Artificial systems for the diagnosis of Meniere's disease: A review

Meniere hastalığının teşhisinde Yapay Sistemler: Bir Derleme

Abstract

Meniere's Disease (MD) is a complex, multifactorial inner ear disorder characterized by episodes of spontaneous vertigo, unilateral fluctuating sensorineural hearing loss, aural fullness, and tinnitus. Although endolymphatic hydrops (EH) is often considered a histopathological hallmark of MD, the 2015 diagnostic guidelines emphasize that its presence is not essential for diagnosis. Magnetic Resonance Imaging (MRI) has emerged as a valuable tool for detecting EH, though it remains in a developmental phase.

Recently, artificial intelligence (AI)—a rapidly advancing field that simulates human cognitive processes—has garnered significant attention in the study of MD. This paper reviews the current literature on the application of AI and deep learning in the diagnosis, monitoring, and treatment of Meniere's Disease. Our review encompasses seven relevant studies sourced from PubMed, Scopus, Web of Science, and ScienceDirect. Among these, four articles focus on the use of MRI to detect and quantify endolymphatic hydrops. We present these findings within the context of a development trajectory, discuss the limitations of current methodologies, and outline potential avenues for future advancements.

Keywords: Artificial intelligence; deep learning; endolymphatic hydrops; machine learning; MicroRNA

Öz

Meniere Hastalığı (MH) spontan vertigo atakları, tek taraflı dalgalanan sensörinöral işitme kaybı, işitsel dolgunluk ve tinnitus ile karakterize karmaşık, multifaktöriyel bir iç kulak hastalığıdır. Endolenfatik hidrops (EH) genellikle MH'nin histopatolojik bir özelliği olarak kabul edilse de, 2015 tanı kılavuzları bunun varlığının tanı için gerekli olmadığını vurgulamaktadır. Manyetik Rezonans Görüntüleme (MRG), gelişim aşamasında olmasına rağmen EH'yi tespit etmek için değerli bir araç olarak ortaya çıkmıştır.

Son zamanlarda, insan bilişsel süreçlerini simüle eden ve hızla ilerleyen bir alan olan yapay zeka (YZ), MH çalışmalarında önemli bir ilgi görmüştür. Bu makale, Meniere Hastalığı'nın teşhisi, izlenmesi ve tedavisinde YZ ve derin öğrenmenin uygulanmasına ilişkin mevcut literatürü gözden geçirmektedir. İncelememiz PubMed, Scopus, Web of Science ve Science Direct'ten elde edilen yedi ilgili çalışmayı kapsamaktadır. Bunlar arasında dört makale, endolenfatik hidropsu tespit etmek ve ölçmek için MRG kullanımına odaklanmaktadır. Bu bulguları bir gelişim yörüngesi bağlamında sunuyor, mevcut metodolojilerin sınırlamalarını tartışıyor ve gelecekteki ilerlemeler için potansiyel yolları özetliyoruz.

Anahtar Sözcükler: Derin öğrenme; endolenfatik hidrops; makine öğrenmesi; Meniere hastalığı; MikroRNA; yapay zeka

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Received/*Geliş* : 26.09.2024
Accepted/*Kabul*: 23.12.2024

DOI: 10.21673/anadoluklin.1555477

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INTRODUCTION

Meniere's disease (MD) is a multifactorial inner ear disorder characterized by episodes of spontaneous vertigo attacks, unilateral fluctuating sensorineural hearing loss, aural fullness, and tinnitus. The disease has a prevalence of approximately 34-190 per 100.000 (1). Prevalence shows uncertainty due to the difficulty faced when diagnosing the disease. The disease is hard to diagnose, especially in the early stages since not all the symptoms can be examined, and also it is difficult to distinguish from related disorders such as migraine associated vertigo (2,3).

Pathophysiology of MD is defined by progressive cochlear and vestibular dysfunction, yet the cause of the mechanism is not clearly described (4). Histopathologic findings include distension of scala media and bulging of Reissner's membrane into scala vestibuli, known as endolymphatic hydrops (EH) (5). EH is considered to be a histological marker for MD but is not essential for diagnosis according to 2015 guidelines (1, 6). EH can be detected by inner ear tests and MRI, therefore MD diagnosis can be made with clinical symptoms combined with inner ear tests and MRI. No specific test for MD exists.

