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ORIGINAL RESEARCH

Laryngoscope Investigative Otolaryngology

# Gray-tone appearances on 4-hour delayed gadolinium-enhanced magnetic resonance imaging indicate severe inner ear pathology and symptoms in sudden sensorineural hearing loss

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## Abstract

**Objective:** Hybrid of reversed image of positive endolymph signal and negative image of perilymph signal (HYDROPS) in delayed gadolinium-enhanced magnetic resonance imaging (MRI) typically depicts normal inner ear as "white-tone" and endolymphatic hydrops as "black-transparent" appearances, whereas ears with auditory and vestibular disorders are occasionally depicted as "gray-tone." This study aimed to investigate the pathological basis of sudden sensorineural hearing loss (SSNHL) patients with "gray-tone" appearances on HYDROPS.

**Methods:** Delayed gadolinium-enhanced MRI examinations were conducted on 29 subjects with unilateral SSNHL. We mainly analyzed positive perilymph image (PPI) and positive endolymph image (PEI), which were components HYDROPS.

**Results:** On PPI, signal intensity (SI) values extracted from the cochlear and vestibular region of interest (ROI) were higher in the SSNHL ears with dizziness/vertigo symptom at the first visit compared to the healthy ear. Additionally, the PPI/PEI enhancement pattern in the vestibule was associated with a high prevalence of hearing and vestibular deteriorations at the first visit and poor hearing improvement after treatment.

**Conclusion:** Enhancement on PPI/PEI may result from leakage of gadolinium into the inner ear following breakdown of the blood-labyrinth barrier, with high SI being correlated with the amount of leakage. Particularly, a significant leakage into the endolymphatic space, defined as PPI+/PEI+, indicates severe inner ear pathology. Ultimately, we emphasize that the "gray-tone" appearance in the inner ear on

HYDROPS comprises enhancements on both PPI and PEI and propose a new classification for evaluating SSNHL Peri- and Endolymphatic image Enhancement pattern in Delayed gadolinium-enhanced MRI (SPEED).

**Level of Evidence:** 4.

**KEYWORDS**

blood-labyrinth barrier, positive endolymph image, positive perilymph image, signal intensity ratio, SPEED classification

## 1 | INTRODUCTION

Four-hour delayed gadolinium-enhanced magnetic resonance imaging (MRI) is used to evaluate auditory and vestibular disorder and cardiac disease. The hybrid of reversed image of positive endolymph signal and negative image of perilymph signal (HYDROPS) sequence is a heavily-T2-weighed MRI sequence specifically developed to facilitate the visualization of endolymphatic hydrops, which has been linked to Meniere's disease.[1–3] HYDROPS consists of two types of three-dimensional (3D) fluid-attenuated inversion recovery (FLAIR) images with different inversion times (TIs): a positive perilymph image with TI = 2.250 ms (PPI) and a positive endolymph image with TI = 2.050 ms (PEI). On HYDROPS, a healthy cochlea and vestibule exhibit a relatively homogeneous "white-tone" appearance, whereas endolymphatic hydrops appear as a "black-transparent" region within the "white-tone" background (Figure 1A).[1–5] However, we occasionally encounter "gray-tone" or "mosaic-tone" appearances on HYDROPS in patients with auditory and vestibular disorders, which can be classified as neither "white-tone" nor "black-transparent" (Figure 1B,C). These imaging findings have not been extensively investigated and are considered to represent "another pathologic basis" distinct from Meniere's disease.[3]

More than half of patients with sudden sensorineural hearing loss (SSNHL) exhibit partial enhancement of the inner ear on MRI.[6–8] This enhancement has been associated with vestibular dysfunction and poor hearing improvement.[6,8,9] In this study, we aimed to elucidate the pathologic basis behind the "gray-tone" appearance on HYDROPS by separately analyzing PPI and PEI in patients with SSNHL who underwent delayed gadolinium-enhanced MRI.

## 2 | MATERIALS AND METHODS

The subjects were informed about the utilization of contrast agents and delayed gadolinium-enhanced MRI during their consultation with otorhinolaryngology specialists. A well-informed and written consent was obtained from all subjects. This study obtained approval from the Ethics Committee of Nippon Life Hospital (institutional review board 2023-028).

