The Journal of Laryngology & Otology

cambridge.org/jlo

A systematic review on delayed acquisition of post-gadolinium magnetic resonance imaging in Ménière's disease: imaging of the endolymphatic spaces

A Han[1] and G Kontorinis[1,2]

[1]Medical School University of Glasgow, Glasgow, Scotland, UK and [2]Department of Otorhinolaryngology, Head and Neck Surgery, Queen Elizabeth University Hospital, Glasgow, Scotland, UK

Review Article

Dr G Kontorinis takes responsibility for the integrity of the content of the paper

Cite this article: Han A, Kontorinis G. A systematic review on delayed acquisition of post-gadolinium magnetic resonance imaging in Ménière's disease: imaging of the endolymphatic spaces. *J Laryngol Otol* 2023; **137**:239–245. https://doi.org/10.1017/S0022215122001347

Accepted: 29 May 2022
First published online: 8 June 2022

Key words:
Endolymphatic Hydrops; Gadolinium; Meniere Disease; Magnetic Resonance Imaging

Author for correspondence:
Dr G Kontorinis, Department of Otorhinolaryngology, Head and Neck Surgery, Queen Elizabeth University Hospital, 1345 Govan Rd, Glasgow G51 4TF, Scotland, UK
E-mail: gkontorinis@gmail.com
Fax: +44 141 347 8029

Abstract

Objective. This study aimed to assess the clinical implications of delayed-acquisition post-gadolinium magnetic resonance imaging in identifying endolymphatic hydrops in Ménière's disease.

Method. This study was a systematic review using Medline and Embase and following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines with predetermined criteria, namely Ménière's disease, post-gadolinium magnetic resonance imaging and endolymphatic hydrops. The Quality Assessment of Diagnostic Accuracy Studies-2 tool was used to assess bias.

Results. Eleven studies were included; they all used 3T magnetic resonance imaging, with three-dimensional fluid-attenuated inversion recovery being the most common sequence. Intravenous gadolinium administration was more widely used compared with the intratympanic route. As for the timing of acquisition, 4 hours post-administration was universally used for the IV gadolinium and 24 hours was used for the intratympanic gadolinium. Despite patient-selection associated bias, all studies reported adequate visualisation of the endolymphatic spaces.

Conclusion. The use of delayed-acquisition magnetic resonance imaging is increasingly supported in visualising the endolymphatic spaces in Ménière's disease. Although the accessibility of 3T magnetic resonance imaging questions its wider applicability, it is a promising tool for the near future.

Introduction

Ménière's disease is an inner ear disorder that is characterised by recurrent spontaneous episodes of a range of symptoms that can include vertigo, fluctuating low-frequency sensorineural hearing loss, tinnitus and aural fullness.[1] The prevalence of Ménière's disease in the US population in 2010 was 190 per 100 000.[2] Furthermore, it is a disease more common among adults, especially for those who are in their fourth decade of life, and patients usually first experience symptoms between the ages of 20 and 60 years.[3] Patients initially have symptoms on one side with some patients developing symptom bilaterality after many years.[4] The male to female ratio varies from nearly equal for both sexes to a slight female preponderance that can go up to 1:1.3.[3] The diagnosis of Ménière's disease is not always straightforward as there are no widely accepted confirmatory diagnostic tests. Patients with Ménière's disease may not present with all of the classical symptoms as described above during the first encounter. Therefore, Ménière's disease can only be diagnosed at a later stage when the patient already has more than one episode of disease flare-up.[1–6] Currently, most studies are using the diagnostic criteria for Ménière's disease set by the American Academy of Otolaryngology–Head and Neck Surgery (AAO–HNS) criteria in 1995, which take into account the natural history of the disease; Ménière's disease is classified as certain, definite, probable or possible.[1]

The pathological hallmark of this disease is believed to be endolymphatic hydrops, which was first observed in post-mortem examination of patients with Ménière's disease in 1938; however, a causal relationship has never been proven.[4] Endolymphatic hydrops is the distension of the membranous labyrinth of the inner ear, which can occur in both the vestibule and the cochlea.[4] This hydrops was conventionally thought to cause the symptoms experienced by the patients affected with the disorder because the sensory and neural elements of the inner ear are damaged as a result of the release of the endolymphatic fluid into the perilymph.[4,5] Thus, visualising endolymphatic hydrops could be a potential tool in confirming the diagnosis and monitoring the progress of Ménière's disease *in vivo*. However, endolymphatic hydrops can also be caused by trauma, viral infections, autoimmune diseases and electrolyte imbalance, which can potentially confound the findings of magnetic resonance imaging (MRI).

