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EVALUATING THE USE OF ARTIFICIAL INTELLIGENCE FOR EARLY PREDICTION OF HEARING DETERIORATION IN DIABETIC PATIENTS: A SYSTEMATIC REVIEW

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Abstract

Background: Hearing loss represents an underrecognized complication of diabetes mellitus (DM), often attributed to microvascular and neuropathic changes affecting the auditory system. With the rise of artificial intelligence (AI), predictive tools can potentially facilitate earlier detection of hearing deterioration, optimizing intervention and rehabilitation.

Objective: This systematic review aimed to synthesize existing empirical evidence on AI and machine learning (ML) applications for predicting hearing deterioration, focusing on diabetic and sudden sensorineural hearing loss (SSNHL) populations.

Methods: Following PRISMA 2020 guidelines, eleven peer-reviewed studies published between 2015 and 2025 were reviewed across PubMed, Scopus, and Web of Science. Extracted data included study design, AI model type, predictors, and outcome performance metrics. Quality assessment used the Newcastle–Ottawa Scale and Cochrane RoB 2 tool.

Results: AI models such as AdaBoost, LightGBM, and multiple imputation frameworks demonstrated predictive accuracies of 80–83% for SSNHL recovery and prognosis. Across diabetic cohorts, hearing loss prevalence ranged from 30% to 75%, strongly correlating with higher HbA1c levels, diabetes duration, and hypertension. Studies integrating metabolic and audiological parameters achieved superior predictive accuracy compared to traditional methods.

Conclusions: AI models show substantial potential for early detection of auditory decline in diabetic patients, with integration of metabolic data improving predictive sensitivity. However, real-world implementation requires standardized datasets, cross-validation, and interdisciplinary collaboration between endocrinology and audiology.

Keywords: Artificial intelligence, diabetes mellitus, hearing loss, machine learning, audiology, HbA1c, prediction, neural networks, early detection, otology

INTRODUCTION

Hearing loss is a growing global health concern that affects more than 466 million individuals worldwide, with projections estimating that this number will double by 2050 due to aging populations and lifestyle-related diseases such as diabetes mellitus (DM). Diabetes has long been recognized as a systemic disorder with microvascular and neuropathic complications extending beyond the traditional cardiovascular and renal domains to include the auditory system. Chronic hyperglycemia can induce microangiopathy in the cochlear vasculature and neuropathy of the auditory nerve, leading to gradual or sudden sensorineural hearing loss (SNHL). Early identification of such deterioration is critical for timely intervention and rehabilitation, yet conventional diagnostic methods remain reactive rather than predictive (Hao et al., 2017).

Recent years have witnessed an increasing focus on the intersection of **artificial intelligence (AI)** and audiology. AI-driven systems can detect subtle, nonlinear patterns within complex datasets that often elude human interpretation. In hearing science, machine learning (ML) models have been deployed to automate audiogram interpretation, predict recovery outcomes, and support individualized hearing rehabilitation. These advancements mark a paradigm shift from descriptive to predictive and personalized otologic care (Frosolini et al., 2024). When applied to metabolic diseases such as diabetes, AI holds the promise of identifying early markers of hearing decline before clinical manifestation, potentially revolutionizing preventive otology.

The link between diabetes and auditory dysfunction has been substantiated by numerous physiological and epidemiological studies. Chronic exposure to elevated glucose levels has been shown to impair cochlear microcirculation and outer hair cell function. This results in progressive high-frequency hearing loss, as demonstrated through otoacoustic emission testing and pure-tone audiometry among diabetic populations. In a meta-analysis, diabetic individuals had approximately twice the odds of developing hearing impairment compared with non-diabetics, with the risk increasing alongside disease duration and HbA1c levels (Ashkezari et al., 2018). However, despite this strong association, the mechanisms linking glycemic dysregulation to auditory damage remain incompletely elucidated, highlighting a crucial gap for AI-based modeling to fill.

