Recent developments in microsurgical techniques for removal of acoustic neurinoma and treatment of vertigo, tinnitus, and hemifacial spasm require detailed anatomical knowledge of the facial nerve (FN) and each component of the eighth cranial nerve in the internal auditory canal (IAC) and cerebellopontine cistern to avoid or minimize postoperative neurological deficits. It is impossible to differentiate clinically or preoperatively between neurinomas originating in the superior vestibular nerve (SVN) and the inferior vestibular nerve (IVN), and some breakthrough in imaging studies is needed. Although some cases of vertigo and tinnitus are reported to be caused by vascular compression of the eighth nerve, no clear diagnostic criteria have yet been established. Partial neurotomy of the eighth nerve in the IAC or cerebellopontine cistern has been performed for the treatment of intractable tinnitus and Ménière’s disease. For these reasons, it is important to determine the precise topography of the FN and the three components of the eighth cranial nerve, as well as spatial relationships among these nerves and blood vessels in the IAC and the cerebellopontine cistern. However, there are some discrepancies in the literature concerning the topography of the FN, the two vestibular components (SVN and IVN), and the cochlear nerve (CN) in the IAC and the cerebellopontine cistern. All the anatomical studies in the literature were performed in cadavers, and no studies in living humans have been reported. There is, however, always some risk in cadaver studies that the anatomical relationships of the components of the nerves in the IAC and cerebellopontine cistern may have been altered by the absence of cerebrospinal fluid (CSF) and blood pressure. Therefore, anatomical studies must be conducted in living humans to define the true anatomical relationships among the nerves, as well as blood vessels, in the IAC and cerebellopontine cistern. Accordingly, we studied the topography and the spatial relationships of the FN, each of the components of the eighth cranial nerve, and the blood vessels in the IAC and cerebellopontine cistern of normal adults by using magnetic resonance (MR) cisternography with a heavily T2-weighted two-dimensional fast spin–echo technique.
Topography of the facial and eighth cranial nerves

**Clinical Material and Methods**

The IAC and cerebellopontine cistern were examined using MR cisternography in 30 normal adults (13 women and 17 men; age range 24–80 years, mean 50.3 years). The IAC and cerebellopontine cistern were examined bilaterally in four subjects. We will refer to the IAC and cerebellopontine cistern on the same side as "one side," so that a total of 34 sides (18 IACs and cerebellopontine cisterns on the right side and 16 on the left side) were examined in this study.

A 1.5-tesla superconducting magnet with a standard head coil (Signa Horizon; GE Medical Systems, Milwaukee, WI) was used. The MR cisternography studies of axial sections of the brainstem and oblique sagittal sections perpendicular to the IAC were acquired using T$_2$-weighted 2-D Fourier transform FSE sequences with the parameters of TR 2000–4000 msec, TE 200 msec, an echo train length (ETL) of 24, a receiver bandwidth of 21.4 kHz, four to six excitations, a 512$^3$ matrix, a 19- to 20-cm field of view, and a 3-mm slice thickness (interleaved sections with 0-mm gap).\textsuperscript{25,26} Three-dimensional (3-D) Fourier transform FSE images (TR 4000 msec, TE 80–100 msec, 32 ETL, 14 × 14-cm field of view, 256 × 256 matrix, 0.7–0.9 partition thickness, 6 × 10 slabs with 24 overlapping slices) were also obtained to confirm the findings on the 2-D Fourier transform images. However, 2-D Fourier transform was adopted for representative images in this report because of the better signal-to-noise (S/N) ratio and the better in-plane resolution (0.37–0.49 mm in 2-D FSE compared with 0.54 mm in 3-D FSE). A frequency-selected fat saturation pulse was also used. In total, an approximately 20-minute imaging time was required.

Figure 1 shows the basic lines and angles that we defined and measured in the IAC and cerebellopontine cistern on the cross-sectional images of the IAC. The FN/SVN line is that connecting the centers of the FN and SVN. The angles between this line and the horizontal line at the fundus, porus acusticus (center) and the most medial portion of the cerebellopontine cistern at which the four components can be identified (right), respectively. ant. = anterior; C = CN; F = FN; h = horizontal line; I = IVN; inf. = inferior; post. = posterior; S = SVN; sup. = superior. The antero-posterior and superoinferior directions in the images in all figures are the same, whether on the right or left side. Asterisks indicate blood vessels. Directions apply to a person in the standing position.

