Tempor al bone MRI with 3D-FIESTA in the evaluation of facial and audiovestibular dysfunction

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KEYWORDS
Temporal bone; Magnetic resonance imaging; Facial and audiovestibular dysfunction

Abstract
Purpose: To evaluate the clinical usefulness of magnetic resonance imaging (MRI) of the temporal bone using three-dimensional fast imaging employing steady-state acquisition (3D-FIESTA) sequences in patients with facial and audiovestibular dysfunction.
Methods: We retrospectively reviewed the MR images of 1263 patients who presented with hearing loss (n = 429), peripheral facial palsy (n = 96), tinnitus (n = 341) or vertigo (n = 397). There were 605 men and 658 women, with a mean age of 46.97 ± 16.95 (SD) years (range: 2—83 years). Positive MRI findings that were responsible for clinical manifestations in individual patients were categorized according to the anatomic sites and etiologies of the lesions.
Results: Positive MRI findings possibly responsible for clinical manifestations were found in 232/1263 (18.37%) patients, including 86/429 (20.05%) patients with hearing loss, 21/96 (21.88%) patients with facial palsy, 62/341 (18.18%) patients with tinnitus, and 63/397 (15.87%) patients with vertigo.
Conclusion: Although the use of MRI of the temporal bone using 3D-FIESTA shows positive findings in only 18.37% of patients, it provides important information in those with facial and audiovestibular dysfunction. However, for patients with normal MRI of the temporal bone, other etiological factors should be investigated in order to clarify or elucidate the cause of clinical manifestations.

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Many patients with facial and audiovestibular dysfunction undergo magnetic resonance imaging (MRI) in routine daily practice. Currently, computed tomography (CT) is used in the evaluation of cerebellopontine angle cistern and bone labyrinthine pathologies. However, its contribution to membranous labyrinthine diseases and small lesions of the internal auditory canal is limited. On the opposite, MRI owing to superior contrast resolution and multiply an imaging capability, helps to detect small lesions of the membranous labyrinth and internal auditory canal. In the evaluation of patients with audiovestibular dysfunctions such as sensorineural hearing loss, tinnitus and vertigo, MRI is currently the most informative imaging method \([1-4]\). In such an evaluation, MRI is used to exclude retrocochlear pathologies, especially in patients with asymmetrical sensorineural hearing loss, unilaterial tinnitus or vestibular findings \([5]\). The most frequently detected retrocochlear lesion is vestibular schwannoma whereas tumors of the cerebellopontine angle cistern, or of the internal auditory canal (facial schwannoma, meningioma, hemangioma, paraganglioma, cholesteatoma and metastatic neoplasms), and demyelinating, ischemic or vascular lesions are less frequently encountered lesions \([5]\). MRI obtained after intravenous administration of gadolinium-chelate has been reported as a useful diagnostic procedure for the evaluation of temporal bone in patients with facial and audiovestibular dysfunction \([6]\).

Recently, three-dimensional fast imaging employing steady-state acquisition (3D-FIESTA) images have been introduced. The 3D-FIESTA sequences provide much higher spatial resolution and clearer depiction of small structures like cranial nerves especially within the cisternal spaces. The 3D-FIESTA is an ultrafast pulse sequence that produces high-resolution images with outstanding image contrast between the cerebrospinal fluid, vessels and cranial nerves. High signal-to-noise-ratio also makes small structures conspicuous \([7,8]\). The 3D-FIESTA sequence has been reported to be a reliable method in showing the retrocochlear pathologies especially in auditory dysfunction such as tinnitus and hearing loss \([8]\).

The purpose of this study was to evaluate the clinical usefulness of MRI of the temporal bone using the 3D-FIESTA sequence in patients with facial and audiovestibular dysfunction.

