Am J Otolaryngol
5:270–280, 1984

Radiologic Evaluation of Eighth Nerve Tumors

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The refinement of surgical techniques for removal of acoustic neuromas by use of the surgical microscope and the discovery of new surgical approaches to the internal auditory canal have motivated attempts to diagnose these lesions earlier. In the past, an acoustic neuroma was not suspected until it involved multiple cranial nerves and caused an increase in intracranial pressure or an elevation of the cerebrospinal fluid protein level. Currently, the possibility of an acoustic neuroma is considered in all patients with unilateral sensorineural hearing loss or vestibular loss of unknown origin.

The insidious nature of this tumor probably explains its diagnosis, in many patients, only after it has reached a size that would make complete extracapsular removal very hazardous or impossible. Physicians, and especially otologists, should be aware of this fact and remember that as many as 10 per cent of unilateral hearing and vestibular losses are produced by acoustic neuromas. Only by routine audiometric, vestibular, and radiologic screening in all cases of unilateral sensorineural hearing or vestibular loss can these lethal tumors be discovered early enough to permit complete removal by a relatively safe surgical procedure.

PATHOLOGIC FEATURES

According to the literature, acoustic neuromas account for approximately 8 per cent of all intracranial tumors and for 80 per cent of cerebellopontine angle tumors.[1,2] In the series of more than 1,200 surgically proved tumors of the cerebellopontine angle described in this article, 90 per cent were acoustic neuromas.

At least two thirds of eighth cranial nerve tumors originate from the vestibular division of the nerve and less than one third from the cochlear portion. Most, but not all, acoustic neuromas originate within the internal auditory canal, presumably at the junction between the neurilemmal sheath and the neuroglial fibers extending peripherally from the brainstem.

SYMPTOMATOLOGY

Owing to the presence of the subarachnoid space within the internal auditory canal and in the cerebellopontine cistern, acoustic neuromas do not produce appreciable symptoms in the early stages. As the tumor grows and impinges on the nerves and vessels, clinical manifestations begin to appear. Tumors arising within the internal auditory canal, where the subarachnoid space is relatively small, become symptomatic much earlier than tumors arising in the cerebellopontine cistern, which often reach voluminous dimensions before producing clinical manifestations.

Early symptoms result from impairment of eighth cranial nerve function. Usually, unilateral sensorineural hearing loss is followed by slight dizziness or imbalance and, less frequently, by true vertigo. In some cases, however, the vestibular involvement may precede the auditory findings. The hearing loss is slowly progressive, as the nerve adapts to the pressure of the expanding lesion. Tumor compression of the internal auditory arteries or veins ultimately occurs and produces ischemia or hydrops of the inner ear, with a sudden decrease in hearing acuity. Seventh cranial nerve dysfunction is rarely an early sign because the motor fibers of the facial nerve are quite resistant to pressure. As the tumor grows outside the internal auditory canal into the cerebellopontine cistern, the adjacent cranial nerves become involved. In the series described in this article, involvement of the fifth cranial nerve, with diminished corneal reflexes and, sometimes, numbness of the face, was present in approximately 30 per cent of the cases.

Received December 12, 1983, from the Departments of Radiology and Otolaryngology-Head and Neck Surgery, University of Illinois Eye and Ear Infirmary, Chicago; accepted for publication January 18, 1984.

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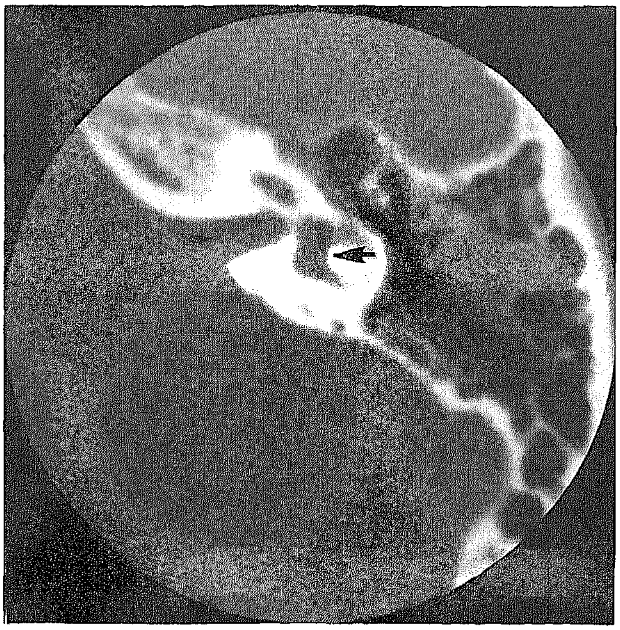
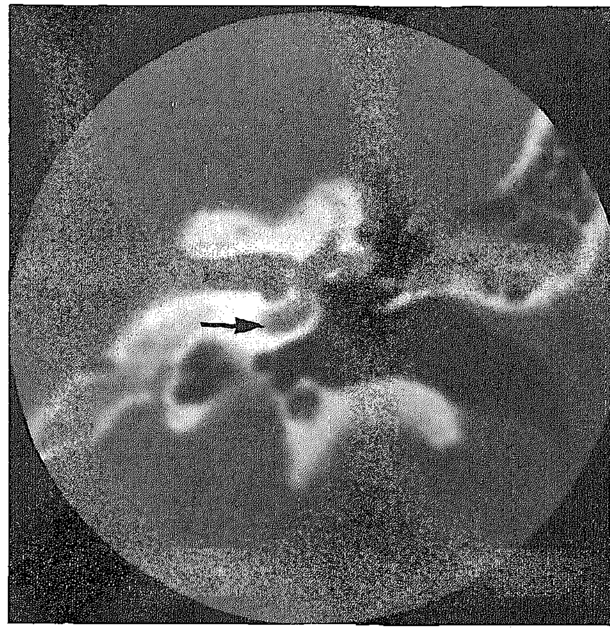



Figure 1 (left). Axial CT section of a normal left petrous pyramid at the level of the internal auditory canal (*arrowhead*). Arrow indicates vestibule.

Figure 2 (right). Coronal CT section of a normal left ear. The crista falciformis is visible within the lateral portion of the internal auditory canal (*arrowhead*). Arrow indicates cochlea.