**Results**

**Position of the Meatal Loop of the Anterior Inferior Cerebellar Artery**

We classified the participants into two groups according to the position of the meatal loop of the anterior inferior cerebellar artery (AICA), because it was assumed that the spatial relationship of the FN and the three components of the eighth cranial nerve would change according to the position of the artery. The position of the meatal loop in the IAC was clearly visible in both the axial view of the brainstem and the cross-sectional slice of the IAC (Figs. 2 and 3). In 19 (55.9%) of the 34 sides, the meatal loop of the AICA remained in the cerebellopontine cistern without entering the IAC, and these sites were classified as Group I. In the remaining 15 sides (44.1%) the meatal loop entered the IAC, and these sides were classified as Group II. The entire length of the IAC was covered by four to six 3-mm-thick cross-sectional slices. Figures 2 and 3 show the topography of the FN and each component of the eighth cranial nerve along their course in the IAC and cerebellopontine cistern.
FIG. 2. Magnetic resonance cisternograms obtained on the left side in a typical individual in whom the meatal loop of the AICA does not enter the IAC (Group I). a–i: Cross sections showing the IAC and cerebellopontine cistern from lateral to medial. j: Axial view of the IAC and cerebellopontine cistern. Note that the FN and the three components of the eighth cranial nerve (8th N) tend to move into the posteroinferior quadrant of the IAC and that the latter come closer together to create a comma shape as they approach the porus acusticus. Arrows and asterisks indicate blood vessels, and ant., post., sup., and inf. indicate these direction in a person in the standing position. Co = cochlea; remaining abbreviations as in Fig. 1.
FIG. 3. Magnetic resonance cisternograms obtained on the right side in a typical individual in whom the meatal loop of the AICA enters the IAC (Group II). a–j: The FN and the three components of the eighth cranial nerve are situated in a way similar to those in the individual in Fig. 2. Note that the meatal loop of the AICA is clearly seen to rotate in the IAC (arrow and asterisk) and that the FN and the three components of the eighth cranial nerve are unaffected by the presence of the blood vessels. Abbreviations are the same as in Figs. 1 and 2; 8th N = eighth cranial nerve.
Topography of the FN and Eighth Cranial Nerve in the IAC

In the fundus of the IAC, the FN was located in the anterosuperior quadrant of the IAC, the SVN in the posterosuperior quadrant, the IVN in the posteroinferior quadrant, and the CN in the anteroinferior quadrant (Figs. 2a and 3a). The IVN (“saccular nerve” is the correct nomenclature in this position) was slightly smaller and less clear, whereas the FN and the SVN were more clearly and densely visualized in this position. The CN was also clearly visualized and was located very close to the wall of the ventrocaudal quadrant of the IAC in the fundus. The transverse crest could occasionally be recognized between the FN/SVN and the CN/IVN complexes (Fig. 4).

Leaving the fundus, the saccular nerve became more clearly visible after the posterior ampullary nerve (PAN) joined it to form the true IVN (Figs. 2b and 3b). In some participants, part of the singular canal, in which the PAN courses, could be seen merging into the IAC in its posteroinferior quadrant in this slice (Fig. 3b).

In approximately the middle of the IAC, the SVN moved slightly inferior and the IVN moved toward the SVN, and the two nerves approached each other. All of the components of the eighth cranial nerve and the FN began to move posteroinferiorly, although the FN retained its position slightly separated from the other nerves (Figs. 2c and d and 3c and d). On most of the sides, the SVN, IVN, and CN fused in a “comma” shape when they came close to the porus acusticus (Figs. 2e and f and 3e–g). The shape of the comma varied from one individual to another. In some it was almost straight, whereas in others it was very curved, and in rare cases it was almost triangular (Fig. 5).

The FN, on the other hand, kept its position slightly apart from the eighth cranial nerve, although in some participants the distance between the FN and the SVN diminished as these nerves approached the porus acusticus (Fig. 2a–e and j).

Topography of the FN and Eighth Cranial Nerve in the Cerebellopontine Cistern

When the FN and eighth cranial nerve entered the cerebellopontine cistern, they ran in parallel toward the brainstem, although in some cases their course changed slightly and they proceeded in a more posterior direction (Fig. 2j). The shape of the eighth cranial nerve and the topography of the three components were almost unchanged in the cerebellopontine cistern (Figs. 2g–i and 3h and i). A cleavage between the vestibular complex and the CN and between the SVN and IVN was recognized in the cerebellopontine cistern in a few cases (Figs. 2h and 3h). When the eighth cranial nerve approached the choroid plexus it became very difficult to identify. The FN was always located anterior to the eighth cranial nerve in the cerebellopontine cistern. The distance between the FN and the SVN in the cerebellopontine cistern became slightly larger as they exited the porus acusticus and approached the brainstem (Fig. 2j).