The potential to visualise the endolymphatic hydrops *in vivo* was first established in an animal study using post-intratympanic gadolinium MRI.[7] Since then, various projects have studied the use of MRI to visualise endolymphatic hydrops after intravenous (IV) or intratympanic administration of gadolinium.[8,9] In an additional study, three-dimensional (3D) fluid-attenuated inversion recovery (FLAIR) and 3D-real IR (three-dimensional real inversion recovery) sequences are used in post-gadolinium endolymphatic hydrops imaging because they can produce images that differentiate between the endolymphatic space and the perilymph.[10] The delayed acquisition of MRI scan post-gadolinium is also important because the perilymph is most enhanced after around 3.5 to 4.5 hours, appearing as a bright signal in the image of 3D-FLAIR.[11] Conversely, the endolymph is non-enhanced, appearing as a dark signal in the image of 3D-FLAIR.[11] This is because the perilymph is more permeable to the gadolinium contrast compared with the endolymphatic space and the presence of the blood-labyrinth barrier does not allow the contrast to easily enter the endolymph.[10]

In order to assess the presence and severity of endolymphatic hydrops using MRI, Nakashima *et al.* have developed a grading system to categorise the endolymphatic hydrops in both the vestibule and cochlea as none, mild or significant.[12] Vestibular endolymphatic hydrops is graded as none when the ratio is less than 1:3, mild when the ratio is between 1:3 and 1:2, or significant when the ratio is more than 1:2.[12] As for cochlear endolymphatic hydrops, the grading is dependent on the displacement of the Reissner's membrane.[12] Cochlear endolymphatic hydrops is graded as none if no displacement of the Reissner's membrane can be identified, mild if the Reissner's membrane is displaced but not exceeding the space occupied by the scala vestibuli or significant if the Reissner's membrane is displaced to the point of exceeding the scala vestibuli.[12] An alternative to this grading system is to evaluate the morphology of the saccule and compare this with the utricle to form the inversion of saccule and utricle ratio as it was noted that the saccule is more commonly affected in endolymphatic hydrops compared with the utricle.[13]

Despite the recent reports on delayed-acquisition post-gadolinium MRI and endolymphatic hydrops, a systematic review of the current literature with a focus on the techniques used and their clinical implications is missing. On these grounds, our objectives were to assess imaging methods that are optimal for visualising endolymphatic hydrops in patients with Ménière's disease and to evaluate the use of visualising endolymphatic hydrops in aiding the diagnosis of Ménière's disease.

Materials and methods

Review question

The topic of interest for this review was the strength of delayed acquisition of post-gadolinium MRI in diagnosing Ménière's disease. The key question that arose from this topic was 'Is visualisation of endolymphatic hydrops using post-gadolinium MRI adequate to diagnose Ménière's disease?'

Inclusion and exclusion criteria

We searched for studies assessing the strengths and limitations of delayed-gadolinium MRI for detecting endolymphatic hydrops. We specifically focused on whether delayed-gadolinium MRI can detect endolymphatic hydrops and what the clinical implications of such findings are. We also documented the technical parameters used by each study with focus on the route of gadolinium administration and the delay between gadolinium administration and MRI acquisition. Table 1 demonstrates the inclusion and exclusion criteria used to perform the literature search in this review.

Table 1. Inclusion and exclusion criteria

Parameter	Inclusion	Exclusion
Patient demographics	Diagnosed with Ménière's disease based on the AAO–HNS diagnostic criteria[1]	Non-Ménière's disease patients
Imaging techniques	Post-gadolinium magnetic resonance imaging through intravenous or intratympanic routes	Other imaging techniques
Items visualised	Endolymphatic hydrops	Other items that are not related to endolymphatic hydrops

AAO–HNS = American Academy of Otolaryngology–Head and Neck Surgery

Search strategy

Medline and Embase were used in the systematic search. In addition to that, the reference sections listed in relevant studies were manually searched to find other potential studies that met the inclusion criteria. The literature search included the criteria: Ménière's disease, post-gadolinium MRI and endolymphatic hydrops, with articles in the English language and without a time limit; case reports were excluded. Preferred Reporting Items for Systematic Reviews and Meta-analyses ('PRISMA') guidelines were used for the methodology of this review.[14]

Out of a total of 30 results, we ruled out 17 based on their title and abstracts. Finally, a total of 11 studies were included for review. Any duplicates that were found during the manual search were excluded from this review. The methodology of the search strategy carried out is summarised in Figure 1.