### 2.1 | Subjects

This retrospective study included 29 patients with unilateral SSNHL treated at our department from 2018 to 2022. SSNHL was defined as a rapid onset of hearing loss, occurring within 72 h, with a sensorineural hearing loss of at least 30 dB in three contiguous frequencies on pure-tone audiometry.[10] Exclusion criteria comprised patients with normal hearing or with hearing loss due to other causes, such as otitis media, Meniere's disease, otosclerosis, congenital deafness, presbycusis, vestibular schwannoma, and inner ear malformation.

Hearing levels were evaluated with pure-tone audiometry before treatment and at 2 weeks and 3 months after treatment. Air and bone conduction were evaluated at frequencies of 250, 500, 1 k, 2 k, 4 k, and 8 kHz. The average hearing level was calculated with air conduction at 500, 1 k, 2 k, and 4 kHz. If no response was elicited, the maximum sound intensity generated by the audiometer was increased by 5 dB, evaluating the level within "scale out" range.

Audiogram patterns were categorized into 4 types based on the Demeester's criteria[11]: Ascending, average hearing level of 250–500 Hz was 15 dB higher than that of 4–8 kHz; Descending, average hearing level of 4–8 kHz was 15 dB higher than that of 250–500 Hz; Flat, the difference between the average hearing level of 250–500, 1 k–2 k, and 4 k–8 kHz was <15 dB; Profound, almost similar to Flat type, but including at least 2 frequencies falling within the "scale-out" range; and Other, any audiogram that did not qualify for categorization into any of the aforementioned 4 types, including "valley" types.

All enrolled patients received either systemic steroid therapy or intratympanic (IT) steroid injections. The standard treatment for SSNHL involved administering intravenous prednisolone (80 mg) for 2 days, followed by 8-day weaning periods (60 mg for 2 days, 40 mg for 2 days, and 20 mg for 2 days, for adults weighing 60 kg). An IT steroid injection was administered to patients who had uncontrolled diabetes mellitus or did not achieve more than partial recovery 2 weeks after treatment, according to the Siegel's criteria.[12] Patients received twice-weekly IT steroid injections for 3 consecutive weeks with a concentration of 1.65 mg dexamethasone. Additional treatments, such as prostaglandin E1, or vitamins, were used as adjunctive therapies.

Hearing outcomes 3 months after treatment were categorized based on the Siegel's criteria[12]: Complete recovery, a final hearing level <25 dB HL; Partial recovery, a gain of >15 dB with a final hearing level between 25 and 45 dB HL; Slight response, a gain of >15 dB with a final hearing level >45 dB HL; and No improvement, a gain of <15 dB or a final hearing level >75 dB HL.

