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Original Article

Functional magnetic resonance imaging evidence in patients with sudden sensorineural hearing loss

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Abstract: Objective: To investigate the clinical predictors of magnetic resonance imaging in the diagnosis and treatment of sudden sensorineural hearing loss (SSNHL). Methods: One hundred twenty patients with SSNHL underwent auditory evaluations and MRI examinations. Their audiometric parameters, clinical presentation and MRI results were analyzed to explore which types of patients with SSNHL should undergo MRI examination. Results: The MRI examination revealed that 42 cases out of 120 (35%) proved to be abnormal. The exact clinical predictors of SSNHL were found for 14 cases out of 42 (11.7%) while possible clinical predictors were found for 10 cases (8.3%) out of 42 were found. The 14 patients whose MRI results revealed the exact clinical predictors with SSNHL. Meanwhile, all 14 patients with exact clinical predictors presented with vertigo (78.6%) or severe or profound sensorineural hearing loss (85.7%). Chi-square test analysis showed that the incidence of finding the exact etiology of SSNHL with MRI was significantly greater for the group with severe or profound hearing loss than for those with SSNHL below the severe stage ($P < 0.05$). Conclusion: When patients with SSNHL have severe or worse sensorineural hearing loss and no response for ABR tests, MRI imaging seems to be a useful examination, especially for patients with profound SSNHL. The purpose of MRI should not be just to exclude specific causes of retrocochlear hearing loss using appropriate imaging techniques; MRI imaging can also be applied to analyze common etiologies of SSNHL.

Keywords: Magnetic resonance imaging (MRI), sudden sensorineural hearing loss (SSNHL), acoustic neuroma, angioneoplasm, internal auditory canal

Introduction

Sudden sensorineural hearing loss (SSNHL), first described by Wilson in 1980, is most commonly defined as a sensorineural hearing loss of 30 dB or greater over at least three contiguous audiometric frequencies and developing within a 72-hrs period. Despite extensive research to clarify the pathophysiologic characteristics of SSNHL, the majority of SSNHL patients have no identifiable cause of hearing loss and are classified as “idiopathic”. Although the potential mechanisms underlying SSNHL are not completely understood, the pathology of SSNHL is generally attributed to viral infection, vascular compromise, disruption of the cochlear membranes, autoimmunity and so on. Current common therapies for SSNHL include the systemic administration of corticosteroids [1], hyperbaric oxygen therapy and so on [2-4], but their general effectiveness is only 50% [5]. Given the unknown etiology of SSNHL, treatment effectiveness is different. However, the exact pathology of SSNHL is clarified only in approximately 10% of patients. A recent study reported that acoustic neuroma [6], angioneoplasm in the internal auditory canal, inner ear hemorrhage [7, 8], cerebral infarction [9], inner ear inflammation, and malformation of the cochlea and vestibule can also lead to SSNHL. These clinical predictors are bound to affect treatment protocols and their effectiveness. Therefore, a clear etiology is critical for the treatment of SSNHL. Causes may be determined with further research including medical and physical examination, audiovestibular tests, blood examinations, and magnetic resonance imaging (MRI) studies with and without gadolinium administration.

The 3D fluid-attenuated inversion-recovery (FLAIR) sequence is part of the routine protocol for MRI of the brain [10]. A growing body of emerging data in the scientific literature shows

