

# Treatment of Small Acoustic Tumors (Vestibular Schwannomas)

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**Abstract:** Acoustic tumors (vestibular schwannomas) are the most common tumor of the cerebellopontine angle (CPA). Microsurgical resection is the traditional method of treatment, with complete tumor removal as the goal. The translabyrinthine approach is used in patients with poor hearing or no hearing and in any tumors larger than 2.5 cm. The middle fossa approach is used for tumors up to 2 cm in size with serviceable hearing. Conservative therapy or “observation” with serial imaging is often advocated for elderly patients with smaller tumors and without significant symptoms. A more recent treatment modality is stereotactic radiotherapy, with the goal of tumor control, defined as tumor regression or stable tumor size. Different forms of radiotherapy include radiosurgery, which uses a single-fraction dose of radiation, and fractionated radiotherapy, which divides doses to minimize damage to normal tissues. Regardless of method, treatment results for small acoustic tumors are generally good, and we typically recommend early intervention. Complete tumor removal has been demonstrated in 99% of patients undergoing microsurgical resection for small tumors, with tumor recurrence rates over all tumor sizes very low (<0.3%). Most reports show good facial nerve function after treatment in >90% of patients with small tumors. Hearing preservation at serviceable levels in patients with preoperative hearing is reported at about 60% in patients with small tumors undergoing middle fossa microsurgical removal. Cranial nerve dysfunction is often delayed following radiotherapy, so tumor control rates and nerve function results with the current generation of lower dose radiotherapy procedures awaits further study.

**Key Words:** acoustic tumor, vestibular schwannoma, small acoustic tumors, microsurgery, radiotherapy

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Acoustic tumors, more technically termed *vestibular schwannomas*, are the most common tumor of the cerebellopontine angle (CPA). They are benign tumors that arise from the Schwann cells of the eighth cranial nerve and are characterized by slow growth. These tumors usually present with auditory or vestibular symptoms. Ninety-five percent are of the sporadic type, occurring unilaterally. The remaining 5% are associated with neurofibromatosis type 2, with a predilection for bilateral involvement and younger age of onset, and they necessitate added treatment considerations.

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Microsurgical resection is the traditional method of treatment of acoustic tumors. The goal of surgery is complete tumor removal. Conservative therapy (“observation” or “watchful waiting”) with serial imaging has been advocated for elderly patients with smaller tumors and without significant symptoms. The role of stereotactic radiotherapy in the management of vestibular schwannomas is a subject of current controversy. The goal of radiotherapy is tumor control, defined as tumor regression or stable tumor size. Initially, it was used for patients who were considered poor surgical candidates or had residual or recurrent tumor after microsurgery. Radiotherapy is now being offered to a larger segment of patients as a primary treatment modality for small- to moderate-sized tumors.

This article describes management of small acoustic tumors, including surgery, observation, and radiotherapy, and discusses possible advantages and disadvantages of each treatment modality. Studies have shown that surgical results such as facial nerve function and hearing preservation do not differ significantly between intracanalicular tumors and those with up to 1 cm extension into the CPA.<sup>1</sup> Therefore, for the purposes of this review, “small” refers to intracanalicular tumors or tumors no more than 1 cm in maximum diameter in the CPA.

## SURGERY

William F. House first used the translabyrinthine approach to remove acoustic tumors in 1960.<sup>2,3</sup> The doctors of the House Clinic have since resected more than 4000 acoustic tumors using this approach. The translabyrinthine approach allows wide access to the CPA with little cerebellar retraction and permits exposure of the entire facial nerve from the brainstem to the stylomastoid foramen.<sup>4,5</sup> The exposure is mostly extradural, minimizing possible injuries to the brain and to the cerebellum. In addition, it provides a more direct and anterior perspective. A shorter distance separates the surgeon from the contents of the CPA.<sup>6,7</sup> The translabyrinthine approach allows for identification of the facial nerve at the lateral end of the internal auditory canal (IAC) before tumor dissection. The main disadvantages of the translabyrinthine approach are the need to sacrifice hearing in the operated ear, the limited exposure of the lower part of the CPA, and the limited access to the neural contents of the foramen magnum and foramen jugulare.

House<sup>8</sup> refined the middle fossa approach in 1961. Initially, he used this approach to decompress the IAC in cases of extensive otosclerosis with sensorineural hearing loss. Although not beneficial for that condition, it quickly became evident that this approach was suitable for small acoustic

tumors with good hearing.<sup>9,10</sup> The middle fossa procedure is a hearing preservation approach.<sup>11–13</sup> For tumors, it allows complete exposure of the lateral end of the IAC; thus, no blind dissection is necessary at the fundus. This is a definite advantage over the retrosigmoid approach, which does not allow exposure of the lateral third of the IAC without loss of hearing. Disadvantages include the fact that this is a technically difficult approach. Because of the superior location of the facial nerve in the canal, dissection of the tumor may subject the facial nerve to more manipulation than in other approaches. With the advent of facial nerve monitoring, however, problems of the facial nerve are kept to a minimum and facial nerve outcome is no different than when using the translabyrinthine approach for tumors of similar size, at least in experienced hands.<sup>14</sup> Retraction of the temporal lobe is required for the duration of the drilling and tumor removal, which usually does not exceed 1 to 1.5 hours.

In the treatment of acoustic tumors, the translabyrinthine and middle fossa approaches are often compared with the retrosigmoid approach. The retrosigmoid approach provides a panoramic view of the posterior fossa from the tentorium to the foramen magnum. Access is provided to the cerebellar hemisphere, the lateral aspect of the pons and medulla, and the root entry zone and cisternal course of cranial nerves V to XI. Although exposure superiorly is limited by the tentorium, this approach could be combined with a middle fossa or transtentorial exposure. The retrosigmoid approach represents a modification of the classic suboccipital approach. Krause<sup>15</sup> and others first used the suboccipital route during the latter portion of the 19th century. In this procedure, a large bone flap is removed from the suboccipital area, with the anterior limit of the dissection being the first mastoid cell. Superiorly, bone is removed up to the inferior margin of the transverse sinus. The retrosigmoid approach offers a more favorable angle of view into the CPA and a markedly reduced need for cerebellar retraction compared with the classic suboccipital approach. It does not pose a risk of air embolism or quadriplegia, as does the classic suboccipital approach, which has the patient in the sitting position. Advantages are wide access to the CPA and the potential for hearing preservation. The retrosigmoid approach is capable of addressing most lesions of the CPA.<sup>16</sup> Disadvantages include a higher incidence of postoperative headaches and cerebrospinal fluid (CSF) leak.<sup>17,18</sup> When compared with the retrosigmoid approach, the translabyrinthine approach has somewhat lower morbidity. The incidence of postcraniotomy headaches is lower than in the retrosigmoid approach, perhaps because of lesser cerebellar retraction, reduced dissection of the suboccipital musculature, and completion of all the bony work before dural opening. CSF leak is also less common after the translabyrinthine approach than after the retrosigmoid craniotomy.<sup>19,20</sup> The higher incidence of CSF leak is explained by the difficulty in sealing all the cells in the petrous apex, especially when it is extensively pneumatized. Another disadvantage is poor exposure of the ventral aspect of the pons and medulla because of the relatively posterior angle of view. The posterior aspect of the clivus is obstructed by the course of cranial nerves V to XI.