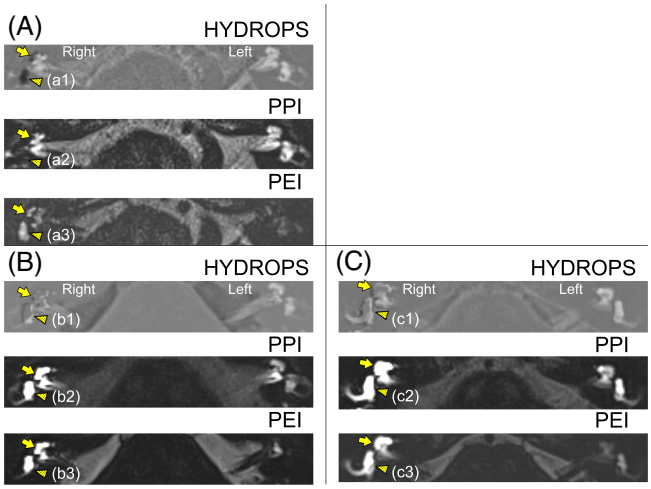



**FIGURE 1** HYDROPS generated by PPI and PEI and their appearances in each patient. (A): A 48-year-old man with right Meniere's disease. The cochlear and vestibular transparent regions on positive perilymph image (PPI) were indicated by the arrow and arrowhead (a2), respectively. Additionally, the cochlear and vestibular enhancements on positive endolymph image (PEI) were indicated by the arrow and arrowhead (a3). Consequently, hybrid of reversed image of positive endolymph signal and negative image of perilymph signal (HYDROPS), generated by subtracting PEI from PPI, exhibited a partial "black-transparent" appearance, by the arrow and arrowhead (a1). (B): A 71-year-old woman with right sudden sensorineural hearing loss (SSNHL) and dizziness/vertigo. Partial "gray-tone" appearances on HYDROPS in the cochlea and vestibule, neither "white-tone" nor "black-transparent," were indicated by the arrow and arrowhead (b1). The "gray-tone" originated from enhancements on both PPI and PEI, indicated by the arrows and arrowheads (b2) and (b3), respectively. (C): A 45-year-old woman with right SSNHL and dizziness/vertigo. Similar to Figure 1B, partial "gray-tone" appearances on HYDROPS in the cochlea and vestibule were indicated by the arrow and arrowhead (c1). PPI exhibited enhancements in both the right cochlea [arrow (c2)] and vestibule [arrowhead (c2)], defined as positive, PPI+. These enhancements differed from those in the left and healthy ear. Similarly, PEI showed differences in enhancements in both cochlea [arrow (c3)] and vestibule [arrowhead (c3)]

## 2.2 | MRI

Four-hour delayed contrast-enhanced MRI was conducted after intravenous injection of a single dose (0.1 mmol/kg) of gadobutrol (Gadovist, Bayer, Leverkusen, Germany) using a 3 T Magnetom Skyra system (Siemens, Erlangen, Germany) equipped with a 20-channel array head coil. 3D-FLAIR sequences proposed by Naganawa et al. were obtained in all subjects to discriminate between perilymphatic and endolymphatic fluid space.[3] First, heavily T2-weighted MR cisternography was conducted to confirm anatomical structure. Second, heavily T2-weighted 3D-FLAIR imaging was acquired using TI = 2.250 ms (PPI) and TI = 2.050 ms (PEI) in 3D volume format.[3] PPI and PEI acquisition required ~15 min. HYDROPS images were generated by subtracting PEI from PPI using a computational method by two or more radiologists with over 10 years of experience on a Picture Archiving and Communication System (PACS) viewer (SYNAPSE, Fujifilm Medical, Tokyo, Japan).

## 2.3 | Preliminary analysis: enhancement on PPI and PEI

Cochlear and vestibular appearances of enhancement were roughly evaluated on PPI and PEI, respectively (Figure 1B,C). Laterality of enhancement on PPI between left and right ears was defined as positive PPI enhancement (PPI+); the absence of laterality was defined as negative (PPI−). Similarly, PEI+ and PEI− were determined based on the laterality of enhancement. As a result, PPI+ in the cochlea and vestibule was observed in 20 of 29 SSNHL subjects, whereas 9 of 29 subjects exhibited PPI−. Additionally, 13 subjects exhibited PEI+ and 16 exhibited PEI−.

## 2.4 | Regions of interest (ROIs) and calculation of signal intensity ratio

The preliminary analysis indicated that more subjects exhibited prominent appearances of enhancement on PPI, compared to PEI. Therefore, for the main analysis, an appearance of enhancement was evaluated on a single PPI slice, not PEI.

In preparation for comprehensive analysis, elliptical ROIs measuring 8–10 $mm^2$ were positioned in the area of prominent enhancement on PPI in the SSNHL and healthy ears (Figure 2A,B). The ROI was in a portion of the cochlear basal turn and the vestibule, not including the semicircular canals and internal auditory meatus. As a reference, a circular ROI of ~30 $mm^2$ was positioned in the cerebellar medulla at the contralateral side to SSNHL ear (Figure 2B).[13]

The mean signal intensity (SI) values in the cochlear and vestibular ROI were independently extracted by PACS viewer from each single slice on PPI. The SI values were subsequently divided by the corresponding values of the reference ROI. This divisional operation enabled standardization of SI values, which is expressed as SI ratio (SIR). Standardization is crucial to compensate for individual variations in SI values and background noise.[13]

## 2.5 | Analysis

First, factors of subject were tabulated based on 2 subgroups of complication of dizziness/vertigo symptom at the first visit; age, gender, underlying disease, hearing level at the first visit, audiogram pattern, wait time from symptom onset to examination, or hearing outcome after treatment. Each factor was analyzed by Student's *t*-test, Fisher exact test, and Mann-Whitney *U* test, and *p*-values were respectively calculated.

