Int. J. Radiation Oncology Biol. Phys., Vol. 54, No. 5, pp. 1410–1421, 2002

0360-3016/02/$–see front matter

ELSEVIER

PII S0360-3016(02)03651-9

CLINICAL INVESTIGATION **Brain**

TREATMENT OF ACOUSTIC NEUROMA: STEREOTACTIC RADIOSURGERY VS. MICROSURGERY

MARIANNA KARPINOS, M.D.,* BIN S. TEH, M.D.,*† OTTO ZECK, PH.D.,† L. STEVEN CARPENTER, M.D.,*† CHRIS PHAN, M.D.,* WEI-YUAN MAI, M.D.,* HSIN H. LU, M.D.,*† J. KAM CHIU, M.D.,*† E. BRIAN BUTLER, M.D.,*† WILLIAM B. GORMLEY, M.D.,† AND SHIAO Y. WOO, M.D.*†

*Department of Radiology/Section of Radiation Oncology, Baylor College of Medicine, Houston, TX; †Gamma-Knife Department, Memorial Hermann Hospital, Houston, TX

Purpose: Two major treatment options are available for patients with acoustic neuroma, microsurgery and radiosurgery. Our objective was to compare these two treatment modalities with respect to tumor growth control, hearing preservation, development of cranial neuropathies, complications, functional outcome, and patient satisfaction.

Methods and Materials: To compare radiosurgery with microsurgery, we analyzed 96 patients with unilateral acoustic neuromas treated with Leksell Gamma Knife or microsurgery at Memorial Hermann Hospital, Houston, Texas, between 1993 and 2000. Radiosurgery technique involved multiple isocenter (1–30 single fraction fixed-frame magnetic resonance imaging) image-based treatment with a mean dose prescription of 14.5 Gy. Microsurgery included translabyrinthine, suboccipital, and middle fossa approaches with intraoperative neurophysiologic monitoring. Preoperative patient characteristics were similar except for tumor size and age. Patients undergoing microsurgery were younger with larger tumors compared to the radiosurgical group. The tumors were divided into small <2.0 cm, medium 2.0–3.9 cm, or large >4.0 cm. Median follow-up of the radiosurgical group was longer than the microsurgical group, 48 months (3–84 months) vs. 24 months (3–72 months).

Results: There was no statistical significance in tumor growth control between the two groups, 100% in the microsurgery group vs. 91% in the radiosurgery group ($p > 0.05$). Radiosurgery was more effective than microsurgery in measurable hearing preservation, 57.5% vs. 14.4% ($p = 0.01$). There was no difference in serviceable hearing preservation between the two groups. Microsurgery was associated with a greater rate of facial and trigeminal neuropathy in the immediate postoperative period and at long-term follow-up. The rate of development of facial neuropathy was significantly higher in the microsurgical group than in the radiosurgical group (35% vs. 0%, $p < 0.01$ in the immediate postsurgical period and 35.3% vs. 6.1%, $p = 0.008$, at long-term follow-up). Similarly, the rate of trigeminal neuropathy was significantly higher in the microsurgical group than in the radiosurgical group (17% vs. 0% in the immediate postoperative period, $p < 001$, and 22% vs. 12.2%, $p = 0.009$, at long-term follow-up). There was no significant difference in exacerbation of preoperative tinnitus, imbalance, dysarthria, dysphagia, and headache. Patients treated with microsurgery had a longer hospital stay (2–16 days vs. 1–2 days, $p < 0.01$) and more perioperative complications (47.8% vs. 4.6%, $p < 0.01$) than did patients treated with radiosurgery. There was no correlation between the microsurgical approach used and postoperative symptoms. There was no difference in the postoperative functioning level, employment, and overall patient satisfaction. There was no correlation between the radiation dose, tumor size, number of isocenters used, and postoperative symptoms in the radiosurgical group.

Conclusion: Radiosurgical treatment for acoustic neuroma is an alternative to microsurgery. It is associated with a lower rate of immediate and long-term development of facial and trigeminal neuropathy, postoperative complications, and hospital stay. Radiosurgery yields better measurable hearing preservation than microsurgery and equivalent serviceable hearing preservation rate and tumor growth control. **© 2002 Elsevier Science Inc.**

Acoustic neuroma, Stereotactic radiosurgery, Microsurgery, Gamma Knife.

INTRODUCTION

Acoustic neuroma, also known as vestibular schwannoma, is a benign tumor arising from Schwann cells, which comprise the myelin sheath of the vestibulocochlear nerve (CN VIII). It usually arises from the vestibular portion of the nerve and can be located inside the internal acoustic meatus or the cerebellopontine angle, or it can have both intracanal-

Reprint requests to: Shiao Y. Woo, M.D., Department of Radiation Oncology, The Methodist Hospital, 6565 Fannin, MS 121-B, Houston, TX 77030. Tel: (713) 790-2637; Fax: (713) 793-1300; E-mail: sclark@bcm.tmc.edu

This manuscript was presented at the Forty-third Annual Meeting of the American Society for Therapeutic Radiology and Oncology (ASTRO), November 4–8, 2001, San Francisco, CA.

Acknowledgment—The authors wish to thank Shirley Clark for her assistance in the preparation of this manuscript.

Received Mar 12, 2002, and in revised form Jul 16, 2002. Accepted for publication Jul 18, 2002.

icular and cerebellopontine angle components (1, 2). The symptoms of small and medium tumors include unilateral sensorineural hearing loss, unsteadiness, dizziness, tinnitus, mastoid pain or otalgia, headache, and facial numbness. Larger tumors may present with facial weakness, dysarthria, dysphagia, and hydrocephalus (3–5). The most common diagnostic tools are audiogram and magnetic resonance imaging (MRI) with contrast (5, 6). Once the tumor is diagnosed, three treatment options are available to patients: observation, surgery, or radiotherapy.

Surgical removal of acoustic neuroma was first performed in 1894 (7). Since then, the surgical procedure has evolved and now includes translabyrinthine, suboccipital, and middle fossa approaches with subtotal and complete tumor removal. Probability and severity of morbidity associated with microsurgery depend on tumor size (8). Possible complications of surgery include hearing loss, dizziness, ataxia, facial weakness and numbness, brainstem injury, cerebrospinal fluid (CSF) leak, stroke, myocardial infarction, hydrocephalus, meningitis, or death. The Translabyrinthine approach is incompatible with hearing preservation (9), and suboccipital and middle fossa approaches are associated with 25% to 77% hearing loss, depending on the tumor size (8, 10, 11).

Radiosurgery with the Gamma Knife was originally described by Leksell in 1951. This technique involves focusing multiple beams of radiation on an intracranial target using cobalt sources (12). The first radiation treatment of acoustic neuroma was proposed in 1969 and was used in 1971 (13). Complications in the use of the Gamma Knife include hearing loss, facial weakness and numbness, tinnitus, imbalance, headache, dysarthria, dysphagia, cystic necrosis, and hydrocephalus. There are numerous publications discussing radiosurgery and microsurgery separately but there are very few articles that make a direct comparison (14, 15). We report a retrospective nonrandomized study comparing radiosurgery and microsurgery performed in a single institution with respect to tumor growth control, hearing preservation, rate of facial and trigeminal neuropathy, complication rates, functional outcome, and patient satisfaction.