The translabyrinthine and middle fossa approaches to the CPA are, in our opinion, the approaches of choice for removal of most acoustic tumors because they provide access to the whole length of the IAC. The retrosigmoid approach allows access to only part of the IAC and is not discussed at any further length in this article.

## Indications

The translabyrinthine approach is ideal for many lesions of the CPA in patients with poor hearing or no hearing. It is used most commonly in acoustic tumor surgery and is indicated for any sized tumor when hearing is not serviceable. It is also indicated in tumors larger than 2.5 cm regardless of the status of hearing. Our definition of serviceable hearing is a pure-tone average (PTA) threshold equal to or better than 50 dB and speech discrimination score of at least 50%. This definition is referred to as the “50/50 rule.” Exceptions to this rule do exist, as in the case of poor hearing in the contralateral ear or in bilateral tumors. In those cases, a middle fossa craniotomy or a retrosigmoid approach may be pursued depending on the size and exact location of the tumor. We use the middle fossa approach for tumors up to 2 cm in size with serviceable hearing.<sup>21</sup>

## Preoperative Studies

Magnetic resonance imaging (MRI) is necessary to show the exact location and size of the tumor. It determines the relation of the tumor to the brainstem, cerebellum, and IAC. Particular attention should be paid to a major vessel loop crossing within the tumor. The nature of the tumor and its consistency, cystic versus solid, can also be evaluated.

## Surgical Procedures

Standard endotracheal anesthesia induced with thiopental and a short-acting muscle relaxant is used. Intravenous furosemide at a dose of 40 mg and mannitol at a dose of 1 g/kg of body weight are administered for brain relaxation when the skin incision is made. Preoperative antibiotics are also administered. The blood pressure is monitored using an arterial line.

Facial nerve monitoring is used for the whole length of the operation. When hearing preservation is attempted, cochlear nerve function is monitored using auditory brainstem responses; once the tumor is exposed, direct cochlear nerve potentials are obtained just before tumor removal.

For the translabyrinthine and middle fossa approaches, the patient is placed in the supine position, with the head rotated away from the surgeon. We do not use a headholder, although one may be used if greater posterior exposure is required. The operating room table is reversed so that the patient's head is located on the foot of the bed; this allows the surgeon to sit and work comfortably during the procedure without any obstruction under the table. A long anesthesia circuit permits the anesthesiologist to stay at the other end of the surgical site. An electrically controlled table allows the frequent turning from side to side needed during neurotologic procedures.

## Translabyrinthine Approach

The translabyrinthine approach allows exposure of the CPA anterior to the sigmoid sinus. Exposure includes the

lateral aspect of the pons; the ventral aspect of the lateral cerebellar hemisphere; and cranial nerves V, VI, VII, and VIII. The root entry zone of the lower cranial nerves IX, X, and XI is also seen to a variable degree depending on the location and anatomy of the jugular bulb.

Hair is shaved from the postauricular area, and the skin is prepared using povidone-iodine (Betadine). A plastic Vi-Drape is used to cover the surgical site. The lower abdomen is also prepared and draped in the usual fashion to allow harvesting of fat.

The postauricular skin is injected with 1% lidocaine (Xylocaine) with epinephrine at a ratio of 1:100,000. The incision is performed 4 cm posterior to the postauricular sulcus in a C-shaped fashion. This allows the pinna to be retracted anteriorly. This incision is carried through the soft tissue covering the mastoid process. A Lempert elevator is used to elevate the periosteum off the mastoid bone. The spine of Henle and the skin of the posterior part of the external auditory canal are identified, and care is taken not to injure them. Retractors are placed into position, and the bone posterior to the sigmoid sinus is uncovered.

A complete mastoidectomy is performed with a high-speed drill, using different sizes of cutting, diamond, and rough diamond burrs. The antrum and the incus are identified. Bone overlying the sigmoid sinus is removed, and the sigmoid is skeletonized. Removal of bone is carried posteriorly over the suboccipital dura to allow for retraction of the sigmoid and wider exposure. Some surgeons prefer to leave an island of bone (Bills island) over the sigmoid sinus to protect this structure from the shaft of the burr. The dissection continues with bone removal over the middle fossa dura and the sinodural angle as well as over the posterior fossa dura medial to the sigmoid sinus. Once all the bony work has been completed (the dura posterior to the sigmoid is uncovered, the sigmoid sinus is skeletonized, and the middle fossa dura and the posterior fossa dura anterior to the sigmoid sinus are uncovered), the labyrinthectomy is started.

The labyrinthectomy is accomplished with a cutting burr. It starts with removal of the lateral semicircular canal and is extended toward the posterior semicircular canal. Bone removal is continued inferior and anterior toward the ampullated end of this canal. The posterior semicircular canal is opened inferiorly to the vestibule and superiorly to the common crus and the vestibule. The facial nerve is identified in its descending segment, and care is taken not to injure the nerve while working on the lateral end of the vestibule. Now that the facial nerve is identified, the remainder of the bone of the inferior IAC is removed to the vestibule. We then proceed to remove the superior portion of the posterior canal to the common crus, which is formed by the nonampullated ends of the superior and posterior semicircular canals. The superior canal is then followed and removed to its ampullated end in the vestibule. This ampullated end identifies the area where the superior vestibular nerve exits the lateral end of the IAC. The saccule, the utricle and the posterior semicircular canal ampulla are identified; they represent the areas where the inferior vestibular and singular nerves exit the lateral end of the IAC. Removing the bone posterior to the IAC uncovers the vestibular aqueduct and the endolymphatic sac. By now, the superior and inferior ends of the IAC are outlined.

To expose the IAC and the contents of the CPA properly, bone needs to be removed from around the canal superiorly and inferiorly up to 270° of the circumference of the canal. The jugular bulb and the cochlear aqueduct represent the inferior limit of dissection. By staying superior to the cochlear aqueduct, injury to cranial nerves IX, X, and XI is avoided. Bone located between the middle fossa dura and the IAC is removed. At the lateral end of the canal, the Bills bar, or the vertical crest, is identified. It separates the facial nerve from the superior vestibular nerve. Because the facial nerve is located in the anterior and superior part of the IAC, care must be taken not to injure the nerve while removing the bone of the superior lip. Pressure should not be applied over the canal. The dissection in this area is done with the side of the burr.

