Microanatomical variations in the cerebellopontine angle associated with vestibular schwannomas (acoustic neuromas)

Prakash Sampath, M.D., David Rini, M.F.A., and Donlin M. Long, M.D., Ph.D.
Departments of Neurological Surgery and Art as Applied to Medicine, Johns Hopkins School of Medicine, Baltimore, Maryland

Great advances in neuroimaging, intraoperative cranial nerve monitoring, and microsurgical technique have shifted the focus of acoustic neuroma surgery from prolonging life to preserving cranial nerve function in patients. An appreciation of the vascular and cranial nerve microanatomy and the intimate relationship between neurovascular structures and the tumor is essential to achieve optimum results. In this paper the authors analyze the microanatomical variations in location of the facial and cochlear nerves in the cerebellopontine angle (CPA) associated with acoustic neuromas and, additionally, describe the frequency of involvement of surrounding neural and vascular structures with acoustic tumors of varying size. The authors base their findings on their experience treating 1006 consecutive patients who underwent surgery via a retrosigmoid or translabyrinthine approach.

Between July 1969 and January 1998, the senior author (D.M.L.) performed surgery in 1022 patients for acoustic neuroma: 705 (69%) via the retrosigmoid (suboccipital); 301 (29%) via translabyrinthine; and 16 (2%) via middle fossa approach. Patients undergoing the middle fossa approach were excluded from the study. Patients were subdivided into three groups based on tumor size: Group 1 tumors (609 patients [61%]) were smaller than 2.5 cm; Group 2 tumors (244 patients [24%]) were between 2.5 and 4 cm; and Group 3 tumors (153 patients [15%]) were larger than 4 cm. Operative notes were analyzed for each patient. Relevant cranial nerve and vascular "involvement" as well as anatomical location with respect to the tumor in the CPA were noted. "Involvement" was defined as intimate contact between neurovascular structure and tumor (or capsule), where surgical dissection was required to free the structure. Seventh and eighth cranial nerve involvement was divided into anterior, posterior, and polar (around the upper or lower pole) locations. Anterior and posterior locations were further subdivided into upper, middle, or lower thirds of the tumor.

The most common location of the seventh cranial nerve (facial) was the anterior middle third of the tumor for Groups 1, 2, and 3, although a significant number were found on the anterior superior portion. The posterior location was exceedingly rare (< 1%). Interestingly, patients with smaller tumors (Group 1) had an incidence (3.4%) of the seventh cranial nerve passing through the tumor itself equal to that of patients with larger tumors. The most common location of the seventh cranial nerve complex was the anterior inferior portion of the tumor. Not surprisingly, larger tumors (Group 3) had a higher incidence of
involvement of sixth cranial nerve (41%), fifth cranial nerve (100%), ninth-11th cranial nerve complex (99%), 12th cranial nerve (31%), as well as superior cerebellar artery (79%), anterior inferior cerebellar artery (AICA) trunk (91.5%), AICA branches (100%), posterior inferior cerebellar artery (PICA) trunk (59.5%), PICA branches (79%), and the vertebral artery (93.5%). A small number of patients in Group 3 also had AICA (3.3%), PICA (3.3%), or vertebral artery (1.3%) vessels within the tumor itself.

In this study, the authors show the great variation in anatomical location and involvement of neurovascular structures in the CPA. With this knowledge, they present certain technical lessons that may be useful in preserving function during surgery and, in doing so, hope to provide neurosurgeons and neurootologists with valuable information that may help to achieve optimum cranial nerve outcomes in patients.

Key Words * vestibular schwannoma * acoustic neuroma * anatomy * microsurgical * cerebellopontine angle

Since Sir Charles Ballance first described the successful removal of an acoustic tumor in 1894,[4] surgeons have been challenged by lesions of the cerebellopontine angle (CPA) and have striven to improve outcomes in patients. In recent years, great advances in neuroimaging, cranial nerve monitoring, and microsurgery have shifted the focus of acoustic neuroma surgery from prolongation of patient life to preservation of cranial nerve function,[37] which has led to extraordinary improvements in patient outcomes, with reports from modern series of up to 90% postoperative normal or near-normal facial nerve function[1,3,19,22,25,33,36] and 40% hearing preservation.[2,7,12,15,16,21,23,27,34] A significant number of patients, however, still develop postoperative cranial nerve dysfunction. Consequently, further efforts to refine operative techniques and improve intraoperative monitoring to preserve maximum cranial nerve function continue to be made. This need is underscored by the challenge to the traditional treatment of acoustic tumors, which is gross-total microsurgical resection, by newer treatment strategies such as subcapsular partial removal,[20] conservative observation with serial imaging,[5] and radiosurgery.[8,9,14,26,39]