METHODS AND MATERIALS

Patients in this study were divided into two treatment groups, radiosurgery and microsurgery. Patients were not randomized. Between 1993 and 2000, 75 patients with 77 acoustic neuromas were treated with Leksell Gamma Knife radiosurgery. Two patients with neurofibromatosis had bilateral tumors and were excluded. During the same time, 25 patients with 27 tumors were treated with microsurgery at Memorial Hermann Hospital in Houston. Again, 2 patients with neurofibromatosis had bilateral tumors and were excluded. Patients in the two groups were retrospectively evaluated. All patients in our series underwent evaluation with high-resolution neurodiagnostic imaging including computed tomography (CT) and MRI. All patients underwent a clinical hearing and trigeminal and facial nerve function evaluation. Our protocol for follow-up included clinical examination and repeated imaging studies whenever possible at 6-month intervals for the first year and yearly thereafter. Available MRIs were serially evaluated for tumor size. All patient charts were retrospectively evaluated for presenting symptoms, reasons for the type of management used, and clinical outcome. Charts were also reviewed with respect to serial audiological assessment. These serial studies were compared by tumor size, radiation dose and number of isocenters, and microsurgical approach used to evaluate for any correlation. Telephone contact with patients was performed to maximize follow-up.

Tumor size and measurement of growth

Many different ways are used to measure the size of acoustic neuromas. Tumor size can be evaluated by measuring the largest diameter of the cerebellopontine angle component alone or by including the largest diameter of the intracanalicular component as well (16). Based just on the posterior fossa extension, most microsurgeons have classified acoustic neuromas into small $<$2.0 cm, medium 2.0–3.9 cm, or large $>$4.0 cm (15). Taking into account the discrepancy in tumor size evaluation, the largest diameter of the intracanalicular and cerebellopontine angle components of the tumor were measured in axial, coronal, and sagittal dimensions and were included in the calculation of the tumor size. Tumor size evaluation was done by taking an average of the largest tumor diameters in three dimensions to approximate the exact tumor shape. Based on estimates of neuroimaging and measurement error, a change in the average extrameatal tumor diameter of at least 2.6 mm was required to consider any two tumor measurements to be "objectively" different (17–20). Tumor measurements were compared with the ones noted by the radiologist, neurosurgeon, or radiation oncologist as was documented in the patients' charts.

Cranial nerve function

Preoperative and postoperative hearing was graded according to the Gardner-Robertson (GR) modification of the classification system of Silverstein (21). Facial strength was classified according to the House-Brackmann grading system (22). Trigeminal function was assessed according to whether the patient had normal facial sensation, decreased sensation, or no sensation. The strict follow-up criteria included any subjective facial numbness or paresthesia and were counted as an incidence of trigeminal neuropathy regardless of whether the symptoms of neuropathy were present on physical examination.

Functional outcome and patient satisfaction

Patients were assessed with respect to length of hospital stay, perioperative complications, and employment and performance status before and after treatment. Performance status was classified according to Karnofsky performance scale (KPS). Patient satisfaction with the treatment was also

Table 1. Radiosurgery parameters

Radiation treatment parameter	Range	Average
Central tumor dose	20–48	28.6
Tumor margin dose	10–24	14.5
Isocenter #	1–30	8.5
Isodose line	40–90	50.9
Focal diameter of collimator helmet	4–18	9.0

assessed by asking the patients if the treatment met their expectations, if it was a good choice for them retrospectively, and whether they would recommend it to a friend.

Radiosurgical technique

The radiosurgical technique was described in detail in previous publications (23–25). MRI high-resolution, gadolinium-enhanced, T1-weighted sagittal scout images were obtained to localize the area of interest. Multiplan volume acquisition contrast-enhanced MRI (divided into 28 axial MRI slices of 2 mm thickness covering the entire lesion and surrounding critical structures) was performed to determine the radiosurgery target volume. Planning was performed on axial images supplemented by coronal and sagittal reconstructed images. The treatment parameters used are shown in Table 1. A plan was achieved using 1 to 30 isocenters of different diameters (4–18 mm). After finalizing the plan, a minimal dose to the tumor margin was determined. Dose planning enclosed the tumor contour within 50% isodose line in 69 patients, 70% isodose line in 2 patients, 90% isodose line in 1 patient, and 40% in 1 patient. The treatment isodose, maximal dose, and dose to the margin were decided jointly by a neurosurgeon, radiation oncologist, and medical physicist. Radiosurgery was performed with a 201-source cobalt-60 Leksell Model U Gamma Knife (Elekta Instruments) by positioning the targets serially at the X, Y, and Z coordinates.

Surgical techniques

Microsurgical resection was performed by experienced acoustic neuroma surgeons using suboccipital, translabyrinthine, or middle fossa approaches. Microsurgical technique was described in detail in previous publications (8, 26–29). Translabyrinthine approach was used for 12 (52%) patients. Two (9%) patients underwent a middle fossa translabyrinthine approach and 1 (4%) underwent a suboccipital transmeatal approach. Suboccipital approach was used in 7 (30%) patients and middle fossa approach was used in 1 (4%) patient. In 21 (91.3%) patients the tumors were resected completely and in 2 (8.7%) patients a subtotal resection was achieved. A neuro-otological surgeon assisted with drilling of the internal auditory canal and opening the meninges in 19 of 23 (82.6%) cases. Intraoperative neurophysiological monitoring of brainstem evoked responses as well as facial nerve monitoring were performed on all patients.

Statistical analysis

The analysis of variance table and the chi-square test were used to determine the relation between categorical variables and to compare the means of variables between the two treatment groups. P values less than 0.05 were considered statistically significant.

Determination of patient eligibility

Indications for microsurgery included worsening symptoms, enlargement of the tumor, regrowth after previous resection in younger patients, enlargement of the tumor after radiosurgery and patient decision. Patients were considered to be eligible for treatment with radiosurgery if their tumor size was less than 30 mm in average diameter and they met at least one of the following criteria: (*1*) The patient with increasing symptoms was greater than 40 years of age. (*2*) The patient could not undergo surgery due to significant medical problems. (*3*) The tumor was present in the only hearing ear. (*4*) The patient had bilateral acoustic tumors. (*5*) The tumor recurred despite previous surgical resection. (*6*) The patient refused direct microsurgical removal. Patients with neurofibromatosis (NF) type II were not considered to be radiosurgical candidates unless they were treated palliatively.

Patient characteristics

Characteristics of patients treated with microsurgery and radiosurgery are listed in Table 2. Patients with NF II had bilateral tumors and were excluded from the study.

RESULTS

In the radiosurgical group, 55 (76.4%) serial MRI scans and 49 (67%) patients were available for follow-up, which ranged from 3 to 84 months with a mean of 46.7 months and median of 48 months. In the surgical group, 14 (60.8%) serial MRI scans and 18 (78%) patients were available for follow-up that ranged from 3 to 72 months with an average of 31 months and median follow-up of 24 months. Immediate follow-up included the time spent in the hospital after treatment. All of the patients' charts in the radiosurgical and surgical groups were available for follow-up immediately after surgery.

Tumor growth control

The results of serial postoperative imaging studies in 55 patients treated with radiosurgery with at least 3 months follow-up are shown in Table 3. 36.4% of tumors decreased in size, 54.5% stayed stable, and 9% increased in size with an overall control rate of 91%. The onset for change in tumor size was 1 year after radiosurgery. None of the patients treated by microsurgery experienced tumor recurrence (growth control of 100%). There was no statistical significance between the two groups ($p > 0.05$).

