval after intervention is crucial, because immediately after radiosurgery 100% of patients have useful hearing; at 6 months 50% of our patients still had useful hearing; at 1 and 2 years, 45% of patients had retained useful hearing. We also found that hearing preservation was more likely if the preoperative tumor volume was less than 1000 cu mm (which corresponds primarily to intracanalicular tumors). Small beam geometry (accurate 4- and 8-mm isocenters), total reliance on intraoperative high-resolution contrast-enhanced MR imaging, and precise conformal radiation dose planning (placement of the 50% to 70% isodose at the irregular tumor borders) characterize the technology we utilize.

The dose-response relationship of the auditory nerve to radiosurgery remains to be clarified in a larger study. Both early effects (edema or demyelination) and late effects (vascular injury) may be implicated in hearing deterioration. Our clinical experience also supports the concept that special sensory nerves (auditory or optic nerves) may be more sensitive to single-fraction radiation doses than are other sensory or motor nerves. Results after radiosurgery for skull base and cavernous sinus meningiomas and for nonacoustic basal schwannomas substantiate this statement.

The gradual hearing loss that characterizes radiosurgically managed patients may be of benefit to patients who can adapt more slowly to the hearing loss and prepare themselves by learning alternative means of communication. We have been less successful in the preservation of hearing in patients with bilateral acoustic NF2. Although some hearing was preserved in three of 12 NF2 patients, no patient retained an SD score of more than 50%. Patients with NF2 often benefit from preservation of any hearing, because sentence recognition scores may be significantly better than word list recognition and even sound localization may be of benefit to those patients who are completely deaf contralaterally. We are currently using both clinical and animal models to assess the differential effect of radiosurgery on cranial nerve function.

Facial Nerve Preservation

Preservation of facial nerve function is a critical outcome measure of the successful management of a patient with an acoustic nerve tumor. The point at which analysis is performed is crucial, because patients do not develop facial nerve dysfunction immediately after radiosurgery. Instead, if problems are to develop they usually occur between 6 and 18 months after irradiation. Partial or full resolution is usually complete by approximately 24 months. At this point, 17 (89.5%) of 19 patients who had normal preoperative facial function also had preservation of facial function. No patient in this series was left with worse than House-Brackmann Grade III function, including the single patient who underwent delayed microsurgical removal. Our increasing success with facial nerve preservation reflects experience with dosage selection based on emerging dose-volume concepts, our reliance on image-integrated dose planning workstations, MR imaging target definition,
and the intrinsic precision of the technology when coupled with a strenuous commitment to quality assurance.

**Trigeminal Nerve Preservation**

We adopted a rigorous definition of potential trigeminal nerve response after radiosurgery; we count as evidence of trigeminal nerve symptoms any patient report of paresthesias related to this area after radiosurgery. In this series, 75% of patients continue to have no manifestations of trigeminal nerve involvement after radiosurgery. Detectable trigeminal nerve sensory loss was rare in this series, but patients tended to have smaller tumors than in other reports (all had preserved hearing). Such a rigorous outcome measure for microsurgical series has not been applied; most reports do not mention trigeminal nerve outcome, even in patients with large acoustic nerve tumors that are often associated with trigeminal nerve symptoms prior to microsurgery.

**Tumor Control**

The outcome of radiosurgery has been criticized by those surgeons who offer only microsurgery to their patients for several reasons. First, radiosurgery offers the potential for tumor control only instead of tumor removal as often accomplished during microsurgery. The twin goals of radiosurgery are tumor control and cranial nerve preservation. Of interest, in our overall acoustic nerve tumor experience, 20% of our patients had already undergone one or more attempts at surgical removal. Even patients undergoing complete removal require long-term follow-up examination to assess the possibility of delayed tumor recurrence. Providing that the long-term morbidity of radiosurgery is sufficiently small, we believe that tumor control is a satisfactory outcome, especially when associated with a low risk of significant cranial nerve dysfunction. Because the minimum 2-year (maximum 4-year) assessment of the patients in this report does not constitute a complete long-term evaluation, we continue to follow patients at 1- or 2-year intervals with neuroimaging.

Second, tumor control estimates have been impugned by the concept that acoustic tumors are slow-growing benign neoplasms of uncertain growth rate: radiosurgery results may be only the natural history of such tumors. We have examined this concept using retrospective natural historical controls and our experience with NF2 patients who have contralateral untreated control tumors; statistically significant control has been defined using both models. Third, long-term tumor control rates have not been established according to microsurgical expectations. Norén and colleagues recently analyzed 22 years of acoustic tumor experience and documented that the long-term tumor control rates were in excess of 84%. Patients whose tumors had not shown signs of growth within the first 5 years after radiosurgery did not develop later growth. We agree that conservative observation in selected patients is reasonable when the growth rate of an individual tumor has not been established. The indications for delayed microsurgical resection of an acoustic tumor previously treated by radiosurgery require better analysis. We believe that delayed microsurgery is required only if serial imaging studies reveal significant tumor growth associated with progressive neurological dysfunction or mass effect. Microsurgery should be avoided during the transient phase of cranial nerve deterioration that is found in some patients; such patients seem to have a poor outcome, with most sustaining permanent new cranial nerve dysfunction. We observed no patient in the present series who developed delayed hydrocephalus, a condition that seems to occur in approximately 4% of patients with acoustic tumors independent of whether they underwent radiosurgery or microsurgery.

**Quality of Life Issues**

After gamma knife radiosurgery all patients returned to their preoperative level of function and employment status within 3 to 5 days. Maintenance of that level was sustained in all patients. Patients who had persistent preoperative complaints of tinnitus or imbalance were just as likely to improve after radiosurgery as they were to remain unchanged or worsen. Hospital stays after radiosurgery were minimal, lasting at most 24 hours; some patients underwent radiosurgery as outpatients. Such features proved to reduce costs of radiosurgery in comparison to microsurgery for acoustic tumors. Patients with small growing acoustic tumors and useful hearing preoperatively should also consider stereotactic radiosurgery as a primary management option.

**ADDENDUM**

Since this paper was submitted, Haines, et al., published their excellent results with hearing preservation after intracanalicular tumor resection (J Neurosurg 79:515–520, 1993).

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