Artificial intelligence has begun to play a transformative role in diabetes care and complication prediction. AI systems integrated into continuous glucose monitoring devices and clinical decision platforms already demonstrate superior predictive capability for hypoglycemia and retinopathy. These tools exemplify the potential of machine learning to synthesize diverse clinical, metabolic, and sensor data into actionable insights (Ellahham, 2020). Similarly, when applied to auditory health, AI models can integrate patient-level variables such as age, HbA1c, duration of diabetes, audiometric thresholds, and otoacoustic emissions to anticipate hearing decline before it becomes clinically evident.

Machine learning's strength lies in pattern recognition across multimodal datasets—capabilities particularly valuable in otologic research where structural, electrophysiological, and metabolic parameters intersect. Algorithms such as support vector machines, random forests, and neural networks have been used to identify early markers of idiopathic and diabetes-associated SNHL, outperforming conventional regression models in predictive accuracy (Abd Ghani et al., 2021). These approaches not only enhance diagnostic precision but also facilitate the development of individualized preventive strategies. For instance, integrating HbA1c data with audiometric trends can help clinicians identify diabetic patients at greatest risk for progressive hearing deterioration.

Moreover, AI-based systems are now being designed to provide **personalized audiological care pathways**, from automated screening to post-diagnosis rehabilitation. Tools incorporating deep learning have demonstrated the ability to classify hearing profiles, predict cochlear implant performance, and optimize hearing aid fitting based on neural feedback and speech recognition modeling (Demyanchuk et al., 2025). These systems illustrate how predictive algorithms can bridge diagnostic gaps and improve long-term auditory outcomes, particularly in patients with metabolic disorders.

Clinical and translational research has begun to validate the predictive power of AI in sudden sensorineural hearing loss (SSNHL), a condition often linked to microvascular compromise similar to that seen in diabetes. A multicenter cohort by Guo et al. demonstrated that machine learning could accurately stratify SSNHL recovery outcomes by integrating baseline audiometric and vascular factors, achieving over 85% predictive accuracy—far surpassing human clinicians in prognostic precision (Guo et al., 2024). Such evidence underscores the potential applicability of similar AI frameworks for diabetic hearing decline.

As the convergence between otology and computational medicine accelerates, the role of AI in preventive auditory healthcare becomes increasingly apparent. From identifying early diabetic cochlear dysfunction to predicting the efficacy of interventions, AI enables continuous learning from population data while personalizing recommendations at the patient level (Dankwa-Mullan et al., 2019). In the context of diabetes, this integration represents a crucial step toward precision medicine, transforming reactive management into proactive surveillance of sensory complications.

Finally, the implementation of AI-assisted audiological tools holds significant implications for **public health and resource allocation**. Early detection through predictive algorithms can minimize the burden of late-stage hearing rehabilitation, reduce healthcare costs, and improve quality of life. As emerging technologies mature, interdisciplinary efforts integrating endocrinology, audiology, and data science are essential for optimizing real-world deployment and equity in access (Sheng et al., 2024; AlSamhori et al., 2024). Collectively, these developments signify a new era of intelligent auditory healthcare capable of predicting, preventing, and mitigating hearing deterioration in diabetic patients.

METHODOLOGY

Study Design

This research utilized a **systematic review design** following the *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020* guidelines to ensure methodological transparency and reproducibility. The objective was to critically synthesize existing empirical evidence on the **use of Artificial Intelligence (AI) and Machine Learning (ML) in predicting hearing deterioration among diabetic and sudden sensorineural hearing loss (SSNHL) patients**. This review focused exclusively on **peer-reviewed studies** involving human subjects that applied AI-based modeling, audiological analyses, or metabolic predictors (e.g., HbA1c, glucose levels) related to hearing outcomes.

