

Advances in Artificial Intelligence, Nanotherapeutics, and Neuroprotective Interventions for Speech and Hearing Disorders Associated with Neurological and Metabolic Diseases

Authors:

Arun Banik¹, Vivek Kumar Jha², Aastha Yadav^{3*}

¹Arun Banik, Professor (Speech & Hearing), Vinayaka Mission's Research Foundation (Deemed to be University), AVMC Hospital Campus, Kirmampakkam, Puducherry.

²Professor (Speech Pathology and Audiology), Department of Audiology and Speech Language Pathology, School of Allied Health Sciences, Shree Guru Gobind Singh Tricentenary University, Gurugram, Haryana.

³Shikhar Institute of Pharmacy, Badaun, UP.

***Corresponding Author:**

Aastha Yadav, Shikhar Institute of Pharmacy, Badaun, UP. Email: aasthay2233@gmail.com

DOI: <https://doi.org/10.5281/zenodo.20470435>

Received: 16 March 2026, Accepted: 15 April 2026, Online First: 30 April 2026

ABSTRACT:

Speech and hearing disorders associated with neurological and metabolic diseases represent an expanding global healthcare challenge with significant social, cognitive, and psychological implications. Recent developments in artificial intelligence (AI), nanotherapeutics, phytomedicine, precision drug delivery systems, and neuroprotective interventions have transformed the diagnostic and therapeutic landscape of audiology and speech-language pathology. AI-assisted predictive analytics, machine learning algorithms, digital therapeutics, and personalized rehabilitation platforms are enabling early diagnosis and optimized patient-centered care. Simultaneously, nano-enabled drug delivery systems, phytoconstituent-based therapeutics, and neuroprotective bioactives are demonstrating considerable potential in managing neurodegenerative and metabolic complications affecting auditory and speech functions. This review comprehensively discusses recent advances in AI-driven healthcare technologies, pharmaceutical nanotechnology, neuroprotective interventions, and precision therapeutics relevant to speech and hearing disorders linked with neurological and metabolic diseases. Additionally, translational challenges, ethical concerns, regulatory perspectives, and future interdisciplinary research opportunities are critically analyzed.

Keywords: Artificial intelligence, Hearing disorders, Speech disorders, Metabolic diseases, Neurological disorders, Precision medicine, Audiology, Machine learning

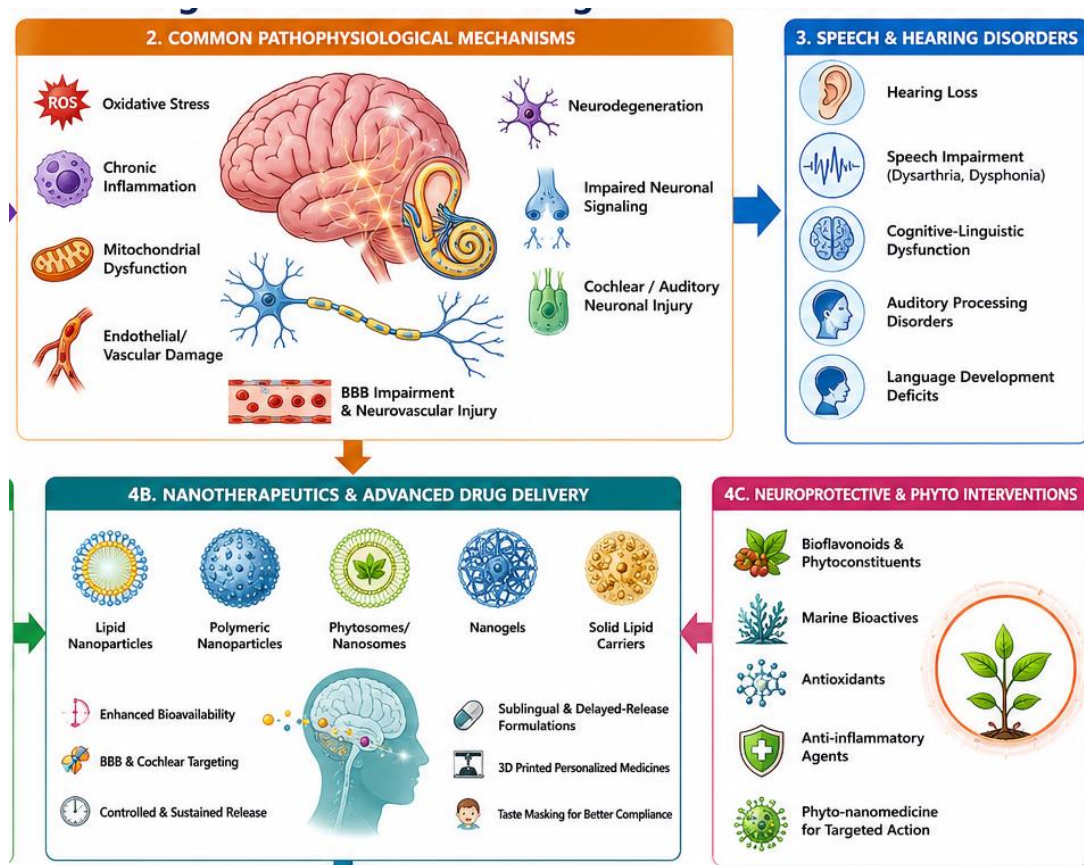
1. INTRODUCTION:

Speech and hearing disorders constitute major public health concerns worldwide and are increasingly associated with neurological, inflammatory, vascular, and metabolic abnormalities. Neurodegenerative diseases such as Parkinson's disease, Alzheimer's disease, autism spectrum disorder (ASD), attention deficit hyperactivity disorder (ADHD), stroke, neuropathic disorders, and epilepsy frequently present with impairments in speech, cognition, auditory processing, and language development [1-3].

Metabolic disorders including diabetes mellitus, obesity, nonalcoholic fatty liver disease (NAFLD), hypertension, chronic kidney disease, and hepatic dysfunction are also strongly associated with neurovascular injury and auditory dysfunction [4-7]. Chronic inflammation, oxidative stress, mitochondrial dysfunction, endothelial damage, and impaired neuronal signaling are common mechanisms contributing to speech and hearing abnormalities in these conditions. Conventional therapeutic approaches often demonstrate limited efficacy because of poor drug penetration across biological barriers, systemic adverse effects, inadequate patient

compliance, and delayed diagnosis. Consequently, advances in artificial intelligence (AI), machine learning, nanotechnology, phytopharmaceuticals, and precision

drug delivery systems are emerging as transformative strategies for improving diagnosis, monitoring, and treatment outcomes [8]. Fig-1



FigNo.1: Interventions for Speech and Hearing Disorders

2. Artificial Intelligence in Speech and Hearing Healthcare:

Artificial intelligence has revolutionized healthcare diagnostics, disease prediction, therapeutic optimization, and patient management [9]. AI algorithms are increasingly utilized in speech-language pathology and audiology for real-time data analysis, automated diagnosis, and personalized rehabilitation.

2.1 AI-Assisted Diagnostic Technologies:

Machine learning and deep learning systems are capable of detecting subtle acoustic, phonetic, and cognitive abnormalities associated with neurodegenerative diseases [10]. AI-based diagnostic systems can evaluate:

- Speech fluency and articulation
- Voice frequency and pitch variations
- Auditory processing behavior
- Cognitive-linguistic patterns
- Hearing aid performance
- Neurocognitive deterioration biomarkers

Voice biomarker analysis is gaining importance in early detection of Parkinsonism, Alzheimer's disease, diabetic neuropathy, and autism-related speech impairments [11].

2.2 AI in Pharmaceutical Research and Precision Medicine:

AI-assisted pharmaceutical research accelerates drug discovery, formulation optimization, computational modeling, and personalized therapeutics. Computational intelligence has facilitated in silico drug design for cancer therapeutics and receptor-targeted interventions.