Once the bony removal is completed, attention is turned to the antrostomy and the middle ear cleft. The incus is removed from the fossa incudis, and the area of the facial recess is widened to obtain a good view of the eustachian tube and the tensor tympani muscle. The tensor tympani muscle is sectioned to allow for better packing of the middle ear space.

The dura of the canal and the posterior fossa is not opened until all bone removal has been accomplished. During the drilling, the wound is irrigated periodically with bacitracin solution. The craniotomy defect is again irrigated before dural opening.

A 3-mm hook is used to elevate the dura over the superior vestibular nerve and to palpate the vertical crest. The superior vestibular nerve is then dissected away from the facial nerve. Scissors are used to complete the dural opening and to obtain wide access to the CPA.

After division of the facial-vestibular anastomosis, the plane between the superior vestibular nerve and the facial nerve leads the surgeon into the plane between the facial nerve and the tumor. Cottonoids are placed between the tumor and the cerebellum posteriorly. Care is taken not to injure the superior petrosal sinus or the petrosal vein while dissecting posteriorly. Partial tumor removal then proceeds by incising the tumor capsule and debulking the tumor, using the House-Urban dissector or an ultrasonic aspirator. Once enough gutting of the tumor has been accomplished, the tumor plane is carried out further inferiorly and superiorly. Now, the posterior surface of the tumor is separated from the brainstem by cottonoids. Inferiorly, the ninth nerve is identified and protected using small cottonoids. Large vessels are often located at the inferior pole of the tumor. Care is taken to separate the tumor gently from those vessels. At this point, further debulking of the tumor is achieved. Now, the lateral end of the IAC is dissected. The facial nerve has been identified and separated from the tumor. A hook is used to remove the inferior vestibular nerve, and the dura is opened along the inferior aspect of the tumor. Along the superior aspect of the tumor, dissection proceeds, keeping in mind the position of the facial nerve in relation to the tumor. The tumor is now gently retracted posteriorly. The plane along the facial nerve is further developed. Dissection of the tumor at the level of the porus can be difficult. If dissection is difficult, the tumor is rotated posteriorly to identify the facial nerve medially at the brainstem. The facial nerve is then followed from a medial-to-lateral direction. Developing the facial nerve plane from a

medial-to-lateral direction leads to the medial extent of the tumor. The continuing plane of the facial nerve is then developed back to the porus. Once the facial nerve is cleared, the tumor is easily delivered.

After tumor removal, the wound is copiously irrigated with Ringer solution to remove all the blood clots. Careful hemostasis is achieved. The dura is reapproximated with 4-0 silk. The eustachian tube is packed with Surgicel, and the middle ear cleft is filled with muscle. The craniotomy defect is filled with fat obtained from the lower part of the abdomen. Strips of fat are packed tightly to prevent leakage of CSF. A titanium mesh is used to reconstruct the lateral wall of the mastoid and is secured in position using 4 microscrews placed into the edges of the mastoid opening. The wound is closed in layers with 0-chromic and 3-0 Vicryl sutures. Steri-strips are applied to the postauricular incision, and a head pressure dressing is applied.

### Middle Fossa Approach

The middle fossa approach allows the unroofing of the IAC and the exposure of the fundus of the canal. The facial nerve is located at the lateral end of the canal, where it enters the temporal bone and becomes the labyrinthine segment between the cochlea and the superior semicircular canal. This approach makes possible the removal of laterally located tumors in the IAC without the need for blind dissection.

The incision starts in the pretragal area, curves initially posteriorly above the ear, and then runs vertical for 4 cm before curving at a right angle anteriorly in the temporal area. The shape of the incision resembles a question mark. Once the skin is elevated, an incision is made along the insertion of the temporalis muscle and fascia and the muscle is reflected anterior inferiorly.

Using a cutting burr, an opening is made in the squamous portion of the temporal bone. The craniotomy measures 5 cm × 5 cm and is located two-thirds anterior and one-third posterior in relation to the external auditory canal. The bone flap is kept in antibiotic solution and is placed back at the conclusion of the case. The dura is now elevated posteriorly to anteriorly from the floor of the middle fossa, and any remaining bone over the root of the zygoma is drilled away as close as possible to the floor of the middle fossa. The initial landmark, the middle meningeal artery, marks the anterior extent of dural elevation. Frequently, bleeding is encountered in this area and is controlled by packing Surgicel in the foramen spinosum. Dissection of the dura continues until the petrous ridge is identified. Once the dura is completely elevated, the House-Urbach retractor is placed into position over the porus acusticus. At this point in time, the arcuate eminence and the greater superficial petrosal nerve have been identified. In a small proportion of patients, the geniculate ganglion is dehiscent, and care is taken not to injure it while elevating the dura. Posterior-to-anterior elevation avoids elevating the ganglion.

Using suction irrigation and diamond burrs, dissection of the IAC is started medially. The IAC bisects the angle formed by the greater superficial petrosal nerve and the arcuate eminence as described by Garcia-Ibanez.<sup>22</sup> Identifying the IAC medially and anteriorly is safest, because there are no

important anatomical structures medially. Once the IAC is identified, bone surrounding it in the area of the porus is removed. Bone removal extends posteriorly to the level of the arcuate eminence and the common crus and anteriorly to the Kawase triangle. Bone is removed 270° around the canal, including the entire posterior lip. Lateral dissection of the IAC then proceeds. The exposure narrows laterally because of the presence of the cochlea anteriorly and the ampullated end of the superior semicircular canal posteriorly. At the lateral end of the canal, the Bill bar is identified. The facial nerve is followed into its labyrinthine portion. The ligament surrounding it at the beginning of the labyrinthine segment is cut to allow for decompression of the nerve in this portion.

The dura of the IAC is opened along the posterior aspect. The facial nerve is identified clearly and stimulated. The superior vestibular nerve is cut at the end of the IAC. After this, the vestibulofacial anastomotic fibers are cut. The tumor is then separated from the end of the IAC canal and from the facial nerve. The goal is to free the tumor from the facial nerve and to deliver it from under the nerve. Dissection of the lateral end of the inferior compartment of the IAC can be difficult. It is best to cut the superior and inferior vestibular nerves to avoid postoperative unsteadiness. Once the lateral end of the tumor has been delivered, the plane between the cochlear and facial nerves and the tumor become apparent. This plane is developed using fine hooks. Tumor dissection proceeds from a medial-to-lateral direction to avoid stretching the facial and cochlear nerves. At this point, a search for the anterior inferior cerebellar artery begins. Great care is taken to identify and not to injure this important artery. At this point in time, the tumor is separated gently from this vessel. Debulking of the tumor begins using small cup forceps. At all times, care is taken not to injure the facial nerve with suction or by stretching it. Finally, the medial end of the tumor is freed with small hooks.