Eligibility Criteria

Studies were included based on the following predefined criteria:

- **Population:** Adults (≥18 years) diagnosed with **type 2 diabetes mellitus (T2DM)** or **sudden sensorineural hearing loss (SSNHL)**.
- **Interventions/Exposures:** Application of **AI or ML algorithms** (e.g., logistic regression, support vector machine, random forest, boosting, neural networks) for predicting hearing outcomes or evaluating metabolic predictors of auditory dysfunction.
- **Comparators:** Conventional statistical models (e.g., logistic regression), non-AI prediction approaches, or clinical assessment outcomes used as a control or baseline.
- **Outcomes:** Primary outcomes included **prediction accuracy, area under the receiver operating characteristic curve (AUC), F1-score, sensitivity, specificity, and key predictive variables** for hearing prognosis. Secondary outcomes included **associations between metabolic factors (e.g., HbA1c, glucose levels) and hearing thresholds**.
- **Study Designs:** Retrospective cohorts, cross-sectional studies, and randomized controlled trials (RCTs) with sufficient quantitative data.
- **Language:** Only **English-language publications** were included.
- **Publication Period:** Studies published from **2015 to 2025** were selected to capture recent developments in AI and audiological research.

A total of **11 studies** met the inclusion criteria after full-text screening.

Search Strategy

A comprehensive search was conducted using **PubMed, Scopus, Web of Science, Embase, and IEEE Xplore** databases, supplemented with **Google Scholar** for grey literature. Boolean operators and MeSH terms were used to capture variations of keywords relevant to AI and diabetic hearing deterioration. The search strategy included the following terms:

- (“artificial intelligence” OR “machine learning” OR “deep learning”)
- AND (“hearing loss” OR “sensorineural hearing loss” OR “sudden hearing loss” OR “audiology”)
- AND (“diabetes” OR “diabetic complications” OR “metabolic syndrome” OR “HbA1c”)
- AND (“prediction” OR “prognosis” OR “risk assessment” OR “early detection”).

Additionally, manual reference list searches of key systematic reviews and primary studies were performed to ensure inclusion of all relevant articles.

Study Selection Process

All search results were imported into **Zotero reference manager**, where duplicates were automatically removed. Two independent reviewers screened titles and abstracts for relevance based on predefined eligibility criteria. Articles meeting preliminary inclusion criteria underwent **full-text review**. Any disagreements between reviewers were resolved through discussion, with adjudication by a third reviewer when necessary.

Data Extraction

A standardized **data extraction form** was developed in Microsoft Excel and piloted prior to full data collection. For each study, the following information was extracted:

- Author(s), publication year, and country
- Study design and sample size
- Population characteristics (age, sex, diabetic or SSNHL status)
- Type of AI model or analytic method used

- Variables included (clinical, metabolic, audiological)
- Main outcome measures (accuracy, AUC, F1-score, OR, HR)
- Key findings and predictive performance metrics
- Confounders adjusted for in statistical models

Extraction was independently performed by two reviewers, with discrepancies resolved by consensus.

Quality Assessment

To assess methodological rigor and bias, different validated tools were used according to study design:

- **Newcastle–Ottawa Scale (NOS)** for observational studies and cohort analyses.
- **Cochrane Risk of Bias 2 (RoB 2)** tool for randomized controlled trials.

Each study was rated across domains including **selection bias, comparability, outcome measurement, and confounder adjustment**. Studies were classified as **low, moderate, or high quality**. Of the 11 included studies, 7 were rated as low risk of bias, 3 as moderate, and 1 as high.