AI-based immunotherapy prediction systems are also improving prognosis prediction and personalized oncology therapeutics]. Similarly, AI-integrated healthcare scheduling systems enhance healthcare accessibility and clinical workflow optimization.

2.3 Digital Therapeutics and Tele-Audiology:

Digital therapeutics supported by AI enable remote speech rehabilitation, adaptive cognitive training, tele-audiology services, and personalized auditory therapy [12]. Such technologies are particularly beneficial for elderly patients, pediatric neurodevelopmental disorders, and rural healthcare populations.

3. Nanotherapeutics and Advanced Drug Delivery Systems:

Nanotechnology-based therapeutics have emerged as highly promising approaches for overcoming limitations of conventional therapies [13]. Nanocarriers enhance drug stability, bioavailability, tissue targeting, and controlled release.

3.1 Controlled and Sustained Drug Delivery Systems:

Advanced pharmaceutical formulations such as sustained-release tablets, delayed-release systems, sublingual formulations, phospholipid complexes, and matrix tablets significantly improve therapeutic efficacy and patient compliance [14].

Matrix-based sustained-release systems facilitate prolonged therapeutic action and minimize dose frequency [15]. Delayed-release and sublingual formulations improve rapid absorption and reduce first-pass metabolism [17,18].

Taste masking technologies further improve acceptability and adherence in pediatric and geriatric populations requiring long-term neurological therapies [21].

3.2 Nanocarriers in Neurological and Auditory Disorders:

Nanostructured drug carriers such as lipid nanoparticles, polymeric nanoparticles, phytosomes, nanogels, and solid lipid microparticles improve therapeutic penetration across the blood-brain barrier and cochlear tissues [16,19].

Solid lipid microparticles and semi-herbal nanogels represent innovative approaches for targeted delivery and enhanced therapeutic efficacy [22,23]. Nanotechnology-based systems also facilitate controlled release of antioxidants, neuroprotective agents, anti-inflammatory compounds, and phytochemicals.

3.3 Personalized Nanomedicine and 3D Printing:

Personalized medicine has significantly evolved with the development of 3D-printed pharmaceutical formulations. QbD-assisted pregabalin formulations for neuropathic pain management represent important advances in individualized therapeutics [24].

Personalized nanoformulations may offer substantial advantages in managing neurodegenerative disorders associated with hearing loss and speech dysfunction.

4. Neuroprotective and Phytopharmaceutical Interventions:

Neuroprotection is central to preserving auditory neurons, cognitive pathways, and speech-related brain functions.

4.1 Oxidative Stress and Neuroinflammation:

Oxidative stress and chronic inflammation are key contributors to neuronal degeneration and auditory dysfunction. Bioflavonoids, phytoconstituents, and natural antioxidants demonstrate promising neuroprotective effects through modulation of inflammatory signaling pathways.

Studies investigating hepatotoxicity, metabolic dysfunction, and inflammatory disorders further emphasize the role of oxidative injury in systemic neurological impairment [25,26].

4.2 Phytoconstituents and Phyto-Nanomedicine:

Phytochemicals possess antioxidant, anti-inflammatory, antimicrobial, and neuroprotective properties. Advanced extraction technologies are improving identification, purification, and standardization of therapeutic phytoconstituents [27].

Phyto-nanomedicine combines nanotechnology with herbal therapeutics to improve bioavailability, targeted delivery, and neuroprotective efficacy [19]. Pentacyclic triterpenoids and marine bioactives have demonstrated promising applications in neurodevelopmental and neurodegenerative disorders [28,29].

4.3 Marine Bioactives and Neurodevelopmental Disorders:

Marine-derived neuroprotective compounds exhibit anti-inflammatory, antioxidant, and cognitive-enhancing effects. Such compounds may improve behavioral, cognitive, and speech abnormalities associated with ADHD, autism spectrum disorders, and neurodevelopmental conditions.