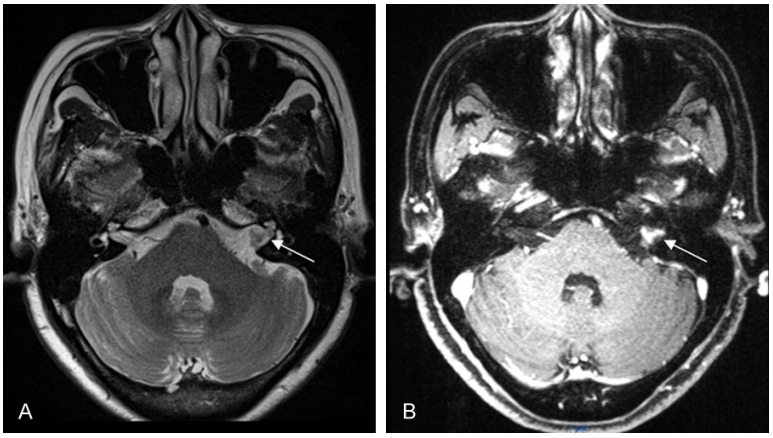

Figure 1. The MRI features of acoustic neuroma in the left ear. A. There was asymmetrical isointensity in the left inner auditory canal on the T1WI image (white arrows). B. It could be strengthened on T2W1-auditory neuroma (white arrows, the patient was a 46 years old female with SSNHL and vertigo. The ABR test was normal and the MRI results showed auditory neuroma).

that the 3D-FLAIR sequence may provide useful information for the diagnosis of SSNHL and thus improve our ability to detect inner ear fluid anomalies by identifying alterations in the inner ear's fluid protein composition [11]. These factors are difficult to identify on T1- and T2-weighted MRIs. However, the 3D-FLAIR sequence of MRI is not recommended by all specialists because of its high cost and the low diagnostic yield in the evaluation of SSNHL. There is also controversy on regarding when MRI is necessary for SSNHL.

In the current prospective study, we carried out MRI examinations of 120 patients with SSNHL. We aimed to evaluate the role of MRI identifying the etiology of SSNHL and to determine which criteria can be used to increase the diagnostic yield of the MRI examination in patients presenting with SSNHL.

One hundred twenty patients with SSNHL seen at The First Affiliated Hospital, Sun Yat-Sen University were chosen for this prospective study. They all underwent auditory evaluations and MRI examinations between January 2015 and October 2015. Audiometric parameters, clinical presentation and MRI results were analyzed to explore which types of patients with SSNHL should undergo MRI examination. The purpose of the present study was to evaluate the association between clinical and audiometric factors and to determine the etiology of SSNHL.

Materials and methods

Ethics

The subjects' written informed consent to participate in the study was obtained according to the Guangdong guidelines and approved by the ethical committee of The First Affiliated Hospital, Sun Yat-Sen University. The entire experimental procedure is shown in the schematic diagram in **Figure 1**.

Subjects

This was a prospective study conducted from January 2015 to October 2015. It included 120 patients with SSNHL at the Otorhinolaryngology Hospital, the first affiliated hospital of Sun Yat-Sen University (Guangdong, China) with a clinical diagnosis of definite SSNHL according to the diagnostic scale of the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS). According to these criteria, definite SSNHL must meet the following criteria: 1) Sudden hearing loss is defined as the rapid onset over a 72-hour period, of a subjective sensation of hearing impairment in one or both ears. 2) The most frequently used audiometric criterion is a decrease in hearing of ≥30 decibels (dB), affecting at least 3 consecutive frequencies. 3) It can be combined with vertigo, tinnitus, nausea and vomiting. We selected patients (66 males, 54 females) with SSNHL. They suffered a rapid onset over a 72-hour period of a subjective sensation of hearing impairment in one ear. All those patients, aged from 8 years to 70 years (median 36.5±5.5 years), had experenced SSNHL for an average of 8.3±2.6 days. When patients agreed to participate in the study, they were informed that they must provide information about the frequency and duration of hearing loss and episodes of vertigo, tinnitus, nausea and vomiting they had experienced.

All patients underwent complete physical and neurologic examinations and an otological examination that included otomicroscopy, puretone audiometry, impedance audiometry, acoustic immittance, and auditory brain stem response (ABR). Hearing staging for each pa-

Table 1. The inner ear MRI results of 120 patients suffered with SSNHL (abnormal)