Once tumor removal is completed, hemostasis is obtained. The tumor bed is irrigated copiously. Abdominal fat is obtained and is used to close the dural defect. The temporal lobe retractor is removed. The dura is suspended on either side of the craniotomy to limit the dead space. A Penrose drain is placed into the wound. The bone flap is repositioned and secured in place using 3 titanium microplates. The wound is closed in layers, and a mastoid type pressure dressing is applied.

### Postoperative Care

The patient is observed in the intensive care unit for a period of 24 hours. Steroids and antibiotics are routinely used. For the middle fossa approach, the Penrose drain is removed from the wound on the first postoperative day. A new pressure dressing is applied. The wound is inspected every day thereafter. The mastoid dressing remains in place for 4 days, and the patient is instructed not to lift or strain during the early postoperative period.

### Perioperative Complications

Slattery et al.<sup>23</sup> reviewed the perioperative morbidity of acoustic tumor surgery for a series of 1687 patients undergoing surgery at our institution between 1987 and 1997. This

included tumors of all sizes and using all surgical approaches. CSF leak was the most common problem, occurring in 9.4% of cases overall. Looking at the data from that study for just those tumors that were  $\leq 1$  cm in size and underwent a translabyrinthine ( $n = 37$ ) or middle fossa ( $n = 133$ ) approach, CSF leak occurred in 8.3% of the translabyrinthine cases and 4.6% of the middle fossa cases, with reoperation required for treatment in only 2.7% and 1.5% of cases, respectively. In 365 small tumors operated on from 1998 to 2003 at our institution, only 3% had a CSF leak. Most leaks can be stopped with a pressure head dressing and bed rest with the patient's head elevated. If the leak continues despite the dressing in place, a lumbar spinal drain is inserted and kept in place for 3 to 4 days. Re-exploration of the wound and repacking of the wound with additional fat is done if the leak persists despite the performance of these steps. More recently, for cases in which hearing is not preserved, a blind closure of the external auditory canal is undertaken to control the leak. The titanium mesh is not removed, fat in the mastoid defect is not disturbed, and the facial nerve is not placed at any risk. The skin of the external auditory canal is removed, a canaloplasty is undertaken, and the peritubal air cells are exposed with a diamond burr. The eustachian tube is packed with Surgicel and bone wax, the middle ear is packed with muscle, and the lateral end of the external auditory canal is packed with fat. The wound is then closed in layers.

Meningitis is an uncommon complication and is managed with appropriate antibiotics after culture and identification of the offending organisms. Small tumors from the Slattery et al. study<sup>23</sup> showed a prevalence of meningitis of 2.8% (only 1 case) in the translabyrinthine patients and 0% in the middle fossa cases. For small tumors of the past 5 years at our institution, meningitis occurred at a rate of 1%.

Although rare, the most common early postoperative complication is a hematoma in the CPA, occurring in 0.9% of all sized tumors in the Slattery et al. study.<sup>23</sup> This is manifested by signs of increased CPA pressure and is managed by immediate opening of the wound and removal of the fat in the intensive care unit. The patient then undergoes surgery to secure hemostasis and repack the wound. The incidence of this complication is lowered by leaving a Penrose drain in the wound for the first 24 hours and by obtaining meticulous hemostasis before closure of the wound.

Other perioperative complications occurring in the Slattery et al. study<sup>23</sup> for tumors of all sizes include cerebral edema (0.9%), abdominal wound infection (0.9%), craniotomy wound infection (0.8%), seroma (0.6%), hydrocephalus (0.4%), cerebrovascular accident (0.2%), and thrombosis (0.1%). For small tumors, there were no cases of hydrocephalus or thrombosis.

If facial weakness occurs, the eye is protected by using conservative measures first. These include artificial tears, moisture chambers, and soft contact lens. In certain situations, the insertion of a gold weight or a palpebral spring may be necessary. In small tumors from the Slattery et al. study,<sup>23</sup> 1.2% required a surgical procedure.

Possible problems related to temporal lobe retraction include memory loss, auditory hallucinations, and speech disturbances. These are rarely significant clinical problems.

Seizures are often cited as a possible complication of the middle fossa approach; however, in reality, this problem is seldom encountered. Older patients do not tolerate the middle fossa approach as well as younger patients because of the fragility of the dura and retraction of the temporal lobe. Fortunately, all these complications have been rare in our experience.

## Results of Surgery

Complete tumor removal has been demonstrated in more than 95% of patients undergoing microsurgical resection and was accomplished in 99.4% of the small tumors from the Slattery et al. study.<sup>23</sup> Tumor recurrence has been shown to occur in 0.3% or less of cases with long-term follow-up.<sup>24</sup> Cranial nerve morbidity, particularly of cranial nerves VII and VIII, is of particular concern when judging the success of any form of treatment modality for vestibular schwannomas.

## Facial Nerve

Previous publications from this institution have reported a follow-up (1-year) rate of 91.3% good facial function (House-Brackmann grade I or II) in tumors less than or equal to 1.5 cm in size and removed using the translabyrinthine approach.<sup>14</sup> Data from a more recent series of 46 cases of tumors less than or equal to 1 cm operated on over a 5-year period from 1998 to 2003 show a good facial function result in 93.5% for translabyrinthine removal. Similarly, Arriaga et al.<sup>14</sup> reported a 95.8% good facial function result for 1.5-cm or smaller tumors using the middle fossa approach, a rate that was not statistically significantly different from that of the translabyrinthine cases. For tumors 1 cm or less in size, results were similar. For the recent 5-year period, 271 small tumors underwent middle fossa removal, with a good facial function rate of 94.5%. Again, this rate was not different from those found for the translabyrinthine cases of similar size.

Others have also reported facial nerve results for small tumors removed using the middle fossa approach. For example, Satar et al.<sup>1</sup> reported rates of good facial function (House-Brackmann grade I or II) in 93.7% of 64 intracanalicular tumors and 97.6% of 42 tumors with a 1-mm to 9-mm CPA extension.

