



The usefulness of inner ear magnetic resonance imaging in patient with Ménière's disease

A narrative review

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ABSTRACT

Ménière's disease (MD) is a multifactorial disorder with typical symptoms of recurrent vertigo, tinnitus, fluctuating hearing loss, and sensations of ear fullness. This disease greatly reduces the quality of life for patients. Unfortunately, it is difficult to diagnose and predict the prognosis using only diagnostic methods, including audiometry. Therefore, since the mid-2000s, various efforts have been made to directly identify endolymphatic hydrops (EH), a histologic hallmark of MD, through magnetic resonance imaging (MRI) of the inner ear. Various studies have revealed significant correlation among degree of EH on inner ear MRI, patient symptoms, and test results. Although there are some limitations, inner ear MRI is expected to be widely used for differential diagnosis of MD, recurrent low-frequency hearing loss, non-specific vertigo, and vestibular migraine. In addition, as an automated analysis system of EH using the convolutional neural network algorithm has been developed, the usefulness of inner ear MRI is increasing. This algorithm can generate results that are highly consistent with those generated by manual calculation and can do so more quickly. Although there are some limitations to be overcome, inner ear MRI is expected to be widely used for differential diagnosis of various EH-related diseases in the not-too-distant future.

Keywords: Artificial intelligence; Deep learning; Magnetic resonance imaging; Meniere disease; Vertigo

INTRODUCTION

Ménière's disease (MD) was named after the French physician Prosper Ménière (1799 to 1862) at the end of the 19th century. MD is characterized by (1) sudden vertigo attack, (2) fluctuating sensorineural hearing loss, (3) tinnitus, and (4) aural pressure or fullness. The name MD is believed to have been derived from Adam Politzer's use of the name 'Symptom der Meniereschen

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Krankeitform' in 1867 [1].

Although MD was first discovered by Prosper Ménière, he did not provide accurate pathological findings [2]. In 1938, the Hallpike et al. [3] and Yamakawa [4] group almost simultaneously published pathophysiological evidence of MD. They described endolymphatic hydrops (EH) in temporal bones of patients with symptoms of MD. Their findings were confirmed by several different histopathological observations, and EH is almost universally accepted as the most important pathological manifestation of MD (Fig. 1) [3,4].

The globally accepted diagnostic criteria have changed several times. In 1972, 'A hearing balance subcommittee under the American Academy of Otolaryngology' set definitions and diagnostic criteria, and after that, the 'American Association of Otolaryngology-Head and Neck Surgery (AAO-HNS)' changed the criteria in 1985 and 1995 [5]. The most widely used diagnostic criteria today, created by a committee of the Bárány Society in 2015, have removed the "certain" and "possible" MDs (Table 1) [6].

Results from epidemiological studies of the prevalence of MD vary by race or region, with reports ranging from 17 to 513 cases per 100,000 people [7]. The age of onset varies from 20 to 60 years of age, but the highest prevalence is seen in the 40s [8]. Such diversity in prevalence is due to racial and genetic differences, but at the same time, due to the lack of objective and definitive diagnostic methods [9]. Currently, patients' symptoms are very important for the diagnosis of MD, and the only objective test other than that is pure tone audiometry (PTA).

The most objective method for diagnosing MD is to identify EH as a histological hall marker in the cochlear or vestibule,

but it has been impossible to identify it for a long time directly. However, epochal changes began to occur with the development of magnetic resonance imaging (MRI) and post-image processing protocols for MRI in the mid-2000s [9].

At present, many groups have reported the study results for EH visualized by intratympanic (IT) or intravenous (IV) injection of a contrast media in MRI. Accordingly, MD-related research, which has been somewhat stagnant for the past several decades, is entering a new phase. Therefore, we summarize the usefulness of inner ear MRI in the diagnosis and treatment of MD.