Table 2. Pretreatment patient characteristics

Characteristics		Radiosurgery	Microsurgery	*p* values
Age range		34–84	17–75	<0.05
Average		61.6	44.8	
Median		62.5	48	
Sex				
Male		23 (31.5)	6 (26.1)	0.623
Female		50 (69.4)	17 (73.9)	
Tumor location				
L		35 (47.9)	11 (47.8)	0.480
R		38 (52.1)	12 (52.1)	1.00
Intracanalicular		23 (31.9)	2 (8.7)	0.053
Cerebellopontine		22 (30.1)	11 (47.8)	0.135
Intracanalicular and cerebellopontine		28 (38.8)	10 (43.5)	0.808
Tumor size				
Small		54 (75)	8 (34.8)	<0.05
Medium		17 (23.6)	9 (39.1)	
Large		2 (2.7)	6 (17.4)	
Prior treatment				
Craniotomy/resection		10 (13.9)	6 (26.1)	0.205
Radiation		0	0	
Signs and symptoms				
Increase in size		46 (63.9)	3 (13)	0.318
Increase in symptoms		20 (28)	11 (47.8)	0.223
Hearing loss		68 (93.2)	22 (95.7)	0.058
Gardner-Robertson class	I	5 (6.9)	1 (4.3)	0.719
	II	12 (16.7)	6 (26.1)	
	III	20 (27.4)	5 (21.7)	
	IV	21 (29.2)	7 (30.4)	
	V	15 (20.8)	4 (17.4)	
Facial neuropathy				0.317
House-Brackmann class	I	52 (72.2)	15 (65.2)	
	II	7 (9.7)	2 (8.7)	
	III	0	1 (4.4)	
	IV	3 (4.2)	0	
	V	4 (5.6)	3 (13)	
	VI	0	2 (8.7)	
Trigeminal neuropathy				0.138
Normal sensation		61 (83.6)	16 (69.6)	
Decreased sensation		12 (16.7)	6 (26.1)	
No sensation		0	1 (4.3)	
Imbalance		47 (64)	15 (52.2)	0.629
Headache		14 (19)	6 (26.1)	0.560
Tinnitus		35 (49)	8 (34.8)	0.337
Dysarthria		2 (2.8)	3 (13)	0.090
Dysphagia/aspiration		6 (8.3)	0	0.330
Hydrocephalus		3 (4.2)	1 (4.3)	1.000

Hearing preservation

The results of the follow-up evaluation after radiosurgery and microsurgery compared with results of preoperative testing are listed in Table 4 and shown in Figs. 1–3. There was no significant difference in preservation of serviceable hearing in the two groups (44% for radiosurgery vs. 40% for microsurgery, $p = 0.227$). (The hearing preservation in patients who had any measurable hearing was significantly worse in the microsurgical group than the radiosurgical group [57.5% for radiosurgery vs. 14.4% for microsurgery $p = 0.01$].) Useful or serviceable hearing was present in 9 (18.4%) patients before radiosurgery. Any measurable hearing defined as GR class I, II, III, or IV was present in 40 (81.6%) patients. At a long-term follow-up, 22 (44.9%) patients reported a decrease in hearing after radiosurgery and 14 (28.6%) patients who had some measurable hearing before radiosurgery experienced complete hearing loss. Four (8.2%) patients with preoperative serviceable hearing experienced hearing loss. Three (6.1%) patients experienced improvement in hearing level, and 24 (49%) patients experienced no change in preoperative hearing level. Hearing was preserved at the preradiosurgical level in all patients in the immediate postoperative period. There was no correlation between the peripheral and central tumor radiation dose ($p = 0.099$ and 0.564), the number of isocenters used ($p = 0.527$), and tumor size ($p = 0.198$) and hearing preservation.

Table 3. Tumor growth control

Tumor size	Radiosurgery Number (%)	Microsurgery Number (%)
Increased	5 (9)	0
Decreased	20 (36.4)	14 (100%)
Unchanged	30 (54.5)	0

Useful or serviceable hearing was present in 5 (29.4%) patients before microsurgery. Any measurable hearing (GR class I, II, III, IV) was present in 14 (82.3%) patients. Fifteen (88.2%) patients experienced complete hearing loss after microsurgery. Three (17.6%) of the patients who had serviceable hearing lost their hearing completely. Two (11.8%) patients who had serviceable hearing preoperatively maintained serviceable hearing. Patients with small tumors treated with suboccipital or middle fossa approach had a 25% hearing preservation rate, and those with large tumors had a 0% hearing preservation rate. There was no correlation between approach used and hearing preservation ($p = 0.449$).

Facial nerve function

The immediate and long-term postoperative scores of radiosurgical and microsurgical patients are shown in Tables 5 and 6. Long-term follow-up results are shown in Fig.

Table 4. Hearing preservation after radiosurgery versus microsurgery

Gardner-Robertson class	Number of patients (%)			
	Radiosurgery		Microsurgery	
	Before	After	Before	After
Good/serviceable	9 (18.4)	4 (8.2)	5 (29.4)	2 (11.8)
Poor/nonserviceable	31 (63.3)	19 (38.7)	9 (52.9)	0
Absent	9 (18.4)	26 (53.1)	3 (17.6)	15 (88.2)

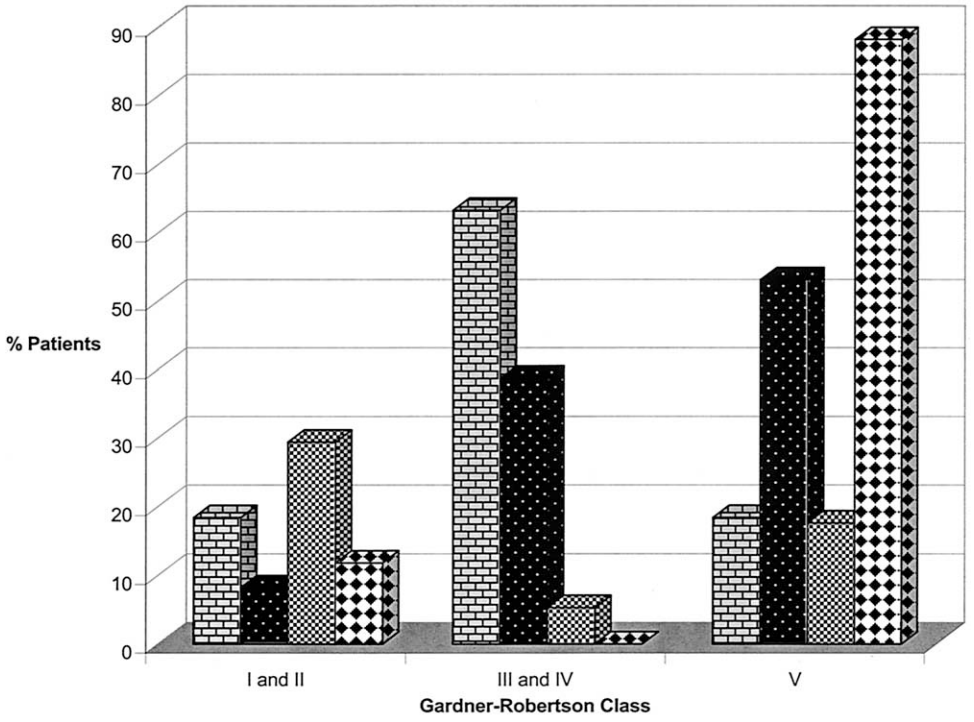

Fig. 1. Hearing preservation before and after radiosurgery and microsurgery. Columns with brick-like pattern — before radiosurgery; black stippled — after radiosurgery; crisscrossed columns — before microsurgery; white-and-black diamonds — after microsurgery.