The difficulty in microsurgical removal of acoustic tumors can be attributed, in part, to the great anatomical variation in the location of cranial nerve and vascular structures associated with the tumor capsule in the CPA.[31] To date, attention has generally been directed to the location of cranial nerves distal to the tumor in the lateral aspect of the internal auditory canal (IAC) after removal of the posterior meatal wall (porus acusticus).[24,31,32,38] At this site, there is a consistent set of relationships of facial and vestibulocochlear nerves. The facial nerve can be identified anterior to the vertical creasae, separating the facial nerve from the superior vestibular nerve, and above the transverse plate, which separates the cochlear nerve and inferior vestibular nerve from the facial and superior vestibular nerves. Less attention has been given to the microanatomy of the brainstem surface facing an acoustic tumor.[28-30] Here again, consistent landmarks on the pons, medulla, and cerebellum, such as the pontomedullary sulcus, the foramen of Luschka, the flocculus, the cerebellopontine and cerebellomedullary fissures and nerve root entry zones of the glossopharyngeal, vagus, and accessory nerves, can be very helpful in identifying displaced cranial nerves on the medial aspect of the tumor capsule. It is in the CPA itself, however, that the greatest variation in cranial nerve displacement can be found, especially for the facial and cochlear nerves. Moreover, the paucity of consistent landmarks in this area can lead to inadvertent injury of these and other important neurovascular structures.[17,18]

The purpose of this paper is to identify the different anatomical locations of the facial and cochlear
nerves associated with the tumor capsule of acoustic tumors in the CPA. In addition, we describe the frequency of involvement of surrounding neural and vascular structures with acoustic tumors of varying size. This in-depth analysis is based on careful documentation of cranial nerve and vascular anatomy during microsurgical removal of acoustic tumors in 1006 patients over a 29-year period. With this knowledge, we outline a number of intraoperative techniques that can help surgeons avoid injuring cranial nerves. We hope to provide neurosurgeons and neurootologists with information that may be valuable in the surgical handling of these complex lesions and may allow for the best possible cranial nerve outcomes in patients.

**CLINICAL MATERIAL AND METHODS**

Between July 1969 and January 1998, the senior author (D.M.L.) performed microsurgical resection of acoustic neuromas in 1022 consecutive patients. The operative approach was described in detail for each patient and was dictated by the size of the tumor and the patient's preoperative hearing status. In patients with absent hearing and tumors of small-to-moderate size, a translabyrinthine approach was used. In patients with preserved hearing or moderate-to-large tumor size, a retrosigmoid or suboccipital approach was used. In selected patients with small intracanalicular tumors and intact hearing, a middle fossa approach was used. For this report, patients who underwent middle fossa approaches were not studied further because their tumors were small and located outside the CPA.

The remaining 1006 patients were divided in three groups according to tumor size. Group 1 included patients with tumors that were smaller than 2 cm in maximum dimension; Group 2 combined patients with intermediate-sized tumors from 2.5 to 4 cm; and Group 3 included patients with tumors that were larger than 4 cm in maximum dimension.

Lesions were resected by the senior author by using standard microsurgical technique. All patients undergoing suboccipital (retrosigmoid) approaches to their tumor underwent operation in the lateral (park-bench) position as described previously.[6,22,30,35] Translabyrinthine approaches were performed in conjunction with a neurootological team, as described elsewhere.[13]

At the time of operation, the frequency of adjacent cranial nerve and arterial and venous structure involvement with the tumor capsule was identified and documented. In addition, the exact anatomical location of the facial and cochlear nerves on the tumor capsule in the CPA was noted. Operative notes were analyzed for each patient when available. Involvement was defined as intimate contact between cranial nerve or vascular structure and the tumor capsule, where surgical manipulation or dissection was required to free the structure; neurovascular structures without actual adherence to the tumor were not documented. The cranial nerve type was confirmed by intraoperative monitoring (that is, facial nerve electromyography or brainstem auditory potential [BAEP] monitoring) whenever possible. Otherwise, identification of the cranial nerve was based, after careful inspection, on the impression of the surgeon.