NORMAL INTERNAL AUDITORY CANAL AND CEREBELLOPONTINE CISTERN

Clear knowledge of the normal anatomy is essential for the recognition and appraisal of pathologic changes.

Anatomy

The petrous pyramids lie in the skull base at approximately 45 degrees to the sagittal plane. The internal auditory canal enters the petrous pyramid from its posteromedial surface at the junction of the anterior two fifths with the posterior three fifths of the long axis of the pyramid. The long axis of the canal forms a right angle with the sagittal plane of the skull and an angle of about 45 degrees with the long axis of the petrous pyramid (Fig. 1).

The internal opening, or porus, of the canal is shaped much like the bevel of a needle, with its maximum diameter in the same axis as the petrous pyramid. The posterior, superior, and inferior lips of the porus are prominent and are composed of dense bone; the anterior lip is usually poorly demarcated, such that the anterior wall of the canal blends smoothly with the posteromedial wall of the petrous apex. A well-defined cortical or capsular line surrounds the lumen of the canal.

The internal auditory canal contains the facial nerve, the nervus intermedius, the acoustic nerve (which divides within the canal into its cochlear and vestibular portions), and the internal auditory artery. All three nerves are enclosed within a common sheath. Occasionally, the anteroinferior cerebellar artery loops into the internal auditory canal.

The lateral end of the canal is closed by a vertical plate (lamina cribrosa). Arising from the lamina cribrosa is a horizontal crest (crista falciformis), which divides the lateral part of the internal auditory canal into two unequal portions, with the inferior portion being the larger (Fig. 2). Beneath the crista falciformis are three sets of foramina: the anterior foramina for the cochlear nerve; a posterior opening for the singular nerve, which terminates at the ampulla of the posterior semicircular canal; and a lateral set for the branches of the inferior vestibular nerve to the saccule. Above the crista falciformis are two groups of foramina: the anterior for the facial nerve and nervus intermedius, and the posterior for the superior vestibular nerve, which terminates in the utricle, saccule, and lateral and superior semicircular canals. A vertical bony ridge (Bill's bar) separates the facial from the vestibular nerve.

To establish the limits of normal variation among individuals, the internal auditory canals were measured in 100 anatomic specimens and on 400 coronal tomograms from patients who

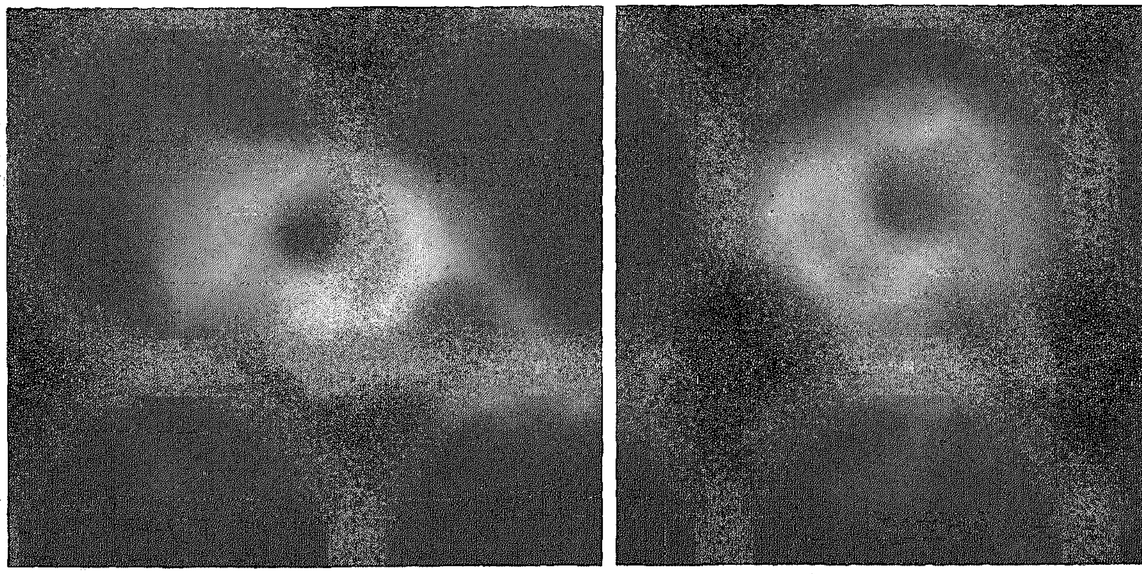


Figure 3. Left acoustic neuroma. *Right*, lateral tomographic section of the left internal auditory canal; *left*, comparison view of the normal right side. The left internal auditory canal is enlarged, and the cortical outline of its posterior wall is eroded.

had undergone radiographic examinations for conditions unrelated to the internal auditory canal.[3,4]

SHAPE. Four shapes were identified: 1) straight (less than 1 mm difference in diameter), in 50 per cent of the cases; 2) oval (midportion 1 mm or more larger than the medial and lateral ends), in 20 per cent of the cases; 3) narrowed medially, in 25 per cent of the cases; and 4) wide medially, in 5 per cent.

VERTICAL DIAMETER. This measurement ranged from 2 to 10 mm (average, 5 mm). However, in more than 90 per cent of the cases, the difference in vertical diameters between the internal auditory canals on the two sides in the same subject did not exceed 1 mm.

LENGTH OF THE POSTERIOR WALL. This length was measured as the shortest distance between the lamina cribrosa and the medial concave lip of the posterior canal wall. It ranged from 4 to 14 mm (average, 8 mm). In more than 90 per cent of the subjects, the difference in length between the two sides did not exceed 2 mm.

CRISTA FALCIFORMIS. This structure is extremely variable in length and thickness but is always located at or above the midpoint of the vertical diameter of the internal auditory canal. In more than 90 per cent of the cases, the difference in the positions of the cristae on the two sides, measured from the cristae to the superior and inferior walls of the canals, did not exceed 1 mm.

The cerebellopontine cisterns are lateral, symmetric extensions of the pontine cistern. Close to its base, each cistern divides into two branches. The main branch, which varies considerably in size, extends along the posteromedial aspect of the petrous pyramids. This branch may be so small as to reach only the porus of the internal auditory canal or large enough to extend to the vertical portion of the sigmoid sinus. Most commonly, the cistern extends to a plane crossing the vestibule. The smaller branch of the cistern enters the internal auditory canal and completely lines its walls.