Abnormality	No.	Percentage (%)
Exact etiology	14	11.7%
Acoustic neuroma	3	
Angioneoplasm of the internal auditory cannal	1	
Inner ear hemorrhage	6	
Cerebellar infarction	1	
Cerebral infarction caused by the occlusion of the vertebral artery	1	
Large vestibular aqueduct	1	
Malformation of the cochlea	1	
Possible etiology	10	
Multiple ischemic wihte matter lesions	3	8.3%
Lacunar infarction	3	
Stenosis of the anterior-inferior artery in the cerebellum	2	
Sclerosis of the vertebral artery	2	
Unrelated etiology	18	
Mastoiditis	4	15%
Arachnoid cyst	3	
Meningioma of the tentorium cerebelli	1	
Malformation of the blood vessels in the brain	2	
Cerebral atrophy	3	
Diseases of alba	1	
Cerebral ventricle cyst	3	
Aneurysm of the posterior cerebral artery	1	
Total	42	35%

tient with definite SSNHL was defined based on the mean of the four-tone average of 0.5, 1.0, 2.0, and 4.0 kHz according to the AAO-HNS criteria: stage 1, normal (#25 dB); stage 2, mild (26-40 dB); stage 3, moderate (41-70 dB); 4, stage 4, severe (71-75 dB).

Patients that presented with vertigo underwent neurologic examination that included spontaneous gaze-evoked nystagmus, the head thrust test and the standard caloric test.

Exclusion criteria

We excluded patients with progressive or fluctuating hearing loss, ear surgery, recurrent infection of the middle ear and any known disorder (rheumatism, immune system related hearing loss) mimicking SSNHL, according to the diagnostic scale of the AAO-HNS.

MRI protocol

Conventional MRIs were performed on a 3.0-T system (Siemens Magnetom TrioTim, Munich, Germany) with a high sensitivity-encoding head coil. All patients underwent MRI of the temporal bones using either a conventional or acoustic protocol.

(1) Fast-inflow steady-state acquisition in 3 dimensions (3D FIESTA). The conventional protocol included sagittal T1, axial T2 fast spin-echo (FSE), and axial T2 fluid attenuated inversion recovery (FLAIR). Coronal: Axial GRE T1W1 repetition time (TR)/echo time (TE), 600 ms/14 ms; T2W1 TR/TE, 2500 ms/80-120 ms (T1/TR/TE, 2100 ms/7000 ms/350-400 ms), slice thickness, 3 mm; 3D-TSE (TR/TE, 1000 ms/132 ms, slice thickness, 0.5 mm). Flip angle, 600; isotropic voxel, 0.4 mm; acquisition time (TA), 10 minutes, 28 seconds; number of excitations (NEX), 2; bandwidth, 62.50 kHz; field of view (FOV), 14 cm, acquired in the axial plane to obtain high anatomic detail. One-millimeter reconstructed axial, coronal and sagittal slices of acoustic nerve from the 3D sequences were reviewed. (2) 3D-FLAIR; TR, 11.000 milliseconds; TE, 134 milliseconds; inversion time, 2581 milliseconds; bandwidth, 41.7 kHz; FOV, 25.6 cm; TA, 10 minutes 53 seconds; isotropic voxel, 1 mm using a 256×256 matrix (512×512 zip); echo train, 180; parallel

Table 2. A comparison of the clinical characteristics and MRI results between two groups of 120 patients with SSNHL

Groups	Cases	Combined with vertigo	Abnormal MRI results	Exact etiology
Less than severe SSNHL group	50	13	18	2
Severe or worse SSNHL group	70	42	24	12
χ^2		13.581	0.038	4.889
P		< 0.01	0.846	0.027

Note: For two subgroups divided according to hearing level (severe or worse and less than severe), the rates of vertigo and obvious etiology detected with MRI were compared, with χ^2 13.581 and 4.889, *P* values < 0.01 and 0.027, respectively. The χ^2 value and *P* value were 0.038 and 0.846, respectively, for their comparison of abnormal MRI rates between the two subgroups. The severe or worse group included the severe or profound group.

imaging; sagittal acquisition; fat-suppression pulse acquired in the sagittal plane covering the entire brain volume. One-millimeter reconstructed axial, coronal and sagittal slices of the acoustic nerve from the 3D-VIBE-T1W1 were reviewed. (3) Both sequences (1) and (2) may be reformatted in all planes while maintaining the same signal to noise ratio. (4) T1 Fast-spin echo (FSE); TR, 600 milliseconds; TE, 18 milliseconds; TE, 3 milliseconds; FOV, 16 cm; thickness, 2.5 mm; gap, 0.3; TA, 3 minutes 29 seconds; matrix, 320×256; NEX, Postcontrast images were obtained shortly after IV administration of gadolinium (Gadovist; Bayer Schering Pharma) at a dose adapted to weight (0.1 mL/kg; flux, 1 mL/second) using both 3D-FLAIR and T1 FSE with fat-suppression sequences for comparison.