Cochlear and facial nerve involvement was divided into anterior, posterior, and polar (around the upper or lower pole) locations. In addition, anterior and posterior locations were further subdivided into upper, middle, or lower thirds of the tumor capsule. When possible, the origin of the tumor from either the superior or inferior vestibular nerve was noted.

Occasionally, a cranial nerve or vessel was seen to pass through the tumor itself or to become completely enfolded by the tumor. In a minority of cases, the tumor also was seen to infiltrate into cranial nerve sheaths.
RESULTS

Of the 1006 patients studied over a 29-year period, 705 (70%) were treated via the suboccipital (retrosigmoid) approach, and 301 (30%) via the translabyrinthine approach. When tumor size was considered, 609 patients (61%) had small-sized tumors (Group 1); 244 (24%) had intermediate-sized tumors (Group 2); and 153 (15%) had large-sized tumors (Group 3). More tumors appeared to arise from the superior vestibular nerve (410 patients [40.75%]) than from the inferior vestibular nerve (372 patients [37%]), although this could not be determined in 224 patients (22.26%).

Frequency of Neural Involvement

Facial Nerve. The most common location of the facial nerve was on the anterior middle third of the tumor capsule, regardless of the tumor size (Fig 1).
In Group 1 patients, the facial nerve was found on the anterior middle portion of the tumor in 244 cases (40%); the anterior superior third in 204 (33.5%); the anterior inferior third in 30 (4.9%); the superior pole in 85 (14%); and the inferior pole in 15 (2.5%). The posterior location was rare and was found in only 10 patients (1.6%): five facial nerves (0.8%) were located on the posterior superior, two (0.3%) on the posterior middle, and three (0.5%) on the posterior inferior portion of the tumor. The facial nerve passed through the tumor itself in 21 patients (3.4%): 15 (2.5%) had tumor infiltrating the nerve sheath, whereas six (0.9%) had the tumor enfolding the nerve completely. In Group 2 patients, the facial nerve was found on the anterior middle portion of the tumor in 98 cases (40.2%); the anterior superior third in 81 (33.2%); the anterior inferior third in 12 (4.9%); the superior pole in 34 (13.9%); and the inferior pole in six (2.5%). Posterior location was found in six patients (2.5%): two facial nerves (0.8%) were located on the posterior superior, two (0.8%) on the posterior middle, and two (0.8%) on the posterior inferior portion of the tumor. The facial nerve passed through the tumor itself in seven patients (2.9%): three (1.2%) had tumor infiltrating the nerve sheath, whereas four (1.6%) had the tumor enfolding the nerve completely. In Group 3 patients, the facial nerve was found on the anterior middle portion of the tumor in 61 cases (39.8%); the anterior superior third in 50 patients (32.7%); the anterior inferior third in eight (5.2%); the superior pole in 21 (13.7%); and the inferior pole in four (2.6%). Posterior location was found in four patients (2.6%): two facial nerves (1.3%) were located on the posterior superior, one (0.65%) on the posterior middle, and one (0.65%) on the posterior inferior location. The facial nerve passed through the tumor itself in five patients (3.3%): four (2.6%) had tumor infiltrating the nerve sheath, whereas only one (0.65%) had the tumor enfolding the nerve completely.

**Cochlear Nerve.** The cochlear nerve, not surprisingly, was found on the anterior inferior portion of the tumor in the majority of cases (Fig. 2).
In Group 1, the cochlear nerve was on the anterior inferior third of the tumor in 468 patients (76.8%); the anterior middle portion in 73 (12%); and the inferior pole in 61 (10%). Posterior involvement occurred in six patients (9.8%) and only on the inferior third of the tumor. In no patient was there a superior pole or anterior superior location. Only one patient (1.6%) had tumor infiltrating the nerve. In Group 2, the cochlear nerve was on the anterior inferior third of the tumor in 188 patients (77%); the anterior middle portion in 30 (12.3%); and the inferior pole in 24 (9.8%). The nerve was located posteriorly in two cases (8.2%) on the inferior aspect. Again, the nerve was not encountered on the superior pole or anterior superior location in any patient. In Group 3, the cochlear nerve was on the anterior inferior third of the tumor in 118 patients (77.1%); the anterior middle portion in 26 (17%); and the inferior pole in nine (5.9%). The nerve was not encountered in a posterior, superior pole, or anterior superior location in any patient. Interestingly, the nerve did not pass through the tumor in any patient with a large- or intermediate-sized tumor.