The formation of EH in the inner ear and the function of cochlea, saccule, utricle, and semicircular canals (SCC) can be examined with an inner ear test battery. These tests enable the localization of EH and extent of damage it causes on inner ear structures. Test battery includes audiometry, vestibular-evoked myogenic potential (VEMP), and caloric tests. Audiometry is used to measure the hearing level of the patient. VEMP tests consist of cVEMP and oVEMP and are used to determine utricular and saccular function. cVEMP is used to examine saccular hydrops, while oVEMP is used to examine utricular hydrops. A caloric test, in which the ear is irrigated with an airflow, is found to be an effective way to determine the SCC function (7).

MRI is also a useful method to determine the presence of EH, yet it is still in the development stage (3). Visualization of EH with MRI allows physicians to detect EH in living patients, even in asymptomatic ones. This technique was used on patients first when Nakashima and colleagues developed by using intratympanic Gadolinium injection (8). It makes detecting EH in living patients possible but has handicaps. It is an invasive technique and requires a long waiting time. Then Naganawa developed an IV Gadolinium-enhanced MRI technique, which is non-invasive with a shorter waiting time (9). Both methods have been studied since then. Recently, artificial intelligence has been used to evaluate MRI findings.

Artificial intelligence (AI) is a new discipline that uses technology to develop and evaluate theories, methods, and systems in a similar way to human intelligence (10). In recent years, artificial intelligence has become increasingly widespread in the field of healthcare. AI systems work fast and effectively, create more time for physicians, and lower the workload. AI has a wide range of applications including radiology, endoscopy, surgery, and drug production (10). Furthermore, the development of deep learning brought a new insight in AI usage. Deep learning can transform large inputs into various kinds of outputs, evaluates, classifies, and create multiple layered connections between them, without a human direction. The system derives its own rules from the data set itself and shows great performance with large data sets (11). Since the healthcare industry generates vast amounts of data each and every day, using deep learning to evaluate the patients' data could save time, money, and human effort. Consequently, research about the usage of AI and deep learning mechanisms in Meniere's disease gained acceleration over the past few years.

The usage of AI and deep learning in audiology has aimed to enable automated criteria for diagnosis and function as a support system for clinical decisions (12). For instance, in 2021 van der Lubbe et al. developed a machine learning system that used radiomics from MRI scans to distinguish the patients from the control group (13). Also, Gürkov et al. volumetrically quantified endolymph and perilymph spaces and created three-dimensional EH images with AI, to provide a standardized basis for therapeutic monitoring of MD (14). Lastly, but not limited to, in 2023 Bragg et al. applied machine learning algorithms to subjective visual vertical and VEMP tests, in order to establish an algorithm to predict acute versus chronic MD (15). These studies and several more, expressed both the effectiveness and weaknesses of machine learning procedures. This review aims to systematically assess the performance of AI and machine learning processes in the diagnosis of Meniere's Disease.

MATERIAL AND METHODS

A systematic literature search in five databases (PubMed, Scopus, Web of Science, Google Scholar, and ScienceDirect) was conducted. All relevant studies related to Meniere disease diagnosis via artificial intelligence methods are reviewed as shown in Figure 1. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses diagram was used to choose articles. The following terms were used to search the five databases: "Meniere's disease AND artificial intelligence, Meniere's disease and deep learning, Meniere's disease and machine learning, diagnosis of Meniere's disease OR Meniere's disease and artificial intelligence". Ethics committee approval is not required for this study.

Inclusion and exclusion criteria

First, the titles and abstracts of the articles were scanned. Then, the articles were examined in detail and it was determined whether they met the inclusion criteria. Studies using artificial intelligence in the diagnosis of Meniere's disease and those published in English were included. Studies related to Meniere's disease and artificial intelligence, but not on topics other than the diagnosis of Meniere's disease, and those not in English were excluded from the review.