Data extraction

Two investigators conducted the data extraction independently. The following information was extracted from the articles that met the eligibility criteria: number of patients with Ménière's disease, how the diagnosis of Ménière's disease (or no Ménière's disease) was set, type (strength of magnetic field) of scan and sequences used, dose and route of gadolinium, number of hours post-gadolinium administration that the MRI was acquired, items or areas of interest assessed on the scans, assessment of endolymphatic hydrops and where exactly in the inner ear this was assessed, the person(s) who carried out the assessment and whether the assessment was blinded or not (including information on whether the scan assessment was performed by multiple assessors independently and in such case reports on inter-observer reliability), and side effects. The data were extracted and then tabulated in the form of an Excel® spreadsheet.

Assessment of bias

We used the Quality Assessment of Diagnostic Accuracy Studies-2 tool to assess the bias in the included studies.[15]

https://doi.org/10.1017/S0022215122001347 Published online by Cambridge University Press

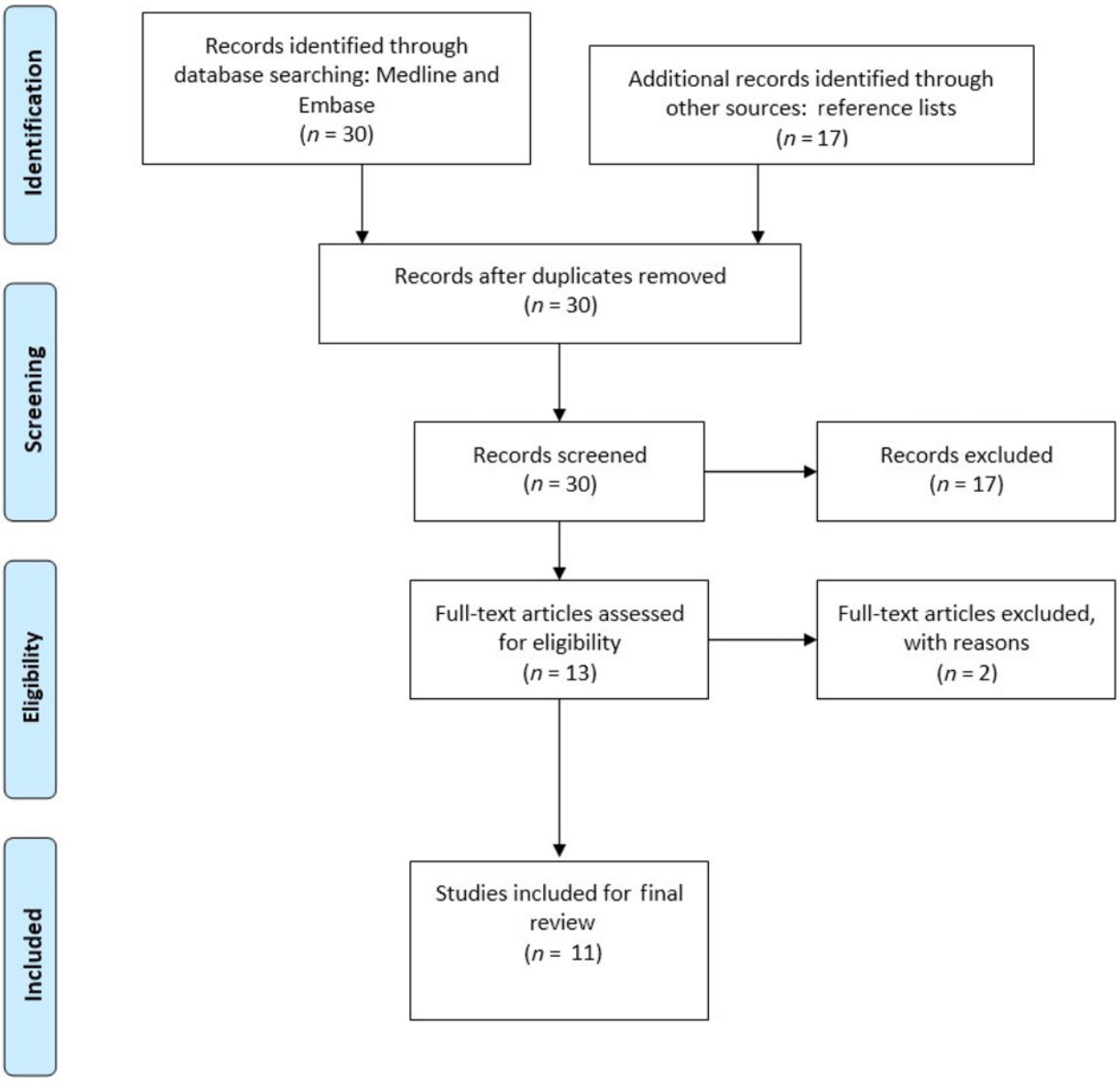

Fig. 1. Flow diagram adapted from Preferred Reporting Items for Systematic Reviews and Meta-Analyses ('PRISMA') 2009.[14]