The imaging data for the 3D-FLAIR sequences were compared with those of 20 age-matched patients scanned using the same sequence for abnormalities that did not involve the inner ear. We also compared the data of the affected ear with that of the unaffected ear in cases of unilateral involvement. All patients with other brain lesions, regardless of the presence of a high-intensity signal in the inner ear, were excluded from the study.

Statistical analysis

The clinical characteristics, auditory results and MRI results of 120 patients with SSNHL were collected to explore the relationship between the positive rate of MRI on exploring etiology and clinical auditory results. Comparisons of clinical and audiometric characteristics were made between patients with an abnormal MRI and patients with incidental or normal MRIs. We used χ^2 tests to compare the relationship between specific clinical and audiometric variables ($P < 0.05$).

Results

The MRI characteristics of 120 patients with SSNHL

MRI examination revealed that 42 cases out of 120 (35%) were abnormal. The exact clinical predictors of SSNHL were found in 14 cases out of the 42 (11.7%), while possible clinical predictors were found for 10 cases (8.3%) out of 42. Eighteen cases out of 42 (15%) presented unknown factors (**Table 1**). Meanwhile, all 14 patients with exact clinical predictors presented with vertigo (78.6%) or sensorineural hearing loss (SNHL) that was at least severe (85.7%). Chi-square test analysis showed that the incidence of finding the exact etiology of SSNHL with MRI was significantly greater for the group with severe or profound hearing loss than for those with SSNHL below the severe stage ($P < 0.05$) (**Table 2**). The MRI results of the 14 patients for whom the exact clinical predictors were found included 3 cases of acoustic neuroma, 1 of angioneoplasm in the internal auditory canal, 6 patients of inner ear hemorrhage, 2 of cerebral infarction and 2 of malformation of cochlea and vestibule (**Table 3**).

MRI examination is necessary for the following two types of patients with SSNHL: 1) the exact etiology was found for 6 out of 35 patients with severe or profound SSNHL, the positive rate is 17.1%; 2) 55 patients with SSNHL who showed an ineffective response after 1 week of treatment underwent MRI examination. The exact etiology was found for 8 out of these 55 patients, the positive rate is 14.5% (**Table 4**).

When patients with SSNHL have severe sensorineural hearing loss and no response to ABR tests, MRI imaging seems to be a useful exammination especially for patients with profound SSNHL. The purpose should not be just to exclude specific retrocochlear changes using by

Table 3. The clinical, audiological and MRI characteristics of the 14 patients whose exact etiologies were identified

Etiology	Cases	Combined with vertigo	MRI results	Audiological characteristics	ABR results
Acoustic neuroma	3	3	1 case > 2 cm	Ponderosity SSNHL	No response for 2 of patients
			2 cases < 1 cm	Severe SSNHL	
				Moderate SSNHL	Normal
Angioneoplasm of the internal	1	1	Strengthened shadow of micronodules	Profound SSNHL	No response on the affected side
Auditory canal					
Cerebellar infarction	1	1	Right cerebellar infarction	Profound SSNHL	No response on the affected side
Cerebral infarction	1	1	Severe stenosis of the left, vertebral artery; the distant branch disappeared	Severe SSNHL	No response on the affected side
LVAS	1	0	LVAS on the right	Moderate to severe SSNHL	Normal on the affected side
Malformation of the inner ear	1	0	Malformation of the right cochlea and vestibule	Severe SSNHL	No response on the affected side
Inner ear hemorrhage	6	6	Abnormal signal in the cochlea and vestibular, high signal in T_1WI and the affected inner ear showed high signal in T2-FLAIR	Profound SSNHL	No response on the affected side

Table 4. The reasons for MRI examination for the 120 patients with SSNHL

Reasons	Cases	Exact etiology by MRI	Positive
ABR positive	16	0	0
Profound SSNHL	35	3 cases of inner ear hemorrhage	17.1%
Combined with vertigo		2 cases of Cerebellar infarction	
		1 cases of angioneoplasm of the internal auditory canal	
Ineffective response after treatment for 1 week	55	3 cases of internal auditory canal tumor	14.5%
		3 cases of inner ear hemorrhage	
		1 case of malformation of the inner ear	
		1 case of LVAS	
Patient requested an MRI	14	0	0

appropriate imaging techniques; MRI imaging can also be applied to analyze common etiologies of SSNHL such as labyrinthitis, inner ear hemorrhage, angioneoplasm in the internal auditory canal, and malformations of the cochlea and vestibule.