Data extraction

A general search was made from the title and abstract, and only those related to Meniere's disease and artificial intelligence were examined. All potentially relevant studies (n=31) were retrieved. Their titles and abstracts were recorded in an Excel file. Among these articles, there were studies related to artificial intelligence in diseases with sensory loss such as Meniere's disease. In these articles, only articles that included Meniere's disease and did not additionally examine any other diseases with sensory loss were included in the study. Other articles were excluded from the study (n=11). Two of these were related to the classification of imaging in patients with Meniere's disease, meaning it was not used for diagnostic purposes. Two of them were patient support programs developed using artificial intelligence. These four articles were excluded and the other seven were included (n=7). The articles were examined in detail and certain data were extracted. These extracted data were: "Publication year, purpose, method, sample size, artificial intelligence model used, accuracy, specificity, sensitivity".

RESULTS

We reviewed 7 studies that met our search criteria. The distribution of studies by country was as follows: 2 each from South Korea and the USA, and 1 each from the Netherlands, Germany, and Switzerland. Four of the articles are about radiological imaging, one is about the use of Transient-evoked otoacoustic emission (TEOAE) and Pure tone audiometry in the diagnosis of Meniere's disease, one is about the importance of MicroRNA in the diagnosis of Meniere's disease, and another article is about the role of vestibular tests in Meniere's disease as summarized in Table 1.

In the study published by Gurkov, R. et al. in 2014, it was aimed to evaluate the diagnosis, treatment, and disease process of Meniere by measuring the endolymph and perilymph volumes by performing MRI on 16 unilateral Meniere's disease patients (14). They measured the endolymph/total fluid area by applying a machine learning algorithm (Random Forest Classification model was used for total fluid volume segmentation in T2 SPACE sequence, while Niblack local threshold algorithm model was used for endolymph/perilymph segmentation and reduction of contrast heterogeneity) to the combination of MRI T2 SPACE sequence (separates total fluid from surrounding bone) + REAL-IR sequence (separates endolymph from perilymph-bone structure). The endolymph/total fluid area (EL/TFS) ratio, as a measure of the severity of endolymphatic hydrops, was 2–25%, 15% (minimum to maximum; mean) for the cochlea, and 12–40%, 28% (minimum to maximum; mean) for the vestibulum. Therefore, a wide range of endolymphatic hydrops degrees were measured volumetrically. The cochlear EL/TFS ratio was significantly correlated with hearing loss. This correlation was not found between semicircular canal paresis and vestibular EH. The Pearson correlation coefficient for both the ICC (intraclass correlation coefficient) and EL/TFS volume ratio was 0.99 for both the cochlea and the vestibulum. In contrast, the ICC of the manually segmented EL/

TFS area ratios was 0.87 for the cochlea and 0.91 for the vestibulum.

The study published by Cho, Y. S. and colleagues in 2020 aimed to create an automatic analysis system that can accurately and quickly measure the endolymphatic hydrops (EH) rate in real-time in the diagnosis of Meniere's disease (16). For this purpose, 124 patients underwent contrast-enhanced MRI. Then, the sections were evaluated by 1 neuroradiologist and 1 neuro-otologist, and the boundaries of the vestibule and cochlea were manually drawn. In addition, the MR images were read to the Visual Geometry Group (VGG-19)-based INHEARIT (INner ear Hydrops Estimation via ARtificial InTelligence) artificial intelligence model. The artificial intelligence model also determined the boundaries of the vestibule and cochlea. Then, the manually and automatically determined boundaries were compared. The agreement between the EH rates calculated manually by doctors and the rates estimated by the INHEARIT model was also analyzed using ICC (intraclass correlation coefficient) values. The average ICC value was found to be 0.971. These results demonstrate that the AI model is fast and accurate in analyzing IV-Gd inner ear MRI images.

In the study published by Park, C. J. and their colleagues in 2021, the participants were divided into two groups (17). The first group was the,124 patient group in the previous study conducted in 2020 using Machine Learning in the diagnosis of Meniere's by measuring Endolymphatic Hydrops with MRI, and the second group was a new group of 60 people (33 people with possible Meniere's, 17 people with hearing loss and vertigo, and 10 people without symptoms) in addition to this group. The aim of this study was to create a fully automated artificial intelligence model with Deep Learning in the diagnosis of Meniere's. In the MR image segmentation phase, 3into3Inception and 3intoUnet and INHEARIT-v2 artificial intelligence models were used via Python 3.5. Imaging was performed with Gadobutrol 3.0-T MRI. The model was trained with T2-weighted magnetic resonance cisternography annotated images and magnification was performed for segmentation. Segmentation was performed using 3into3Inception and 3intoUnet. The INHEARIT-v2 model selected representative slices for each class according to the size of the segmented area. Positive perilymph images and positive endolymph images were used to evaluate EH. The EH ratio was measured using the HYDROPS-Mi2 image. HYDROPS images were obtained by subtracting positive endolymph images from positive perilymph images. The results of the model are Intraclass correlation coefficient (ICC): 0.968 in vestibule sections, ICC: 0.914 in cochlea sections, and mean ICC: 0.941.