Because of the predominantly experimental nature of the studies, it was difficult to identify a bias tool that suited the needs of the current review; however, as we were primarily looking into diagnostic accuracy, the four-domain Quality Assessment of Diagnostic Accuracy Studies-2 tool was the most appropriate one. Additionally, we used screening of the studies by two independent investigators to eliminate any bias. The results of the Quality Assessment of Diagnostic Accuracy Studies-2 tool are highlighted in Table 2 and Figure 2.

Results

Study characteristics and magnetic resonance imaging settings

The number of participants for each study varied, ranging from 6 to 68 participants; they were all diagnosed with Ménière's disease using the AAO–HNS diagnostic criteria.[1] The type of scanner used for all of the studies was the 3T MRI scanner, with 3D-FLAIR being the most common sequence used; 8 of 11 studies used 3D-FLAIR only, 1 of 11 studies used 3D-real IR only, and 2 of 11 studies used both 3D-FLAIR and 3D-real IR.

As for the route of gadolinium administration, most of the studies used IV only (8 of 11) with the rest being either intratympanic only (2 of 11), or both IV and intratympanic (1 of 11). The dose of gadolinium used for the IV route varied from 0.1 mmol/kg (6 of 11) to 0.2 mmol/kg (3 of 11), whereas the dose for the intratympanic route ranged from 5-fold dilution (1 of 11) to 8-fold dilution (2 of 11). In terms of the time of acquisition of MRI post-gadolinium, 4 hours was the most widely used (8 of 11) for the IV route. As for the intratympanic route, 24 hours was used (3 of 11). Shi *et al.* and Sano *et al.* used multiple times of acquisition, including 3 hours, 6 hours and 12 hours for Shi *et al.* and 10 minutes for Sano *et al.*[22,24] Additionally, Attyé *et al.*[20] reported an acquisition time of between 4.5 and 5.5 hours. Table 3 demonstrates the number of patients and the imaging techniques used in each study.

https://doi.org/10.1017/S0022215122001347 Published online by Cambridge University Press

Table 2. Results of Quality Assessment of Diagnostic Accuracy Studies-2 assessment[15]

	Risk of bias				Applicability concerns		
Study	Patient selection	Index test	Reference standard	Flow & timing	Patient selection	Index test	Reference standard
Yoshida *et al.*[16]	High risk	High risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Barath *et al.*[17]	High risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Sepahdari *et al.*[18]	High risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Tagaya *et al.*[19]	High risk	High risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Attyé *et al.*[20]	Low risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Attyé *et al.*[13]	Low risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Claes *et al.*[21]	High risk	High risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Sano *et al.*[22]	High risk	High risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Pakdaman *et al.*[23]	High risk	Low risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Shi *et al.*[24]	High risk	High risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk
Naganawa *et al.*[25]	High risk	High risk	Unclear risk	Low risk	Low risk	Low risk	Unclear risk