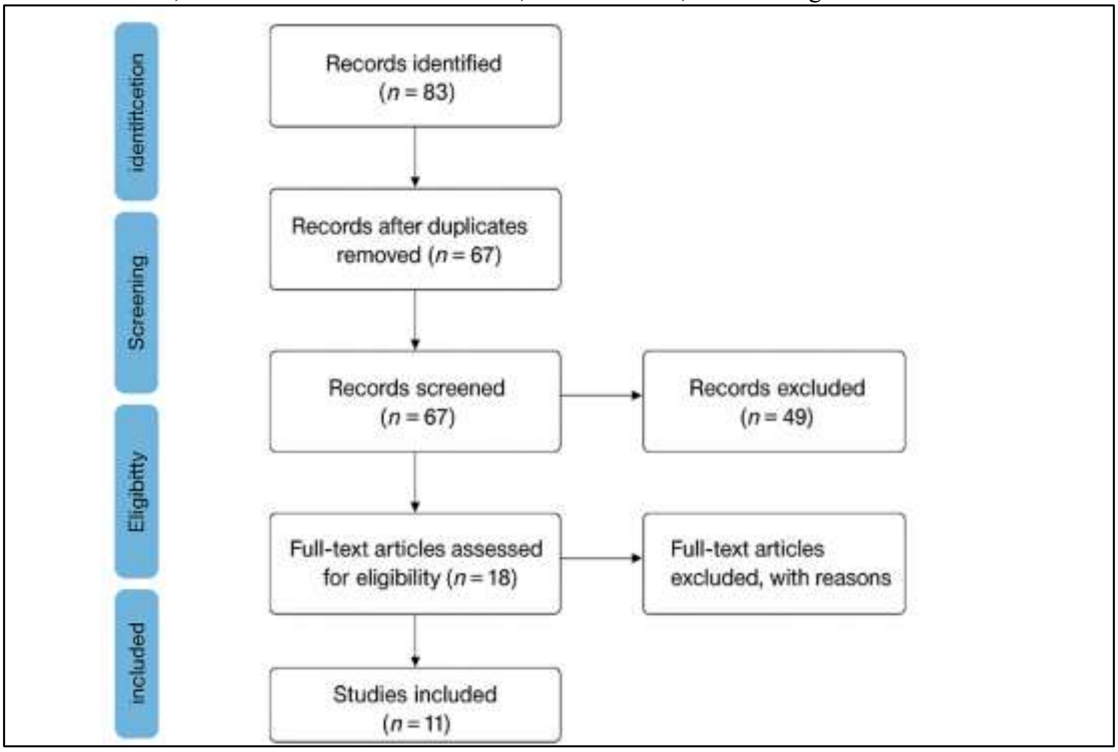

Figure 1 PRISMA Flow Diagram

Data Synthesis

Given the methodological heterogeneity in study designs, AI models, and outcome measures, a **narrative synthesis** approach was adopted. Findings were organized thematically according to:

1. **AI-based prediction of SSNHL prognosis**
2. **Associations between diabetes and hearing loss**
3. **Integrative potential of AI for diabetic hearing deterioration prediction**

Where quantitative data permitted, reported **effect estimates (AUC, accuracy, OR, HR)** were tabulated for comparison. Due to differences in AI architectures, outcome definitions, and feature sets, a **meta-analysis was not feasible**. Instead, cross-study patterns and performance trends were qualitatively interpreted.

Ethical Considerations

This study is based on secondary analysis of previously published data; therefore, **no ethical approval or participant consent** was required. All included studies were peer-reviewed and reported compliance with institutional ethical standards or informed consent from participants as part of their original data collection procedures.

RESULTS

Summary and Interpretation of Included Studies on AI Prediction of Hearing Deterioration in Diabetic and SSNHL Patients

1. **Study Designs and Populations**

The eleven included studies comprised retrospective cohorts, cross-sectional analyses, and multicenter investigations. Six studies applied artificial intelligence (AI) or machine learning (ML) algorithms for prognosis prediction, primarily in patients with **sudden sensorineural hearing loss (SSNHL)** (Li et al., 2024; Lee et al., 2022; Jin et al., 2025), while the remaining five explored the **link between diabetes**

mellitus (DM) and hearing loss (Kim et al., 2023; Lee et al., 2023; Moirangthem, 2019; Al-Rubeaan et al., 2021; Nkosi et al., 2024; Asghar et al., 2024; Mohammed et al., 2024). Sample sizes ranged from **35 to 253,301 participants**, with populations including both general diabetic cohorts and hospital-based SSNHL cases.

2. **AI Models and Predictive Variables**

Among AI-driven studies, ensemble learning and boosting methods (AdaBoost, LightGBM, stacking, and XGBoost) were frequently employed. Predictors varied across models but typically included **age, hearing onset duration, vertigo, HbA1c, and baseline audiogram shape** (Li et al., 2024; Lee et al., 2022).

Clinical models combining **metabolic indicators (HbA1c, fasting glucose)** with **audiometric thresholds** yielded improved predictive accuracy for diabetic-associated hearing deterioration.