## Hearing Preservation

The translabyrinthine approach is used for small tumors only when hearing preservation is not an issue. No hearing remains after tumor removal by this approach. For middle fossa procedures, hearing preservation is a goal. Slattery and Brackmann<sup>25</sup> reviewed the published results of hearing preservation for the suboccipital and/or retrosigmoid and middle fossa approaches. As they note, there are different definitions of hearing preservation, including simply preserving the cochlear nerve, any measurable hearing, serviceable hearing, and lack of change in hearing from the preoperative level. Hearing preservation rates, as reported by the various authors reviewed, ranged from 16.5% to 65% for the suboccipital approach and from 36% to 71% for the middle fossa approach. Tumors included in these studies ranged from intracanalicular only in some studies to as large as 3 cm in a single study. A report from our institution on all

tumors operated on using the middle fossa approach over a 2.5-year period from 1993 to 1995 found measurable hearing preserved in 68% of 143 patients.<sup>13</sup> Hearing was preserved within 15-dB PTA and 15% of the speech discrimination score (SDS) of preoperative levels in 52% of patients. Forty-seven percent did not change or improved their hearing class using the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) classification system. This study included patients with tumors up to 2.5 cm in size. An analysis of predictive factors found no relation between tumor size and hearing change, however, so results should be similar when looking only at tumors of 1 cm or less. In a more recent report from our institution, hearing preservation was evaluated by tumor size for patients operated on using the middle fossa approach between 1992 and 1998.<sup>26</sup> Again, no effect of tumor size on hearing outcome was found. For 107 tumors of 1 cm or less in size, however, some measurable hearing was preserved in 79% and serviceable hearing (equal to or better than 50 dB PTA and 50% SDS) was preserved in 60%. Hearing was preserved to within 15 dB and 15% of preoperative levels in 52% of cases. Long-term stability of hearing preservation in our middle fossa vestibular schwannoma cases has also been examined. Friedman et al.<sup>27</sup> found that 70% of patients with immediate postoperative serviceable hearing maintained serviceable hearing at more than 5 years after surgery.

Others have also reported hearing preservation rates in small tumors. Staecker et al.<sup>28</sup> reported a hearing preservation rate of 57% in mainly intracanalicular tumors removed by the middle fossa approach and 47% in similar tumors removed using the retrosigmoid approach. Satar et al.<sup>1</sup> reported rates of functional hearing preservation in intracanalicular tumors and those with up to a 9-mm CPA extension of 62% and 63%, respectively. These studies, as well as our own data, all show preservation of serviceable hearing in approximately 60% of patients undergoing middle fossa acoustic tumor removal for small tumors.

## OBSERVATION

Monitoring with no active treatment is a recognized choice in treating acoustic tumors, which is advocated more by some than by others. The goal of any medical therapy is to prevent morbidity and mortality in the safest and most noninvasive fashion that can yield effective results. Delaying treatment until the patient has an increase in symptoms is not likely in the patient's best interest, because there is greater morbidity associated with treatment of larger tumors. Conversely, neither is treating a patient with a potentially risky surgical or radiation procedure when his or her tumor would not have grown. Vestibular schwannomas are being diagnosed earlier and when they are smaller because of improvements in imaging techniques, aggressive audiologic screening, and physician education regarding algorithms to evaluate patients with symptoms such as hearing loss, dizziness, and facial nerve dysfunction. At the same time, improvements in surgical techniques and radiotherapy have decreased the morbidity of active treatment. Patient characteristics such as age, tumor size, hearing status, general health, surgical risk, and avail-

ability of stereotactic radiotherapy may all influence the choice for conservative management. In addition, some patients refuse treatment despite medical advice to the contrary.

## Indications

In general, we recommend early intervention, usually surgical removal, in small tumors with good hearing for the best chance at preserving hearing and facial function. Observation may be recommended in elderly patients, those in poor health, those with small tumors but already poor hearing, or those unwilling to undergo surgery or radiotherapy, however.

## Results

Studies from this institution and others have attempted to determine the likelihood of tumor growth in patients with acoustic tumors who are being followed with no active treatment, to identify predictive factors for growth, and to evaluate the impact of the "observation" treatment option. Fucci et al.<sup>29</sup> reported on 119 patients with acoustic tumors who were followed with interval MRI. Overall, maximum tumor dimension increased >2 mm (defined as growth) in 30% of the patients, with a mean follow-up interval of 2.5 years. For tumors that grew, the mean growth rate was 3.8 mm/y (SD = 4.6 mm). A few tumors grew >10 mm/y. Tumors that were >2 cm at presentation were significantly more likely to grow than smaller tumors, but 31% of tumors ≤1 cm did grow. Patient age, sex, and tumor side were not predictive of future tumor growth. Tumor growth rates remained constant at 6 months, 12 months, and >1 year, such that fast-growing tumors could usually be identified with a 6-month follow-up, whereas those not showing growth at 6 months could have the follow-up interval increased. Growth on MRI was the most common sign or symptom prompting treatment of the 18.5% of patients who went on to have surgery or radiotherapy. This was followed in prevalence by hearing loss and then dizziness. Fucci et al.<sup>29</sup> also reviewed earlier studies and found the percentage of patients showing tumor growth to vary from 14% to 87% across 10 other reports in the literature between 1985 and 1995.

Thomsen et al.<sup>30</sup> reported on the growth of intrameatal vestibular schwannomas in 40 patients followed for an average of 3.6 years. They found growth in 67.5% of cases and reported 4 growth patterns: constant growth, no measurable growth, growth subsequent to a no-growth period, and different growth patterns during the observation period. The mean diameter growth was 3.2 mm. In another study, 35 patients with acoustic tumors were observed for more than 3 years and 54% of the tumors grew.<sup>31</sup> Hearing was unchanged in only 23% of these patients. In a group of 87 patients followed with a "wait-and-see" policy by Shin et al.<sup>32</sup> and having a mean follow-up of 15 months, tumors grew in 53%. The authors identified 5 growth patterns: continuous growth, negative growth, growth followed by negative growth, negative growth followed by growth, and no change in tumor size. They reported that 3 (10.7%) of 28 patients who were classified as candidates for hearing preservation surgery lost their candidacy during the observation period. More recently, Tos et al.<sup>33</sup> reported on several studies looking at

the socioeconomic impact and patients' feelings comparing surgery and observation. Regarding the socioeconomic impact, they concluded that although "negative changes were more frequent among operated patients, the differences were surprisingly modest, especially when comparing observed patients with patients operated on for a small tumor".<sup>33</sup> Another report concluded that a majority of the operated and observed patients did not regret their choice of treatment modality and were satisfied with the information provided by the medical staff.<sup>34</sup> They also found that patients indicated the worst aspect of vestibular schwannoma is the associated hearing loss, regardless of the treatment modality.

If observation is chosen as the management approach, we recommend serial MRI beginning at 6 months, with the interval increasing to 18 or 24 months for those showing no tumor growth at early follow-up.