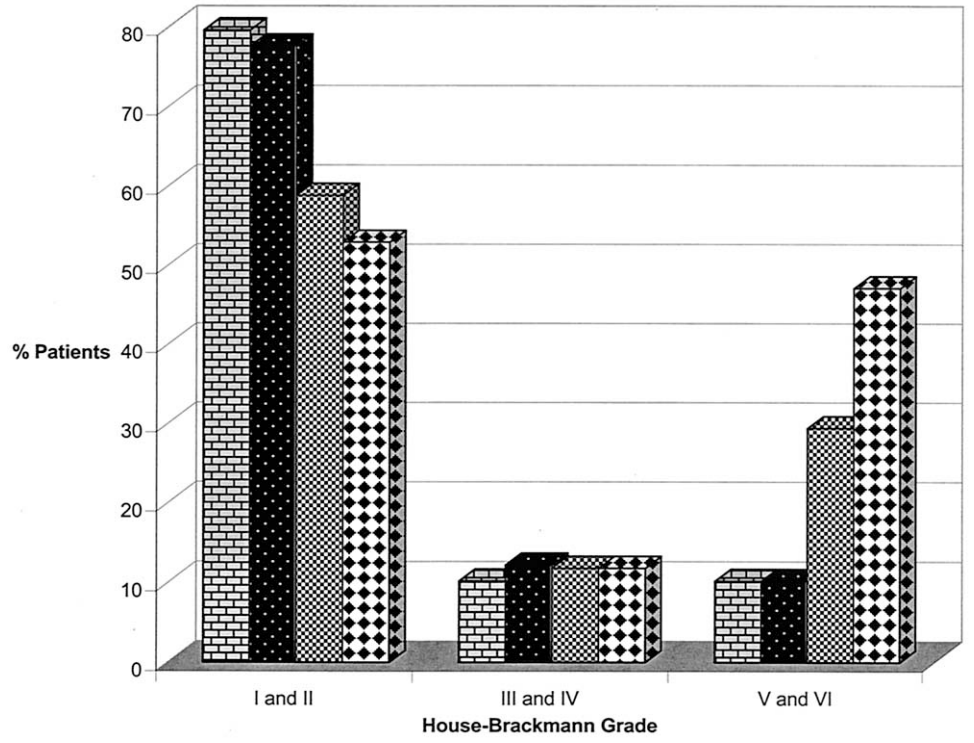

Fig. 2. Facial nerve function at long-term follow-up after radiosurgery and microsurgery. Columns with brick-like pattern — before radiosurgery; black stippled — after radiosurgery; crisscrossed columns — before microsurgery; white-and-black diamonds — after microsurgery.

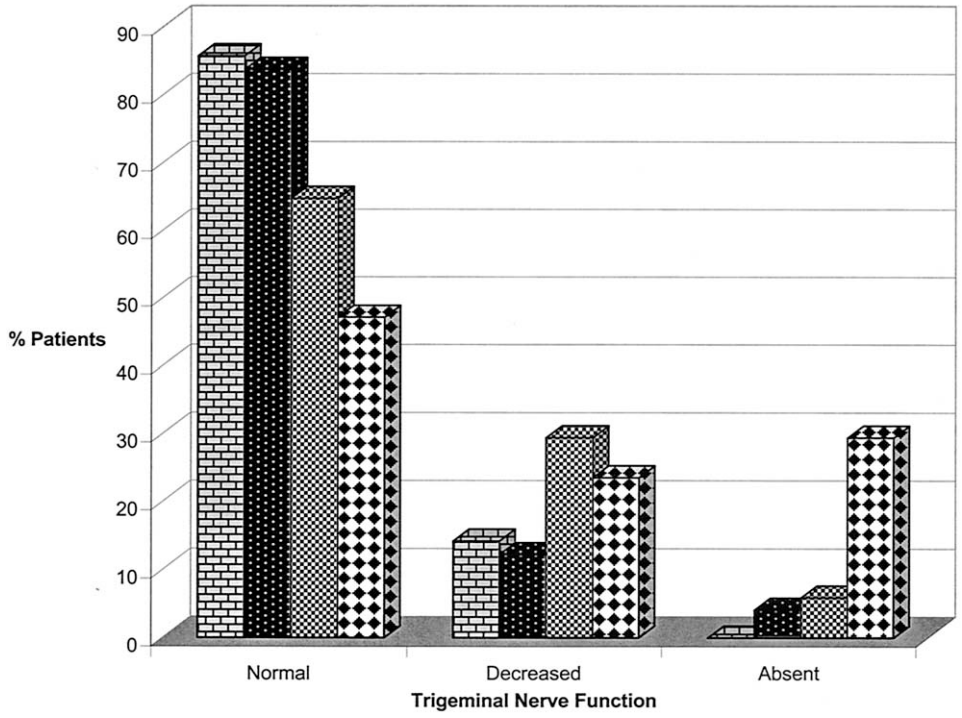

Fig. 3. Trigeminal nerve function at long-term follow-up after radiosurgery and microsurgery. Columns with brick-like pattern—before radiosurgery; black stippled—after radiosurgery; crisscrossed columns—before microsurgery; white-and-black diamonds—after microsurgery.

2. The rate of development of facial neuropathy was significantly higher in the microsurgical group than in the radiosurgical group (35% vs. 0%, $p < 0.01$ in the immediate postsurgical period and 35.3% vs. 6.1% $p = 0.008$ at long-term follow-up). At long-term follow-up, 43 (87.7%) radiosurgical patients experienced no change in facial nerve function, 3 (6.1%) patients experienced an improvement in facial nerve function, and 3 (6.1%) patients experienced a decrease in facial nerve function. Two (4.1%) patients developed new onset facial neuropathy. One patient developed complete facial nerve paralysis 6 months after treatment. This patient had a small tumor and received 15 Gy to the tumor periphery at the 50% isodose line with central tumor dose of 30 Gy. He was noted to have cystic necrosis and edema of the tumor on neuroimaging studies 6 months after treatment. The patient required a facial nerve implant and recovered part of his facial nerve function to House-Brackmann Grade III. The second patient experienced Grade V facial nerve paralysis 3 weeks after treatment when he developed hydrocephalus requiring surgical intervention. This patient was noted to have a cystic component of the tumor on neuroimaging studies before radiosurgery. He recovered partial facial nerve function to House-Brackmann Grade III 6 months after treatment. Forty-three (87.8%) patients reported no change in facial nerve function, 3 (6.1%) patients reported an improvement in their symptoms,

Table 5. Immediate postoperative facial and trigeminal nerve function

	Number of patients (%)				
	Radiosurgery		Microsurgery		
	Before	After	Before	After	*p* value
House-Brackmann grade					<0.000
I and II	58 (79.4)	58 (79.4)	17 (73.9)	13 (56.5)	
III and IV	7 (9.7)	7 (9.7)	1 (4.4)	1 (4.4)	
V and VI	7 (9.7)	7 (9.7)	5 (21.7)	9 (39)	
Trigeminal nerve function					<0.000
Normal	61 (83.6)	61 (83.6)	16 (69.6)	13 (56.2)	
Decreased sensation	12 (16.7)	12 (16.7)	6 (26.1)	8 (34.8)	
No sensation	0	0	1 (4.3)	2 (8.7)	

Table 6. Long-term postoperative facial and trigeminal nerve function

	Number of patients				
	Radiosurgery		Microsurgery		
	Before	After	Before	After	(%) p value
House-Brackmann grade					0.002
I and II	39 (79.6)	38 (77.6)	10 (58.8)	6 (35.3)	
III and IV	5 (10.2)	6 (12.2)	2 (11.8)	2 (11.8)	
V and VI	5 (10.2)	5 (10.2)	5 (29.4)	9 (52.9)	
Trigeminal nerve function					0.004
Normal	42 (85.7)	41 (83.7)	11 (64.7)	8 (47.1)	
Decreased sensation	7 (14.2)	6 (12.2)	5 (29.4)	4 (23.5)	
No sensation	0	2 (4.1)	1 (5.9)	5 (29.4)	

and 3 (6.1%) patients experienced increased weakness. No patient developed facial neuropathy in the immediate postoperative period. There was no correlation between peripheral and central tumor radiation dose ($p = 0.099$ and 0.564), number of isocenters used ($p = 0.527$), tumor size ($p = 0.442$), and postoperative facial nerve function in patients treated with radiosurgery.