**Trigeminal Nerve.** Trigeminal nerve involvement was quite rare in smaller tumors, occurring in only 36 (5.9%) of Group 1 patients. In contrast, 221 (90.6%) of Group 2 patients and all 153 (100%) of Group 3 patients had trigeminal involvement (Table 1).

<table>
<thead>
<tr>
<th>TABLE 1</th>
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<tbody>
<tr>
<td><strong>FREQUENCY OF INVOLVEMENT OF OTHER CRANIAL NERVES WITH THE TUMOR CAPSULE IN THE CPA IN 1006 PATIENTS WHO UNDERWENT SURGERY FOR ACOUTIC NEUROMA</strong></td>
</tr>
<tr>
<td><strong>Involved Nerve</strong></td>
</tr>
<tr>
<td>trigeminal</td>
</tr>
<tr>
<td>trochlear</td>
</tr>
<tr>
<td>hypoglossal</td>
</tr>
<tr>
<td>IX, X, XI complex</td>
</tr>
</tbody>
</table>

**Glossopharyngeal, Vagus, and Spinal Accessory Nerves.** Surprisingly, the ninth, 10th, and 11th complex of nerves was involved in 211 patients (34.6%) with small tumors (Group 1). In the tumors in Group 2 patients, involvement did not increase substantially and was encountered in 97 (39.8%), whereas in Group 3, almost all patients (151 [98.7%] of 153) had ninth, 10th, and 11th cranial nerve complex involvement.

**Trochlear Nerve.** Involvement of the fourth cranial nerve increased as a function of tumor size and was only seen in Group 2 (11 patients [4.5%]) and Group 3 (62 patients [40.5%]) tumors.

**Hypoglossal Nerve.** The 12th cranial nerve was encountered on the anterior medial inferior portion of the tumor capsule in 13 Group 2 tumors (5.33%), and 47 Group 3 tumors (30.7%).
**Frequency of Vascular Involvement**

**Superior Cerebellar Artery.** The superior cerebellar artery was involved with the tumor capsule only in Group 3 patients (121 [79.1%]).

**Anterior Inferior Cerebellar Artery.** The anterior inferior cerebellar artery (AICA) is the artery that is most closely associated with acoustic schwannomas (Table 2). The main trunk was adherent to the tumor capsule in one Group 1 patient (0.16%), 91 Group 2 patients (37.3%), and 140 Group 3 patients (91.5%). The AICA branches, which include the labyrinthine artery that supplies the meatal segment of the facial nerve, were encountered and surgically dissected in 243 Group 1 patients (40%), 141 Group 2 patients (57.8%), and all 153 Group 3 patients (100%). The AICA or its branches was noted to traverse through the tumor itself in five Group 2 and five Group 3 patients (2.1% and 3.3%, respectively).

**Posterior Inferior Cerebellar Artery.** The posterior inferior cerebellar artery (PICA) and its branches are important arteries to identify during surgery, because inadvertent injury can lead to serious neurological sequelae including lateral medullary syndromes (such as Wallenberg’s syndrome). The main trunk of PICA was not involved in small Group 1 tumors but was adherent to tumor capsules in 37 Group 2 and 91 Group 3 patients (15.2% and 59.5%, respectively). The PICA branches were involved in the tumors of 18 Group 1 (3%), 47 Group 2 (19.3%), and 121 Group 3 patients (79.1%). The PICA or its branches was seen to pass into the tumor itself only in large tumors (Group 3), which occurred in five cases (3.3%).

**Vertebral Artery and Basilar Trunk.** Involvement of the vertebral and basilar arteries increased as a function of tumor size and was only seen in Group 2 (54 cases [22.1%]) and Group 3 (143 cases [93.5%]) tumors. The vertebrobasilar artery was seen to pass through the tumor in only two cases (1.3%) of Group 3 patients.