In a multicentric study published by Van der Lubbe, M. F. J. A and colleagues in 2021, MR imaging was performed on 120 Meniere's patients and 140 controls (patients with idiopathic asymmetric hearing loss in whom the labyrinth was natural) from 4 centers (13). There is a study in the literature that aimed to diagnose Meniere's using radiomics, but this study aimed to combine Radiomics with Machine Learning (ML). Manual MR-T2 sequence segmentation was performed from conventional MRI scans and 812 features were determined with radiomics, and the 15 most important variations were detected with Principal Component Analysis. Then, a radiomics model was created using a Multi-layer perceptron classifier. This model was introduced to ML. ML was evaluated with two methods. Train-test split and K-fold cross-validation. The accuracy rate of the training model was 72.9%, the Area Under the Curve (AUC) was 80.6%, sensitivity was 80.2%, and specificity was 65.6%. The test model had an accuracy rate of 82.3%, an Area Under the Curve (AUC) of 86.9%, a sensitivity of 83.4%, and a specificity of 81.8%. The 10-fold cross-validation results showed an accuracy rate of 80.0%, an Area Under the Curve (AUC) of 83.6%, a sensitivity of 78.3%, and a specificity of 77.5%.

In the study published by Liu YW and his colleagues in 2020, it was aimed to create an artificial intelligence model that predicts the prognosis of hearing loss in Meniere patients using Transient-evoked otoacoustic emission (TEOAE) signals. (18) For this purpose, 30 Meniere patients were prospectively followed for 6 months after an acute attack. During this period, TEOAE and pure tone audiometry (PTA) tests were performed at 1, 2, 3, 4 weeks, 2 months, 3 months, and 6 months. TEOAE signal parameters were determined as signal energy at 1 and 2 kHz and group delay. PTA results were divided into two groups: 14 patients with improvement (increase of 15dB or more in any of the

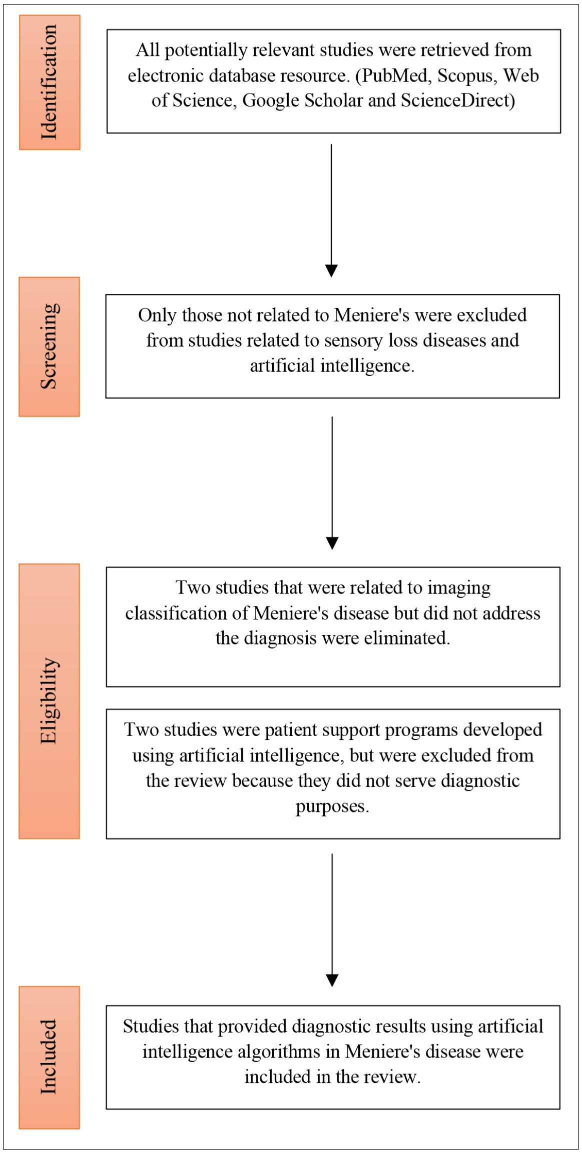

Figure 1. Process for sifting search results and selecting studies for inclusion.