Immediately after microsurgery, 8 (35%) of 23 patients developed facial nerve palsy. Four (17.4%) patients with Grade I and II function developed facial neuropathy. Two developed Grade III and IV and 2 developed Grade V and VI palsy. One patient with Grade I function developed Grade II palsy, 1 patient with Grade III function developed Grade IV palsy, and 2 patients with Grade V function developed Grade VI palsy. Two patients with Grade V and VI palsy did not recover facial nerve function and required surgical intervention. One of these patients had a small tumor, and the other had a medium size tumor. One patient with Grade II neuropathy experienced complete recovery 3 months after surgery. Two patients with Grades III and V function experienced improvement in function in 3 and 6 months to Grades II and III respectively. Five (29.4%) patients who had preoperative facial neuropathy did not experience a change in function, and 7 (39%) patients who had normal facial nerve function preoperatively maintained their function. The rate of facial neuropathy was 1 (14.3%) for small tumors, 2 (40%) for medium size tumors, and 3 (60%) for large size tumors. There was no correlation between approach used and facial nerve function ($p = 0.738$).

Trigeminal nerve function

The results for immediate and long-term follow-up for radiosurgical and microsurgical patients are shown in Tables 5 and 6. Long-term follow-up results are shown in Fig. 3. The rate of trigeminal neuropathy was significantly higher in the microsurgical group than in the radiosurgical group (17% vs. 0% in the immediate postoperative period, $p < 0.01$, and 22% vs. 12.2%, $p = 0.009$, at long-term follow-up). At long-term follow-up, 41 (88.7%) patients in the radiosurgical group had normal facial sensation, 6 (12.2%) patients experienced a decrease in sensation, and 2 (4%) patients lost their sensation completely. Four (8%) patients developed new trigeminal neuropathy 3 months after treatment. One patient recovered normal function after 6 weeks. Two of the patients were treated with high doses of radiation at 15 and 24 Gy at the 50% isodose line with 30 and 48 Gy central tumor dose respectively. Forty-three (87.8%) patients reported experiencing no change in facial sensation, 4 (8.2%) patients experienced improvement, and 2 (4.1%) patients reported having more numbness. No patient developed trigeminal neuropathy immediately after radiosurgery. There was no correlation between the peripheral and central dose of radiation used ($p = 0.691$ and 0.352), number of isocenters ($p = 0.231$), and tumor size ($p = 0.309$) and postoperative trigeminal nerve function.

In the microsurgical group, 4 (17%) out of 23 patients developed trigeminal nerve dysfunction immediately after surgery. Three of these patients recovered function in 3 months, and 1 patient had decreased sensation at 3 years of follow-up. At a long-term follow-up, 4 (22%) patients experienced an increase in facial numbness. One of these patients experienced new onset trigeminal nerve palsy, 2 patients who had decreased sensation before lost all of their sensation, and 1 patient who had normal trigeminal nerve function preoperatively developed decreased sensation. Fourteen (82.4%) patients reported no change in the trigeminal nerve function. The rate of trigeminal neuropathy was 2 (28.5%) for small tumors, 1 (25%) for medium size tumors, and 3 (60%) for large size tumors. There was no correlation between surgical technique used ($p = 0.198$) and postoperative trigeminal nerve function in the microsurgical group.

Other symptoms

The results for other symptoms experienced by the radiosurgical and microsurgical patients are shown in Table 7. In the radiosurgical group there was no correlation between the size of the tumor, dose of radiation used, and number of isocenters and postoperative symptoms ($p > 0.05$). In the microsurgical group there was no correlation between tumor size, surgical technique used, and postoperative symptoms ($p > 0.05$).

Table 7. Preoperative and postoperative symptoms

	Radiosurgery			Microsurgery			
	Better	Worse	No change	Better	Worse	No change	*p* value
Tinnitus	5 (10.2)	13 (26.5)	31 (63.3)	1 (6)	0	16 (94.1)	0.04
Imbalance	7 (14.3)	11 (22)	31 (63.3)	4 (23.5)	4 (23.5)	10 (58.8)	0.932
Dysarthria	1 (2)	2 (4.1)	46 (93.9)	1 (5.9)	3 (17.6)	14 (82.4)	0.445
Dysphagia	1 (2)	2 (4.1)	46 (93.9)	0	1 (5.9)	16 (94.1)	0.759
Headache	4 (8.2)	3 (6.1)	42 (79.6)	1 (5.9)	0	16 (94.1)	0.654

Tinnitus

Patients in the radiosurgical group experienced significantly more tinnitus at a long-term follow-up than did microsurgical patients (26.5% vs. 0%, $p = 0.04$). Thirteen (26.5%) radiosurgical patients experienced an increase in tinnitus, 5 (10.2%) patients experienced a decrease in tinnitus, and 31 (63.3%) patients had no change in the level of ringing. One (2%) patient experienced new onset of tinnitus. One of the patients who experienced an increase in tinnitus was treated with 24 Gy to the periphery at the 50% isodose line with 48 Gy central tumor dose, and the other patients were treated with 14 Gy to the periphery at 50% isodose line with 28 Gy central tumor dose. One (6%) microsurgical patient experienced a decrease in the level of ringing, and 16 (96.1%) patients experienced no change in tinnitus.

Imbalance

There was no significant difference in experiencing worsened imbalance between the two groups (23.5% for radiosurgery vs. 22.4% for microsurgery, $p = 0.932$). Eleven (22.4%) radiosurgical patients experienced an increase in imbalance, 7 (14.3%) experienced a decrease in unsteadiness, and 31 (63.3%) patients experienced no change. Three (6.1%) patients experienced new onset of imbalance. One of the patients developed tumor necrosis and edema requiring surgical intervention. One of the patients who developed increased imbalance was treated with 24 Gy to the periphery at 50% isodose line with 48 Gy central tumor. Four (23.5%) microsurgical patients experienced an increase in their imbalance, 10 (58.8%) patients experienced no change in their symptoms and 4 (23.5%) patients reported a decrease in imbalance. One (6%) patient developed new onset of imbalance. This patient had a small intracanalicular tumor and was treated with a translabyrinthine approach.

Headache

There was no significant difference in experiencing worsened headache between the two groups (6.1% for radiosurgery vs. 0% for microsurgery, $p = 0.475$). Three (6.1%) radiosurgical patients who presented with headaches experienced an increase in their symptoms, 4 (8.2%) patients experienced an improvement, and 42 (87%) patients reported no change. One patient developed a new onset of headaches, which lasted for 6 weeks on the ipsilateral side 6 months after treatment. This patient was treated with 15 Gy to the periphery at the 50% isodose line with 30 Gy central tumor dose. One (5.9%) microsurgical patient experienced a decrease in their headache, and 16 (94.1%) patients experienced no change in their symptoms. No patient developed new onset headache.

Dysarthria and dysphagia

There was no significant difference in experiencing worsened dysarthria between the two groups (4.1% for radiosurgery vs. 0% for microsurgery, $p = 0.445$). Two (4.1%) radiosurgical patients who presented with dysarthria experienced worsening, 1 (2%) patient reported an improvement. Forty-six (93.9%) patients experienced no change. Two (4.1%) radiosurgical patients who presented with dysphagia experienced worsening, 1 (2%) patient reported an improvement. Forty-six (93.9%) patients experienced no change. One (2%) patient developed new dysarthria and dysphagia. This patient was treated with 14 Gy at 50% isodose line and 28 Gy central tumor dose. Three (17.6%) microsurgical patients who presented with dysarthria experienced no change in their symptoms.

Functional level and treatment satisfaction

Results for functional level and treatment satisfaction for radiosurgical and microsurgical patients are shown in Table 8.

Hospital stay

Hospital stay for microsurgical patients was significantly higher than for radiosurgical patients (1–2 days vs. 2–16 days, $p < 0.01$). Seventy (97%) radiosurgical patients were discharged from the hospital in 24 h. There was no correlation between the approach used and size of the tumor and the duration of hospitalization in the microsurgical group ($p = 0.413$ and 0.112).