**Bridging Petrosal Veins and the Vein of the Cerebellopontine Fissure.** Bridging petrosal veins adherent to tumor were encountered in no Group 1 (0%), 83 Group 2 (34%), and 148 Group 3 patients (97%) (Table 3). Sacrifice of this vein occurred in six (1%), 32 (13%), and 83 (54%) patients (Groups 1, 2, and 3, respectively). In Groups 1 and 2, sacrifice was always for control of hemostasis, not tumor removal; in Group 3, sacrifice was performed usually in the course of tumor removal. The vein of the

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**TABLE 2**

<table>
<thead>
<tr>
<th>Artery</th>
<th>Involved</th>
<th>Group 1 (609 patients)</th>
<th>Group 2 (244 patients)</th>
<th>Group 3 (153 patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCA</td>
<td>not seen</td>
<td>not seen</td>
<td>121 (79.1%)</td>
<td></td>
</tr>
<tr>
<td>AICA - main trunk</td>
<td>1 (0.16%)</td>
<td>91 (37.3%)</td>
<td>140 (92%)</td>
<td></td>
</tr>
<tr>
<td>AICA - branches</td>
<td>243 (40%)</td>
<td>141 (56%)</td>
<td>153 (100%)</td>
<td></td>
</tr>
<tr>
<td>AICA - intratumoral</td>
<td>not seen</td>
<td>5 (2.1%)</td>
<td>5 (3.3%)</td>
<td></td>
</tr>
<tr>
<td>PICA - main trunk</td>
<td>not seen</td>
<td>37 (15.2%)</td>
<td>91 (59.5%)</td>
<td></td>
</tr>
<tr>
<td>PICA - branches</td>
<td>18 (3%)</td>
<td>47 (19.3%)</td>
<td>121 (79.1%)</td>
<td></td>
</tr>
<tr>
<td>PICA - intratumoral</td>
<td>not seen</td>
<td>not seen</td>
<td>5 (3.3%)</td>
<td></td>
</tr>
<tr>
<td>VA/BA</td>
<td>not seen</td>
<td>54 (22.1%)</td>
<td>143 (93.5%)</td>
<td></td>
</tr>
<tr>
<td>VA/BA - intratumoral</td>
<td>not seen</td>
<td>not seen</td>
<td>2 (1.3%)</td>
<td></td>
</tr>
</tbody>
</table>

* SCA = superior cerebellar artery; VA/BA = vertebral and basilar arteries.
cerebellopontine fissure was involved in 67 patients (11%) in Group 1, 163 (67%) in Group 2, and 153 (100%) in Group 3.

**TABLE 3**

<table>
<thead>
<tr>
<th>Involved Venous Structure</th>
<th>Group 1 (609 patients)</th>
<th>Group 2 (244 patients)</th>
<th>Group 3 (153 patients)</th>
</tr>
</thead>
<tbody>
<tr>
<td>petrosal veins</td>
<td>not seen</td>
<td>83 (34%)</td>
<td>148 (97%)</td>
</tr>
<tr>
<td>sacrificed</td>
<td>6 (1%)</td>
<td>73 (30%)</td>
<td>83 (54%)</td>
</tr>
<tr>
<td>vein of the CP fissure</td>
<td>67 (11%)</td>
<td>163 (67%)</td>
<td>153 (100%)</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Acoustic neuromas are closely related to the CPA. The CPA is a distinct V-shaped anatomical area with boundaries formed by the folding of the cerebellum around the pons and medulla and with the middle cerebellar peduncle as its floor.[30] As the cerebellum folds around the pons, it forms two clefts that comprise the superior and inferior limbs of the cerebellopontine fissure. The two limbs merge laterally to form an apex that represents the lateral extent of the CPA. Important cranial nerves arise from the pontomedullary junction just anterior to the limbs of the cerebellopontine fissure, including the facial and vestibulocochlear nerves inferiorly and the trigeminal nerve superiorly. In addition, the AICA bifurcates in this region to form a rostral and caudal trunk that encircles the pons and sends branches to the nerves entering the IAC.

We have shown that, regardless of tumor size, the facial nerve can traverse any aspect of the tumor capsule in the CPA, but it is most commonly found anterior to the tumor in the middle third of the capsule. In a minority of cases the facial nerve may pass through the tumor itself. Interestingly, the frequency with which this occurs is not a function of tumor size and is seen equally in small and in large tumors. This great variability of facial nerve location in acoustic neuromas has important implications for safe microsurgical resection and preservation of facial nerve function postoperatively. First, because the exact location of the facial nerve on the tumor capsule in the CPA is unpredictable, internal tumor debulking should proceed cautiously. We believe that the tumor can be entered most safely through a small opening in the capsule posteriorly in the middle portion (the least frequently used location). Tumor debulking should proceed with caution given the small, but not insignificant, incidence of the facial nerve passing through the tumor itself. A facial nerve stimulator can sometimes provide added reassurance that the tumor capsule has been penetrated safely. The tumor should only be debulked to the point at which gentle retraction of the capsule does not place undue traction on surrounding neurovascular structures. At this point, identification of cranial nerves should become a priority.