Second, a two-way mixed-design analysis of variance (ANOVA) was employed for the SIR datasets, incorporating one between-subjects factor and one within-subjects factor. The between-subjects

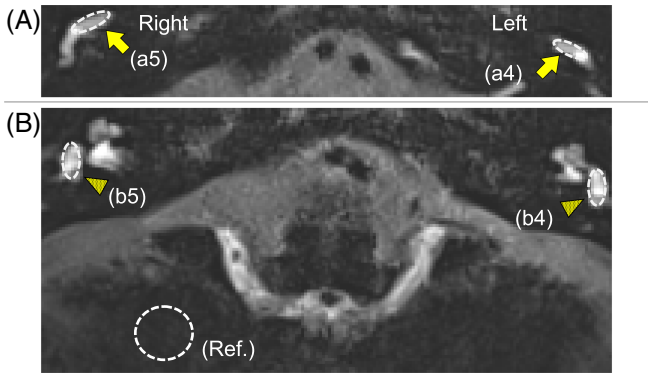



**FIGURE 2** Regions of interest (ROIs). A 55-year-old man with left sudden sensorineural hearing loss (SSNHL) and without dizziness/vertigo. ROIs for analysis were placed in the cochlea (A) and vestibule (B) on positive perilymph image (PPI). (A): Elliptical ROIs were positioned in the left cochlear basal turn exhibiting enhancement, indicated by arrow (a4), and in the right by arrow (a5). Mean signal intensity values within the ROI were extracted using the Picture Archiving and Communication System viewer. (B): ROIs were positioned in the left vestibule, indicated by arrowhead (b4), and in the right, by arrowhead (b5). A circular ROI for reference was positioned in the cerebellar medulla at contralateral side to SSNHL ear, indicated by (Ref.). The signal intensities extracted from the reference ROI were used to standardize those of the cochlea and vestibule.

factor was defined as "complication of dizziness/vertigo symptom at the first visit" encompassing dizziness/vertigo (+) and (−). The within-subjects factor was defined as "both ears" encompassing the SSNHL and healthy ears. Main effects and interactions of these factors were separately analyzed in cochlea and vestibule.

The result of preliminary analysis showed that more subjects exhibited PPI+ and PEI+ in the vestibule than in the cochlea. Therefore, third, subjects were categorized into subgroups based on the following criteria: (i) PPI and PEI enhancement patterns in the vestibule [absence of enhancement on PPI and PEI (PPI−/PEI−), enhancement on PPI only (PPI+/PEI−), or enhancement on both PPI and PEI (PPI+/PEI+)]; (ii) absence or presence of dizziness/vertigo symptoms at the first visit (dizziness/vertigo− or dizziness/vertigo+). The relationship between (i) and (ii) was determined by Fisher's exact test, and Bonferroni test for multiple comparisons was additionally analyzed as a post hoc.

We hypothesized that subjects with PPI+/PEI+ enhancement would have different degrees of auditory and vestibular disorders from other enhancement patterns. Therefore, fourth, the relationships between PPI/PEI enhancement on vestibular ROI and hearing levels at the first visit and hearing outcomes after treatment were investigated: (iii) PPI/PEI enhancement patterns in the vestibule were categorized into two subgroups (PPI−/PEI− and PPI+/PEI− or PPI+/PEI+); (iv) average hearing level at the first visit; (v) hearing outcome after treatment was confirmed into 4 criteria (Complete recovery, Partial recovery, Slight response, or No improvement). The relationship between (iii) and (iv) was analyzed by Student's *t*-test, and between (iii) and (v) was by Mann-Whitney *U* test.

Fifth, factors of subject were tabulated based on two subgroups of PPI/PEI enhancement pattern; age, gender, underlying disease, audiogram pattern, or wait time from symptom onset to examination.

All statistical analyses were conducted using the open source EZR software on R commander (http://www.jichi.ac.jp/saitama-sct/SaitamaHP.files/statmed.html).[14] *p*-value < 0.05 was considered significant.

## 3 | RESULTS

Table 1 presents the details of subjects, categorized into two subgroups based on the absence or presence of dizziness/vertigo symptoms at the first visit. Results indicate no differences between the two subgroups regarding age, gender, underlying disease, and wait time for MRI examination. However, differences were observed in hearing level at the first visit, audiogram pattern, and hearing outcome after treatment.