Functional level

There was no significant difference in KPS and Eastern Cooperative Oncology Group (ECOG) scale grades between the two groups (12.2% for radiosurgical patients vs. 11.7% for microsurgical patients, $p = 0.796$ for KPS and $p = 0.543$ for ECOG). Six (12.2%) patients in the radiosurgical group experienced a decrease in functional level according to the Karnofsky and ECOG scales. Three (6.1%) patients presented with a decreased functional level before radiosurgery and experienced a decline due to comorbid conditions. Two (11.7%) patients in the microsurgical group

Table 8. Postoperative functional level and patient satisfaction

	Radiosurgery			Microsurgery			
	No change	Better	Worse	No change	Better	Worse	*p* value
KPS	43 (87.8)	0	6 (12.2)	15 (88.2)	0	2 (11.8)	0.796
Employment	Before	After		Before	After		0.778
	25 (51)	22 (44.9)		11 (64.7)	9 (52.9)		
Hospital stay	Range (days)	Average		Range	Average		<0.05
	1–2	1.1		3–16	6.2		
Satisfaction	Met expectations	Recommend		Met expectations	Recommend		0.216 and 0.171
	47 (95.9)	47 (95.9)		16 (94.1)	17 (100)		

experienced a decrease in functional level according to the Karnofsky and ECOG scales.

Employment

There was no significant difference in loss of employment after treatment between the two groups (6.1% for radiosurgery vs. 11.7% for microsurgery, $p = 0.778$). Twenty-one of 25 (84%) patients who were employed before treatment returned to work within 1 week of radiosurgery. One patient who was treated for a 5-mm recurrence after surgical removal of a large acoustic neuroma and complete facial paralysis returned to work after 6 months. Three (6.1%) patients experienced functional decline and became unemployed due to an increase in symptoms related to acoustic neuroma.

Patient satisfaction

There was no significant difference in patient satisfaction between the two groups: 94.1% patients treated with microsurgery said that they were satisfied with treatment vs. 81.6% for radiosurgery ($p = 0.216$). One hundred percent of the patients treated with microsurgery said they would recommend it to a friend vs. 89.8% treated with radiosurgery ($p = 0.171$). Nine (18.4%) patients said that the Gamma Knife did not meet their expectations. These patients were not satisfied because the treatment did not remove the tumor completely. One (5.9%) patient said that microsurgery did not meet his expectations.

Other complications

The complications experienced by radiosurgical and microsurgical patients are shown in Table 9. Patients treated with microsurgery developed significantly more postoperative complications than patients treated with radiosurgery (4.6% for radiosurgery vs. 47.8% for microsurgery, $p < 0.01$). In the radiosurgical group, 3 (4.2%) patients developed cystic necrosis of the tumor with resulting hydrocephalus, imbalance, and nausea. Two patients developed diplopia. One patient had a cystic component of the tumor on preradiosurgical imaging studies and one had a preexisting hydrocephalus with a ventriculoperitoneal shunt placement. Two of the patients required a cyst decompression, which has alleviated their symptoms. The patient who developed cystic necrosis in a solid tumor was treated at 17 isocenters with 11.5 Gy to periphery and 23 Gy central tumor dose. Two patients died one of metastatic prostate cancer, and one of an acute myocardial infarction.

In the microsurgical group, 5 (21.7%) patients developed infection. Two patients developed elevated white blood cell count in the CSF, 1 patient developed elevated temperature and sore throat, 2 patients developed thrush, and 1 patient developed herpes zoster on the ipsilateral side of the face. Ten (43.5%) patients developed imbalance, and 3 (17.6%) patients experienced nausea and vomiting. Five patients developed a CSF leak; 2 required a ventriculoperitoneal (VP) shunt placement, and 2 required a lumbar drain. Two (11.2%) patients developed edema and 1 developed hydrocephalus requiring surgical decompression. One (4.3%) patient developed diplopia, visual motor disorganization, and left side body weakness. One (4.3%) patient developed a seizure within 24 h after microsurgery. One patient had an air embolus, developed lethargy, and had to be intubated. One patient died 2 months after surgery due to rupture of a colonic viscus.

Table 9. Treatment complications

	Number of patients (%)		*p* value
	Radiosurgery	Microsurgery	<0.01
Edema	3 (4.2)	2 (8.7)	
Hydrocephalus	3 (4.2)	1 (4.3)	
Diplopia	2 (4.1)	1 (4.3)	
Imbalance	3 (4.2)	10 (43.5)	
Nausea	3 (4.2)	3 (13)	
CSF leak	0	5 (21.7)	
Seizure	0	1 (4.3)	
Infection	0	5 (21.7)	
Intubation	0	1 (4.3)	

DISCUSSION

In the past century, several treatment options for patients with acoustic neuroma have been developed. Now patients and physicians are faced with a choice between conventional microsurgery, radiosurgery, and observation. These treatment options should be evaluated according to the individual patient characteristics to obtain an optimal result. Tumor size, hearing level, comorbid conditions, expected treatment outcome and complications, and patient preference are some of the variables that should be taken into account before proceeding with any treatment modality. These variables should also be considered when deciding which microsurgical approach to use and when formulating a radiosurgical plan. Patients with tumors greater than 3 cm are usually not considered to be candidates for radiosurgery unless a microsurgical approach is not feasible due to comorbid conditions or patient preference.

There are three basic microsurgical approaches: middle fossa, translabyrinthine, and suboccipital. A middle fossa approach is useful for hearing preservation surgery in small tumors, which reach the lateral end of the internal auditory canal. It has been associated with greater immediate facial nerve palsies, possibly related to the increased manipulation of the superiorly located facial nerve in the internal auditory canal (30). A translabyrinthine approach is used for small and medium sized tumors. It yields a good identification of the facial nerve but does not allow hearing preservation. A retrosigmoid approach is used for all sized tumors for hearing conservation surgery, but carries a risk of cerebellar injury. Tumors are removed using a total or a subtotal resection. Total resection should be attempted on all patients if at all possible. Subtotal resection is used in the case of adherence of the tumor to the facial nerve or brainstem, age, treatment of a tumor affecting a solitary hearing ear, and the patient's request (8, 31, 32). It has been shown that in patients treated with radiosurgery, larger tumor size and a smaller number of isocenters used are associated with a higher rate of total hearing loss and facial and trigeminal neuropathy. Increased peripheral dose is associated with a greater rate of vestibular disturbances. Lowering the peripheral tumor dose improved hearing preservation in patients with intracanalicular tumors (20, 33–35).

The results of our study show that stereotactic radiosurgery was as effective in controlling tumor growth as microsurgery. Patients treated with radiosurgery had a 91% tumor growth control rate compared with 100% growth control rate for patients treated with microsurgery. Several studies have reported a similar good control rate of 86–100%, (with a high growth control rate for small tumors close to 100%) at 2–12-year follow-up for patients treated with radiosurgery (19, 28, 36–39). Our study did not show a correlation between tumor size and growth control rate, but Forster *et al.* showed that larger tumors have a lower growth control rate than smaller ones. At a 6.6-year follow-up, tumors that measured greater than 3 cm had a control rate of 33%, those that were 2–3 cm had an 86% growth control rate, and tumors measuring 2 cm had an 89% control rate (35). Growth control rate for tumors treated with microsurgery correlated closely with the amount of tumor that was removed. Gormley *et al.* reported a growth control rate of 100% for tumors treated with total resection (8). For tumors removed by subtotal resection, growth rate of 45% to 95% has been reported (8, 40, 41).