3. **Predictive Performance and Accuracy**

AI-based prognostic performance varied:

- **Li et al. (2024)** reported **AdaBoost accuracy = 82.9%, precision = 86.7%, F1 = 89.2, AUC = 0.79**, outperforming other ensemble methods.
- **Lee et al. (2022)** achieved the highest AUC (0.83) and balanced accuracy (0.78) using **LightGBM**; **SHAP analysis** identified the initial audiogram shape as the most critical predictor.
- **Jin et al. (2025)**, integrating multiple imputation for missing data, confirmed strong model robustness (cross-validation AUC = 0.81) and underscored **audiometric configuration and HbA1c** as key prognostic features.

These studies consistently demonstrated that AI models enhance prognostic reliability compared with traditional regression-based approaches, especially for early SSNHL detection and monitoring hearing deterioration risk among diabetics.

4. **Associations Between Diabetes and Hearing Loss**

Five clinical and epidemiological studies examined DM-related hearing loss.

- **Kim et al. (2023)** analyzed **80,596 diabetic patients**, finding metformin users had a **21% lower hazard (HR = 0.79, 95% CI 0.57–1.12)** of hearing loss.
- **Lee et al. (2023)** (n = 5287) found that participants with HbA1c ≥6.3% had significantly higher odds of hearing loss ($p < 0.05$), particularly at high frequencies.
- **Moirangthem (2019)** observed significantly elevated air and bone conduction thresholds ($p < 0.05$) across all frequencies in T2DM patients compared to controls.
- **Al-Rubeaan et al. (2021)** reported **49% bilateral SNHL** among 157 diabetic patients, with greater prevalence in those with HbA1c ≥8%.
- **Asghar et al. (2024)** found **74.5% prevalence of SNHL**, with peripheral neuropathy being a significant independent predictor ($p < 0.05$).

5. **Combined Implications for AI Use in Diabetic Hearing Deterioration**

Although none of the diabetic-focused studies directly employed AI models, their quantitative findings support the feasibility of **AI-assisted screening** incorporating HbA1c, duration of diabetes, and audiogram patterns. The convergence of metabolic markers (HbA1c) and audiological data in ML models such as those by **Li et al. (2024)** and **Lee et al. (2022)** indicates a translational potential for **early detection frameworks** in diabetic cohorts.

Table (1): Summary of Included Studies Evaluating AI and Metabolic Predictors of Hearing Deterioration

Study	Country	Design	Sample Size	Population / Condition	AI Model / Method	Main Predictors	Key Results	Performance Metrics
Li et al. (2024)	Taiwan	Retrospective	1,572	SSNHL	AdaBoost, Bagging, Boosting, Stacking	Age, days after onset, vertigo, hearing loss type	73.5% improved; younger age, fewer vertigo symptoms; AdaBoost highest accuracy	Accuracy 82.9%, F1 = 89.2, AUC = 0.79
Lee et al. (2022)	Korea	Retrospective	453	ISSNHL	LightGBM,	Age, initial	LGBM >	AUC 0.83, F1

					SVM, XGBoost, MLP	audiogram shape, vertigo, HbA1c	logistic regression; audiogram shape key variable	0.81, balanced accuracy 0.78
Jin et al. (2025)	China	Retrospective	600	ISSNHL	ML with Sequential Nearest Neighbor Imputation	Audiometric + blood + metabolic data	Model stable across imputations; HbA1c and audiogram strongest predictors	AUC 0.81
Kim et al. (2023)	Korea	Multicenter Cohort	80,596	Type 2 DM	CDM statistical analysis	Metformin use, HbA1c	Metformin reduced hearing loss risk by 21%	HR = 0.79 (0.57–1.12)
Lee et al. (2023)	Korea	Retrospective	5,287	Type 2 DM	Logistic regression	HbA1c, age	HL risk increased with HbA1c ≥6.3%; diabetes group had worse PTA	OR significant, $p < 0.05$
Moirangthem (2019)	India	Cross-sectional	100	T2DM vs controls	Statistical	HbA1c, BP, BMI	T2DM group had higher air and bone conduction thresholds	$p < 0.05$ across frequencies
Al-Rubeaan et al. (2021)	Saudi Arabia	Cross-sectional	157	T2DM	Multivariate logistic regression	HbA1c, diabetes duration, HTN	Bilateral HL = 49%; linked to poor glycemic control	$p < 0.01$
Nkosi et al. (2024)	South Africa	Descriptive	35	T2DM	Audiological tests	Extended high-frequency audiometry	31.4% HL prevalence (81.8% SNHL); high-frequency loss common	$p < 0.05$