The acoustic nerve exits from the brainstem at the cerebellopontine recess formed by the junction of the pons, medulla, and cerebellum 2 to 4 mm posterior to the facial nerve. The two nerves cross the subarachnoid space and merge, at the porus of the canal, with the internal auditory artery to form a single neurovascular bundle. The anteroinferior cerebellar artery also enters the cerebellopontine cistern, where it forms its loop and is closely related to the seventh and eighth cranial nerves. The loop reaches the porus of the canal without entering it in about 25 per cent of persons and actually enters the internal auditory auditory canal in 15 per cent.[5]

RADIOGRAPHIC DIAGNOSIS

Even the most sophisticated audiometric and neurologic studies are far from consistently reliable for the diagnosis of space-occupying lesions in the internal auditory canal and cerebellopontine cistern. In the final analysis, the pres-

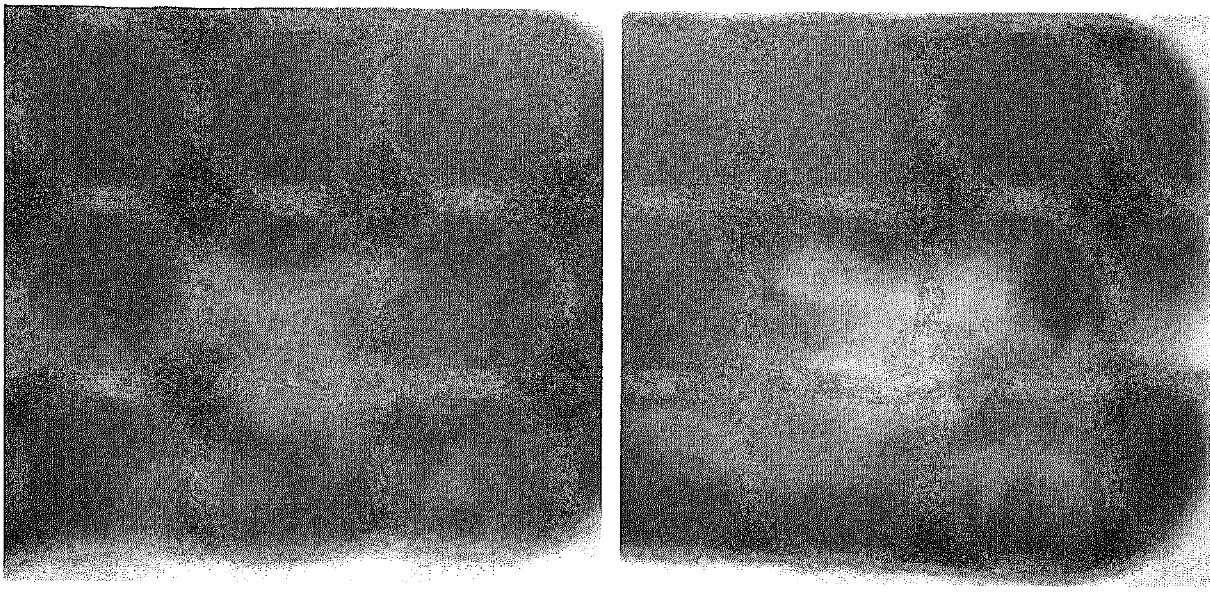


Figure 4. Right acoustic neuroma. *Left,* coronal tomographic sections of the right internal auditory canal; *right,* comparison view of the normal left side. Enlargement of the right internal auditory canal and increased distance between the crista falciformis and the canal floor are evident. This is indicative of a tumor arising in the inferior compartment of the canal.

ence or absence of an acoustic neuroma must be proved either radiographically or by surgical exploration. The task of the radiologist, however, is not confined to detection of the presence or absence of a tumor but extends to establishing the exact size of the lesion, which is important in determining the type of surgical approach that will be used.

Radiographic assessment of the cerebellopontine cistern and internal auditory canal consists of screening and diagnostic tests. Screening tests are used for the evaluation of the internal auditory canals and diagnostic tests for the actual demonstration of the tumor mass.

Screening Tests

CONVENTIONAL RADIOGRAPHY. On the basis of anatomic considerations, the frontal projection is best for the study of the internal auditory canal in its full length. I prefer a transorbital view, obtained with a small cone centered on each orbit in the anteroposterior projection. In the Stenvers view, the porus of the internal auditory canal is well visualized en face, but the canal itself is foreshortened. Unfortunately, conventional radiography is unsatisfactory unless the bone erosion from tumor is extensive, because superimposition of other structures makes recognition of the normal or altered walls of the internal auditory canal difficult or impossible. This is particularly true when the petrous pyramids are extensively or asymmetrically pneumatized.

TOMOGRAPHY. Either a multidirectional tomographic unit or a late-generation computed tomographic (CT) scanner must be used. Tomography should always be performed on both sides for the purposes of comparison, since differences between the two canals in size and shape are more meaningful than absolute measurements. In addition, the study should be performed in two planes, since the second projection may demonstrate that an asymmetry noticed in one plane is due merely to rotation of the long diameter of the canal. Whenever multidirectional tomography is used, the study should include coronal and sagittal sections 2 mm apart. If CT scanning is used, the examination should consist of targeted axial and coronal sections at 1.5-mm increments.

The internal auditory canal is considered abnormal[6] whenever the following features are present: 1) erosion of the cortical or capsular line surrounding the lumen of the canal (Fig. 3); 2) widening of 2 mm or more of any portion of the internal auditory canal under investigation in comparison with the corresponding segment of the opposite canal (Figs. 4 and 5); 3) shortening of the posterior wall by at least 3 mm in comparison with the opposite side (Fig. 6); and 4) situation of the crista falciformis closer to the inferior than to the superior wall of the internal auditory canal or a difference in position of 2 mm or more from the normal side.