The results of our study for hearing preservation showed that there was no difference in serviceable hearing preservation in radiosurgical and microsurgical groups, but patients in the microsurgical group experienced a significantly higher rate of measurable hearing loss. Serviceable hearing preservation rates were 44% and 40% for radiosurgery and microsurgery, respectively, and measurable hearing preservation rates were 57.5% and 14.4% for patients treated with radiosurgery and microsurgery, respectively. Serviceable hearing preservation rates for patients treated with a middle fossa and suboccipital approaches were 25% for small tumors and 0% for large tumors. Pollack *et al.*, who also made a direct comparison of radiosurgery and microsurgery, reported a significantly higher serviceable hearing preservation rate in patients treated with radiosurgery than those treated with microsurgery (14). Other studies reported 26–65% serviceable hearing preservation at 1–10 years follow-up and 33–68% at 2–7-year follow-up (19, 20, 27, 32, 34, 36–38, 40, 42). Hearing preservation rates in patients treated with microsurgery depend on the size of the tumor and the approach used. Serviceable hearing preservation in small tumors is 32–60%, medium tumors is 12–36%, and in large tumors is 0–24%. Measurable hearing preservation is reported to be 57% for small tumors and 29% for medium and large tumors. A middle fossa approach is associated with better hearing preservation rates than a retrosigmoid approach (8, 15, 41, 43–47).

In our study, radiosurgery was associated with a lower rate of facial neuropathy when compared to microsurgery in both an immediate postoperative period (0 vs. 35%) and at a long-term follow-up (6.1 vs. 35.3%). These results agree with the data published by Pollack *et al.* who reported a significantly greater rate of facial neuropathy in the immediate postoperative period and at long-term follow-up in patients treated with microsurgery than those treated with radiosurgery. They did not find a significant difference in the immediate postoperative period and the long-term follow-up rate of trigeminal neuropathy development (14). Our study also demonstrates that patients treated with microsurgery had a significantly higher rate of trigeminal neuropathy than those treated with radiosurgery at the immediate postoperative period (17% vs. 0%), and at long-term follow-up (22% vs. 12.2%). Other trials reported a rate of 0–32% for facial neuropathy and 0–34% for trigeminal neuropathy for patients treated with radiosurgery. The reported onset of cranial neuropathy was between 1 and 22 months after treatment (19, 20, 28, 32, 38, 48, 49). The rate of cranial neuropathy after microsurgery was shown to depend largely on the size of the tumor. Small tumors are associated with 0% to 6% facial neuropathy, medium tumors were reported

to have 8% to 24% rate of facial neuropathy, and large tumors have a facial palsy rate of 40% to 80% (8, 48, 50–52). Ninety percent of patients who have postoperative facial paralysis with anatomically preserved nerve can expect a partial return of function. If more than 4 months elapses from the time of onset of paralysis, complete recovery will not occur (53).

Patients treated with radiation had a shorter hospital stay and a lower rate of perioperative complications. Radiosurgical patients developed significantly more tinnitus than microsurgical patients. Both treatments had an equivalent rate of development and worsening of imbalance, dysarthria, dysphagia, and headache. These data are similar to the ones presented by Pollack *et al*. In their study, Pollack *et al*. also reported that direct charges were 53% less for patients treated with radiosurgery than those treated with microsurgery (14).

Radiosurgery has been proposed as an alternative treatment to microsurgery for tumors less than 3 cm in diameter in several trials (7, 14, 16, 35, 54). Our trial has also shown that radiosurgery yields equivalent results to microsurgery. There is a question that has been raised in previous studies: Are the results that are being seen with radiosurgery true effects of treatment or manifestations of the natural disease progression (14, 16)? Pollack *et al*. present extensive data which show that the tumor growth control rate is significantly better with radiosurgery than with observation. Rosenberg presented data from several trials which showed that acoustic neuromas have a variable growth pattern and that 14% to 57.8% of tumors eventually increased in size and required intervention. He also reported that the percentage of people requiring intervention was lower after radiosurgery (16). In their article, Pollack *et al*. advocate observation in elderly patients with stable symptoms because postoperative facial function and hearing preservation depend on the tumor size (14).

The authors (Karpinos *et al*.) recognized the small numbers and uncontrolled variables inherent in this retrospective analysis. However, this study represents one of only a few articles on this subject comparing these two modalities (radiosurgery vs. microsurgery) at a single institution. It is also noted that the radiosurgical dose prescriptions encompass a broad range of 10–24 Gy. The lower end (10 Gy) raises concerns of poor tumor control, and the upper end (24 Gy) raises concerns of excessive cranial neuropathies, particularly hearing. The extreme ends were delivered to patients initially treated before any scientific data on tumor control or toxicity. A majority (69 patients) received a tumor margin dose of 14.5 Gy.

CONCLUSION

Radiosurgical treatment for acoustic neuroma is an alternative to microsurgery. It is associated with a lower rate of immediate and long-term development of facial and trigeminal neuropathy and postoperative complications. Radiosurgery yields equivalent rates of serviceable hearing preservation and tumor growth control. Because our study was not a controlled randomized trial and both groups had a different number of patients with significantly different characteristics, a strong comparison can not be made. Still, our data agree with the ones published in the literature and therefore can be used to assess effectiveness of both treatment modalities. Further studies, including a randomized controlled trial, are needed to achieve a good comparison of both treatments.

REFERENCES

1. Clemis JD, Ballad WJ, Baggot PJ, *et al*. Relative frequency of inferior vestibular schwannoma. *Arch Otolaryngol* 1986;3: 153–157.
2. Neely JG, Hough J. Histologic findings in two very small intracanalicular solitary schwannomas of the eighth nerve. *Ann Otol Rhinol Laryngol* 1986;95:460–465.
3. Hardy DG, Macfarlane R, Baguley D, *et al*. Surgery for acoustic neurinoma: An analysis of 100 translabyrinthine operations. *J Neurosur* 1989;71:799–804.
4. Thomsen J, Zilstorff K, Tos M. Acoustic neuromas (diagnostic value of testing the function of the trigeminal nerve, cerebellum and opticokinetic nystagmus). *J Laryngol Otol* 1983;97:801–812.
5. Portmann M, Sterkers JM. The internal auditory meatus. In: Portmann M, Sterkers JM, Charachon R, Chouard CH, editors. Tumors of the internal auditory meatus and surrounding structures. Edinburgh: Churchill Livingstone; 1975. p. 193–232.
6. Johnson EW. Results of auditory tests in acoustic tumor patients. In: House WF, Luetjec CM, editors. Acoustic tumors. Vol. I. Baltimore: University Park Press; 1979. p. 209–227.
7. Pitts LH, Jacker RK. Treatment of acoustic neuromas. *N Engl J Med* 1998;339:1471–1473.
8. Gormley WB, Sekhar LN, Laligam N, *et al*. Acoustic neuromas: Results of current surgical management. *Neurosurgery* 1997;41:50–60.
9. Whittaker CK, Luetje CM. Vestibular schwannomas. *J Neurosurg* 1992;76:897–900.
10. Staecker H, Nadol Jr JB, Ojenman R, *et al*. Hearing preservation in acoustic neuroma surgery: Middle fossa versus retrosigmoid approach. *Am J Otolaryngol* 2000;21:399–404.
11. Arriaga MA, Chen DA, Fukushima T. Individualizing hearing preservation in acoustic neuroma surgery. *Laryngoscope* 1997;107:1043–1047.
12. Leksell L. Stereotactic method of radiosurgery for brain. *Acta Chir Scand* 1951;201:316–319.
13. Leksell LA. A note on the treatment of acoustic tumors. *Acta Chir Scand* 1971;137:763–765.
14. Pollack BE, Lunsford DL, Kondziolka D, *et al*. Outcome analysis of acoustic neuroma management: A comparison of microsurgery and stereotactic radiosurgery. *Neurosurgery* 1995;36:215–224.
15. Sekhar LN, Gormley WB, Wright DC. The best treatment of vestibular schwannoma (acoustic neuroma): Microsurgery or radiosurgery? *Am J Onc* 1996;17:676–682.
16. Rosenberg SI. Mosher Award honorable mention: Natural history of acoustic neuromas. *Laryngoscope* 2000;110:497–508.
17. Kodziolka D, Lunsford LD, McLaughlin MR, *et al*. Long-term outcomes after radiosurgery for acoustic neuromas. *N Engl J Med* 1998;339:1426–1433.