THE HISTORY OF INNER EAR MRI FOR MÉNIÈRE'S DISEASE

Since the mid-2000s, various attempts have been made to identify EH in humans with the development of imaging technology using MRI. In 2004, Duan et al. [10] first successfully identified EH in the inner ear organ using 4.7 T MRI in live guinea pigs. The Nakashima group at Nagoya University in Japan confirmed EH after IT and IV injections of contrast media to MD patients using 3T MRI [11]. Since then, efforts to confirm EH using MRI have increased worldwide. In particular, IV-gadolinium (Gd)-enhanced inner ear MRI has several advantages over IT methods [12,13]. The IV contrast enhancement method is less invasive and much more efficient than the IT method (because it requires less time after contrast injection (4 hours vs. 24 hours) In addition, the IT method requires injection of both ears in order to evaluate both sides simultaneously, but the IV method can evaluate both sides simultaneously with a single IV injection [14]. Several studies

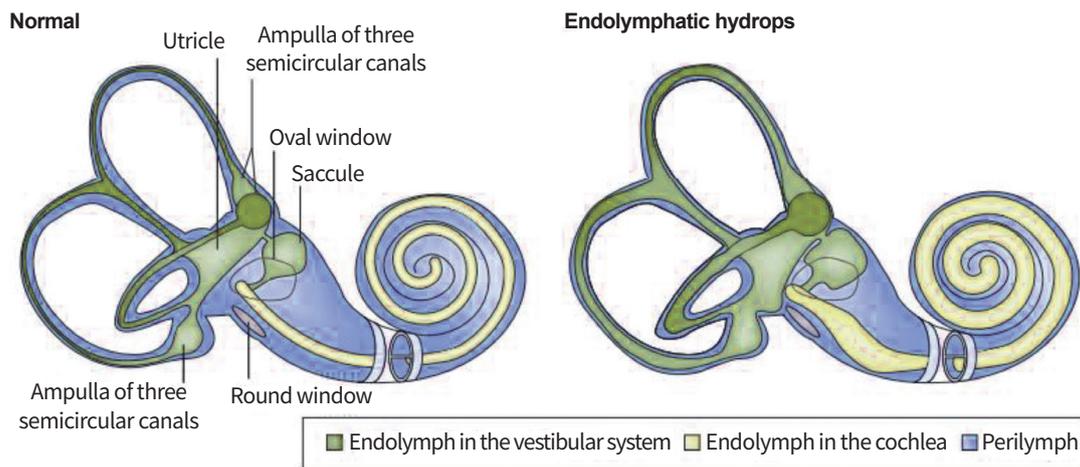


Fig. 1. Endolymphatic hydrops (EH), a histologic marker of Meniere's disease. EH increases the endolymphatic space, which can affect the inner and cause symptoms. Progression of MD is associated with progression of EH.

PRECISION AND FUTURE MEDICINE
Analysis of endolymphatic hydrops using MRI

Table 1. The AAO-HNS 1995 criteria and 2015 proposed new criteria for Meniere's disease

	AAO-HNS 1995 criteria	2015 new criteria by Barany Society
Certain Meniere's disease	Definite Meniere's disease, plus histopathological confirmation	Deleted
Definite Meniere's disease	At least two definite spontaneous episodes of vertigo lasting at least 20 minutes Audiometrically documented hearing loss on at least one occasion Tinnitus or aural fullness in the treated ear Other causes excluded	At least two spontaneous episodes of vertigo, each lasting from 20 minutes to 12 hours Audiometrically documented low- to medium-frequency sensorineural hearing loss in one ear, defining the affected ear on at least one occasion before, during, or after one of the episodes of vertigo Fluctuating aural symptoms (hearing, tinnitus, or fullness) in the affected ear Not better accounted for by another vestibular diagnosis
Probable Meniere's disease	One definitive episode of vertigo Audiometrically documented hearing loss on at least one occasion Tinnitus or aural fullness in the treated ear Other causes excluded	At least two episodes of vertigo or dizziness, each lasting from 20 minutes to 24 hours Fluctuating aural symptoms (hearing, tinnitus, or fullness) in the affected ear Not better accounted for by another vestibular diagnosis
Possible Meniere's disease	Episodic vertigo of the Meniere type without documented hearing loss Sensorineural hearing loss, fluctuating or fixed Other causes excluded disequilibrium, but without definitive episode Other causes excluded	Deleted