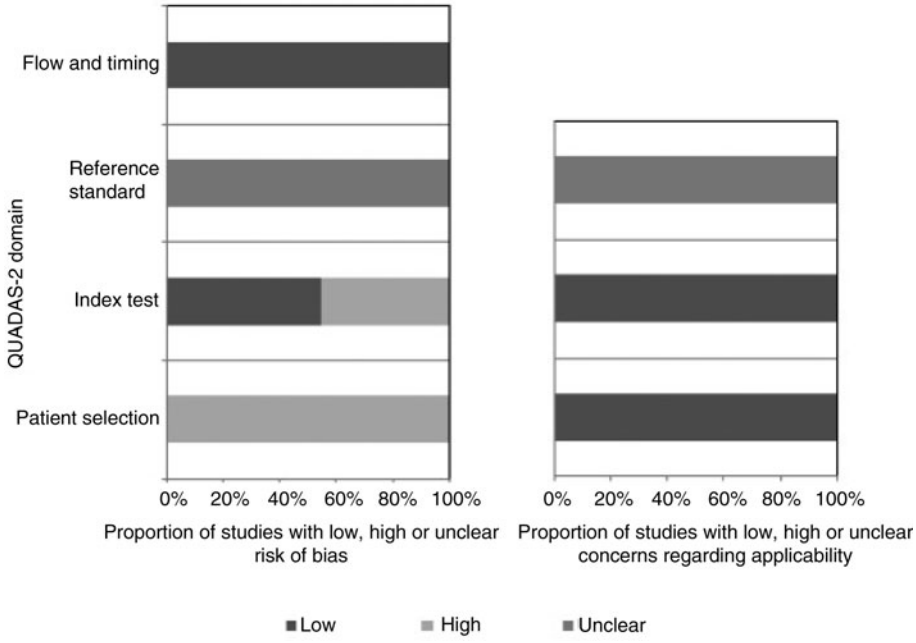

Fig. 2. Graph illustrating the proportion of studies with low, high or unclear risk of bias and concerns regarding applicability using the Quality Assessment of Diagnostic Accuracy Studies-2 tool.[15] QUADAS = Quality Assessment of Diagnostic Accuracy Studies-2 tool

Radiological assessment and findings

Table 4 outlines the structures that were visualised in the MRI, measurements that were used to evaluate endolymphatic hydrops and the persons who evaluated the scans for each study. Endolymphatic hydrops of both the vestibuli and cochlea were evaluated for almost all of the studies (9 of 11), with two studies that only evaluated the vestibular endolymphatic hydrops. All of the studies that investigated cochlear endolymphatic hydrops determined its presence by observing if there was any dilatation of the cochlear duct. As for vestibular endolymphatic hydrops, the cut-off values for the vestibular endolymphatic space to the entire vestibule ratio included 33.3 per cent (7 of 11), 45 per cent (1 of 11) and 50 per cent (2 of 11). Additionally, Attyé *et al.* also described the use of saccule to utricle ratio inversion technique to determine the presence of endolymphatic hydrops in the vestibule.[13,20]

As for the number of radiologists or persons who evaluated the scans for each study, 6 of 11 had 2 people evaluating the scans, 3 of 11 had only one person evaluating the scans and 2 of 11 did not mention who evaluated the scans. A total of 8 of 11 studies stated that the evaluators were blinded to clinical data, and the rest (3 of 11) did not mention any form of blinding.

Discussion

Main findings

This is, to our knowledge, the first review to assess the potential strengths and biases associated with the evaluation of endolymphatic hydrops using the delayed gadolinium MRI, as well as the clinical applicability of this technique. We included a series of main findings of both radiological and clinical significance. Firstly, all studies used the 3T MRI

https://doi.org/10.1017/S0022215122001347 Published online by Cambridge University Press

Table 3. Number of patients and imaging techniques used for each study

Study	Patients with MD (*n*)	Magnetic resonance sequences	Dose of gadolinium administered (mmol/kg)	Route of gadolinium administered	Time between gadolinium & MRI
Yoshida *et al.*[16]	42	3D-FLAIR	0.1	Intravenous	4 hours
Barath *et al.*[17]	53	3D-real IR	0.1	Intravenous	4 hours
Sepahdari *et al.*[18]	11	3D-FLAIR	0.2	Intravenous	4 hours
Tagaya *et al.*[19]	12	3D-FLAIR & 3D-real IR	0.2	Intravenous	4 hours
Attyé *et al.*[20]	20	3D-FLAIR	0.1	Intravenous	Between 4.5 & 5.5 hours
Attyé *et al.*[13]	30	3D-FLAIR	0.1	Intravenous	4 hours
Claes *et al.*[21]	12	3D-FLAIR	Eight-fold dilution	Intratympanic	24 hours
Sano *et al.*[22]	6	3D-FLAIR	0.1	Intravenous	10 minutes, 4 hours
Pakdaman *et al.*[23]	32	3D-FLAIR	0.2	Intravenous	4 hours
Shi *et al.*[24]	6	3D-FLAIR & 3D-real IR	5-fold dilution	Intratympanic	3 hours, 6 hours, 12 hours, 24 hours
Naganawa *et al.*[25]	10	3D-FLAIR	8-fold dilution (intratympanic); 0.1 mmol/kg (intravenous)	Intratympanic & intravenous	24 hours (intratympanic), 4 hours (intravenous)