A tomographic study is considered suggestive of, but not conclusive for, a tumor whenever the

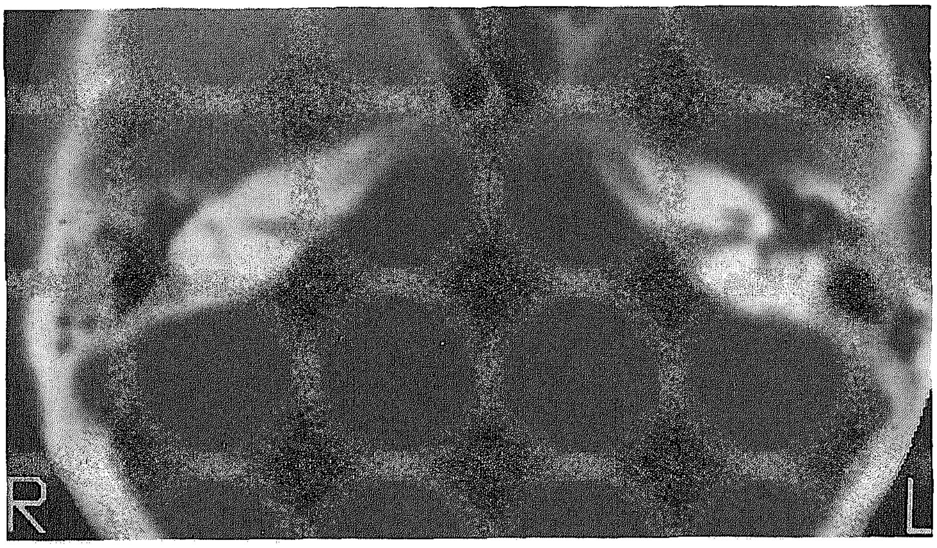


Figure 5. Left acoustic neuroma. Axial CT section demonstrating funnel-shaped enlargement of the left internal auditory canal.

following characteristics are present: 1) demineralization of the cortical outline of the canal; 2) widening of 1 to 2 mm of any portion of the canal in comparison with the corresponding segment of the opposite side; 3) shortening of the posterior wall by 2 to 3 mm; and 4) position of the crista falciformis of the side under investigation differing by at least 1 mm from that of the normal side.

Diagnostic Tests

On the basis of tomographic study results, it is decided whether to perform CT scanning with infusion and cisternography, which constitute the final and most conclusive diagnostic tests. These studies are performed in the following situations: 1) when the tomographic examination has demonstrated an abnormal internal auditory canal, regardless of the result of the audiometric tests; 2) when the results of the different audiometric tests strongly suggest a retrocochlear lesion, whatever the tomographic examination result; 3) when the borderline findings of a tomographic study are coupled with questionable audiometric results.

COMPUTED TOMOGRAPHY. Computed tomography is a noninvasive technique and is done on an outpatient basis. Two series of scans are usually obtained, one prior to and a second after infusion of contrast material.[7] The first series shows the indirect signs of a large tumor mass, such as displacement of the fourth ventricle, narrowing of the opposite cerebellopontine cistern

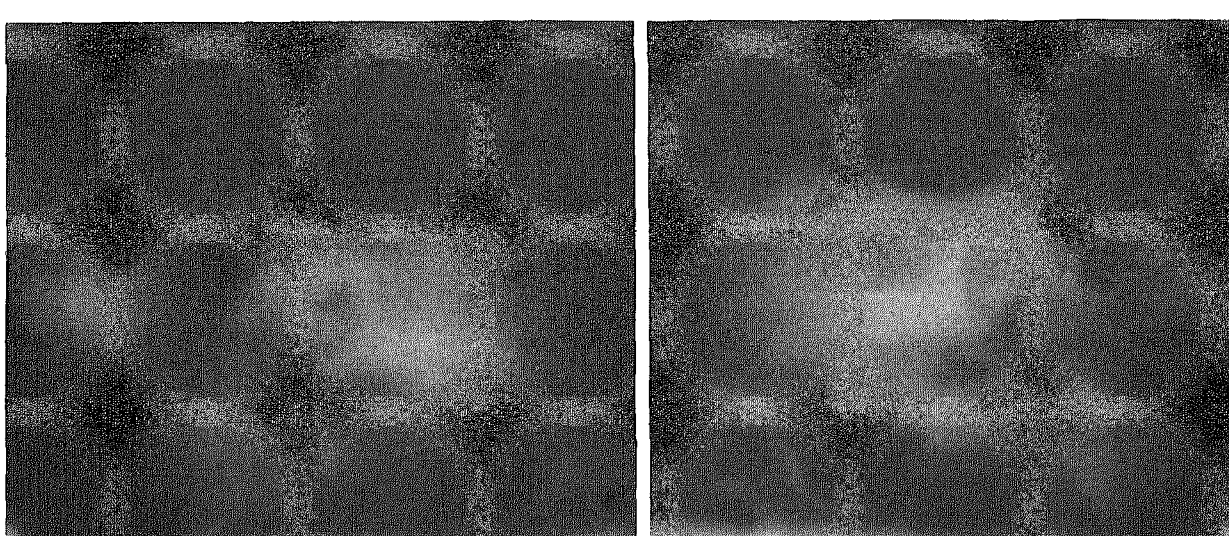


Figure 6. Left acoustic neuroma, coronal tomographic sections. The posterior wall of the left internal auditory canal is partially eroded and far shorter than the right.