5. Metabolic Diseases and Speech-Hearing Dysfunction:

Metabolic diseases are increasingly recognized as major contributors to neurological and auditory impairments.

5.1 Diabetes Mellitus and Auditory Dysfunction:

Diabetes-induced neuropathy, vascular damage, and oxidative stress contribute significantly to hearing loss and cognitive-linguistic dysfunction [1,4]. Bioflavonoid-based interventions modulating MMP-9/TIMP-1, TGF- β , and GLUT-4 pathways demonstrate promising neuroprotective potential.

Monoclonal antibody therapies targeting metabolic inflammation may also contribute to future neuroprotective strategies [30].

5.2 Liver Disease and Neurocognitive Dysfunction:

NAFLD, alcoholic liver disease, and hepatic dysfunction are associated with neuroinflammation, cognitive decline, and auditory abnormalities [31]. Fructose-induced

metabolic dysfunction contributes to systemic inflammation and neurovascular injury.

Dietary interventions and natural hepatoprotective agents may therefore indirectly support neurological and auditory health.

5.3 Hypertension and Chronic Kidney Disease:

Hypertension and chronic kidney disease impair cerebral microcirculation and neuronal signaling. Emerging evidence suggests that vascular dysfunction significantly contributes to age-related hearing loss and speech impairment.

Combination antihypertensive therapies and optimized cardiovascular management may reduce neurodegenerative progression [32].

6. Oncology, Neurotoxicity, and Computational Therapeutics:

Cancer therapies frequently induce neurotoxicity, cognitive dysfunction, and auditory complications. AI-driven computational therapeutics and targeted drug delivery systems are improving precision oncology approaches.

Novel imatinib derivatives, EGFR inhibitors, radiopharmaceuticals, and AI-assisted immunotherapy prediction systems are contributing to safer and more effective cancer treatment strategies [33-34].

Radiopharmaceutical imaging technologies also improve neuro-oncological diagnosis and monitoring [35].

7. Clinical Translation and Ethical Challenges:

Despite significant advancements, several translational barriers remain:

- Regulatory limitations
- High development costs
- Limited large-scale clinical trials
- AI algorithm bias
- Data privacy concerns
- Standardization challenges
- Interdisciplinary implementation gaps

Ethical concerns regarding AI-driven healthcare systems include transparency, accountability, informed consent, and equitable healthcare access [12].

Robust multicenter validation studies and interdisciplinary collaborations are essential for future clinical implementation.

8. Future Perspectives:

Future research should focus on:

- AI-assisted precision audiology
- Smart nanocarrier systems
- Brain-computer interfaces
- Wearable neurodiagnostic devices

- AI-guided drug repurposing
- Personalized neurotherapeutics
- Digital biomarkers for speech disorders
- Multi-omics integration
- Advanced phyto-nanomedicine
- Regenerative neuropharmacology

Collaborative integration of computational intelligence, pharmaceutical nanotechnology, audiology, neurology, and speech-language pathology will play a critical role in next-generation healthcare systems.

9. CONCLUSION:

Artificial intelligence, nanotherapeutics, and neuroprotective interventions are transforming the management of speech and hearing disorders associated with neurological and metabolic diseases. AI-based diagnostics, personalized rehabilitation platforms, and computational therapeutics provide unprecedented opportunities for early detection and precision treatment. Concurrently, nanotechnology-enabled drug delivery systems, phytomedicine, marine bioactives, and neuroprotective interventions demonstrate significant therapeutic potential for neurodegenerative and metabolic auditory disorders.

Future interdisciplinary research integrating computational intelligence, pharmaceutical sciences, audiology, neurology, and precision medicine is expected to significantly improve clinical outcomes and quality of life in affected individuals.

Limitations:

- Limited availability of human clinical evidence
- Heterogeneity among published studies
- Lack of long-term clinical validation
- Regulatory uncertainty
- AI algorithm bias

Funding Statement:

The authors received no specific funding for this work.

Conflict of Interest:

The authors declare no conflict of interest.

Data Availability Statement:

No datasets were generated or analyzed during the current study.