As depicted in Figure 3A, the distribution of cochlear SIR revealed a main effect of the factor "complication of dizziness/vertigo symptom at the first visit" [$F$ (1, 27) = 10.4, $p = 3.2 \times 10^{-3}$]. Similarly, a main effect was observed for the factor "both ears," with significantly higher SIR in the SSNHL ear [$F$ (1, 27) = 9.8, $p = 4.1 \times 10^{-3}$]. Additionally, an interaction was noted between "dizziness/vertigo symptom" and "both ears" [$F$ (1, 27) = 4.6, $p = 0.041$], indicating that the cochlear SIR in the SSNHL ear was higher in patients with dizziness/vertigo at the first visit. Figure 3B demonstrates that the distribution of vestibular SIR also showed main effects for both factors "complication of dizziness/vertigo symptom at the first visit" and "both ears" [dizziness/vertigo, $F$ (1, 27) = 4.8, $p = 0.038$; both ears, $F$ (1, 27) = 8.1, $p = 8.2 \times 10^{-3}$], with significantly higher SIR in the SSNHL ear. An interaction between "dizziness/vertigo" and "both ears" was also observed [$F$ (1, 27) = 6.4, $p = 0.017$], suggesting that SSNHL patients with dizziness/vertigo symptom tended to exhibit increased cochlear and vestibular SIR in the SSNHL ear.

As shown in Figure 4, the cross-tabulation of (i) and (ii) revealed deviation in distribution (Fisher exact test, $p = 9.2 \times 10^{-4}$), with a significant difference between PPI−/PEI− and PPI+/PEI+ subgroups (Bonferroni test, $p = 2.3 \times 10^{-3}$). This suggests that patients with PPI+/PEI+ tended to complicate dizziness/vertigo symptom at the first visit.

Furthermore, as depicted in Figure 5A, hearing levels at the first visit were 58.2 ± 22.7 dB for subjects with PPI−/PEI− or PPI+/PEI−, and 91.6 ± 26.3 dB for those with PPI+/PEI+, indicating a significant difference (Student's *t*-test, $p = 1.0 \times 10^{-3}$). Additionally, Figure 5B shows a difference in hearing outcomes after treatment between subjects with PPI−/PEI− or PPI+/PEI− and those with PPI+/PEI+ (Mann-Whitney *U* test, $p = 0.027$). Thus, subjects with PPI+/PEI+ subjects exhibited more severe hearing loss at the first visit and were difficult to achieve their hearing improvements after treatment.

Table 2 presents the relationship between vestibular enhancement pattern, categorized into two subgroups of PPI+/PEI+ or others, and factor of subjects. Results indicate no differences between

**TABLE 1** Demographic information of SSNHL subjects based on the absence or presence of dizziness/vertigo symptom at the first visit.

| | Dizziness/Vertigo (−) ($N = 13$) | Dizziness/Vertigo (+) ($N = 16$) | *p*-value |
|---|---|---|---|
| Age | 59.8 ± 17.2 years | 55.1 ± 17.6 years | 0.48[a] |
| Gender | 9 men and 4 women | 9 men and 7 women | 0.7[b] |
| Underlying disease (multiple answers) | None, 5; lifestyle disease, 6; cardiovascular, 3; sudden hearing loss, 2 | None, 3; lifestyle disease, 6; cardiovascular, 7; autoimmune, 2; sudden hearing loss, 3 | 0.56[b] |
| Hearing level at first visit | 60.0 ± 23.6 dB HL | 83.9 ± 29.7 dB HL | 0.026[a,*] |
| Audiogram pattern | Ascending, 1; flat, 12 | Ascending, 1; flat, 7; profound, 8 | 0.0038[b,*] |
| Wait time from symptom onset to examination | 21.4 ± 16.6 days | 25.6 ± 13.4 days | 0.46[a] |
| Hearing outcome after treatment | Complete recovery, 3; partial recovery, 5; slight response, 4; no improvement, 0 | Complete recovery, 1; partial recovery, 4; slight response, 2; no improvement, 6 | 0.036[c,*] |

[a]Student's *t*-test.
[b]Fisher's exact test.
[c]Mann-Whitney *U* test.
*Significant difference.