**Materials and methods**

This was a retrospective study and a waiver was obtained from the institutional review board. We retrospectively reviewed the MRI examinations of 1263 patients (605 men and 658 women), with a mean age of 46.97 ± 16.95 (SD) years (range: 2–83 years) who presented with hearing loss proven with audiometric evaluation \((n = 429)\), peripheral facial palsy \((n = 96)\), tinnitus \((n = 341)\) or vertigo \((n = 397)\). Positive MRI findings responsible for the patients’ clinical manifestations were categorized according to the anatomic sites and the etiologies of the lesions.

MRI examinations were obtained with a 1.5-T MR unit (Excite, GE Medical systems, Milwaukee, Wisconsin, USA). The gradient power was 33 mT/s. Axial T1-weighted, T2-weighted, 3D-FIESTA, and contrast enhanced axial and coronal T1-weighted sequences were used for routine temporal MRI in our department, and gadolinium-chelate at a dose of 0.2 mL/kg (gadopentetate dimeglumine, Magnevist\(^\text{TM}\); Schering AG, Berlin, Germany) was used as a contrast agent. Our parameters for imaging were as follows: T1-weighted (TR, 500 ms; TE, 15.7 ms; slice thickness, 3 mm; interslice gap, 0.5 mm; field of view, 20 × 20 cm; matrix, 320 × 224; excitations, 3); T2-weighted (TR, 3000 ms; TE, 104.8 ms; slice thickness, 3 mm; interslice gap, 0.5 mm; field of view, 20 × 20 cm; matrix, 320 × 224; excitations, 3); 3D-FIESTA (TR, 4.8 ms; TE, 1.4 ms; slice thickness, 0.5 mm; field of view, 18 × 18 cm; matrix, 352 × 192; excitations, 4). T2-weighted images were obtained with fast spine echo (FSE) sequences. Fluid-attenuated inversion recovery (FLAIR) (repetition time, 8.402 ms; echo time, 95.5 ms; slice thickness: 5 mm; interslice gap: 1.5 mm; matrix, 288 × 192; excitations, 1) images and diffusion-weighted sequence images (repetition time, 10,000 ms; echo time, 85.8 ms; slice thickness: 4 mm; interslice gap: 1 mm; matrix, 128 × 128) were obtained in some patients to be able to make a differential diagnosis of arachnoid and epidermoid cysts. Diffusion-weighted sequences were performed with echo planar single shot spin echo imaging with b values of 0 and 1000 s/mm\(^2\). Diffusion gradients were applied in three orthogonal directions to generate three sets of diffusion-weighted imaging \((x, y, z\) axes). Apparent diffusion coefficient (ADC) values were automatically calculated.

All MR images were evaluated by three staff radiologists with more than 10 years of experience in neuroradiology. In order to calculate the diagnostic accuracy, a sample of 50 patients were randomly selected, and kappa statistic was used to assess the interobserver and intraobserver values, and agreement ratios were also calculated.

Positive findings that were considered as the cause of symptoms were grouped according to the etiologies. Contrast enhancement of the inner ear, vestibulocochlear nerve pathway and its branches were considered as positive findings. For the facial nerve, contrast enhancement of the cerebellopontine angle cistern, or the internal auditory canal were considered as positive findings. Vascular loop or compression was defined as significant if any prominent vascular structure indentated the cisternal segment, entrance or exit sites of the facial or vestibulocochlear nerves \([6]\).

**Results**

Among the 1263 patients presenting with hearing loss, tinnitus, vertigo and peripheral facial palsy, positive MRI findings possibly responsible for the symptoms were found in 232 (18.37%) patients (Table 1).

Among the 429 patients presenting with hearing loss, 86 (20.05%) patients had positive findings on MRI; of the 341 patients presenting with tinnitus, 62 (18.18%) had positive findings; of the 397 patients with vertigo, 63 (15.87%) had positive findings, and of the 96 patients presenting with facial palsy, 21 (21.88%) had positive findings (Table 2).