The characteristics of the MRI results for the 14 patients with SSNHL whose exact etiology was determined

The MRI results of the 14 patients with exact clinical predictors included 3 cases of acoustic neuroma, 1 of angioneoplasm in the internal auditory canal, 6 of inner ear hemorrhage, 2 of cerebral infarction and 2 of malformation of the cochlea and vestibule. One of the 4 tumors in the internal auditory canal was 5 diameters in size and was strengthened on T2W1 (**Figure 1**). There was no abnormal signal in the right inner auditory canal on the T_1WI image of another patient but a strengthened shadow of micronodules could be observed with strengthened scanning. The signal appeared to be an angioneoplasm (**Figure 2**). The affected ear was on the same side as the infarction side of cerebellum in the 2 patients who had suffered from cerebellum infarction. Moreover, 1 of 2 cases showed vertebral artery stenosis (**Figure 3**). There was asymmetrical isointensity in the affected inner ear on T_1WI image and high signal in 3D-FLALR in all of the 6 patients with inner ear hemorrhage (**Figure 4**).

Discussion

Various investigations have reported that exact causes are found for less than 45% of patients

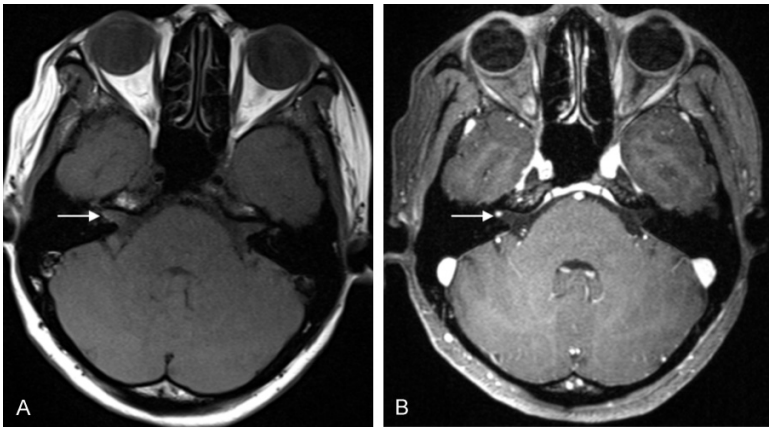

Figure 2. MRI features of angioneoplasm in the right internal auditory canal. A. There was no abnormal signal in the right inner auditory canal on the T1WI image (white arrows). B. The strengthened shadow of the micronodules could be observed after strengthened scanning, suggesting an angioneoplasm (white arrows; 40-year-old female complaining of right ear profound deafness and vertigo).

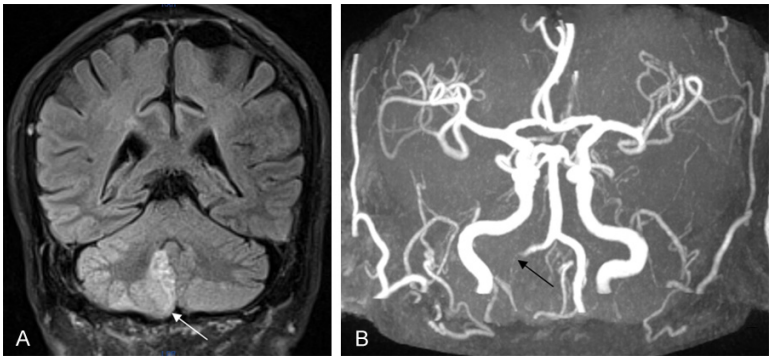

Figure 3. MRI features of infarction in the right cerebellar hemispheres. (A, B) A 58-year-old male complained of right ear profound deafness and vertigo. MRI revealed a wedge-shaped infarction of the right cerebellar hemisphere on T2 WI FLALR (A, white arrows). MRA showed right vertebral arteriostenosis blockage (B, white arrows).