Statistical Analysis

Table 1 shows changes in the angles between the FN/SVN line and the horizontal line and between the SVN/CN line and the horizontal line in the IAC (a–a’9 and b–b’9), in the cerebellopontine cistern (a’–a’9 and b’–b’9’), and throughout the entire course of the nerves in the IAC and cerebellopontine cistern (a–a’9 and b–b’9’). The differences between angles a and a’, a’ and a’’, and a and a’’ on each side were very small, with mean values of 8.4 ± 6.1˚, 10.5 ± 4.7˚, and 10.8 ± 5.3˚, respectively, indicating that the spatial relationship between the FN and SVN is quite constant throughout their course in the IAC and cerebellopontine cistern. There were no statistically significant differences between Groups I and II. The differences between angles b, b’, and b”, on the other hand, were quite variable even in the same individual (data not shown). The mean differences between angles b and b’, b’ and b”, and b and b” were 15.5 ± 8.2˚, 26.6 ± 11.9˚, and 33.6 ± 13.8˚, respectively, in Group I, and 15.1 ± 7.9˚, 25.1 ± 15.8˚, and 36.5 ± 16.7˚, respectively, in Group II. There were no statistically significant differences between the two groups. These findings indicate that the spatial relationship between the CN and the SVN is much more variable than that between the FN and the SVN.

H. Ryu, et al.

628

J. Neurosurg. / Volume 90 / April, 1999
Subgroups of Groups I and II

To identify where most of the change in the spatial relationship between the CN and SVN occurs, that is, in the IAC or the cerebellopontine cistern, each side was further analyzed. On five sides in Group I and four sides in Group II, the spatial relationship between the CN and SVN changed more in the IAC than in the cerebellopontine cistern. These were classified as the “IAC subgroup.” In 14 sides in Group I and 11 sides in Group II, the changes were larger in the cerebellopontine cistern than in the IAC, and they were classified as the “cerebellopontine cistern subgroup.” The mean values and standard deviation (SD) of the degrees of change between angles $b$, $b'$, $b''$ are summarized as follows: in the IAC subgroup, the mean differences between angles $b$ and $b'$, and $b'$ and $b''$ were $27 \pm 12.3^\circ$ and $9.4 \pm 6.4^\circ$, respectively. In the cerebellopontine cistern subgroup, the mean differences between the aforementioned angles were $11.3 \pm 5.3^\circ$ and $31.7 \pm 12.3^\circ$, respectively.

Illustrative Cases

Case 1

This patient was a 52-year-old woman who had difficulty sleeping at night for 10 years because of left-sided pulsating tinnitus. She consulted several otorhinolaryngologists and neurologists but to no avail. Neurootological examination revealed no abnormalities except for slightly decreased hearing in the left ear, of which the patient was unaware. The axial view of the MR cisternogram revealed two vascular loops around the left eighth cranial nerve (one near the porus acusticus and the other in the more proximal portion of the eighth cranial nerve), but the offending vessel could not be identified (Fig. 6k). The cross section of the IAC and cerebellopontine cistern on the MR cisternogram clearly demonstrated compression of the eighth cranial nerve by the vascular loop in the proximal eighth cranial nerve (Fig. 6h). The left cerebellopontine cistern was exposed via a retromastoid approach.
Compression of the CN in its midportion in the cerebellopontine cistern next to the AICA was confirmed, and the nerve was decompressed by lifting the AICA away from it. The tinnitus gradually resolved within 1 week postprocedure, and there were no complications.

Case 2

This 68-year-old woman underwent surgical removal of a tumor in her left breast on July 10, 1997. A left-sided acoustic neurinoma was found incidentally on a computed tomography (CT) scan obtained 2 weeks later to screen for metastatic tumor, although the patient was unaware of any hearing loss in her left ear. Neurootological examination revealed absent left caloric response, nystagmus with quick component to the right, and left hearing loss. The MR cisternography studies revealed that the neurinoma was located in the posterosuperior quadrant of the IAC in the fundus slice, strongly indicating that it originated from the SVN (Fig. 7), although this was never confirmed surgically because the patient refused surgery.