Focal or linear contrast enhancement of different segments of the facial nerve, were detected on temporal MRI in 10 (0.79%) patients. For these 10 patients, history, typical symptoms and clinical findings resulted in the diagnosis of Bell’s palsy (Fig. 1). In 54 (4.28%) patients, vestibular
Temporal bone MRI with 3D-FIESTA

Table 1  Patients with positive findings on MR imaging according to the presenting symptom.

<table>
<thead>
<tr>
<th>Presenting symptom</th>
<th>Number of patients</th>
<th>Number of patients with positive findings on MRI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peripheral facial palsy</td>
<td>96</td>
<td>21 (21.88)</td>
</tr>
<tr>
<td>Tinnitus</td>
<td>341</td>
<td>62 (18.18)</td>
</tr>
<tr>
<td>Vertigo</td>
<td>397</td>
<td>63 (15.87)</td>
</tr>
<tr>
<td>Sensorineural hearing loss</td>
<td>429</td>
<td>86 (20.05)</td>
</tr>
<tr>
<td>Total</td>
<td>1263</td>
<td>232 (18.37)</td>
</tr>
</tbody>
</table>

MRI indicates magnetic resonance imaging.

Table 2  Final diagnosis in patients with positive findings on MRI according to presenting symptom.

<table>
<thead>
<tr>
<th>Final diagnosis based on MRI findings</th>
<th>Number of patients</th>
<th>Sensorineural hearing loss (n = 429)</th>
<th>Tinnitus (n = 341)</th>
<th>Vertigo (n = 397)</th>
<th>Peripheral facial palsy (n = 96)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vestibular schwannoma</td>
<td>54 (4.28)</td>
<td>25 (5.83)</td>
<td>16 (4.69)</td>
<td>9 (2.7)</td>
<td>4 (4.17)</td>
</tr>
<tr>
<td>Middle ear and mastoid inflammation</td>
<td>88 (6.97)</td>
<td>30 (6.99)</td>
<td>25 (7.33)</td>
<td>27 (6.80)</td>
<td>6 (6.25)</td>
</tr>
<tr>
<td>Ischemic foci in brainstem</td>
<td>2 (0.16)</td>
<td>1 (0.23)</td>
<td>1 (0.29)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>Other CPA masses</td>
<td>5 (0.40)</td>
<td>1 (0.23)</td>
<td>2 (0.59)</td>
<td>2 (0.50)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>Meningioma</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Arachnoid cyst</td>
<td>2</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Epidermoid cyst</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Inner ear dysplasia</td>
<td>12 (0.95)</td>
<td>12 (2.80)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>Labyrinthitis</td>
<td>10 (0.79)</td>
<td>10 (2.33)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>Vascular loop with compression</td>
<td>25 (1.98)</td>
<td>7 (1.63)</td>
<td>8 (2.35)</td>
<td>9 (2.7)</td>
<td>1 (1.04)</td>
</tr>
<tr>
<td>Bell’s palsy</td>
<td>10 (0.79)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
<td>0 (0.00)</td>
<td>10 (10.42)</td>
</tr>
<tr>
<td>High jugular bulb</td>
<td>26 (2.06)</td>
<td>0 (0.00)</td>
<td>10 (2.93)</td>
<td>16 (4.03)</td>
<td>0 (0.00)</td>
</tr>
<tr>
<td>Total</td>
<td>232 (18.37)</td>
<td>86 (20.05)</td>
<td>62 (18.18)</td>
<td>63 (15.87)</td>
<td>21 (21.88)</td>
</tr>
</tbody>
</table>

Numbers are raw numbers. Numbers in parentheses are percentages. CPA indicates cerebellopontine angle.