18. Ito K, Kurita H, Sugasawa K, *et al*. Analyses of neuro-otological complications after radiosurgery for acoustic neurinomas. *Int J Radiat Oncol Biol Phys* 1997;5:983–988.
19. Ogunrinde OK, Lunsford LD, Flickinger JC, *et al*. Cranial nerve preservation after stereotactic radiosurgery for small acoustic tumors. *Arch Neurol* 1995;52:73–79.
20. Flickinger JC, Lunsford LD, Linskey ME, *et al*. Gamma knife radiosurgery for acoustic tumors: Multivariate analysis of four year results. *Radiother Oncol* 1993;27:91–98.
21. Gardner G, Robertson JH. Hearing preservation in unilateral acoustic neuroma surgery. *Ann Otol Rhinol Laryngol* 1986; 95:258–291.
22. House JW, Brackmann DE. Facial nerve grading system. *Otolaryngol Head Neck Surg* 1985;93:146–147.
23. Lunsford LD, Flickinger J, Coffey RJ. Stereotactic Gamma Knife radiosurgery: Initial North American experience in 207 patients. *Arch Neurol* 1990;47:169–175.
24. Linskey ME, Lunsford LD, Flickinger JC, *et al*. Stereotactic radiosurgery for acoustic tumors. *Neurosurg Clin North Am* 1992;3:191–205.
25. Linskey ME, Lunsford LD, Flickinger JC. Tumor control after stereotactic radiosurgery in neurofibromatosis patients with bilateral acoustic tumors. *Neurosurgery* 1992;31:829–839.
26. Goel A, Sekhar LN, Langheintich W, *et al*. Late course of preserved hearing and tinnitus after acoustic neurilemoma surgery. *J Neurosurg* 1993;79:515–520.
27. Kondziolka D, Lunsford LD. Neurosurgical forum: Letters to the editor. *J Neurosurg* 1993;78:154.
28. Flickinger JC, Kondziolka D, Pollack BE, *et al*. Evolution in technique for vestibular schwannoma radiosurgery and effect on outcome. *Int J Radiat Oncol Biol Phys* 1996;36:275–280.
29. Brackmann DE, Hitselberger WE, Beneche JE, *et al*. Acoustic neuromas: Middle fossa and translabyrinthine removal. In: Rand RW, editor. Microsurgery. St. Louis: Mosby-Year Book; 1985. p. 311–334.
30. Shelton C, Brackmann DE, House WF, *et al*. Middle fossa acoustic tumor surgery: Results in 106 cases. *Laryngoscope* 1989;99:405–408.
31. Ebersold MJ, Harner SG, Beatty CW, *et al*. Current results of the retrosigmoid approach to acoustic neurinoma. *J Neurosurg* 1992;76:901–909.
32. Hirato M, Inoue H, Zoma A, *et al*. Gamma knife radiosurgery for acoustic schwannoma: Effects of low radiation dose and functional prognosis. *Stereotact Funct Neurosurg* 1996; 66(Suppl. 1):134–141.
33. Linskey ME, Flickinger JC, Lunsford LD. Cranial nerve length predicts the risk of delayed facial and trigeminal neuropathies after acoustic tumor stereotactic radiosurgery. *Int J Radiat Oncol Biol Phys* 1993;25:227–233.
34. Niranjan AM, Lunsford LD, Flickinger JC, *et al*. Dose reduction improves hearing preservation rates after intracanalicular acoustic tumor radiosurgery. *Neurosurgery* 1999;45:753.
35. Forster DMC, Kemeny AA, Pathak A, *et al*. Radiosurgery: A minimally interventional alternative to microsurgery in the management of acoustic neuroma. *Br J Neurosurg* 1996;10: 169–174.
36. Lunsford LD, Kondziolka D, Flickinger JC, *et al*. Acoustic neuroma management: Evolution and revolution. *Radiosurgery* 1998;2:1–7.
37. Kondziolka D, Lunsford LD, McLaughlin MR, *et al*. Long-term outcomes after radiosurgery for acoustic neuromas. *N Engl J Med* 1998;339:1426–1433.
38. Hirsch A, Noren G. Audiological findings after stereotactic radiosurgery in acoustic neurinomas. *Acta Otolaryngol (Stockh)* 1988;106:244–251.
39. Eldridge R, Dailys P. Summary: Vestibular Schwannoma (acoustic neuroma) consensus development conference. *Neurosurgery* 1993;32:878–879.
40. Baldwin DL, King TT, Morrison AW. Hearing conservation in acoustic neuroma surgery via the posterior fossa. *J Laryngol Otol* 1990;104:463–467.
41. Nadol JB, Chiong CM, Ojemann RG, *et al*. Preservation of hearing and facial nerve function in resection of acoustic neuroma. *Laryngoscope* 1992;102:1153–1158.
42. Lunsford LD, Linskey ME, Flickinger J. Stereotactic radiosurgery for acoustic nerve sheath tumors. In: Tos M, Thomsen J, editors. Proceedings of the First International Conference on Acoustic Neuroma. Amsterdam: Kugler Publications; 1992. p. 279–287.
43. Bruzzo M, Broder L, Chays A, *et al*. Our current results with acoustic neurinoma surgery. *Ann Otolaryngol Chir Cervicofac* 2000;117:110–117.
44. Samii M, Matthies C, Tatagiba M. Management of vestibular schwannomas (acoustic neuromas): Auditory and facial nerve function after resection of 120 vestibular schwannomas in patients with neurofibromatosis 2. *Neurosurgery* 1997;40:696–705.
45. Fischer G, Fischer C, Remond J. Hearing preservation in acoustic neurinoma surgery. *J Neuosurg* 1992;76:910–917.
46. Tatagiba M, Samii M, Matthies C. The significance for postoperative hearing of preserving the labyrinth in acoustic neurinoma surgery. *J Neurosurg* 1992;77:677–684.
47. Lowne SP, Drake CG. Radical intracapsular removal of acoustic neurinomas: Long-term follow-up review of 11 patients. *J Neurosurg* 1991;74:422–425.
48. Ito K, Kurita H, Sugasawa K, *et al*. Neuro-otological findings after radiosurgery for acoustic neurinomas. *Arch Otolaryngol Head Neck Surg* 1996;122:1229–1233.
49. Glasscock ME, Kventon JF, Jackson CG, *et al*. A systematic approach to the surgical management of acoustic neuroma. *Laryngoscope* 1986;96:1088–1094.
50. King TT, Morrison AW. Primary facial nerve tumors within the skull: Results of 150 cases. *J Neurosurgery* 1980;52:210–216.
51. Bentivoglio P, Chesman AD, Symon L. Surgical management of acoustic neuromas during the last five years. Part II. Results for facial and cochlear nerve function. *Surg Neurol* 1988;29: 205–209.
52. Hitselberger WE. Hypoglossal-facial anastomosis. In: House WF, Luetje CM, editors. Acoustic tumors. Vol. II: Management. Baltimore: University Park Press; 1979. p. 97–103.
53. Hudgins RW. Patients' attitude about outcomes and the role of Gamma Knife radiosurgery in the treatment of vestibular schwannomas. *Neurosurgery* 1994;34:459–463.