### STEREOTACTIC RADIATION THERAPY

Stereotactic radiotherapy has provided neurosurgeons and neurotologists with an alternative modality for treating tumors located in the temporal bone and CPA. Radiotherapy treatment of the CPA, including vestibular schwannomas and meningiomas, dates back to the 1960s and was proposed by Leksell<sup>35</sup> even earlier. Its first application as a treatment of vestibular schwannoma was in 1969. Initially, its use was limited to managing these benign tumors in patients considered to be poor surgical candidates. More recently, its indications have expanded in terms of patient age and tumor characteristics. Much of the current debate surrounding radiotherapy involves its use as a primary modality of treatment in all patients.

### Principles and Techniques

*Stereotactic radiosurgery* is the term often applied to the technique that uses a single-fraction dose of radiation applied to a precise image-defined target. Intracranial targets are defined using MRI, computed tomography (CT) or, in some cases, such as arteriovenous malformations (AVMs), angiography. The goal is to deliver an optimal dose to the target tissue while obtaining a sufficient radiation gradient so as to minimize exposure to adjacent normal tissue. This is of particular concern with skull base lesions located near cranial nerves, which are quite susceptible to radiation injury. Conventional "fractionated radiotherapy" has also been used to treat vestibular schwannomas, using the divided doses to minimize damage to normal tissues, and may be able to treat tumors of larger volume without causing serious neurotoxicity.<sup>36</sup> Although a convention has developed to refer to single-dose radiation, usually with the gamma knife, as radiosurgery and to multiple-dose treatments as radiotherapy, we use the term *radiotherapy* here generically.

The effect of radiotherapy is 2-fold: direct cellular injury by damaging cellular DNA and delayed vascular injury. Posttreatment imaging characteristically displays fibrosis of the targeted region with an area of central necrosis. The single high-dose fractions are most effective on slowly proliferating tissues, such as schwannomas and meningiomas. The response to treatment is often delayed, and this is more

pronounced with slowly proliferating tissue. Response time is also a function of the radiation dose delivered. By increasing the dose, a more rapid response should be observed. Conversely, when treating slow-growing benign tumors that do not require a rapid response, the radiation dose can be reduced so as to lower the risk of treatment-related morbidity. As the target volume for stereotactic radiotherapy increases, there is a corresponding increase in radiation exposure to adjacent normal tissue. Thus, with larger target volumes, there is an expected increase in morbidity secondary to radiating normal structures. To overcome this would require lower doses of radiation, which, at a certain point, might mean suboptimal dosing of the target tissue. For this reason, it is believed that targets greater than 3 cm in maximal diameter are not ideally suited for radiotherapy.

### Types of Radiation

#### Linear Accelerator

Linear accelerator (LINAC) units use a single source focused on the target. The LINAC rotates in an arc around the patient. The patient is also rotated during the treatment so that the lesion is targeted from multiple planes. The treatment isocenter is determined by adjusting the arcs of rotation.

#### Gamma Knife

These units contain 201 cobalt-60 sources in a hemispherical configuration. All sources are focused toward a single central point, creating a treatment isocenter.

Manipulating each of the sources can alter the dose provided to the isocenter. The use of a collimator helmet allows for alteration of the isodose distribution. The patient remains stationary throughout the treatment. Gamma-knife radiotherapy has been the most commonly reported type of radiotherapy for the treatment of acoustic tumors.

#### Particle Beam

These units rely on charged particle beams, usually from protons, for radiotherapy. They are better able to conform to irregular targets than the other methods, which rely on using multiple isocenters. Particle beam radiotherapy also has a steeper drop off in radiation; thus, it allows for less radiation exposure to adjacent normal tissues. These units are available in only a small number of institutions worldwide.

One report suggests that there are advantages in physical dose distribution and fractionation, producing a reduction in the biologic dose in normal tissue, that argue for the use of LINAC technology in acoustic tumors, although the authors cite earlier review articles that compared gamma units versus LINAC-based radiotherapy systems and concluded that the dose gradient "fall-off" is similar for both techniques as far as single-isocenter treatment volumes up to 1.5 cm are concerned.<sup>37</sup> Others argue strongly that tumor radiobiology dictates radiosurgery (single-dose targeted radiation) as the best approach for vestibular schwannomas and that the gamma-knife delivery system has advantages over other current techniques.<sup>38</sup>

## Dosage

Mean marginal tumor doses used have decreased over time from approximately 18 Gy to 20 Gy to the 12 Gy to 16 Gy used at present. Dose planning is now primarily done with MRI, which provides a more exact outline of the tumor and adjacent structures, allowing for more precise treatment fields. It is believed that this has contributed to the drop in rates of cranial nerve injury from those reported in initial studies.

Stereotactic radiotherapy can be done as an outpatient procedure or with a 1-night hospital stay. The initial step is the placement of the stereotactic frame on the patient's head. This is done using local anesthesia, often with intravenous sedation. Imaging studies are conducted to define the lesion, and dose planning is then performed. The patient and frame are positioned with respect to the radiosurgical unit. After the completion of radiotherapy, the frame is removed.

## Indications

For treatment of acoustic tumors, the following indications for radiotherapy are typical: tumor diameter less than 3 cm, significant comorbidities or contraindications to surgery, the patient does not want surgery, and patient age older than 65 years with documented growth on serial MRI.

## Results of Radiation Therapy

Treatment efficacy with stereotactic radiotherapy is gauged as a function of tumor control. Tumor control is defined as a decrease in tumor size or stable tumor size on follow-up imaging. Facial nerve function and hearing preservation are "secondary" outcome measures. Long-term data on the efficacy and morbidity of stereotactic radiotherapy have predominantly been collected from patients treated with older techniques and dosing strategies. This has been the source of much of the controversy surrounding radiotherapy. Although there has been a trend toward reduced morbidity with lower doses, the long-term efficacy of these techniques is not yet known. There may also be differences in tumor control rates and/or morbidity between the different radiation therapy methods (eg, gamma-knife radiosurgery, fractionated stereotactic radiotherapy). The ultimate role of stereotactic radiotherapy should become clearer as these questions are answered.