schwannomas were detected (Fig. 2). In 88 (6.97%) patients, inflammation of the middle ear or mastoid were detected. In 2 (0.16%) patients, ischemic focus of the brain stem was detected. Other mass lesions of cerebellopontine angle cistern have been detected in 5 (0.40%) of the patients. In 2 patients surgically proven meningoia of the inside of the cerebellopontine angle cistern (Fig. 3), in 2 patients arachnoid cyst (Fig. 4), and in 1 patient epidermoid cyst (Fig. 5) with typical MRI findings were detected. Inner ear dysplasias, detected with 3D-FIESTA sequences, were seen in 12 (0.95%) patients. In 10 (0.79%) patients, labyrinthitis were detected. In 25 (1.98%) patients, prominent vascular loop or contact accepted as possible reason for symptoms were observed. In 26 (2.06%) patients presenting with tinnitus and vertigo, high jugular bulb was detected.

Interobserver kappa values were in the range of 0.835–0.935 [observer 1 versus observer 2: 0.835 (95% CI: 0.70–0.97); observer 1 versus observer 3: 0.897 (95% CI: 0.78–1.00); observer 2 versus observer 3: 0.935 (95% CI: 0.85–1.00)] (P = 0.001), and the agreement ratio between three observers was 96.7%. Intraobserver agreement was studied for observer 1 only. Intraobserver kappa value was 0.897 (95% CI: 0.78–1.00) (P = 0.001), and the agreement ratio was 94%.

Discussion

In this study, the diagnostic yields of MRI of the temporal bone in patients with facial and audiovestibular dysfunction were overall, 18.37% (232/1263).

In our study, positive MRI findings were detected in 21/96 (21.88%) patients with peripheral facial palsy. Ten (10.42%) of these patients were diagnosed with idiopathic peripheral facial palsy, also known as Bell’s palsy. Bell’s palsy refers to facial nerve paralysis with no identifiable cause. Viral inflammation, possibly prior herpes simplex virus infection, has been implicated. On imaging studies, there is enhancement of the canalicular, labyrinthine and geniculate portions of the facial nerve [9,10]. Different segments on the MRI of the facial nerve showed enhancement in Bell’s palsy. Ratios of positive findings reported in the literature concerning Bell’s palsy are high and varying between 43% and 100% [11–13]. In this regard, the normal contrast enhancement of the intratemporal facial nerve should be compared to the contrast enhancement observed in neuritis and tumors. Although gadolinium cannot pass into the cranial nerves under normal conditions, it can penetrate through blood vessels in the presence of inflammation or oedema, resulting in nerve enhancement. On MRI, enhancement is normally seen
at and distal to the anterior genu of the facial nerve related to peri- and epineural venous plexuses. The intracanalicular and labyrinthine segments do not normally enhance with use of contrast material [10,14–16]. In their study involving 93 patients with 186 clinically normal bilateral facial nerves, Gebarski et al. reported that on contrast-enhanced MRI, 142 nerves (76%) were visibly enhanced along at least one segment within the facial canal, and that enhanced images of the nerves of 64/93 (69%) showed right-left asymmetry [15].

The role of neuroimaging is less clear-cut in patients with audiovestibular dysfunction. For patients with sensory deafness or acute vertigo, MRI is the first line imaging method for evaluating the labyrinth, skull base and brain. Unenhanced-CT examination can be used to analyze the bone structures of labyrinth or if MRI is contraindicated [17]. After reviewing the neuroimaging studies, and results of audiovestibular testing in 118 patients with audiovestibular dysfunction, Levy et al. concluded that clinical presentation and audiovestibular testing could not sensitively predict the neuroimaging outcomes [5]. Only 15/118 (13%) of their patients had positive neuroimaging findings related to their presenting symptoms [5]. They found positive imaging findings in 86/429 (20.05%) patients with sensorineural hearing loss [5]. Levy et al. found pathologies in 12/65 (18%) patients with sensorineural hearing loss [5]. In another study, pathological imaging findings were found in 24/78 (31%) patients with acute hearing loss [18]. Park et al. reported that pathological imaging findings were observed in 43/104 (41%) patients with sensorineural hearing loss [6].