frequencies of 500, 1000, 2000, or 3000 Hz in the last PTA test) and 16 patients with no improvement. Then, the two groups were compared using Welch's t-test. While no significant difference was found between the signal energies of the two groups (p: 0.64), a significant difference was found in the group delay parameter at 1 kHz (p: 0.045). Then, this information was introduced to the Support vector machine (SVM) model for training purposes. SVM model results were evaluated using Fivefold Cross-Validation. When the SVM model evaluated the signal energy and group delay parameters together in the TEOAE test, it predicted the prognosis of the patients with over 80% success, while when it evaluated only the signal energy, the prognosis prediction success remained at the level of 71%.

In the study published by Shew, M. et al. in 2020, the aim was to elucidate the pathophysiology of the disease and develop diagnostic and therapeutic methods by performing MiRNA analysis in Meniere's disease based on the knowledge that miRNAs play an important mechanical role in the development of the inner ear and show different expression patterns in the serum of patients with hearing loss. (19) Since miRNA has a wide expression, it was aimed to develop a Machine Learning model in its analysis to make this process easier. In the study, there were a total of 21 patients, including 5 patients who underwent stapedectomy due to otosclerosis, 11 patients who underwent cochlear implantation due to severe sensorineural hearing loss (SNHL), and 5 patients who underwent labyrinthectomy due to uncontrolled Meniere's. During the surgical procedure, 2-5 μL of perilymph was sampled and MiRNA analysis was performed. Then, these MiRNAs were analyzed by the open-source scikit-learn (v 0.21.3; Python v3.7.1) based Machine Learning (ML) model, which introduced all human MiRNAs, and a comparison was made. The model showed 100% accuracy in distinguishing between conductive hearing loss and Meniere's disease and 66% accuracy in distinguishing between SNHL and Meniere's disease.

In the study published by Bragg, P. G. et al. in 2023, the authors aimed to clarify the role of Subjective Visual Vertical (SVV) and Ocular Vestibular Evoked Myogenic Potentials (o-VEMP) tests in terms of which utricular subsystem each test measure, to characterize the acute and chronic status of MD by identifying differences in the relationship between SVV and o-VEMP results among patients with acute and chronic MD, and to find a machine learning algorithm that can predict acute and chronic MD using SVV and o-VEMP (15). For this purpose, 90 unilateral Meniere's patients were included in the study. c-VEMP, o-VEMP and SVV tests were performed on acute-chronic MD patients. Asymmetry rates in VEMPs and deviation degrees in SVV were determined. Statistical analysis was performed with ANOVA and t-test. Pearson's linear correlation coefficient was calculated (r2). Logistic regression (LR), the Naïve Bayes classifier (NB), ran-