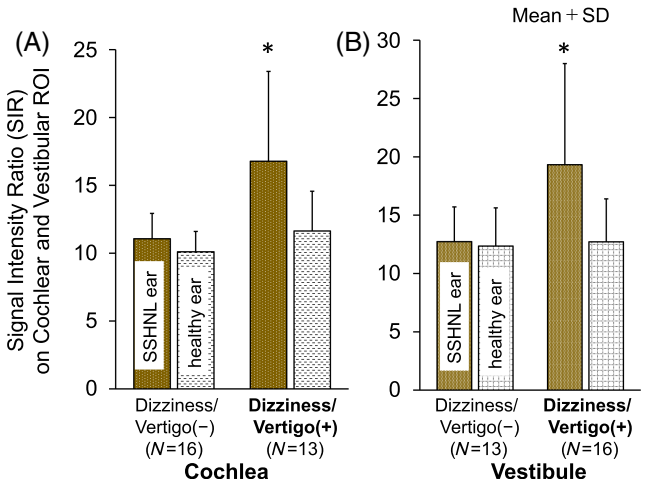



**FIGURE 3** Distribution of signal intensity ratio (SIR) according to dizziness/vertigo symptoms and ears. (A): Cochlear SIR showed main effects for the factors of "dizziness/vertigo symptom" ($p < 0.01$), and "ear" ($p < 0.01$), respectively. Additionally, a significant interaction was observed between the factors of "dizziness/vertigo symptom" and "ear" ($p < 0.05$). (B): Vestibular SIR also showed main effects for the factors of "dizziness/vertigo symptom" ($p < 0.05$), and "ear" ($p < 0.01$), with a significant interaction between both factors ($p < 0.05$). Consequently, SIRs increased in subjects with dizziness/vertigo symptom in the sudden sensorineural hearing loss (SSNHL) ear. *: two-way analysis of variance interaction, $p < 0.05$.

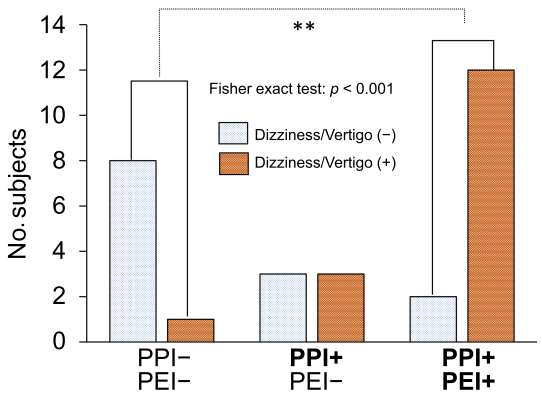



**FIGURE 4** Relationships between PPI/PEI enhancement and complication of dizziness/vertigo symptom at the first visit. There was a significant association between positive perilymph image/positive endolymph image (PPI/PEI) enhancement patterns and dizziness/vertigo symptom ($p < 0.001$). Subjects with dizziness/vertigo tended to exhibit PPI+/PEI+ enhancement, whereas those without it exhibited PPI−/PEI− ($p < 0.01$). **: $p < 0.01$; PPI+, laterality of enhancement between both inner ears on PPI; PEI−, absence of laterality of PEI enhancement between both inner ears.

the two subgroups regarding age, gender, underlying disease, and wait time for examination. However, a difference was observed in audiogram pattern.

## 4 | DISCUSSION

The application of delayed gadolinium-enhanced MRI is suitable for the assessment of Meniere's disease. Obtaining 3D-FLAIR imaging after administration of contrast agent enables visualization of subtle inner ear pathology.[15] In this study, we employed this method to evaluate patients with SSNHL.

Recent studies of 3 T MRI in SSNHL patients have used 3D-FLAIR sequences to examine the inner ear.[6–8] Patients underwent scanning twice—before and immediately after intravenous administration of gadolinium. The combined analysis of pre- and post-contrast images elucidated the pathologic basis as partial cochlear and vestibular enhancements in a majority of SSNHL patients.[6–8] The cochlear and vestibular enhancements indicate an increased amount of protein or hemorrhage on pre-contrast MRI, and a leakage of gadolinium owing to increased vascular permeability on post-contrast MRI.[6,7,16] The enhancement has also been correlated with the degree of hearing and vestibular deteriorations at the first visit, and hearing outcomes after treatment.[6,8,9,16]

In this study, patterns of enhancement in the vestibule on PPI and PEI demonstrated correlations with poor hearing levels and concurrent dizziness/vertigo symptoms at the first visit in the SSNHL patients. Enhancement patterns also demonstrated an association with hearing outcome after treatment. Consequently, we postulate that enhancement patterns on PPI/PEI might serve as objective indicators reflecting hearing prognosis.