Although contrast enhancement of the membranous labyrinth is a specific finding for the pathologies of labyrinth, the sensitivity of contrast-enhanced MRI remains to be demonstrated. The current MR imaging resolution is not sufficient to detect the pathologies in hair cells of Corti organ and cupula, which may be the reason of the predominance of negative imaging findings in patients with audiovestibular dysfunction [4,16,19]. At the same time, hearing loss in older patients is generally secondary to presbycusis [20]. The 3D-FIESTA sequence has been reported to be a reliable method in showing the retrocochlear pathologies especially in auditory dysfunction such as tinnitus and hearing loss [8].

The role of neuroimaging in patients referred for the evaluation of vertigo is more confusing. In our study we found pathologies in 63/397 (15.87%) patients with vertigo. In a study of 20 elderly patients with dizziness, Day et al. reported that the MRI findings in these patients were not different from those of age-matched control group [21]. According to Levy et al. in only 6/65 (9%) patients with vertigo/dizziness/balance difficulty/dysequilibrium neuroimaging studies showed positive findings [5]. Casselman et al. reported that, they have detected a pathology in MRI that can explain vertigo in 54/167 patients with abnormal findings in the vertigo and/or vestibular test [22]. In another series of 79 patients referred for dizziness or rotatory vertigo, neuroimaging studies were positive in 27 (34%) patients [23]. Park et al. reported that they detected MRI pathology in 40/109 (37%) patients with vertigo [6]. There are very few studies in the literature investigating the neuroimaging findings of the patients with tinnitus. Levy et al. reported positive neuroimaging findings possibly responsible for tinnitus in 8/55 (15%) patients [5]. In our study positive neuroimaging findings

Figure 1. A 45-year-old man presenting with right sided Bell’s palsy. T1-weighted spin-echo image (TR/TE = 500/15.7 ms) in the transverse plane obtained after intravenous administration of gadolinium chelate shows enhancing, distal intrameatal segment (arrow) and geniculate ganglion region (double arrow).

Figure 2. A 52-year-old man with surgically proven vestibular schwannoma who presented with sensorineural hearing loss. T1-weighted spin-echo image (TR/TE = 500/15.7 ms) in the transverse plane obtained after intravenous administration of gadolinium chelate shows vestibular schwannoma (arrows) in the left cerebellepontine angle cistern, extending to the internal auditory canal.
Figure 3. A 55-year-old woman with surgically proven meningioma who presented with tinnitus. a: T1-weighted spin-echo images (TR/TE = 500/15.7 ms) in the transverse plane; b: T1-weighted spin-echo images (TR/TE = 500/15.7 ms) in the coronal plane obtained after intravenous administration of gadolinium chelate show meningioma in the right cerebellopontine angle cistern (arrows).

Figure 4. A 42-year-old man with cerebellopontine angle cistern (CPA) arachnoid cyst presenting with tinnitus. a: T2-weighted FSE image (TR/TE = 3000/104.8 ms) in the coronal plane; b: FLAIR image (TR/TE = 8.402/95.5 ms) in the transverse plane shows a CPA arachnoid cyst that is isointense relative to cerebrospinal fluid (arrows); c: diffusion-weighted image (TR/TE = 10,000/85.8 ms) in the transverse plane shows a low signal intensity as a result of cerebrospinal fluid content of the arachnoid cyst (arrow).