Table 1. Summary of published studies using AI to diagnose MD

Study	Year	AI algorithm	Aim	How the AI algorithm was used	Data set	Validation method	Performance (Accuracy)
Gurkov et al. (14)	2014	RF Classifier, Niblack local threshold algorithm	Correlation of ELH/TF ratio with hearing loss and vestibular paresis	Methodology-Segmentation	16	Accuracy analysis and cross validation	In the AI algorithm, automatic segmentation, ICC score and Pearson correlation scores for both vestibule and cochlea were 0.99. In the manual segmentation ICC and Pearson correlation scores were found to be 0.87 for cochlea and 0.91 for vestibule.
Y. S. Cho et al. (16)	2020	INHEARIT model based on CNN and VGG-19	Diagnosis of Meniere's disease by ELH measurement on MRI	Methodology-Segmentation	124	5-fold cross validation	IoU (concat 3 into 1 VGG) :0.497, 0.533, and 0.528. İoU (3into3VGG): 0.620, 0.716, and 0.711 (low, moderate, high augmentation)
M. Shew et al. (19)	2020	LR, RC, k-NN, Decision tree, RF classifier, Gaussian nai ve bays, SVM, Stochastic gradient classifier, Adaboost, Stochastic gradient boost, Bagging tree classifier	Determination of Meniere-specific miRNA in perilymph	Data analysis-Classification	21	8-fold cross validation	Best performing models: KNN, RF, SGB, BTC: %100 SVM: %96
Y. W. Liu et al. (18)	2020	SVM	Predicting whether SNHL developing during a Meniere attack will regress or not with TE-OAE	Data analysis-Classification	30	5-fold cross validation	Prognosis prediction accuracy for different features: (PC1, PC2, PC3): 0.827 Energy: 0.708 GD-1 kHz: 0.841 GD-2 kHz:0.808
C. J. Park et al. (17)	2021	INHEARIT-v2 (ELH measurement), 3into3Inception and 3intoUNet	Diagnosis of Meniere's disease by ELH measurement	Methodology-Segmentation	128-training set, 60 test set	5-fold cross validation	İoU (3into 3Inception):0.784 İoU (3intoUNet):0.811
M. F. J. A. van der Lubbe et al. (13)	2021	Multi-layer perceptron classification	Meniere's diagnosis via MRI images (not ELH measurement)	Data analysis-Classification	260	Test-training split ,10-fold cross validation	Test accuracy: 0,82. 10-fold cross validation: 0,8. ICC (mean): 0,941
P. G. Bragg et al. (15)	2023	LR, the Naïve Bayes classifier, RF, and SVM	Utricular function assessment with SVV and O-VEMP measurement, predicting acute-chronic Meniere's diagnosis	Data analysis-Classification	90	10-fold cross validation	LR, NB, RF>0,7 SVM<0,5

AI: Artificial Intelligence, RF: Random Forest, ELH: Endolymphatic Hydrops, TF: Total Fluid, ICC: Intraclass Correlation, INHEARIT: INner-ear Hydrops Estimation via ARtificial InTelligence, CNN: Convolutional Neural Network, VGG-19: Visual Geometry Group-19, LR: Logistic regression, RC: Ridge classifier, k-NN: k-nearest neighbors, SVM: Support vector machine

dom forest (RF) and support vector machine (SVM) were used to group (training set, testing set). These classes are right acute (RA) MD, right chronic (RC) MD, left acute (LA) MD, and left chronic (LC) MD. Logistic regression (LR), the Naïve Bayes classifier (NB), and random forest (RF) methods provided over 70% accuracy, while the accuracy rate of support vector machine (SVM) remained below 50% (7).

DISCUSSION AND CONCLUSION

Meniere's disease is an important peripheral vestibular system disorder that causes episodic vertigo, tinnitus, a feeling of fullness in the ear, and hearing loss due to flutter. Although the pathophysiology is mostly focused on endolymphatic hydrops, there are many aspects waiting to be elucidated. Studies on vestibular system diseases with machine learning and deep learning models have increased recently. When machine learning studies on Meniere's disease were examined, it was seen that the models used had the potential to significantly facilitate the management of the disease by physicians regarding the radiological diagnosis and course of the disease and to illuminate the dark points regarding the pathophysiology of the disease.

Among the studies where machine learning is used for the diagnosis of Meniere's disease, the detection of endolymphatic hydrops (EH) in MR imaging has an important place. The artificial intelligence models used in these studies have gained automatic segmentation and full stack working features over time, and it has been observed that they have gained the ability to calculate EH that is highly correlated with objective and expert physician evaluation. The effectiveness of EH in disease pathophysiology, follow-up during the treatment process, and correlation with disease duration and severity were examined. It should also be noted that the EH ratio measurement time to be used in disease evaluation has been reduced to seconds, which is valuable in terms of preventing physicians from losing time (16).

Studies on the pathogenesis of Meniere's disease are mainly focused on endolymphatic hydrops. In addition, the value of EH progression in showing Meniere's prognosis is being studied. In addition, EH can be shown on MRI in cases such as vestibular migraine that present with a clinical picture similar to Meniere's, and can have diagnostic value. For these reasons, radiological measurement of EH provides valuable information. Until 2014, there have been many studies evaluating Meniere's disease using endolymphatic hydrops measurement. Zou et al. performed segmentation of endolymph and perilymph spaces on MRI images (20). Nakashima et al. conducted a study on endolymphatic hydrops measurement with MRI after intratympanic contrast injection (8). In the study, perilymph and endolymph could be distinguished on the FLAIR sequence, but endolymph-bone could not be distinguished. In a similar study by Liu et al., Endolymph/Total Fluid Space (EL/TFS) measurements were performed on the cochlea and vestibule on the FLAIR sequence (17). The inability to perform endolymph-bone segmentation was stated as a limitation. Naganawa et al. successfully demonstrated the distinction between endolymph-perilymph-bone with Real-IR sequence in MR (21). Since manual segmentation was performed in these measurements, semiquantitative and subjective results were obtained.