with SSNHL. More than a hundred potential etiologies may account for the SSNHL. The identifiable etiologies are divided into several categories including viral infection, autoimmune disorders, trauma, and vascular, neoplastic, metabolic, and neurological disorders. However, a meta-analysis of 23 studies of SSNHL demonstrated that the most frequent causes identified were infectious (13%), followed by otologic (5%), traumatic (4%), vascular or hematologic (3%), neoplastic (2%), and other (2%) [12]. The AAO-HNS guideline [13] notes that the appropriate tests for SSNHL included MRI, audiometric evaluation (initial and follow-up), and laboratory testing, including hematologic, serologic, and autoimmune testing. MRI examination is critical for the diagnosis of SSNHL. Schick analyzed the MRI findings of 354 inpatients with SSNHL. MRI abnormalities were observed in 122 of the 354 patients (34.5%) [14]. Syed F [15] found that a total of 48 patients had abnormal MRI finds out of 451 patients with SSNHL who underwent MRI testing. Twenty-one of those 48 patients (40%) had a mass of the cerebellopontine angle/internal auditory canal on MRI. Moreover, 15 out of 21 presented as SSNHL associated with an abnormal MRI. The patients with SSNHL underwent MRI to exclude the mass in auditory nerve. With the widely application of MRI in medicine, focused MRI or ultra-high non-enhanced fast spin-echo MRI has been recommended to achieve cost-effective screening for acoustic neuromas. Enhanced MRI, which can be used to evaluate the whole audiovestibular pathway, is necessary to detect abnormalities of the labyrinth and central audiovestibular tract as well as pathological lesions of the internal auditory meatus/cerebellopontine angle.

This was a prospective study from January 2015 to October 2015 that included 120 patients with a clinical diagnosis of definite SSNHL. The MRI examination revealed that 42 cases out of 120 (35%) were abnormal. The exact clinical predictors of SSNHL were found in 14 cases out of 42 (11.7%), while possible clinical predictors were found for 10 cases (8.3%) out of 42. No factors could be determined in 18 cases out of 42 (15%). The MRI results of the 14 patients with the exact clinical predictors included 3 cases of acoustic neuroma, 1 of angioneoplasm in the internal auditory canal, and 6 of inner ear hemorrhage. The MRIs of the 6 patients with inner ear hemorrhage were characterized by a high signal on T1WI that was enhanced during enhancement scanning, which is similar to the

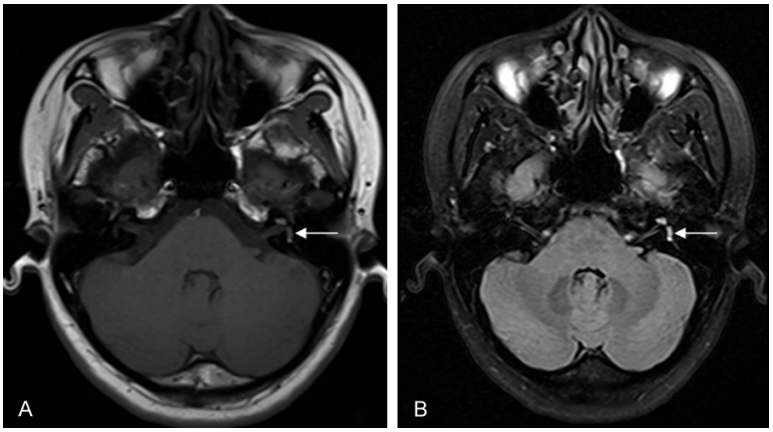

Figure 4. MRI features of inner ear hemorrhage in the left inner ear. A 52-year-old male complained of left ear profound deafness and vertigo. A. Unenhanced T1-weighted images: The high signal shadow was asymmetrical high signal on T1 WI and was located in the left cochlea, semicircular canal and vestibule (arrowhead). B. T2-FLAIR (axial): T2-FLAIR (axial) showed stronger in the left cochlea, semicircular canal and vestibule (arrowhead).