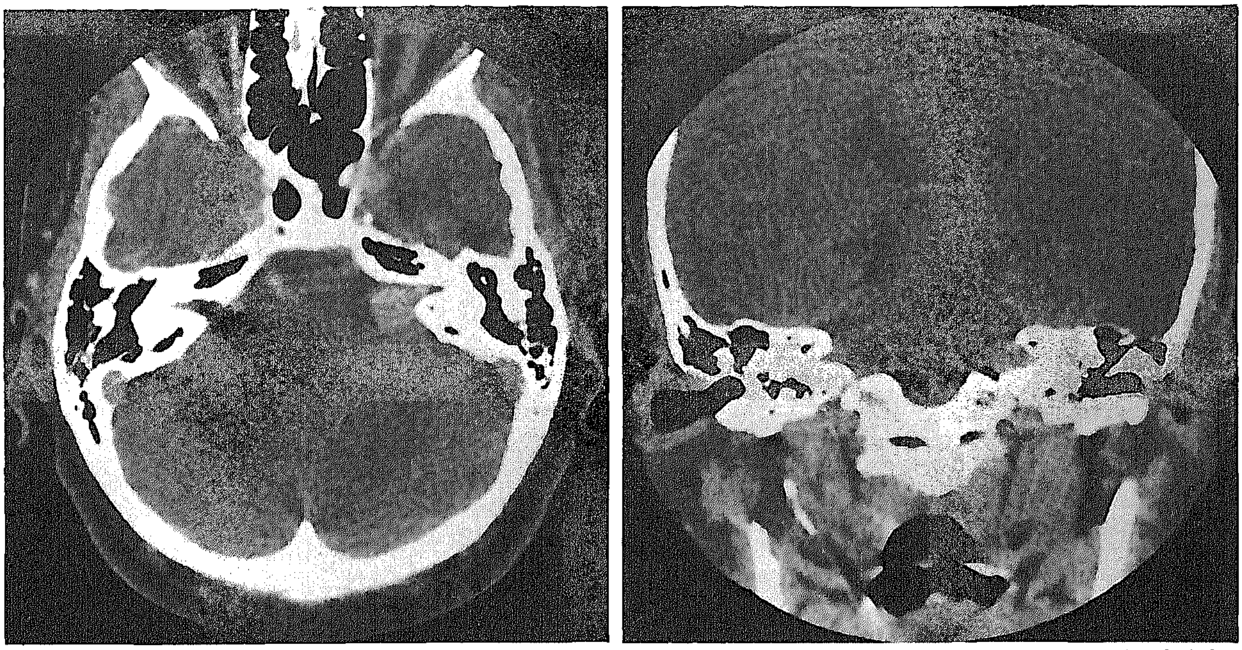


Figure 7. Left acoustic neuroma. *Left,* axial CT section; *right,* coronal CT section. The enhanced tumor mass fills the slightly dilated left internal auditory canal and protrudes into the adjacent cerebellopontine cistern.

by the displaced brainstem, and obstructive hydrocephalus. The tumor mass is usually not recognizable, since its density is quite similar to that of the surrounding brain structures.

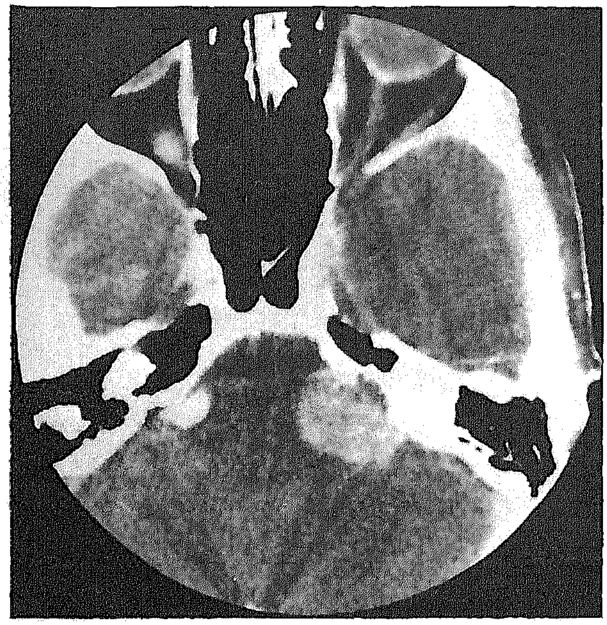
The second series of scans is obtained after the infusion of 300 ml of iodinated contrast material. Since the enhancement of the tumor is usually slow, this series should be obtained not during the infusion but rather 15 to 30 minutes after completion of the infusion. The tumor appears as a well-defined mass enhanced by the contrast medium and not surrounded by edema (Figs. 7 and 8). Often, an area of decreased absorption is noticed within the mass due to central necrosis of the lesion. Cystic tumors are not common but have been observed (Fig. 9). With a late-generation CT scanner, it is possible to visualize tumors as small as 8 mm, if they project from the canal into the cerebellopontine cistern. Entirely intracanalicular lesions are recognizable only if the internal auditory canal is grossly enlarged.

For precise evaluation of the size and extent of the tumor, both axial and coronal sections should be obtained. This is particularly important in large lesions. Axial or horizontal sections provide useful information about the medial and posterior aspects of the tumor and the coronal sections about the superior and inferior extension. Involvement of the tentorium, fifth cranial nerve, tentorial notch, and jugular fossa are best seen in coronal sections.

CISTERNOGRAPHY. Cerebellopontine cisternography and canalography are the final and most conclusive tests in the diagnosis of acoustic neuromas. These tests are performed whenever the infusion CT examination is negative or questionable.

Currently, three methods are used for cisternography of the cerebellopontine angle: 1) iophendylate (Pantopaque) cisternography; 2) CT pneumocisternography; and 3) CT opaque cisternography with hydrosoluble metrizamide.

Iophendylate cisternography. This technique was the procedure of choice prior to the refinement of computed tomography, and it is still performed whenever a high-definition scan is not available.[6,8] Via lumbar puncture, 2 to 3 ml of iophendylate are injected into the subarachnoid space. Under fluoroscopic control, the contrast material is advanced into the posterior cranial fossa by tilting the table into the Trendelenburg position. During this maneuver, the patient is kept in a lateral decubitus position so that the contrast material will collect in the cerebellopontine cistern on the dependent side. Cross-table views with a horizontal x-ray beam are first obtained in the Towne and submental vertex positions. When the internal auditory canals are well visualized and filled normally with contrast material, the study is terminated and considered negative. If the internal auditory canals and cerebellopontine cisterns are not satis-



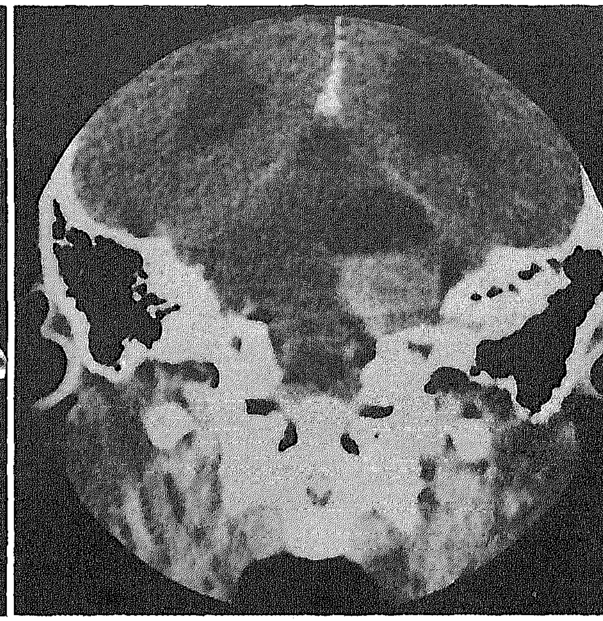


Figure 8 (left). Left acoustic neuroma, axial CT section. The large enhanced tumor mass erodes the posterior aspect of the petrous pyramid.