In 2014, R. Gürkov and colleagues conducted the first study on endolymphatic hydrops measurement using machine learning. Inner ear total fluid space (TFS) segmentation was performed using Random Forest based machine learning model on T2-SPACE and REAL-IR sequences in MR, and endolymph-perilymph segmentation was performed using Niblack local threshold algorithm (14). EL/TFS ratio was determined by providing objective and volumetric measurements from the obtained images. In previous studies, manual segmentation of inner ear volumes was performed, but the fact that manual segmentation was time-consuming and subjective was considered a limitation. When evaluated in terms of meeting the objective data need, the results obtained here showed that machine learning technology will make a significant contribution to the clinical practice of Meniere's disease. In the study, it was seen that cochlear EL/TFS ratio was blunted with hearing loss, but vestibular EL/TFS ratio did not show the same correlation with semicircular canal paresis.

In the study conducted by Young Sang Cho and his colleagues in 2020, a deep-learning model called INHEARIT (INner ear Hydrops Estimation via ARtificial InTelligence) based on VGG-19 was developed to provide automatic segmentation of the cochlea and vestibule and calculate the objective EH ratio (16). Very good results were obtained with a limited data set. In this study, data augmentation was applied to compensate for the scarcity of data. When the manual measurements made by the neurootologist and neuroradiologist were compared with the EH estimate of the INHEARIT model, the ICC score was obtained as 0.971. In the study conducted by Chae Jung Park and his colleagues in 2021, a full-stack model called INHEARIT-v2 was developed using the 3into3Inception and 3intoUNet network base instead of the CNN base used in the previous model (17). In this model, a high correlation was obtained when the measured EH ratio was compared with the measurements of the specialist physician.

The most important limitation observed in the studies was the lack of a sample size that could determine a specific EH ratio as a cut-off value when diagnosing Meniere's disease. In addition, it was observed that the EH ratio evaluation varied from person to person and did not show a clear correlation between clinical presentations. Since normal people without Meniere's diagnosis were not included in the studies when measuring EH values, normal variant measurement could not be performed. Another disadvantage in determining the cut-off value is that it is difficult to determine a definite value between the upper limit of normal EH in a healthy individual and an early-stage Meniere's patient with a low EH ratio (2014). This may not be necessary to determine the response to treatment in a specific patient, but it is important for future studies on EH cut-off. In the previously mentioned studies, machine learning technology was on segmentation. Apart from these, machine learning has been used successfully in classification-data analysis in studies on Meniere's disease from various aspects.

In 2021, Marly F. J. A. van der Lubbe and his colleagues aimed to reach an artificial intelligence-supported Meniere's diagnosis using features obtained with radiomics from MRIs in two groups of patients with Meniere's diagnosis and healthy patients (13). Multi-layer perceptron classification was used as an artificial intelligence model. Unlike other imaging studies, the artificial intelligence model was used in classification-data analysis. Radiomics technology extracted 812 different features from manually segmented MRI images. Using Principal Component Analysis, these features were subjected to essential-non-essential distinction and the number of features was reduced to two digits by removing non-essential features. These features were introduced to the multi-layer perceptron classification model. Unlike other studies, the model was validated with both train-test split and 10-fold classification. Another important detail of this study was that the diagnosis was made with non-contrast MRI. Integrating automatic segmentation into future studies with radiomics will make radiomics more efficient in terms of objectivity and speed.