Discussion

Conventional T₁, weighted MR imaging with gadolinium enhancement enables visualization of small arteries with slow blood flow in the IAC as well as in veins but not of nerve components. On the other hand, MR cisternography with heavily T₂-weighted 2-D FSE using an extremely long ETL, large matrix size, and increased S/N ratio as a result of an additional excitation has great ability to demonstrate fine structures of both cranial nerves and blood vessels in the IAC and cerebellopontine cistern as well as fine structures of the inner ear. The imaging protocol differs among researchers. Harmsberger, et al., used a 3-D FSE technique with phased-array coils, which is suitable for studying structures near the surface of the body such as the labyrinth, endolymphatic duct, or sac. The phased-array coils might provide a better S/N ratio than the standard head coil, but there is some decrease in signal in the remote structures. We used the standard head coil in this study because we needed images with equal homogeneity in the entire length of the FN and the eighth cranial nerve from the fundus of the IAC to the brainstem. Casselman, et al., used 3-D Fourier transformation constructive interference in steady state with a standard head coil to study aplasia and hypoplasia of the eighth cranial nerve in the IAC. To our knowledge, no studies of the spatial relationships and topographical changes in the FN, three components of the eighth cranial nerve, and blood vessels in the IAC and the cerebellopontine cistern have ever been reported.

We used this MR cisternography in the present study and made several discoveries about the topography of the FN and the eighth cranial nerve in the IAC and cerebellopontine cistern. The FN and each of the components of the eighth cranial nerve are well defined in cross-sectional slices of the IAC. The FN and the SVN maintain their spatial relationship almost unchanged in the IAC, but they sometimes come slightly closer together as they approach the porus acusticus. They still do not change their course in the cerebellopontine cistern and run in parallel toward the brainstem, although in some cases they change their course slightly and travel in a more posterior direction when they leave the porus acusticus and enter the cerebellopontine cistern to reach the brainstem (Fig. 2). The distance between the FN and the eighth cranial nerve gradually increases as they approach the brainstem. As shown in Table 1, the angle between the FN/SVN line and the horizontal line is almost unchanged throughout the IAC and the cerebellopontine cistern. Even in cases in which the meatal loop of the AICA entered the IAC, the spatial relationship of the FN and the SVN was unaffected by the loop. Therefore, the entire course of the FN and the eighth cranial nerve can be visualized in a single slice in the axial view of MR cisternograms as shown in Figs. 2j and 3j, although it is impossible to identify each component of the eighth cranial nerve.

The location of the four components (FN, SVN, IVN, and CN) in the fundus of the IAC has been described in the literature. The IVN (actually, the saccular nerve) is less dense and smaller in diameter than the others but becomes as dense and large in diameter as the others when the IVN enters the cerebellopontine cistern. This phenomenon has never been reported previously, because the normal spatial relationship of the four components in the IAC was lost as a result of the absence of CSF and blood pressure in cadaver studies.

The most prominent finding in the IAC is the positional change in the CN and IVN. They come close to the SVN as they travel toward the porus acusticus, and the three nerves fuse to form a comma shape, with the SVN, IVN, and CN arranged in a superior to anteroinferior configuration (Figs. 2 and 3). Silverstein, et al., reported that...
Topography of the facial and eighth cranial nerves

Fig. 6. Magnetic resonance cisternograms obtained in Case 1 (left-sided tinnitus). a–j: Cross sections showing the IAC and cerebellopontine cistern. k: Axial view revealing two vascular loops around the left eighth cranial nerve: one near the porus acusticus and the other in the more proximal portion of the eighth cranial nerve. The cross section of the IAC and cerebellopontine cistern on the MR cisternogram clearly demonstrated compression of the eighth cranial nerve by the latter loop (h). The patient had severe intractable pulsating tinnitus, and vascular compression of the eighth cranial nerve was confirmed at surgery. This patient has been free of tinnitus since neurovascular decompression of the eighth cranial nerve. See Figs. 1 and 2 for definitions of abbreviations and symbols.
the SVN, IVN, and CN rotate forward approximately 90° in the IAC and that only slight rotation occurs in the cerebellopontine cistern. Lang,11 on the other hand, reported that rotation of the eighth cranial nerve occurs mainly in the cerebellopontine cistern. In the reports by Rhoton17 and Martin, et al.,13 these nerves are described as running parallel without rotation in the IAC. However, our study revealed that the spatial relationship between the FN and SVN is quite constant with no rotation through the IAC and cerebellopontine cistern and that the CN and the IVN pass beneath the SVN rather than rotate in the posteroinferior quadrant of the IAC as they approach the porus acusticus. These spatial changes in the CN, IVN, and SVN occurred mainly in the IAC on nine sides (26.5%) and mainly in the cerebellopontine cistern on 25 sides (73.5%). The average angle between the SVN/CN line and the horizontal line in the IAC (angle b–b') in the IAC subgroup group was 27 ± 12.3° compared with 31.7 ± 12.3° in the cerebellopontine cistern (angle b'-b'') in the cerebellopontine cistern subgroup. The maximum change was 75° between the fundus and the most medial portion of the cerebellopontine cistern. There was no single case in which there was a 90° change in either the IAC or cerebellopontine cisterns, in contrast to the reports by Silverstein, et al.,23 and Lang.11