All studies were performed in a 3T MRI scanner. MD = Ménière's disease; MRI = magnetic resonance imaging; 3D-FLAIR = three-dimensional fluid-attenuated inversion recovery; 3D-real IR = three-dimensional real inversion recovery

Table 4. Outline of items visualised on the scan, assessments used to identify EH, person who assessed the scans and whether the assessors are blinded or not for each study

Study	Items visualised on the scans	Measurements to identify EH	Who evaluated the scan	Were the evaluators blinded
Yoshida *et al.*[16]	EH of vestibule & cochlea	Vestibular EH = VES to entire vestibule ratio >33.3% Cochlear EH = dilatation of the cochlear duct	Radiologist	Yes
Barath *et al.*[17]	EH of vestibule & cochlea	Vestibular EH = VES to entire vestibule ratio >50% Cochlear EH = dilatation of the cochlear duct	2 neuroradiologists	Yes
Sepahdari *et al.*[18]	EH of vestibule	Vestibular EH = VES to entire vestibule >45%	2 neuroradiologists	Yes
Tagaya *et al.*[19]	EH of vestibule & cochlea	Vestibular EH = VES to entire vestibule ratio >33.3%	Radiologist	Yes
Attyé *et al.*[20]	EH of the vestibule	SURI ≥1 = EH	2 neuroradiologists	Yes
Attyé *et al.*[13]	EH of vestibule & cochlea	SURI ≥1 = EH Vestibular EH = VES to entire vestibule ratio >33.3% Cochlear EH = dilatation of the cochlear duct	2 radiologists	Yes
Claes *et al.*[21]	EH of vestibule & cochlea	Vestibular EH = VES to entire vestibule ratio >33.3% Cochlear EH = dilatation of the cochlear duct	Not stated; reviewed independently in radiology & otolaryngology departments	No
Sano *et al.*[22]	EH of vestibule & cochlea	Vestibular EH = VES to entire vestibule ratio >33.3% Cochlear EH = dilatation of the cochlear duct	Radiologist	Yes
Pakdaman *et al.*[23]	EH of vestibule	Vestibular EH = VES to entire vestibule ratio >50%	Post-doctorate research fellow & neuroradiologist	Yes
Shi *et al.*[24]	EH of vestibule & cochlea	Vestibular EH = VES to entire vestibule ratio >33.3% Cochlear EH = dilatation of the cochlear duct	Not mentioned	No
Naganawa *et al.*[25]	EH of vestibule & cochlea	Vestibular EH = VES to entire vestibule ratio >33.3% Cochlear EH = dilatation of the cochlear duct	2 neuroradiologists	No

EH = endolymphatic hydrops; VES = vestibular endolymphatic space; SURI = saccule to utricle ratio inversion

https://doi.org/10.1017/S0022215122001347 Published online by Cambridge University Press

scanner, with 3D-FLAIR being the most commonly used MRI sequence to assess endolymphatic hydrops. Secondly, the IV route of administering gadolinium was overall found to be more ubiquitous than the intratympanic route. Thirdly, all studies used some form of semi-quantitative grading systems in their assessment of endolymphatic hydrops. As for the timing of acquisition of MRI, four hours appeared to be the most commonly used for IV gadolinium. In contrast, 24 hours is more commonly used for intratympanic gadolinium. Moreover, most of the studies included experienced radiologists who were blinded to clinical data for assessing endolymphatic hydrops of both the vestibule and cochlea. Despite the relatively small number of studies carried out so far, the protocols used appear grossly uniform with only minor modifications.

However, we identified bias mostly in the patient selection but also in the methodology of scan assessment (lack of independent or blind review in some studies); to overcome these limitations further studies will be required to strengthen the evidence of using MRI for diagnostic purposes in Ménière's disease.

Technical considerations and clinical implications

There are several explanations as to why certain parameters were used more frequently in these studies. Firstly, 3D-FLAIR was used more frequently than 3D-real IR as it is more sensitive to gadolinium contrast and no post-imaging processing is required.[10] Additionally, administering gadolinium through the IV route provides a shorter acquisition time than the intratympanic route and allows for visualising of both the inner ears.[10] As for the dose of gadolinium used, it is dependent on the optimisation of the imaging sequence. Lower concentrations are needed for heavily T2-weighted 3D-FLAIR, which makes it more ideal in clinical settings as it could reduce any concerns about potential side effects of gadolinium on the patients.[22] There are multiple semi-quantitative grading systems used in these studies, which demonstrates the lack of standardisation in assessing endolymphatic hydrops. Therefore, the objectivity of determining endolymphatic hydrops on MRI scans is difficult to examine.