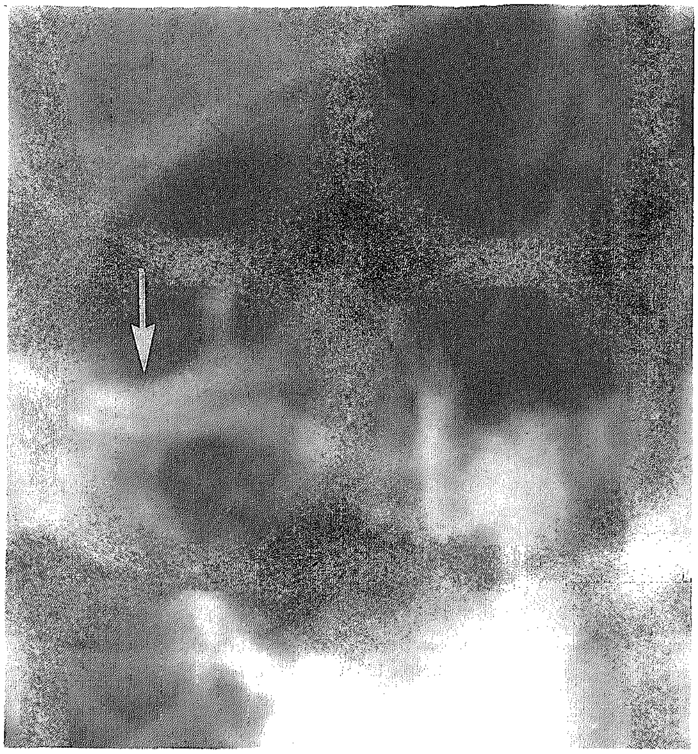
Figure 9 (right). Left acoustic neuroma. Coronal CT section demonstrating that the upper half of the large tumor mass is cystic. The dilation of the lateral ventricles is due to obstructive hydrocephalus.

factorily visualized or if a lesion is demonstrated, the patient's head is rotated first to a Stenvers-like position and then face down (Fig. 10). Several spot films are obtained with varying degrees of rotation, flexion, and extension of the head. In some institutions, iophendylate cisternography is performed without fluoroscopy. After injection of iophendylate, the patient is placed in the Trendelenburg position on the multidirectional tomographic table, and the tomograms are obtained in several projections.

Intracanalicular tumors usually obstruct the internal auditory canal and produce a cutoff of the radiopaque column (Fig. 11). The lateral cutoff margin outlines the medial surface of the tumor and forms a concave contour facing laterally. Whenever the tumor extends into the cistern and the cisternal mass is less than 1.5 cm in diameter, the contrast material that infiltrates between tumor, cerebellum, and brainstem clearly outlines the entire lesion (Fig. 12). If the tumor is larger and adjacent or adherent to the brainstem and cerebellum, however, the contrast material cannot outline the medial aspect of the mass, making determination of the size of the tumor difficult. In these situations, it is not unusual for the radiologist to underestimate the actual size of the tumor mass.

CT pneumocisternography. Computed tomographic pneumocisternography requires use of a high-definition scanner and 1.0- or 1.5-mm sections. Via lumbar puncture, 2 to 4 ml of air are injected into the subarachnoid space with the patient in a lateral decubitus position lying on the normal side.[9,10] Oxygen or carbon dioxide is often used rather than air, since they cause fewer headaches after the examination owing to their faster absorption. Following injection, the patient is instructed to lift the head and torso while resting on the elbow for 15 to 30 seconds. At the same time, the chin is tilted upward so that the air ascends into the cerebellopontine angle. As soon as the air enters the posterior cranial fossa and cerebellopontine cistern, the patient usually complains of sudden pressure and pain in the region of the ear. The head is then lowered, and, following scout view centering, four to eight sections are obtained at 1.0- or 1.5-mm increments. If the sections obtained are satisfactory, the patient is instructed to turn rapidly into a prone position and then onto the opposite side. After waiting one or two minutes to allow the air to ascend into the other, and now higher, cerebellopontine cistern, the scan is repeated with the same modalities.

When no tumor is present, the air outlines the contours of the internal auditory canal and cistern. The seventh and eighth cranial nerves



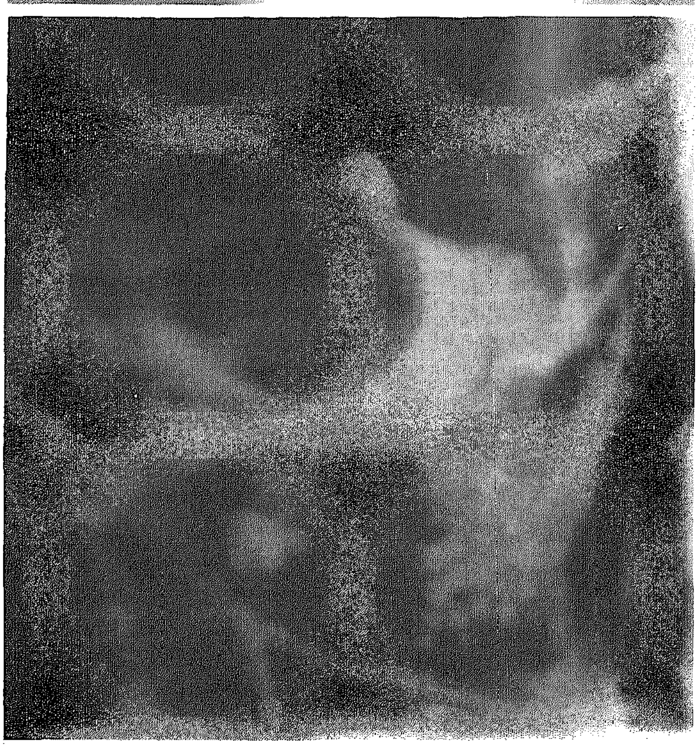


Figure 10 (top left). Normal right iophendylate cisternogram. Iophendylate fills the right cerebellopontine cistern, outlining the notch for the fifth cranial nerve, and fills the internal auditory canal (*arrow*). (Reprinted with permission from Valvassori.[4])

Figure 11 (top right). Right intracanalicular acoustic neuroma. Iophendylate fills the right cerebellopontine cistern and outlines the medial surface of the tumor mass filling the dilated lateral postion of the internal auditory canal (*arrow*).