AAO-HNS, American Association of Otolaryngology-Head and Neck Surgery.

have reported an association between the severity of EH on MRI and symptoms in patients with MD, and IV-Gd inner ear MRI is useful in diagnosing MD by showing a correlation between hearing-vestibular outcome and hydrocephalus. Several studies have reported an association between the severity of EH on MRI and symptoms in patients with MD. These results prove that IV-Gd inner ear MRI is useful for MD diagnosis by showing a good correlation with the previously used audio-vestibular tests [15]. Recently, more detailed and extensive studies are underway beyond simply comparing the EH seen in MD-MRI with various existing results. In particular, studies are underway to accurately determine the degree of EH by dividing the cochlea and vestibule into compartments or implementing a 3D model [15,16].

CURRENT DIAGNOSIS AND DILEMMA OF MÉNIÈRE'S DISEASE

The diagnostic criteria for MD proposed by AAO-HNS have been widely used and recently were revised in 2015 (Table 1).

However, the changed diagnostic criteria are entirely dependent on subjective symptoms, except for PTA, and other vestibular diseases must still be excluded.

In addition to PTA, electrocochleography (EcoG), video head impulse test (vHIT), vestibular evoked myogenic potential (VEMP) test, and the caloric test did not belong to the diagnostic criteria, they have been widely used as additional tests for diagnosis. Among them, EcoG has been the most widely used as an adjunct to MD diagnosis for over 30 years [4]. However, since EcoG cannot directly visualize the endolymph space and EH, the limitations are clear, and the diagnostic value of this test is still controversial in several reports and literature [17]. Several studies have found no significant correlation between EH levels and the interaural difference ratio in cervical VEMP [18,19]. However, some studies have shown that MD progression and VEMP are related based on the decreased amplitude of cervical VEMP in the lesion side of the MD compared to the contralateral ear [20].

Canal paralysis is frequently observed on caloric tests in patients with MD. However, even with canal paresis, vHIT of-

Table 2. The grading system of endolymphatic hydrops using magnetic resonance imaging [23]

Grade of hydrops	Vestibule (area ratio ^{a)})	Cochlea
None	≤33.3%	No displacement of Reissner's membrane
Mild	>33.3%, ≤50%	Displacement of Reissner's membrane, area of cochlear duct ≤ area of the scala vestibuli
Significant	>50%	Area of the cochlear duct exceeds the area of the scala vestibuli

^{a)}Ratio of the area of the endolymphatic space to that of the fluid space (sum of endolymphatic and perilymphatic spaces) in the vestibule measured on tracings of images.