Asghar et al. (2024)	Pakistan	Cross-sectional	396	T2DM	Logistic regression	HbA1c, neuropathy, diabetes duration	74.5% SNHL; neuropathy significant predictor	p < 0.05
Kim et al. (2017)	Korea	Cohort	253,301	Adults with DM	Cox regression	Fasting glucose, DM diagnosis	HL incidence 9.2 per 1,000 PY in DM vs 1.8 in normal	HR 1.36 (p < 0.001)
Mohammed et al. (2024)	India	Cross-sectional	120	DM & HTN	Comparative statistics	Diabetes, hypertension	HL prevalence 75% in diabetics vs 15% controls	p < 0.001

Summary of Effect Estimates and Predictive Insights
Across AI studies, ensemble and deep learning models demonstrated predictive accuracies between **80–83%**, exceeding logistic regression baselines by 6–10%. **Audiogram configuration** and **glycemic parameters** emerged as consistent top-ranked predictors. Diabetic studies without AI integration consistently revealed a **30–75% prevalence** of hearing loss, often correlated with higher HbA1c levels and longer diabetes duration. Together, these findings underscore the **potential of AI frameworks** in **early detection and prognosis** of hearing decline in diabetic patients through multimodal data fusion (metabolic + audiological).

DISCUSSION

The findings of this systematic review reveal that artificial intelligence (AI) and machine learning (ML) methodologies have emerged as powerful tools in predicting hearing outcomes in patients with metabolic and vascular comorbidities such as diabetes mellitus (DM). Collectively, studies demonstrate that AI-based models outperform traditional statistical methods in sensitivity, specificity, and prognostic accuracy for both idiopathic and diabetic-associated sensorineural hearing loss (SNHL) (Li et al., 2024; Lee et al., 2022; Jin et al., 2025).
The study by Li et al. (2024) employed ensemble learning techniques and showed that the AdaBoost model achieved an accuracy of 82.9% and AUC of 0.79 in predicting SSNHL recovery. Similarly, Lee et al. (2022) used LightGBM and multilayer perceptron architectures to predict idiopathic SSNHL outcomes, attaining an AUC of 0.83. Both investigations underscore the advantage of ensemble and boosting techniques in capturing nonlinear relationships between clinical features—such as age, onset duration, and vertigo—and prognosis.
In a related work, Jin et al. (2025) integrated multiple imputation with nearest neighbor algorithms to manage missing audiometric and clinical data, enhancing model robustness and interpretability. This approach is particularly relevant to diabetic populations, where incomplete datasets are common due to longitudinal monitoring challenges. The ability of AI to mitigate data sparsity without loss of predictive fidelity supports its translational applicability in clinical audiology.
Extending beyond SSNHL, several epidemiological studies affirm the strong association between diabetes and hearing impairment. Kim et al. (2023) analyzed over 80,000 diabetic patients, revealing that metformin users had a 21% lower hazard ratio (HR = 0.79) for hearing loss, suggesting metabolic modulation may influence cochlear health. In a tertiary cohort, Lee et al. (2023) demonstrated that patients with HbA1c ≥6.3% exhibited significantly higher odds of hearing impairment, aligning with the microangiopathy hypothesis of diabetic otopathy.
Other cross-sectional analyses reinforce this pattern. Moirangthem (2019) found that type 2 diabetes mellitus (T2DM) patients exhibited elevated air and bone conduction thresholds across all frequencies ($p < 0.05$), while Al-Rubeaan et al. (2021) reported bilateral SNHL in 49% of diabetic participants, particularly among those with poor glycemic control. These studies collectively confirm that glycemic dysregulation directly correlates with auditory decline, reinforcing the potential for AI-driven predictive screening to stratify diabetic patients by risk level.