Additionally, quantitative evaluation of SI values within vestibular ROIs using SIR was consistent with the enhancement pattern results. This consistency may be attributed to the linear relationship between SI values and the severity of the underlying pathologic basis. Generally, SI values on gadolinium-enhanced MRI reflect the distribution of contrast agents within the ROI.[17] Thus, the amount of gadolinium distributed would correspond to the severity of inner ear pathology. The increased distribution of gadolinium into inner ear may be indicative of breakdown of the barrier system in the inner ear, as suggested in previous studies.[6,7,16]

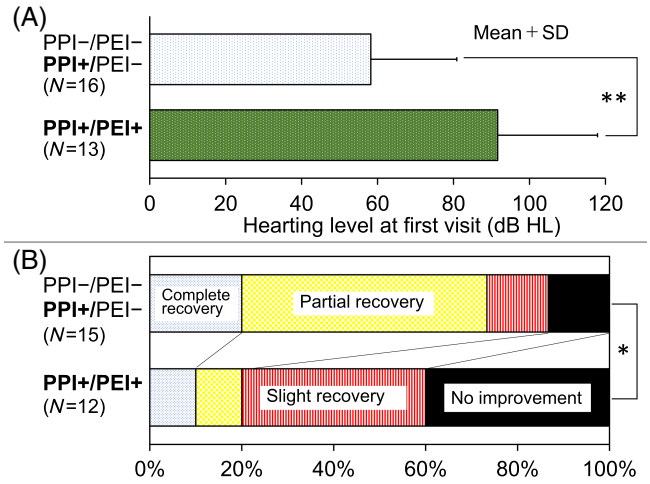



**FIGURE 5** Relationships between PPI/PEI enhancement and hearing level at the first visit or hearing outcomes after treatment. (A): Subjects with PPI+/PEI+ exhibited more severe hearing loss at the first visit compared to those with PPI−/PEI− and PPI+/PEI− ($p < 0.01$). (B): Subjects with PPI+/PEI+ exhibited poor improvements compared to those with PPI−/PEI− and PPI+/PEI− ($p < 0.05$). *: $p < 0.05$; **: $p < 0.01$; PPI, positive perilymph image; PEI, positive endolymph image; PPI+, laterality of enhancement between both inner ears on PPI; PEI−, absence of laterality of PEI enhancement between both inner ears.

Barrier systems are equipped in central and peripheral nervous system, such as the blood-brain barrier. The barrier actively transports essential substances and efficiently eliminates waste products.[18,19] The blood-labyrinth barrier has a crucial role in maintaining neural homeostasis in the inner ear.

In a study of rats with meningitis that received intravenous injection of Evans Blue dye, histological sections showed an increase in leakage of dye into the inner ear.[20] Circulatory disorders and inner ear inflammation can increase the permeability of the blood-labyrinth barrier.[21,22] This suggests that the inner ear inflammation can cause breakdown of the blood-labyrinth barrier. Additionally, a robust correlation was observed between the amount of Evans Blue leakage, duration of hearing impairment, and the decrease in cochlear spiral ganglion neurons.[20] Breakdown of the blood-labyrinth barrier inhibits the function of cochlear hair cells.[23]

PPI+/PEI+ enhancement (Figure 1B,C) could be related to further septum within the blood labyrinth barrier, blood-perilymph barrier, and blood-endolymph barrier.[24–26] Gadolinium contrast agents distribute more easily into perilymph than endolymph because the blood-endolymph barrier is robust and more resistant and less likely to breakdown.[1,27] Moreover, substances distributed in perilymph have limited access to endolymph owing to the perilymph-endolymph barrier.[25,26,28] Therefore, subjects with PPI+/PEI+ enhancement may be severely damaged in the cochlea and vestibule enough to breakdown not only perilymph but also endolymph, associating with hearing and vestibular deteriorations and poor hearing outcomes.

We did not conduct pre-contrast MRI in this study. To conduct both pre-contrast and delayed gadolinium-enhanced imaging, an interval of 4 h before and after gadolinium administration is needed, which would impose an unreasonable burden on the subjects and the hospital.