It is therefore essential that dissection proceeds from known to unknown structures. If preservation of hearing is not a consideration and a translabyrinthine approach is being performed, identifying the facial nerve laterally near the lamina spiralis may allow better appreciation of its relationship with the tumor. If preservation of hearing is a consideration, it is sometimes easier to identify the facial nerve medial to the tumor on the brainstem surface at the zone of nerve root entry, although this is not always possible in larger tumors until considerable debulking has been performed. In the ideal circumstance, the proximal and distal portions of the facial nerve should be identified before dissecting it away from the tumor capsule. Because most of the microvascular blood supply to the facial nerve is in the subarachnoid space,
it is important that dissection of the nerve from the capsule proceed in the correct plane. Overly aggressive dissection of the tumor capsule from the nerve may strip it of its vital microvascular blood supply and lead to postoperative nerve dysfunction.

In the rare circumstance in which the facial nerve is seen passing through the tumor itself, it is necessary to determine whether the tumor is actually infiltrating the nerve sheath or simply enfolding it. In the former case, it is virtually impossible to dissect the tumor away from the nerve completely without causing considerable postoperative deficit. Therefore, we advocate sectioning of the entire nerve segment infiltrated by tumor, followed by immediate primary epineural neurorrhaphy. If immediate repair is not technically feasible, then early postoperative facial nerve reconstruction should be considered.[33] If the tumor enfolds the facial nerve, careful inspection should identify a plane at which the two capsular surfaces are interposed. This avascular plane can then be developed with blunt dissection, eventually freeing the nerve along its entire course through the tumor.

The cochlear nerve has less anatomical variation than the facial nerve and is most frequently found in the anterior inferior portion of the tumor capsule. We show that this nerve is never found in superior location, regardless of tumor size. Furthermore, it is exceedingly rare that the cochlear nerve passes through the tumor itself. In recent years much attention has been placed on attempts to preserve hearing in patients with good-to-moderate preoperative function,[2,7,12,16,23,27,34] especially regarding the inverse relationship between the size of acoustic tumors and postoperative hearing outcome.[12,27,40] In our experience, we find that preservation of functional hearing is a realistic goal even in patients with larger tumors (Groups 2 and 3), but predicting the patient's ultimate hearing status on the basis of anatomical preservation of the cochlear nerve and intraoperative BAEP monitoring is much less predictable. We have had circumstances in which the cochlear nerve is dissected completely free and BAEPs have remained unchanged, only to discover that the patient has poor postoperative hearing. Likewise, a very adherent cochlear nerve that requires considerable surgical manipulation to dissect free with loss of intraoperative BAEPs can sometimes result in remarkable preservation of hearing postoperatively.

Irrespective of the tumor size, however, anatomical preservation of the cochlear nerve should remain a goal of acoustic neuroma surgery when suboccipital (retrosigmoid) approaches are undertaken.[27,34] To this end, we believe the cochlear nerve is best first identified on the medial aspect of the tumor capsule on the brainstem surface. Attempts should then be made to identify the nerve in the IAC, where its location is anterior and below the transverse crest, and finally to follow the nerve along the inferior portion of the tumor capsule. Again, it is important to achieve adequate tumor debulking to minimize traction injury to the nerve from capsular retraction. We agree with previous authors that tumor consistency is not an important factor in preserving cochlear nerve function.[27,34] We also find that the cochlear nerve is particularly susceptible to thermal injury. Therefore, we avoid overly cold irrigation and minimize use of the laser, a tool that has become increasingly popular in recent years,[10,11] especially for use in very vascular tumors. If the laser is used, it is important to use cool intermittent irrigation with continuous suction of the laser plume.