Additionally, all published studies used 3T MRI, which, although more accessible in many places than in the past, is still not widely available. There are no studies using a weaker magnetic field; thus, delayed acquisition post-gadolinium MRI for identifying endolymphatic hydrops is not possible in many areas. This limits its applicability but also restricts the set-up of future studies.

With respect to the clinical implication of the available studies, while the endolymphatic spaces can well be visualised, it remains unclear to what extent the presence or absence of endolymphatic hydrops can confirm or exclude the diagnosis of Ménière's disease. Attyé *et al.* recently showed that endolymphatic hydrops can be related to sensorineural hearing loss rather than the presence of Ménière's disease itself.[20] While the endolymphatic spaces are well visualised, the diagnosis of Ménière's disease cannot be set based on purely radiological grounds. Although MRI can facilitate the diagnosis, Ménière's disease still remains predominantly a clinical diagnosis.

Strengths and limitations of the included studies

There are several limitations of the studies that are included in this review. Firstly, the sample size of each study is small because of the low prevalence of Ménière's disease; additionally, the included studies did not comment on the power of the enrolled cohorts. The small sample size makes it more difficult to validate the effectiveness of these imaging techniques in identifying endolymphatic hydrops and its relation to Ménière's disease. Secondly, some studies only had one radiologist evaluating the scans, which methodologically gives rise to questions about the robustness and the reliability of the measurements. Moreover, some of the studies did not mention any form of blinding, which may lead to biases when it comes to the interpretation of scans in patients with Ménière's disease. Additionally, the majority of these studies did not use healthy controls with no inner ear pathologies to make comparisons with patients diagnosed with Ménière's disease.

We used the Quality Assessment of Diagnostic Accuracy Studies-2 tool to identify and highlight these limitations to include accurate data and meaningful conclusions that help with the clinical significance of such imaging techniques. According to the Quality Assessment of Diagnostic Accuracy Studies-2 tool, patient selection appeared to be at high risk of bias for most of the studies because the patients are not randomly selected; some studies did not include all of the patients recruited in the results for various reasons. Additionally, there is a high risk of bias for the index test domain of the Quality Assessment of Diagnostic Accuracy Studies-2 tool for 6 out of 11 studies in the review.

Conclusion

Recent advances in MRI techniques have enabled us to identify endolymphatic hydrops on delayed acquisition post-gadolinium MRI; this carries potential in aiding the diagnosis of Ménière's disease and also guiding the clinicians to decide on optimal treatment. However, these techniques need to be more thoroughly validated before they can be widely used in the management of patients with Ménière's disease; the availability of a 3T MRI scanner could also be an issue. We identified bias in most of the included studies; thus, future studies including larger number of patients and control groups should help with further improving this developing and promising technique.

Competing interests. None declared

References

1 Surgery N, Monsell M, Balkany TA *et al.* Committee on Hearing and Equilibrium guidelines for the diagnosis and evaluation of therapy in Menière's disease. American Academy of Otolaryngology-Head and Neck Foundation, Inc. *Otolaryngol Head Neck Surg* 1995;**113**:181–5
2 Harris JP, Alexander TH. Current-day prevalence of Ménière's syndrome. *Audiol Neurotol* 2010;**15**:318–22
3 Da Costa SS, De Sousa LCA, De Toledo Piza MR. Meniere's disease: overview, epidemiology, and natural history. *Otolaryngol Clin North Am* 2002;**35**:455–95
4 Harcourt J, Barraclough K, Bronstein AM. Meniere's disease. *BMJ* 2014;**349**:1–5
5 Ghossaini S, Miller M. Meniere's disease. In: https://bestpractice.bmj.com/topics/en-gb/155?q=Meniere%27s disease&c=recentlyviewed [25 April 2021]
6 Lingam RK, Connor SEJ, Casselman JW, Beale T. MRI in otology: applications in cholesteatoma and Ménière's disease. *Clin Radiol* 2018;**73**:35–44
7 Niyazov DM, Andrews JC, Strelioff D, Sinha S, Lufkin R. Diagnosis of endolymphatic hydrops in vivo with magnetic resonance imaging. *Otol Neurotol* 2001;**22**:813–17
8 Fiorino F, Pizzini FB, Beltramello A, Mattellini B, Barbieri F. Reliability of magnetic resonance imaging performed after intratympanic administration

https://doi.org/10.1017/S0022215122001347 Published online by Cambridge University Press