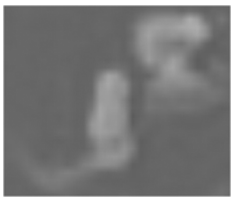
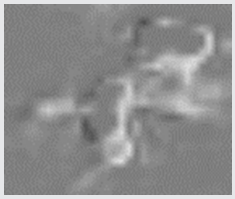
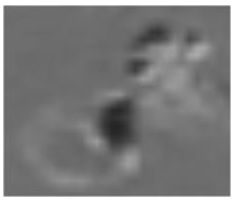
This study has several limitations. First, we treated 121 patients with SSNHL from 2018 to 2022, but only 29 patients (24.0%)

**TABLE 2** Relationship between vestibular enhancement patterns and factors of subject.

| | PPI−/PEI− and PPI+/PEI− ($N = 16$) | PPI+/PEI+ ($N = 13$) | *p*-value |
|---|---|---|---|
| Age | 59.7 ± 16.6 years | 54.1 ± 16.6 years | 0.39[a] |
| Gender | 9 men and 7 women | 9 men and 4 women | 0.7[b] |
| Underlying disease (multiple answers) | None, 6; lifestyle disease, 7; cardiovascular, 6; sudden hearing loss, 2; autoimmune disease, 1 | None, 2; lifestyle disease, 5; cardiovascular, 5; sudden hearing loss, 3; autoimmune disease, 1 | 0.81[b] |
| Audiogram pattern | Ascending, 1; flat, 14; profound, 1 | Ascending, 1; flat, 5; profound, 7 | 0.0065[b,*] |
| Wait times from symptom onset to examination | 19 ± 9.9 days | 29.5 ± 17.9 days | 0.056[a] |

[a]Student's *t*-test.
[b]Fisher's exact test.
*Significant difference.

**TABLE 3** Classification of SSNHL Peri- and Endolymphatic image Enhancement pattern in Delayed gadolinium-enhanced MRI (SPEED).

| SPEED classification | Appearance on HYDROPS in cochlea and vestibule[a] | | PPI/PEI enhancement pattern[a] | Evaluation/Prognosis |
|---|---|---|---|---|
| SPEED: 0 | White-tone |  | PPI−/PEI−<br>PPI+/PEI− | Hearing outcome after treatment: better |
| SPEED: 1 | Gray-tone |  | PPI+/PEI+ | Hearing outcome after treatment: poor |
| SPEED: EH (endolymphatic hydrops) | Black-transparent |  | PPI−/PEI+ | Suspected of Meniere's disease, probably not SSNHL |

Abbreviations: HYDROPS, Hybrid of reversed image of positive endolymph signal and negative image of perilymph signal; PEI, Positive endolymph image; PPI, Positive perilymph image; SSNHL, Sudden sensorineural hearing loss.
[a]Whenever "gray-tone" or "black-transparent" appearances are detected on HYDROPS, the components, PPI and PEI, should be confirmed.

underwent delayed gadolinium-enhanced MRI. As the number of SSNHL subjects was small, a follow-up study with a larger sample size is desirable. Second, although we attempted to conduct MRI examination for all SSNHL patients as soon as possible, the wait time varied depending on the availability of MRI equipment. In the future, we aim to establish efficient treatment plans that delayed gadolinium-enhanced MRI can be conducted within one week for SSNHL patients.

Ultimately, the "gray-tone" appearance on HYDROPS in SSNHL patients indicated severe inner ear pathology characterized by significant leakage of contrast agent owing to breakdown of the blood-labyrinthine barrier. However, note that it is necessary to confirm the PPI and PEI whenever "gray-tone" or "black-transparent" appearances are detected on HYDROPS. The "gray-tone" appearance correlates with the severity of hearing and vestibular deteriorations and predicts poor hearing improvement after treatment. Thus, we propose a new classification for evaluating SSNHL based on differences in PPI/PEI enhancement patterns (Table 3).

## 5 | CONCLUSION

Delayed gadolinium-enhanced MRI, originally developed for the diagnosis of Meniere's disease, can also indicate inner ear pathology in patients with SSHNL. It has the potential to differentiate various auditory and vestibular disorders and should be considered as a screening tool.

## CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

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