In the study published in 2023 by Phillip G. Bragg et al. Subjective Visual Vertical (SVV) and Ocular Vestibular Evoked Myogenic Potential (o-VEMP) tests examining the dynamic and static subsystems of the utricle were used to distinguish between acute and chronic periods of Meniere's disease. (15) In the study where 4 different machine learning models were used, it was observed that SVV and O-VEMP showed linear correlation with acute period Meniere's, but SVV results were normal in chronic period Meniere's. In the study, the classifications made with machine learning models in the distinction of acute and conic period Meniere's were examined. Decision boundary (DB) was taken as the basis for these comparisons. Since DB was observed as linear in the Logistic regression model and nonlinear-flat in the Naïve Bayes classifier (NB) model, these two models were the most sensitive models in classification. Low sensitivity was observed in Random Forest and SVM (Superior Vector Machine) models. While the accuracy rate was >70% in the first 3 models, it was seen that it was <50% in the SVM model. Despite the limited data set with 90 patients, it was seen that a successful classification could be made with the machine learning model especially Logistic regression and NB. The lack of a method to calibrate surface EMG activities in this study may have affected the amplitude values in the o-VEMP results. Future studies may need to perform VEMP and SVV in the same physiological position and include a method to calibrate surface EMG for o-VEMP. These additional measurements may provide more consistent results.

In a study conducted by Matthew Shew et al. in 2020, perilymph samples taken from the preoperative inner ear were examined and MiRNA expression profiles were revealed (19). With the help of machine learning (ML) models, MiRNA profiles associated with Meniere were detected and it was determined that they had a predictive feature in showing the disease diagnosis. It has been revealed in different studies that miRNAs play a role in inner ear development and hearing loss due to various reasons and that there is an increase in MiRNAs showing different expression patterns in inner ear fluids. Since the volume and diversity of these MiRNA patterns are very large, analysis was performed using ML and expression patterns specific to Meniere's disease were determined. It was seen that there was a two-stage ML evaluation in the study. In the first stage, when 11 ML models were subjected to 8-10 cross-validation, the 5 models with the highest accuracy rate were determined. In the second stage, optimal accuracy rates were achieved with hyperparameter tuning using GridSearchCV. The effects of MiRNAs on model accuracy were determined using a permutation-based approach in each model (permutation feature importance score). The fact that perilymph sampling could not be performed on healthy individuals in the study can be considered as a limitation, but it can also be assumed that the inner ear is not affected in otosclerosis patients. Secondly, the accuracy rate of distinguishing between Meniere's and profound SNHL patients being at 60% is thought to be due to the fact that SNHL is also seen in Meniere's, the selected Meniere's patients are advanced stage patients and the small sample size. More meaningful results can be obtained in future studies with larger samples. In addition, the effect of endolymphatic sac surgery and miRNA expressions in early stage Meniere's patients can be investigated in new studies conducted with this technique. Another limitation of the study is that the perilymph examined contained a small portion of the MiRNA content and other parts of the inner ear could not be evaluated. It should also be noted that the method used in this study was expensive.

It's concluded that Meniere's Disease presents many difficulties in terms of diagnosis, prognosis and treatment. Current studies show that endolymphatic hydrops (EH) plays a significant role in pathophysiology. The effect of current treatments in reducing EH progression is uncertain. Therefore, rapid and most accurate measurement of EH with objective criteria is important in monitoring the response to treatments to be developed for EH progression. It is difficult to determine a cutoff value for EH with the current data we have. This limitation can be overcome by studies with larger data groups or by more advanced artificial intelligence technologies, as better results can be obtained with less data. In addition to EH determination, artificial intelligence algorithms supported by audiological-vestibular tests can be used to follow Meniere's disease with objective data and make objective evaluations of prognosis. Although not yet sufficiently studied, the striking results regarding the MiRNA-Meniere relationship with the support of artificial intelligence algorithms can be a guide to reveal the unknowns about the disease.

Main points

- This review examines the advances provided by AI systems for higher accuracy in the diagnosis of Meniere's disease.
- Machine learning and deep learning methodologies can be employed in the diagnosis of Meniere's disease by analyzing radiological imaging findings, detecting specific microRNAs associated with the condition, and monitoring disease progression through the assessment of transient-evoked otoacoustic emissions and vestibular test results.
- The limitations in predicting the diagnosis and prognosis of Meniere's disease can be overcome through the incorporation of objective assessments facilitated by machine learning and deep learning systems.

Conflict-of-interest and financial disclosure

The authors declare that they have no conflict of interest to disclose. The authors also declare that they did not receive any financial support for the study.

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