REFERENCES:

1. Xiong Y, Sharma HP, Goyal RK, Narwal S, Berwal A, Jain S, et al. Bioflavonoid combination attenuates diabetes-induced nephropathy in rats via modulation of MMP-

- 9/TIMP-1, TGF- β , and GLUT-4-associated pathways. *Heliyon*. 2024;10(13).
2. Otayf AY, Agarwal G, Al Khairat M, Khormi EA, Alnemi HH, Alhazmi AA, et al. Fructose, the sweet culprit behind nonalcoholic fatty liver disease and type 2 diabetes. *Current Diabetes Reviews*. 2026;22(2).
3. Chaudhary B, Arya P, Kumar P, Agarwal G, Grewal AS. Neuroprotective Marine Bioactives in Paediatric ADHD: A Focused Review on Therapeutic Potential. *CNS Neurol Disord Drug Targets*. 2026.
4. Agarwal G, Patel M. Review on monoclonal antibodies (Mabs) as a therapeutic approach for type 1 diabetes. *Current Diabetes Reviews*. 2024;20(7):23-28.
5. Agarwal G. Role of combination therapy (Valsartan plus Hydrochlorothiazide) in Hypertension: A Review. *Eur J Biomed Pharm Sci*. 2016;3(1):137-140.
6. Ghouse Z, Patel M, Agarwal S, Singhal R. Understanding emerging trends in the management of hypertension in chronic kidney disease: A systematic review. *Eur Chem Bull*. 2023;12(4):2970-2981.
7. Al Khairat M, Otayf AY, Agarwal S, Agarwal G. Dietary and natural aid for alcoholic liver disease steatosis and cirrhosis. *Afr J Bio Sci*. 2024;6(14):3096-3114.
8. Agrawal G, Tushir S, Arora D, Sangwan K. Artificial intelligence in pharmaceutical drug delivery. 2024 International Conference on Computational Intelligence and Computing Applications. 2024.
9. Syed MU, Agarwal G, Agarwal S. An overview of the role of artificial intelligence and machine learning in pharmaceutical research and development. *Lat Am J Pharm*. 2023;42:1-8.
10. Khurana S, Malik A, Narwal S, Agarwal G, Sangwan K. Potential of artificial intelligence in healthcare sector. 2024 International Conference on Computational Intelligence and Computing Applications. 2024.
11. Devgan M, Karar PK, Agarwal G, Mohan A, Gangwar P. In silico designing of drugs for the inhibition of AMF-HER2 complex in trastuzumab resistant breast cancer. *Indian J Biotechnol*. 2016;15(3):292-298.
12. Narwal S, Chhikara M, Agarwal G, Sangwan K, Sehrawat S, Bhatia L, et al. Transforming Healthcare Through Artificial Intelligence: Clinical, Translational, and Ethical Insights with a Focus on Scheduling and Optimization. 2025 International Conference on Computational Intelligence and Computing Applications. 2025.
13. Agarwal G, Sharma P, Khan S. Enhancing cancer treatment prognosis through AI-driven immunotherapy predictions. *Current Cancer Therapy Reviews*. 2025.
14. Sangwan K, Agarwal G, Kumar S. Design, Synthesis, and Characterization of Some Novel Imatinib Derivatives as Promising Anticancer Agents. *Russian Journal of Organic Chemistry*. 2025;61(10):1959-1967.
15. Agarwal G, Agarwal S, Karar PK, Goyal S. Oral sustained release tablets: an overview with a special emphasis on matrix tablet. *Am J Adv Drug Deliv*. 2017;5(02):64-76.
16. Kar A, Agarwal DG, Agarwal DS. A Review On Nanostructure Drug Carriers for Treatment and Management of Neuroendocrine Cancer. *Int J Pharm Sci*. 2023;14(1).
17. Grover I, Agarwal G. Formulation and evaluation of sublingual tablets of lisinopril. NISCAIR-CSIR, India. 2012.
18. Saudagar WS, Sidram GP, Baburo GS, Agarwal G, Agarwal S, et al. Development and Characterization of Terminalia arjuna Phospholipid Complex and Its Tablet Formulation by QbD Approach. *Int J Lifescience Pharma Res*. 2021;11(3):14-28.
19. Aggarwal D, Kamal CM, Agarwal G, Kumar A, Sharma D. Understanding of phyto-nanomedicine for the management of inflammation and wound healing: an outlook. *Int J Pharm Sci Res*. 2023;14(10):4716-4723.
20. Agarwal G. Formulation & Evaluation of Sustained Release Matrix Tablet of Repaglinide. *Open Access Biostat Bioinforma*. 2018;1(2).
21. Thakker P, Shah J, Mehta T, Agarwal G. Taste Masking of Pharmaceutical Formulations: Review on Technologies, Recent Trends and Patents. *Int J Life Sci Pharma Res*. 2020;10(3).
22. Nagappa AN, Agarwal G, Chikkamath V, Agarwal S, Rani R, Karar P. Formulation and