of gadolinium in the identification of endolymphatic hydrops in patients with Ménière's disease. *Otol Neurotol* 2011;**32**:472–7
9 Carfrae MJ, Holtzman A, Eames F, Parnes SM, Lupinetti A. 3 Tesla delayed contrast magnetic resonance imaging evaluation of Ménière's disease. *Laryngoscope* 2008;**118**:501–5
10 Connor SEJ, Pai I. Endolymphatic hydrops magnetic resonance imaging in Ménière's disease. *Clin Radiol* 2021;**76**:e1–19
11 Conte G, Lo Russo FM, Calloni SF, Sina C, Barozzi S, Berardino S *et al*. MR imaging of endolymphatic hydrops in Ménière's disease: not all that glitters is gold. *Acta Otorhinolaryngol Ital* 2018;**38**:369–76
12 Nakashima T, Naganawa S, Pyykkö I, Gibson WPR, Sone M *et al*. Grading of endolymphatic hydrops using magnetic resonance imaging. *Acta Otolaryngol Suppl* 2009;**129**:5–8
13 Attyé A, Eliezer M, Boudiaf N, Tropres I, Chechin D, Schmerber S *et al*. MRI of endolymphatic hydrops in patients with Meniere's disease: a case-controlled study with a simplified classification based on saccular morphology. *Eur Radiol* 2017;**27**:3138–46
14 Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLoS Med* 2009;**6**:e1000097
15 Whiting PF, Rutjes AWS, Westwood ME, Mallett S, Reitsma JB, Leeflang MMG *et al*. QUADAS-2: a revised tool for the quality assessment of diagnostic accuracy studies. *Ann Intern Med* 2011;**155**:529–36
16 Yoshida T, Sugimoto S, Teranishi M, Otake H, Yamazaki M, Naganawa S *et al*. Imaging of the endolymphatic space in patients with Ménière's disease. *Auris Nasus Larynx* 2018;**45**:33–8
17 Baráth K, Schuknecht B, Monge Naldi A, Schrepfer T, Bockisch CJ, Hegemann SCA. Detection and grading of endolymphatic hydrops in Menière disease using MR imaging. *Am J Neuroradiol* 2014;**35**:1387–92
18 Sepahdari AR, Ishiyama G, Vorasubin N, Peng KA, Linetsky M, Ishiyama A. Delayed intravenous contrast-enhanced 3D FLAIR MRI in Meniere's disease: correlation of quantitative measures of endolymphatic hydrops with hearing. *Clin Imaging* 2015;**39**:26–31
19 Tagaya M, Yamazaki M, Teranishi M, Naganawa S, Yoshida T, Otake H *et al*. Endolymphatic hydrops and blood-labyrinth barrier in Ménière's disease. *Acta Otolaryngol* 2011;**131**:474–9
20 Attyé A, Eliezer M, Medici M, Tropres I, Dumas G, Krainik A *et al*. In vivo imaging of saccular hydrops in humans reflects sensorineural hearing loss rather than Meniere's disease symptoms. *Eur Radiol* 2018;**28**:2916–22
21 Claes G, Van Den Hauwe L, Wuyts F, Van De Heyning P. Does intratympanic gadolinium injection predict efficacy of gentamicin partial chemolabyrinthectomy in Menière's disease patients? *Eur Arch Otorhinolaryngol* 2012;**269**:413–18
22 Sano R, Teranishi M, Yamazaki M, Isoda H, Naganawa S, Sone M *et al*. Contrast enhancement of the inner ear in magnetic resonance images taken at 10 minutes or 4 hours after intravenous gadolinium injection. *Acta Otolaryngol* 2012;**132**:241–6
23 Pakdaman MN, Ishiyama G, Ishiyama A, Peng KA, Kim HJ, Pope WB *et al*. Blood-labyrinth barrier permeability in menière disease and idiopathic sudden sensorineural hearing loss: findings on delayed postcontrast 3D-FLAIR MRI. *Am J Neuroradiol* 2016;**37**:1903–8
24 Shi H, Li Y, Yin S, Zou J. The predominant vestibular uptake of gadolinium through the oval window pathway is compromised by endolymphatic hydrops in Meniere's disease. *Otol Neurotol* 2014;**35**:315–22
25 Naganawa S, Yamazaki M, Kawai H, Bokara K, Iida T, Sone M *et al*. MR imaging of Meniere's disease after combined intratympanic and intravenous injection of gadolinium using HYDROPS2. *Magn Reson Med Sci* 2014;**13**:133–7

https://doi.org/10.1017/S0022215122001347 Published online by Cambridge University Press