Involvement of other cranial nerves with acoustic neuromas, not surprisingly, increases with larger tumor size (Table 1). We find that the trigeminal nerve is adherent to the tumor capsule in a minority of cases, and even if postoperative dysfunction is observed, minor loss of facial sensation in the postoperative period is usually well tolerated. Nevertheless, care should be taken to preserve the trigeminal nerve motor fibers, which generally represent the inferior portion of the third division of the nerve. An
Electromyography stimulator can help to identify these fascicles. The trochlear and hypoglossal nerves are also identifiable somatic motor nerves that are associated with larger acoustic tumors. In our experience, these nerves usually can be dissected free of the tumor capsule anatomically intact and rarely lead to significant postoperative dysfunction.

In contrast, the glossopharyngeal, vagus, and spinal accessory nerves pose a much more difficult problem during acoustic neuroma surgery. We find, even in small tumors, a third of acoustic tumors have fascicles of the ninth, 10th, and 11th cranial nerve complex involving the capsule, and even if these are preserved anatomically, temporary postoperative salivation and taste dysfunction, swallowing difficulty, microaspiration, and hoarseness are quite common. As a result, we recommend careful postoperative evaluation of glossopharyngeal and vagus function even in patients with small tumors. Oral alimentation should proceed cautiously and be withheld in any patient for whom aspiration is a concern. If hoarseness or swallowing problems persist several days after surgery, it is important to formally evaluate the vocal cords with fiberoptic laryngeal examination and cineesophagram prior to discharge from the hospital.

Preservation of surrounding arteriovenous structures in the CPA is also of great importance when performing acoustic neuroma microsurgery. Whereas avoidance of injury to the main trunks of the AICA, superior cerebellar artery, PICA, and vertebrobasilar system is self-evident, the question of whether their smaller branches can be safely sacrificed poses a much more formidable challenge to the surgeon. In our experience, most small branch vessels are end arteries that terminate in the tumor, which can be safely coagulated and cut after careful inspection to ensure no surrounding territory is supplied. The exception to this rule is for AICA branches that pass into the IAC and often contain the labyrinthine artery that supplies the temporal and meatal segments of the facial nerve in the IAC before the geniculate ganglion.[18,31,36] Interruption of this blood supply can lead to often permanent severe postoperative facial nerve dysfunction. The most difficult situation is encountered when a vital artery penetrates the tumor itself. This was seen in a minority of cases (Table 3), with increasing frequency in larger tumors. In some patients the tumor simply enfolds the artery entirely and can be dissected free, as described previously. In the rare circumstance in which an important penetrating artery cannot be liberated, it may be necessary to leave a small portion of tumor along the arterial wall. Unfortunately, these patients almost always require further treatment.

Finally, the venous structures most closely associated with acoustic neuromas are the petrosal veins, which are bridging veins that empty into the superior petrosal sinus, and the vein of the cerebellopontine fissure, which passes from the petrosal surface of the cerebellum above the facial and vestibulocochlear nerves to join tributaries of the superior petrosal sinus.[30,31] We find that sacrifice of bridging petrosal veins rostral to the tumor capsule can be accomplished safely, and we do this routinely in larger-sized tumors (Table 3). Small acoustic tumors (Group 1) rarely require sacrifice of petrosal veins. More care should be taken, however, with the vein of the cerebellopontine fissure. This large vein, which is formed by the convergence of several veins draining the petrosal surface of the cerebellum, is most frequently encountered around the superior pole of the tumor capsule and, if sacrificed, may lead to cerebellar venous infarction and secondary cerebellar hemorrhage.

In summary, we establish the exceptional anatomical variation in the location of the facial and cochlear nerves and also show the frequency of involvement of cranial nerves and vascular structures in the CPA. An appreciation of these topographical relationships can be important in avoiding postoperative cranial nerve or neurological dysfunction after microsurgical resection. This study, based on a large group of patients, is important to neurosurgeons and neurootologists, particularly in light of emerging alternative
treatment options such as radiosurgery. We believe that, with a thorough understanding of the pathophysiological mechanisms and origin of cranial nerve injury,[36] and practical application of the anatomical variability discussed in this paper, microsurgery should allow cure with preservation of cranial nerve integrity for most patients with acoustic neuromas.

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Address reprint requests to: Donlin M. Long, M.D., Ph.D., Department of Neurological Surgery, Meyer 7-109, The Johns Hopkins Hospital, Baltimore, Maryland 21287-7709. email: psamp@welchlink.welch.jhu.edu.