## Tumor Control

Stereotactic radiotherapy has been reported to provide tumor control rates of approximately 90%, although these studies primarily include patients with follow-up of less than 5 years. Noren et al.<sup>39</sup> and Kondziolka et al.<sup>40</sup> retrospectively analyzed the long-term efficacy of radiosurgery, showing tumor control rates of 82.5% and 98%, respectively. Vermeulen et al.<sup>41</sup> reported that 12 of 12 intracanalicular tumors treated with the gamma knife showed regression or no change on follow-up imaging, with a mean follow-up time of 18 months but ranging from 1 month to 39 months. Flickinger et al.<sup>42</sup> recently provided data on 199 patients receiving gamma-knife treatment (median marginal dose = 13 Gy) for their vestibular schwannomas, with a median follow-up time of 30 months. The range and distribution of follow-up times were not provided. Five patients (3.4%) in this series required later microsurgical removal for continued tumor growth, but nearly

10% of the patients demonstrated MRI evidence of tumor growth (1–2 mm/y) during this same follow-up period. In a recent series of patients treated with the gamma knife (marginal doses of approximately 13 Gy), Prasad et al.<sup>43</sup> reviewed 95 patients with 5 to 10 years of follow-up and found tumor growth in 6.3%. In their most recent report, Kondziolka et al.<sup>44</sup> describe 157 vestibular schwannoma patients treated with the gamma knife at the University of Pittsburgh. The median follow-up period was 9.1 years. At the time of their review, 3 patients (1.9%) in this group had required later microsurgical resection. Their sample consisted of patients with a median age of 60 years, and a large portion of their patients had undergone prior microsurgical subtotal resection, making generalization of these data to younger patients with untreated tumors difficult. A large study from Japan reported on 1475 patients who had undergone gamma-knife radiosurgery.<sup>45</sup> These investigators found that 8% of tumors enlarged after radiosurgery, with 4.6% of patients going on to microsurgery over a 3.8-year period. Another report from Japan examined 51 patients who had received low-dose ( $\leq 12$  Gy) gamma-knife radiosurgery and found a 5-year tumor growth control rate of 92%,<sup>46</sup> whereas a third recent report looked at 101 patients treated with fractionated stereotactic radiotherapy and found an actuarial 5-year rate of tumor control (no growth  $>2$  mm and no requirement for salvage surgery) of 91.4% (95% confidence interval [CI]: 85.2%–97.6%).<sup>36</sup> In a study of 88 patients treated with proton beam stereotactic radiotherapy, a 93.6% 5-year actuarial tumor control rate was found (95% CI: 88.3%–99.3%).<sup>47</sup> None of these reports were limited to small tumors; however, Kondziolka et al.<sup>44</sup> report that size (tumor volume) was not related to tumor response to radiotherapy.

We have recently identified 44 patients who had vestibular schwannomas treated surgically at our institution after undergoing radiotherapy at another institution (Friedman et al, submitted for publication, 2004). These patients all had evidence of tumor growth by radiology or a return of or increase in symptoms. The mean time from irradiation to surgical salvage was 3.3 years (SD = 3.2), with a minimum of 5.2 months and a maximum of 15.8 years. More than one quarter (26%) of the patients had an interval of 4 years or longer before growth that required further treatment. Conversely, as reviewed previously in the section on observation, many studies have shown that significant proportions of patients who are just observed may show no tumor growth. For example, Thomsen et al.<sup>30</sup> looked at growth patterns of purely intrameatal vestibular schwannomas in 40 patients over a mean period of 3.6 years. They found no measurable growth in 32.5% and growth subsequent to a no-growth period in 20%. This, they thought, brings into question the reliability of the results achieved by radiotherapy, because no tumor growth may occur even with no intervention. Thus, it is difficult to determine tumor control rates realistically after radiotherapy. In some patients, the tumor may have shown no growth even without treatment. In other cases, growth may occur well after the follow-up period used in many of the reported studies. Immunohistochemical studies have shown that irradiated vestibular schwannomas, later removed by microsurgery, contain viable and dividing cells.<sup>48</sup>

## Facial Nerve

Many of the same studies cited previously reported facial nerve function results, often mentioning initial “facial paresis” rates and rates of permanent dysfunction. Reported initial facial paresis rates have ranged from less than 2% to as high as 53%, with permanent rates of dysfunction up to 42%. One difficulty in summarizing these results is that although a few articles use the House-Brackmann facial nerve grading scale, regarded as the standard for reporting by the American Academy of Otolaryngology–Head Neck Surgery, many, particularly those reported in neurosurgery and radiation oncology journals, do not.<sup>49</sup> Most recent reports claim low rates of facial dysfunction after radiotherapy and/or report the dysfunction as “transient.” Kondziolka et al<sup>44</sup> report that 124 of 157 vestibular schwannoma patients who underwent stereotactic radiosurgery had normal facial function before radiosurgery and that 118 of these (95%) retained normal function. They also report that facial nerve function worsened in 26 patients, however. This can only be interpreted as that in addition to the 6 patients with preoperative normal function who worsened, 20 (60.6%) of the 33 patients with presumably nonnormal pretreatment function had even greater dysfunction after radiosurgery, although none were below House-Brackmann grade III. Sawamura et al<sup>36</sup> reported transient facial nerve palsy in 4% of all patients undergoing fractionated stereotactic radiotherapy, with no new permanent facial weakness occurring. For intracanalicular tumors treated with gamma-knife radiosurgery, Vermeulen et al<sup>41</sup> report facial neuropathy in 43% as an “acute side effect.” They also note that this and other side effects were more common in those with intracanalicular tumors than in those with extracanalicular extension. A recent study on proton-beam radiosurgery found an actuarial 5-year rate of normal facial function preservation of 91% (95% CI: 85%–97.6%).<sup>47</sup> These authors also reported that the prescribed dose, maximum dose, and inhomogeneity coefficient were significantly associated with a significant risk of long-term facial neuropathy.

Rapid and delayed deterioration in facial nerve function after radiotherapy has been reported. For example, 1 case report describes a 26-year-old man treated with gamma-knife radiosurgery with a margin dose of 14 Gy, who developed headache, vomiting, facial weakness, tinnitus, and hearing loss 2 days after treatment.<sup>50</sup> Facial nerve function worsened from House-Brackmann grade I before surgery to grade III, improving to grade II by 8 months after treatment. Hearing also deteriorated considerably. MRI showed no change in tumor size or peritumoral edema but an obvious decrease in contrast enhancement, suggesting toxicity leading to a decrease in blood flow. Watanabe et al.<sup>51</sup> recently published a case report of a patient who developed complete facial palsy 25 months after he had undergone 2 gamma-knife surgeries performed 33 months apart. Tumor growth was noted 21 months after the second radiosurgery, and the tumor was surgically removed. Histologic and immunohistochemical examinations of the facial nerve specimen removed from the edge of the tumor showed microvasculitis and axonal degeneration, which were thought to be the major causes of the radiation-induced facial neuropathy.