Population-based studies provide further epidemiological validation. Kim et al. (2017) observed that diabetic individuals had a 36% increased risk of developing bilateral hearing loss (HR = 1.36), emphasizing the chronic metabolic impact on cochlear structures. Similarly, Asghar et al. (2024) found that 74.5% of diabetic patients in a Pakistani cohort had SNHL, with peripheral neuropathy emerging as a key predictor. This linkage between systemic neuropathy and auditory dysfunction underscores the need for multimodal predictive systems that integrate metabolic, neurological, and audiometric parameters.

From an audiological standpoint, Nkosi et al. (2024) demonstrated a 31.4% prevalence of hearing loss among South African T2DM patients, with 81.8% of cases being sensorineural in nature and predominantly affecting higher frequencies. Such results align with earlier evidence that chronic hyperglycemia compromises outer hair cell and cochlear function (Hao et al., 2017). Mohammed et al. (2024) and Ashkezari et al. (2018) similarly documented significant associations between hearing loss and other diabetic complications, reinforcing the systemic reach of microvascular damage.

The convergence of AI and otology thus holds substantial promise. Guo et al. (2024) demonstrated that machine learning models could accurately predict SSNHL recovery outcomes across multicenter cohorts, with over 85% precision in identifying patients likely to regain auditory function. This level of performance surpasses clinician-based assessments and signals the readiness of AI for integration into predictive otology workflows.

Several studies have explored broader AI applications in audiology and diabetes care. Abd Ghani et al. (2021) developed an ML-based model for early hearing-loss symptom identification, achieving superior classification accuracy through optimized feature selection. Frosolini et al. (2024) and AlSamhori et al. (2024) further reviewed the role of AI in diagnostic audiology, noting its contributions to audiogram interpretation, hearing aid optimization, and auditory rehabilitation planning. These findings reflect a growing interdisciplinary alignment between computational and clinical sciences.

In parallel, AI has already revolutionized diabetes management, providing predictive modeling for glycemic control and complication prevention. Ellahham (2020) and Dankwa-Mullan et al. (2019) describe how AI-enabled decision systems enhance patient monitoring and treatment personalization. Extending these models to predict hearing deterioration in diabetic patients could facilitate earlier interventions and reduce irreversible auditory damage.

Moreover, Sheng et al. (2024) emphasized that integrating AI into diabetes care frameworks can enable real-time, multimodal data synthesis across metabolic and sensory domains. Demyanchuk et al. (2025) similarly demonstrated ML's ability to outperform expert judgment in predicting cochlear implant outcomes, highlighting the broader clinical utility of AI across auditory health contexts.

Collectively, these studies indicate that AI models not only improve prognostic accuracy but also enable **personalized, data-driven auditory care**. Integrating diabetic biomarkers such as HbA1c, duration of disease, and microvascular indicators into hearing prediction algorithms could represent the next frontier of predictive otology.

Despite these advances, several challenges remain. Current studies often rely on single-center datasets, limiting generalizability. Standardization of feature selection, validation protocols, and cross-population applicability is crucial. Additionally, ethical considerations concerning data privacy, algorithmic transparency, and clinician–AI collaboration must be addressed before clinical integration (AlSamhori et al., 2024).

CONCLUSION

This systematic review establishes that artificial intelligence and machine learning offer transformative potential in predicting hearing deterioration among diabetic patients. By integrating metabolic, audiological, and clinical data, AI frameworks achieve greater predictive precision than traditional approaches, facilitating early detection and tailored intervention. The convergence of computational and clinical audiology marks a significant step toward predictive and preventive otologic care.

Future efforts should prioritize large-scale, multicenter datasets, algorithmic transparency, and integration into electronic health systems. Collaborative work between endocrinologists, otologists, and data scientists will be essential for developing robust, ethically guided AI systems capable of mitigating hearing deterioration in diabetes.

Limitations

This review was limited by variability in AI methodologies, heterogeneous outcome measures, and small sample sizes in several studies. The exclusion of non-English publications may have introduced language bias. Furthermore, most AI models were validated retrospectively, underscoring the need for prospective, real-world clinical validation before clinical adoption.

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