Figure 12 (left). Right acoustic neuroma. Iophendylate surrounds and outlines the tumor mass in the right cerebellopontine cistern. Expansion of the internal auditory canal is evident.

are clearly demonstrated as they stretch from the brainstem into the internal auditory canal (Fig. 13).

The CT pneumocisternogram can demonstrate three patterns of acoustic neuromas. When the tumor is very small, gas outlines the localized swelling of the nerve within the internal auditory canal. In larger tumors that fill the internal auditory canal completely, the CT scan shows failure of air to enter the canal and the convex medial contour of the tumor at the porus (Figs. 14 and 15). When the tumor protrudes into the cerebellopontine cistern, CT scanning shows the contour of the extracanalicular mass and the ob-

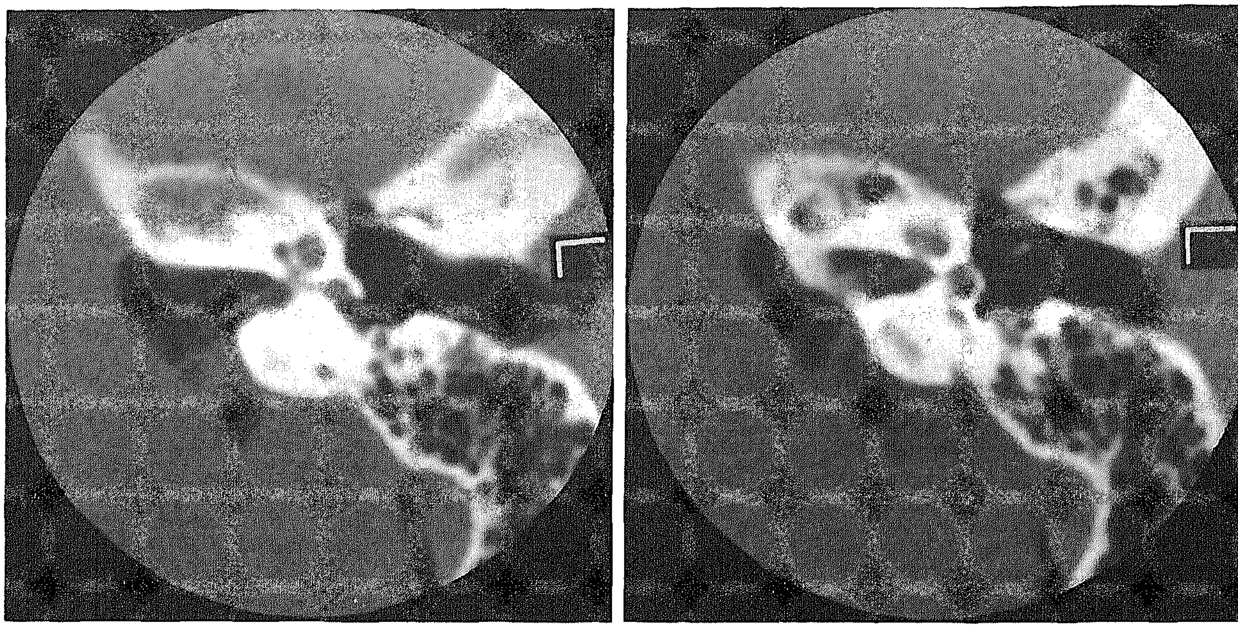


Figure 13. Normal CT pneumocisternogram, axial sections. Gas fills the left cerebellopontine cistern and internal auditory canal. The seventh (anterior) and eighth (posterior) cranial nerves are seen coursing from the brainstem to the fundus of the internal auditory canal.

struction of the internal auditory canal (Figs. 16–17).

CT opaque cisternography. Metrizamide (Amipaque) is used for opaque cisternography. This contrast material, while being absorbed rapidly, is a brain irritant at full strength. To avoid convulsions, it should be used at low concentrations (175 mg/ml). Injection into the subarachnoid space is performed via lumbar puncture, and the patient is then positioned in a slight Trendelenburg position for 10 to 15 minutes. The contrast material diffuses into the intracranial subarachnoid spaces, including the internal auditory canals and cerebellopontine cisterns. Multiple, thin sections are then obtained at 1.0- or 1.5-mm increments.

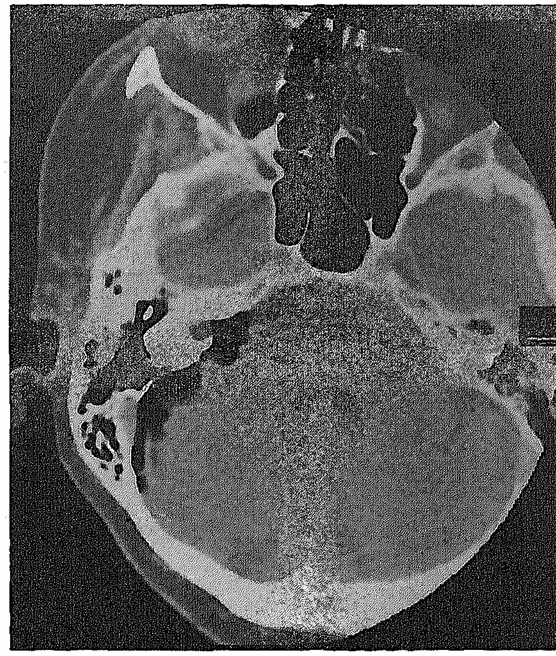
In my opinion, gas cisternography is preferable and safer than metrizamide studies. Especially when the internal auditory canals are narrow, it is far easier to recognize a small amount of intracanalicular gas than metrizamide in the CT sections due to the greater absorption differential between the gas and the surrounding canal walls.