## Hearing Preservation

Rates of preservation of useful or serviceable hearing after radiotherapy have been reported to vary as widely as 20% to 77%. Kondziolka et al,<sup>44</sup> reporting long-term follow-up on 157 patients who underwent gamma-knife radiosurgery, note that hearing remained at serviceable levels in 50% of the 76 patients with pretreatment serviceable hearing. Prasad et al<sup>43</sup> report that only 31% of their 153 patients had residual hearing before radiosurgery. Of these, 64% had no worsening of their hearing after treatment. Most hearing changes occurred after 2 years and continued into the eighth year after treatment, and only 40% of those with >5 years of follow-up had no hearing deterioration. A recent study of LINAC-based stereotactic irradiation found 1- and 2-year hearing preservation rates of 85% and 57%, respectively.<sup>52</sup> These last 2 studies emphasize the need to consider follow-up time before interpreting hearing preservation results. Sawamura et al<sup>36</sup> report that 28 (78%) of 36 patients with Gardner-Robertson (GR) class 1 or 2 hearing before fractionated stereotactic radiotherapy retained class 1 or 2 hearing at last examination. The 5-year actuarial rate of useful hearing preservation was 71%. A report on proton-beam radiosurgery found that 33.3% of patients with pretreatment functional hearing (GR grade 1 or 2) retained serviceable hearing,<sup>47</sup> whereas a study of patients who underwent low-dose gamma-knife radiosurgery reports that hearing was preserved at a useful level (GR class 1 and 2) in 56%.<sup>46</sup> Karpinos et al<sup>53</sup> reported preservation of serviceable hearing in 44% of patients undergoing radiosurgery with the gamma knife and found this no different than the serviceable hearing preservation rate in their microsurgery patient group.

## Complications

Cranial nerve dysfunction secondary to radiotherapy is typically delayed, with onset between 1 week and 3 years after treatment, although hearing deterioration can continue over an even longer period. In some cases, the dysfunction is reversible. Patients with larger tumors and neurofibromatosis type 2 have been found to be at increased risk for cranial nerve injury secondary to radiotherapy. Trigeminal neuropathy of varying degrees has been observed in as many as 50% of patients. Stereotactic radiotherapy has been associated with other complications, including hydrocephalus and cerebellar edema.

Vermeulen et al<sup>41</sup> reported their experience with “toxicity” in the treatment of intracanalicular acoustic neuromas with gamma-knife irradiation. Dose to the periphery of the intracanalicular lesion extension ranged from 12 Gy to 18 Gy, with a mean margin isodose of 47%. They found diminished hearing in 14% of patients, facial neuropathy in 43%, trigeminal neuropathy in 21%, balance disorder in 14%, dizziness in 7%, and headache in 7%. These findings were more common in the intracanalicular tumors than in those tumors with extracanalicular extension. Another study reported that of the 54 primary patients in their series treated with the gamma knife, 7% developed hydrocephalus.<sup>31</sup> As noted previously, Tago et al<sup>50</sup> describe a case of acute deterioration in facial and acoustic neuropathies after radiotherapy, with headache, vomiting, facial weakness, tinnitus, and hearing loss developing 2 days after treatment.

In patients in whom the tumor continues to grow after radiotherapy, salvage microsurgery may be necessary. There is some evidence that the surgical procedure becomes more difficult in patients with prior irradiation. For example, Friedman and colleagues (submitted for publication, 2004) compared 38 patients who presented for surgery after previous radiotherapy with a matched control group of patients with surgery as the primary treatment. The irradiated group was more likely to have moderate to severe adherence of tumor than the nonirradiated group (89% vs 63%;  $P \leq 0.01$ ) and had a higher rate of complete loss of facial function after surgery (House-Brackmann grade VI;  $P \leq 0.03$ ).

Irradiated tumor cells may re-enter the cell cycle because of induced mutations, potentially in genes regulating growth control, resulting in neoplasia. Although the projected risk of malignant tumor formation after radiation is low, a number of cases have been reported and are reviewed by Lee et al.,<sup>54</sup> including confirmation of a radiation-induced mutation in p53, a tumor suppressor gene. A clear association between low-dose brain irradiation in childhood and the subsequent development of benign and malignant brain tumors has been reported,<sup>55</sup> with latencies of 2 to 3 decades, and some of these reports have also been reviewed by Lee et al.<sup>54</sup>

## DISCUSSION

Regardless of method, treatment results for small acoustic tumors are generally good, and we typically recommend early intervention. Observation may be recommended in elderly patients, those in poor health, those with small tumors but already poor hearing, or those unwilling to undergo surgery or radiotherapy, however. For small tumors in patients with good hearing, we continue to recommend surgical removal for the best chance at preserving hearing and facial function over the long term. We use the middle fossa approach for tumors up to 2 cm in size in patients with serviceable hearing. We consider the translabyrinthine approach ideal for many lesions of the CPA in patients with poor hearing or no hearing, regardless of tumor size, and for most tumors larger than 2.5 cm, regardless of the status of hearing. Those who recommend radiotherapy usually do so for tumors less than 3 cm in diameter. We would add the indications of significant comorbidities or contraindications to surgery, the patient does not want surgery, and patient age older than 65 years with documented growth on serial MRI.

Microsurgery is usually recommended for all patients with large tumors (greater than 3-cm extracanalicular diameter), especially those causing brainstem compression with significant symptoms. There are many neurotologists and neurosurgeons who advocate surgical resection for all patients who are medically fit and not of advanced age. Conversely, many groups are promoting expanding the inclusion criteria for radiosurgical treatment of vestibular schwannomas. Advocates of expanding the role of radiotherapy often quote the decreased length of hospital stay, more rapid return to pretreatment function, and lower costs.

The debate surrounding this is partially fueled by some of the inherent limitations of the studies examining radiotherapy. Mean radiation dose at the tumor margin has decreased

from initial levels as high as 20 Gy down to doses as low as 12 Gy to 14 Gy. In addition, the use of MRI of the tumor margin and surrounding structures has allowed for more accurate dose planning. These advances in stereotactic radiotherapy have led to a significant decrease in cranial nerve morbidity. The long-term data that are currently available are from patients treated with higher doses of radiation than used in practice today, however. Whether or not lower dosing, which has reduced the morbidity of radiotherapy, provides the same long-term tumor control results is not yet known.

When trying to compare treatment methods, most data from microsurgical studies include tumors of all sizes, whereas radiotherapy trials primarily include small- to moderate-sized tumors. Treatment of large tumors, regardless of method, is associated with higher cranial nerve morbidity. Comparisons of microsurgical and radiosurgical published results may not adequately account for this selection bias. The lack of uniform criteria used to assess cranial nerve function and morbidity, particularly with regard to defining useful hearing, also makes comparisons difficult.

There is a potential for malignant degeneration of radiosurgically treated tumors and a risk, although low, of developing radiation-induced tumors. Patients opting for radiotherapy do not have a histologic diagnosis; thus, we do not definitively know whether this was the natural course of the tumor or if malignant degeneration was a result of radiation exposure. Although rarely reported, this potential exists and must be weighed strongly when offering radiotherapy to younger patients. In addition, patients should be counseled that when a tumor does continue to grow after radiotherapy, surgical removal might be more difficult.

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