water suppression sequence. The hemorrhage site was located in the cochlea or in the semicircular canals of the vestibule. The pathology is that a small amount of blood into the circulation of the inner ear fluid compartment, and the inner hair cells were undergoing irreversible damage bacause of the alternation of endolymph and perilymph circulation. Meanwhile, the auditory function examination of the 6 patients with inner ear hemorrhage indicated severe SSNHL. Two patients had cerebral infarction with obvious vascular problems. One of 2 was suffered from atherosclerosis in his vertebral artery where the blood flow was almost totally occluded and the ear with SSNHL was just on the same side. The other patient showed a possible pontine infarction based on MRI signal intensity in the pons region, which suggested an ischemic event. Two patients presented with malformation of the cochlea and vestibule.

Nevertheless, since the pathology of SSNHL is still not totally understood, the positive MRI findings for patients with SSNHL is low. Therefore, use of MRI in patients with SSNHL has not been unanimously recommended. Loughran sent a questionnaire to 100 British otolaryngologists in the United Kingdom enquiring about their assessment and management of a patient presenting with SSNHL, and found that 38% would order a magnetic resonance image (MRI) scan at the first presentation [16]. However, contradictions perist regarding when an inner ear MRI is necessary for patients with SSNHL due to the cost of MRI and the low positive findings of MRI for SSNHL patients.

In the present study, of the 14 patients with exact clinical predictors, 12 presented with vertigo, 12 cases showed at least severe sensorineural hearing loss (SNHL) and only 2 showed mild-midrange hearing loss. A statistical analysis of all 120 patients with SSNHL showed that both the incidence of dizziness and finding of an exact etiology on MRI were more significant in the profound hearing loss group than in the mild-midrange-severe hearing loss group ($P < 0.05$).

In this study, 70 out of 120 cases suffered from severe or profound SSNHL, including 14 patients whose exact clinical predictors were shown with MRI, for example, 4 cases of a mass, 6 cases of inner ear hemorrhage, 2 cases of cerebellar infarction and 2 case of malformation of the cochlea and vestibule. The aforementioned exact clinical predictors shown on MRI accounted for 17.1% of the 70 cases with severe to profound SSNHL. We noted a high incidence of inner ear hemorrhage. In cases of very severe sensorineural hearing loss in patients with sudden hearing loss, the inner ear bleeding ratio is relatively high. Thus, in patients with severe or profound SSNHL, if the auditory threshold can not be detected with ABR testing and the possibility of acoustic neuroma, inner ear hemorrhage, cerebellar infarction, malformation of the cochlea and vestibular are not excluded, an MRI examination should be considered.

ABR testing, as a screening test for acoustic neuroma, can not detect the hearing thresholds of ears with severe or worse hearing loss, and it is not sensitive for detecting tumors (< 2 cm), the false negative rate is 17% to 33%. In our investigation, 2 out of 3 patients with acoustic neuroma confirmed by MRI examination made no response on the ABR test. One out of 3 patients with acoustic neuroma show-

ed responses on the ABR test, but the test did not indicate an acoustic neuroma. Therefore, the false negative rate was 33.3%. In 6 cases, the ABR test showed the possibility of acoustic neuroma, but an inner ear MRI indicated that there was no mass in the inner ear canal. The phenomenon suggested that the ABR test is not reliable as a screening test for acoustic neuroma. In addition, in patients with severe or worse SSNHL, if the auditory threshold can not be detected with the ABR test and the possibility of acoustic neuroma, inner ear hemorrhage, cerebellar infarction and malformation of the cochlea and vestibule have not been excluded, an inner ear MRI examination is a good choice.

In summary, when patients with SSNHL present with severe sensorineural hearing loss and no response to ABR tests, MRI imaging seems to be useful especially for patients with profound SSNHL. The purpose of MRI should not be just to exclude specific retrocochlear changes using appropriate imaging techniques; MRI imaging can also be used to analyze the common etiologies of SSNHL, such as labyrinthitis, inner ear hemorrhage, angioneoplasm in the internal auditory canal, and malformations of the cochlea and vestibule.

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Disclosure of conflict of interest

None.

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