Table 3. Previous studies using IT or IV-Gd enhanced inner ear MRI in MD

Study	No. of participants	Type of disease	Injection route	Compared tests	Positive correlation findings with MRI
Gurkov et al. [25]	34	MD	IT	PTA, VEMP, Caloric test, ECoG	PTA, VEMP
Hornibrook et al. [26]	30	MD	IT	EcoG	ECoG
Sun et al. [27]	30	VM and MD	IT	PTA, VEMP	PTA, VEMP (partial)
Seo et al. [28]	26	MD	IT	PTA, EcoG, VEMP	PTA, EcoG
Yamamoto et al. [29]	17	MD	IT	EcoG	ECoG
Fukuoka et al. [30]	20	MD	IT	EcoG	ECoG
Kato et al. [31]	24	MD	IT	Caloric test	
Fiorino et al. [32]	18	MD	IT	EcoG, VEMP, Caloric test	VEMP
Jerin et al. [33]	39	MD	IT	VEMP	
Sephadari et al. [34]	21	MD, delayed EH, SSNHL	IV	PTA	PTA
Quatre et al. [13]	41	MD	IV	PTA, EcoG, DPOAE, VEMP	PTA
Liu et al. [35]	69	MD	IT	PTA, VEMP, Caloric test, vHIT	PTA, VEMP (partial), Caloric test, vHIT
Choi et al. [36]	16	MD	IV	Caloric test	Caloric test
Kahn et al. [37]	31	MD	IV	PTA, vHIT, VEMP	PTA, VEMP (partial)
Sun et al. [38]	21	MD	IT	PTA, EcoG, VEMP, Caloric test, vHIT	PTA, EcoG, VEMP
Neri et al. [39]	35	MD	IT	PTA, Caloric test, VEMP, vHIT	PTA, Caloric test, vHIT
Oh et al. [40]	62	VM and MD	IV	PTA, Caloric test, VEMP, vHIT	PTA, Caloric test
Jasinska et al. [41]	38	MD	IV	PTA, Caloric test, EcoG	PTA, Caloric test, EcoG
Cho et al. [42]	29	MD	IV	PTA, EcoG, VEMP, Caloric test	PTA, EcoG, Caloric test
Yang et al. [43]	50	MD	IT	PTA, Suprathreshold function test, EcoG, Glycerol test	PTA, Suprathreshold function test (partial), EcoG
Jerin et al. [44]	192	MD	IT	PTA, caloric test	PTA

IT, intratympanic; IV-Gd, intratympanic-gadolinium; MRI, magnetic resonance imaging; MD, Ménière's disease; PTA, pure tone audiometry; VEMP, vestibular evoked myogenic potential; ECoG, electrocochleography; VM, vestibular migraine; EH, endolymphatic hydrops; SSNHL, sudden sensorineural hearing loss; IV, intravenous; DPOAE, distortion product otoacoustic emission; vHIT, video head impulse test.

ten shows normal findings. It was hypothesized that this was not because the function of the lateral canal was actually decreased, but because the convection was not occurred well due to the expansion of the endolymphatic space inside the lateral semicircular canal [21]. However, recent studies using human temporal bone specimens and inner ear MRI suggest that this is due to invasion of the saccule or utricle into the ca-

nal rather than the expansion of the endolymphatic space within the canal [22]. Likewise, evaluation of the endolymphatic space through MRI supplements several limitations of existing tests and is still being developed.