This study shows that the CN occupies the most inferi-
or portion of the eighth cranial nerve in the cerebellopontine cistern. This position differs slightly between individuals, as shown in Fig. 5. Silverstein, et al.,23 reported that they were able to identify a clear cleavage between the CN and vestibular nerve in the cerebellopontine cistern in 75% of their surgical cases. There are some reports, on the other hand, that it is very difficult to identify this cleavage during posterior fossa surgery.16,20 The cleavage between the CN and the vestibular nerve was only identified by MR cisternography in a very few cases in our series (Fig. 5). Therefore, the information obtained using MR cisternography combined with direct electrophysiological recording of the compound action potentials of the CN,24,20 will be quite helpful in identifying the exact topography of the CN, SVN, and IVN at surgery. Therefore, selective cochlear neurotomy to treat intractable tinnitus,20 or vestibular neurotomy to treat vertigo in Ménière’s disease in the IAC or cerebellopontine cistern,23,29 will be performed more accurately and safely with the information provided by MR cisternography.

Applebaum and Valvassori1 and Wiet, et al.,27 reported on vascular compression of the eighth cranial nerve in the IAC in patients with vertigo and tinnitus. These authors emphasized the importance of air CT cisternography for detection of the vascular loop in the IAC. However, air CT cisternography cannot provide enough information about the relationships among the blood vessels, the FN, and the eighth cranial nerve. Our study showed a vascular loop in the IAC in 15 (44.1%) of the 34 sides and indicated that the simple presence of a vascular loop in the IAC is not enough to warrant a diagnosis of vascular compression of the eighth cranial nerve.

As illustrated in Fig. 6k and reported by Ryu, et al.,20 vascular compression of the eighth cranial nerve is very clearly, but not completely, visualized on an axial view on MR cisternography. To confirm further vascular compression in the IAC and cerebellopontine cistern, it is quite useful to examine the relationship between the vascular loop and the eighth cranial nerve on the cross-sectional images of the IAC and cerebellopontine cistern, as demonstrated in Fig. 6h. There is some confusion about the origin of acoustic neurinomas and their symptoms. It has been thought that most acoustic neurinomas arise from the vestibular nerve, approximately 90% from the SVN and 10% from the IVN, because 90% of patients with acoustic neurinoma have been found to have a decreased or absent caloric response, indicating impaired function of the SVN, and 10% of patients have demonstrated a normal caloric response.3 Recently, this assumption has been questioned because intracanalicular neurinomas derived from the IVN were found more frequently than those derived from the SVN.3,12,24,28 The origin of neurinomas in these reports was identified at surgery or by serial sectioning of the temporal bone of asymptomatic individuals who died of unre- lated causes. Therefore, it has been impossible to identify the origin of acoustic neurinomas preoperatively even by highly refined neurootological examinations. Magnetic resonance cisternography has the potential to identify the origin of some, but not all, neurinomas of the eighth cranial nerve preoperatively, as described in Case 2 and in our unpublished data, although we need to collect more cases in which the MR cisternography findings have been confirmed at surgery.

Conclusions

The detailed anatomy of intracranial structures has been studied mainly in cadavers, but the absence of CSF and blood pressure distorts normal spatial relationships. This is especially true of the FN and the three components of the eighth cranial nerve and surrounding blood vessels in the IAC and the cerebellopontine cistern. Magnetic resonance cisternography provides quite detailed anatomical information about these structures and enables correct diagnosis of neurovascular compression of the eighth cranial nerve, preoperative identification of the origin of some but not all neurinomas of the eighth cranial nerve, and selection of the best treatment.

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