- evaluation of acyclovir sodium solid lipid microparticles. *Am J Adv Drug Deliv.* 2016;4(5):1078-1084.
23. Agarwal S, Karar PK, Agarwal G. Semi-herbal nanogel of clindamycin phosphate and aloe vera: formulation and evaluation. *Modern Applications of Bioequivalence and Bioavailability.* 2017;2(5):1-5.
 24. Agarwal G. Formulation and Evaluation of 3D Printed Pregabalin Tablets Targeted For Neuropathic Pain By Qbd Approach For Personalized Medicine. *Int J Lifescience Pharma Res.* 2022;11(6):1-13.
 25. Karar PK, Agarwal G, Agarwal S, Devgan M. Effect of dietary protein against excess vitamin A induced hepatotoxicity in rats. *Am J Adv Drug Deliv.* 2017;5(2):59-63.
 26. Agarwal G. Perioperative Medication Errors: Review on Cause, Consequences and Prevention. *Int J Pharma Bio Sci.* 2021;12(2):136-142.
 27. Singh PA, Tushir S, Hazra S, Purewal SS, Agarwal G. Novel approaches for the extraction and identification of phytoconstituents from herbs and spices. *Nat Prod J.* 2025;15(4).
 28. Agarwal SG, Kumar P, Singh SS. Insights into the Recent Breakthroughs in Nanotechnological Outlook of Pentacyclic Triterpenoids: An Updated Approach. *Current Pharmaceutical Design.* 2026.
 29. Aneja S, Mittal A, Dhiman N, Agarwal G. A Review on Phytoconstituents for the Treatment of Psoriasis. *Pharmacogn Rev.* 2023;17(34).
 30. Agarwal G, Patel M. Review on monoclonal antibodies (Mabs) as a therapeutic approach for type 1 diabetes. *Current Diabetes Reviews.* 2024;20(7):23-28.
 31. FDA-Approved Radiopharmaceuticals in Oncologic PET Imaging: Current Status and Clinical Impact. *American Journal of Clinical Oncology.* 2026.
 32. Sangwan K, Agarwal G. Sunvozertinib: a promising oral EGFR inhibitor approved for NSCLC with EGFR Ex20ins mutations. *Investigational New Drugs.* 2025.
 33. Kumar S, Agarwal G, Sangwan K. A review on medicinal approaches of novel imatinib derivatives. *Current Topics in Medicinal Chemistry.* 2025;25(12):1492-1516.
 34. Sharma K, Sanduja M, Kumar A, Singh M, Sharma A, Yadav R, et al. Recent expansions in anti-microbial profile of quinoline analogues: a review. *Current Organic Chemistry.* 2025.
 35. Saiphali K, Al Khairat M, Otayf AY, Agarwal S, Agarwal G. An approach towards green analytical chemistry: spectrophotometric method for the determination of celecoxib in capsule formulations. *Afr J Biol Sci.* 2024;6(9):1198-1212.