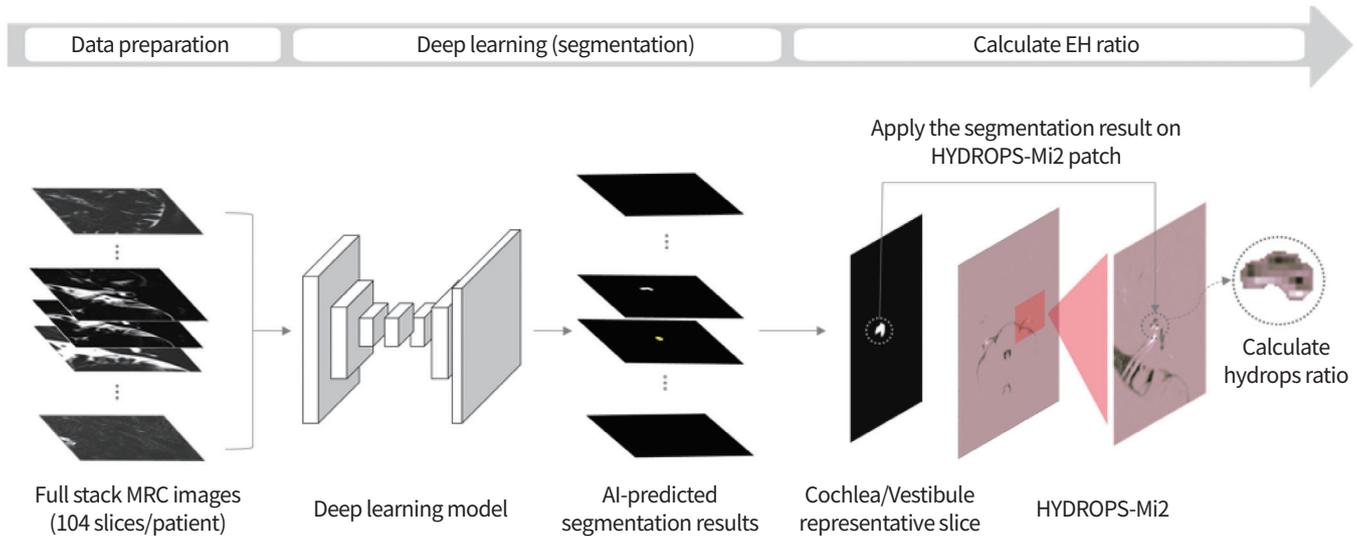


Fig. 2. Process for calculating the endolymphatic hydrops ratio using a convolutional neural network. EH, endolymphatic hydrops; MRC, magnetic resonance cisternography; AI, artificial intelligence; HYDROPS-Mi2, HYDROPS (HYBRID of Reversed image Of Positive endolymph signal and native image of positive perilymph signal) image Multiplied with heavily T2-weighted MR cisternography.

USEFULNESS AND FUTURE OF MRI IN DIAGNOSIS OF MÉNIÈRE'S DISEASE

With the development of technology, MRI has higher resolution, high intuition and convenience, and involves no radiation exposure. Therefore, the use of MRI is expected to increase further in medical diagnosis and follow-up observation. In particular, inner ear MRI, which can directly confirm EH, is getting attention as an innovative test method for MD, which lacks an objective diagnostic method. Clinically, several grading systems have been introduced for reading and diagnosis, the most widely used of which was published in 2009 by Nakashima et al. [23] (Table 2).

IV contrast-enhanced inner ear MRI has been widely recognized for its convenience and accuracy worldwide, and its scope of application is being extended beyond MD to the entire category of "Hydrophic Ear Disease" [24]. As summarized in Table 3 [13,25-44], many researchers have demonstrated that inner ear MRI shows a significant correlation with conventional tests, and the endolymphatic space seen on MRI is consistent with histopathological findings of temporal bone specimens of MD patients [22]. However, there are some limitations to measurement of EH using inner ear MRI. The first is that the image analysis process takes excessive time and effort and requires expertise. Second, since the resolution of MRI is not very high in 3T, errors can occur. Therefore, our group developed a deep learning algorithm using a convolutional neural network (CNN) for the analysis of EH (Fig. 2). Using this algorithm, quantitative analysis of EH in inner ear MRI proceeds

quickly and conveniently, and the accuracy is very similar to that of an experienced radiologist or otolaryngologist. Specifically, compared with that measured by experienced physicians, the average interclass correlation coefficient (ICC) for all cases was 0.953; the average ICC of the vestibules was 0.968, and that of cochleae was 0.914. The time required for the fully automated system to accurately analyze the EH ratio in one patient's one patient's MR image stack stack was approximately 3.5 seconds [45]. Although further research is needed, it is likely that an algorithm using inner ear MRI and CNN will play an important role in the diagnosis of MD in the near future.

CONCLUSION

MD is one of the most difficult diseases to treat because it is difficult to diagnose, and the prognosis is not easy to predict. However, with recent development of MR equipment and the efforts of various researchers, an inner ear MRI protocol has been developed to directly view EH, simplifying clinical access. Although additional efforts such as research using deep learning are needed, the importance of inner ear MRI is expected to increase in various diseases including MD.

CONFLICTS OF INTEREST

No potential conflict of interest relevant to this article was reported.

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Conception or design: YSC, WHC.

Acquisition, analysis, or interpretation of data: YSC, BS.

Drafting the work or revising: YSC, WHC.

Final approval of the manuscript: BHC, WHC.

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