Figure 5. A 40-year-old woman with epidermoid cyst of the cerebellopontine angle cistern (CPA) who presented with vertigo. a: T2-weighted FSE image (TR/TE = 3000/104.8 ms) in the transverse plane; b: FLAIR image (TR/TE = 8.402/95.5 ms) in the transverse plane show a CPA epidermoid cyst, which is mildly hyperintense relative to cerebrospinal fluid content (arrows); c: on diffusion-weighted image (TR/TE = 10,000/85.8 ms) in the transverse plane, the epidermoid cyst demonstrates reduced diffusivity (arrow).
were detected in 62/341 (18.18%) patients with tinnitus. Park et al. have detected positive neuroimaging findings in 39/92 (42%) patients with tinnitus, that can be the possible cause of tinnitus [6]. This ratio is higher than other studies. These results were attributed to the fact that middle ear diseases may be among diseases causing tinnitus. As mentioned in the study of Park et al. we also suppose that the wide variation in positive imaging outcomes in patients with audiovestibular dysfunction is most likely caused by the different fractions of disease entity included in different studies [6].

In our study, we used intravenous paramagnetic agents in order to distinguish mass and inflammation in T1-weighted MRI. If the images were obtained without contrast enhancement, pathologies most likely causing symptoms in 20/232 patients would have been overlooked. In order to decrease the expenses in temporal bone imaging obtained for diagnosing vestibular schwannomas, many studies in the literature suggest using non-contrast high-resolution T2-weighted or 3D-FIESTA sequences [8,24]. However, with this method, inflammatory diseases of the facial or vestibulocochlear nerve and membranous labyrinthine diseases may not be demonstrated.

Vascular lesions in the cerebellopontine angle cistern or internal auditory canal, such as vertebralbasilar dolichoectasia, aneurysm, and vascular loops, can produce facial palsy, sensorineural hearing loss, vertigo, or tinnitus [1,2]. In this study, vascular lesions were shown as the cause of symptoms in 25 patients. In the study by Park et al., vascular lesions were shown as the cause of symptoms in 6 patients [6]. We believe that the high positive findings in our study were due to the use of 3D-FIESTA beside pre- and post-contrast axial and coronal sequences. The FIESTA sequence is a high-resolution T2-weighted MRI sequence that provides outstanding image contrast and high signal-to-noise-ratio. The 3D-FIESTA sequence makes it possible to obtain better imaging of the cranial nerves and small vascular structures with higher anatomical details, besides distinguishing mass and inflammation in T1-weighted MRI after the use of an intravenous paramagnetic agent [7,17,25]. For this reason we used an intravenous paramagnetic agent in our study. 3D-FIESTA images have a limitation in detecting inner ear lesions; however, 3D-FIESTA images can detect inner ear anomalies [8].

Anatomic variations and anomalies of the internal jugular vein at the jugular foramen are common, but asymptomatic in most of the cases. If present, symptoms are related to the jugular foramen mass, and lead to unilateral hearing loss, aural fullness, tinnitus, and vestibular symptoms [26]. In our study, high jugular bulb was detected in 10/341 patients presenting with tinnitus, and in 15/397 patients presenting with vertigo.

This was a retrospective study, and we did not have the information about the follow-up assessments of the study sample which limits our interpretation about the final diagnosis of the patients with negative MRI results. Therefore we could not comment on the sensitivity of MRI on specific diagnostic groups. This is a limitation of this study.

We believe that in the present study both the high number of patients that were evaluated, and the use of 3D-FIESTA sequence, provided more valuable information than previous studies. However, this study was a retrospective observational study. For this reason further comparative study investigating the sensitivity and specificity, as well as the limitations of 3D-FIESTA sequences will be needed.

In conclusion, although the use of MRI of the temporal bone using 3D-FIESTA sequences lead to positive findings in 18.37% of patients, this method is a useful diagnostic tool in the assessment of patients with facial and audiovestibular dysfunction. In addition to the use of 3D-FIESTA sequences, the use of intravenous paramagnetic agents markedly increased the efficiency of MRI by demonstrating inflammatory and mass lesions in the membranous labyrinth, internal auditory canal and cerebellopontine angle cistern. If MRI of the temporal bone does not provide positive findings, other etiological factors which may be responsible for the patients’ clinical manifestations should be investigated.

Disclosure of interest
The authors declare that they have no competing interest.

References
Temporal bone MRI with 3D-FIESTA