CLINICAL EXPERIENCE

During the past 18 years, 12,000 patients have been referred to me for screening tests of the internal auditory canals because of unilateral or asymmetric bilateral sensorineural hearing loss or vestibular loss of unknown origin. On the basis of the criteria previously listed, diagnostic studies were performed in 3,560 patients, or approximately 30 per cent of all of the cases. Space-occupying lesions of the cerebellopontine angle were demonstrated in 1,245 cases, or slightly more than 10 per cent of the cases referred for screening tests. Of the patients in this series who were operated on, acoustic neuromas were found in 90 per cent. In the remaining 10 per cent, other extra-axial lesions involving the cerebellopontine angle were found. In order of decreasing frequency, these lesions were meningiomas, primary cholesteatomas, cysts of various types, facial nerve neuromas, glomus tumors, metastatic tumors, hemangiomas, and aneurysms.

The acoustic neuromas were purely intracanalicular in 10 per cent of the cases. In 65 per cent of the cases, the tumors extended into the cerebellopontine cistern, less than 2 cm in the largest diameter, but did not involve cranial nerves other than the eighth. In 25 per cent of the patients the lesions were larger, with involvement of the fifth and other cranial nerves and, often, with signs of cerebellar or brainstem compression. Bilateral acoustic neuromas, in patients with no known neurofibromatosis, were found in only 12 cases. In only four of these cases were the second lesions proved by surgery.

Conventional radiography demonstrated



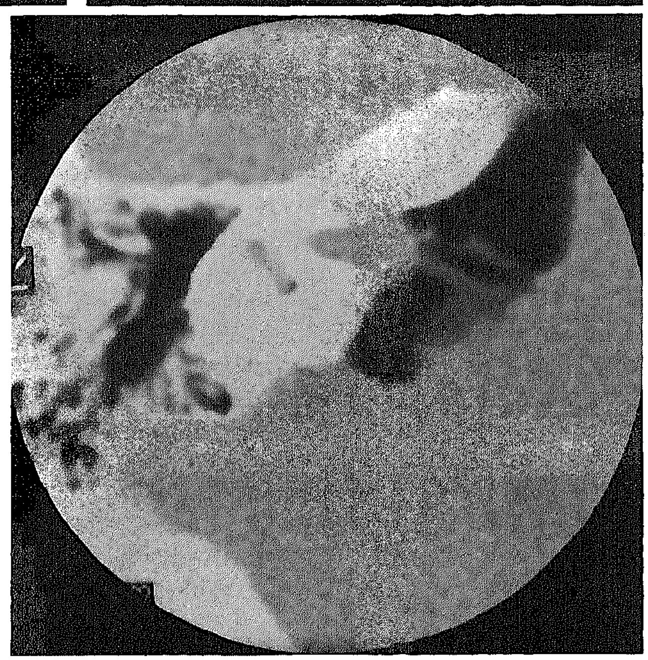


Figure 14 (top left). Left acoustic neuroma, CT pneumocisternogram. A small tumor mass fills the internal auditory canal. The cerebellopontine cistern and cisternal portion of the eighth cranial nerve are normal.

Figure 15 (top right). Right acoustic neuroma, CT pneumocisternogram. A small tumor mass fills the fundus of the right internal auditory canal.

Figure 16 (right). Right acoustic neuroma, CT pneumocisternogram. A tumor mass fills the dilated right internal auditory canal to the region of the porus. The cisternal portion of seventh and eighth cranial nerves is normal.

changes in the contour, size, and shape of the internal auditory canals indicative of lesions in only 45 per cent of the patients. Conventional and computed tomography of the internal auditory canals led to diagnoses of space-occupying lesions in 72 per cent of the cases. The results were of borderline importance in 22 per cent and negative in 6 per cent.

It should be emphasized that the tomographic study provides additional information that is extremely useful to the surgeon when a translabyrinthine approach is selected for the removal of the tumor; useful data include size and pneumatization of the mastoid, position of the lateral sinus and jugular bulb, height of the dura, and course of the facial nerve canal.

In all instances in which computed tomography with infusion revealed enhanced masses in the cerebellopontine cisterns, lesions were found at surgery. It should be mentioned again that intracanalicular lesions or extracanalicular masses less than 8 mm in diameter are usually not identified by this technique. In all questionable cases, a cisternogram can be used for confirmation. A mistake sometimes made by the inexperienced interpreter is to confuse the mod-

Figure 17. Left acoustic neuroma, CT pneumocisternogram. A tumor mass fills the internal auditory canal and protrudes into the cerebellopontine cistern.

erately enhanced lateral aspect of the cerebellar flocculus with a pathologic mass.

Cisternography allows the diagnosis of localized swellings of the eighth cranial nerve and of masses as small as 2 mm in the internal auditory canal and cerebellopontine cistern. In the present series there were no false-negative cisternograms but three false-positive cases in which surgery was performed and no tumor found. In one of these three cases, an arachnoid cyst was probably present and was inadvertently punctured and deflated before actual recognition. To minimize the possibility of diagnostic errors in cases involving small nerve swellings or intracanalicular masses of questionable importance, a conservative approach should be taken to interpretation of a radiographic studies, remembering the benign nature and small size of the possible lesion. In view of the seriousness of the surgery involved for the removal of these lesions, exploratory surgery is probably not justified in questionable cases. Rather, re-examination should be performed a few months later. At that time, an increase in the size of the mass would indisputably indicate the presence of a tumor.

More changes in the diagnosis of acoustic tumors are foreseen in the near future, with the introduction of nuclear magnetic resonance (NMR). This new imaging modality uses not ionizing radiation but rather the interaction between atomic nuclei, a static magnetic field, and radio waves. Preliminary studies have demonstrated tumor masses in the cerebellopontine angle without the use of intravenous or intrathecal contrast material. Since compact bone produces no signal with NMR, even small intracanalicular tumors are clearly identified.

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