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# Optical cochlear implants: recent progress toward light-based hearing restoration

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Optical cochlear implants combine optogenetics and light-based hardware to overcome limits of electrical CIs, promising sharper frequency resolution and more natural hearing.

Cochlear implants (CIs) are among the most successful neuroprosthetic devices in modern medicine, restoring speech perception to hundreds of thousands of people worldwide. Despite this success, hearing with electrical cochlear implants remains far from normal. Understanding speech in noisy environments is difficult, music perception is limited and sound quality is often described as artificial. A fundamental reason is the physical spread of electrical current in the cochlea, which restricts the number of independently addressable frequency channels.

Over the past decade, our group and others have pursued an alternative strategy: optical stimulation of the auditory nerve enabled by optogenetics. By combining gene therapy with light-based stimulation hardware, the optical cochlear implant (oCI) aims to overcome the spatial limitations of electrical stimulation and move closer to physiological sound encoding. This article summarises recent progress toward optical hearing restoration, with a focus on developments most relevant to clinical translation.

Optogenetic hearing restoration is based on rendering spiral ganglion neurons (SGNs) light sensitive by introducing genes encoding light-gated ion channels, most commonly channelrhodopsins. After local delivery of these genes to the cochlea using adeno-associated viruses (AAVs), sound can be converted into spatially patterned light that directly activates SGNs. Conceptually, this parallels electrical cochlear implants but replaces electrical current with light, which can be spatially confined more precisely.

The feasibility of this approach was first demonstrated by Hernandez and colleagues in 2014, who showed that optogenetic stimulation of the auditory nerve activates the entire auditory pathway [1]. This work established optogenetic cochlear stimulation as a biologically viable approach and laid the foundation for subsequent technological and translational advances.

*Schematic of the future optical cochlear implant system consisting of the external (speech processor) and internal (optical cochlear implant) parts, as well as the gene therapy medicinal product and the application kit (symbolised as syringe with catheter). Image reproduced with permission from the Institute for Auditory Neuroscience.*

One of the most compelling advantages of optical stimulation is improved frequency resolution. In a key study, Dieter et al demonstrated near-physiological spectral selectivity of cochlear optogenetics in animal models [2]. Optical stimulation activated narrow regions of the cochlea with minimal overlap, producing sharply tuned responses in central auditory nuclei. Compared with electrical stimulation, optical excitation more closely resembled natural acoustic hearing. For clinicians, this is highly relevant, as limited spectral resolution is a major factor underlying poor speech understanding in noise and limited music appreciation in CI users.

Hearing, however, is not only about frequency but also about timing. Spiral ganglion neurons can fire with sub-millisecond precision at high rates, and early optogenetic tools were too slow to reproduce this temporal fidelity. To address this, fast and ultrafast channelrhodopsins have been engineered, allowing SGNs to follow stimulation rates relevant for speech perception. More recently, fast red-light-activated opsins have been developed. These scatter less in tissue, reduce phototoxic risk and are well suited for integration with advanced optical implants.

In parallel, substantial progress has been made in optical cochlear implant hardware. Early systems used microscale light-emitting diodes integrated into flexible arrays that can be inserted into the cochlea similarly to electrical electrode arrays. These multichannel optical implants restored auditory-driven behaviour in deaf animal models and enabled direct comparison with electrical cochlear implants. More recent designs incorporate laser diodes and polymer waveguides, allowing improved beam shaping and energy efficiency. These developments are essential steps toward human-sized devices.

Recent work has increasingly focused on translation readiness. Alekseev et al demonstrated robust optogenetic auditory responses at low light intensity, emphasising reliability and performance metrics relevant for real-world hearing [3]. In parallel, volume imaging and AI-based image analysis tools now allow quantitative, whole-cochlea assessment of gene and optogenetic therapies, enabling objective evaluation of efficacy and safety at organ scale.

Gene therapy is a key component of optogenetic hearing restoration and naturally raises safety concerns. Importantly, the cochlea is a favourable target for gene therapy due to its small size, compartmentalisation and relative immune privilege. Our group pioneered preclinical AAV-mediated gene therapy for otoferlin-related deafness, demonstrating functional rescue in animal models. These studies paved the way for current clinical trials targeting OTOF mutations. A recent review summarises this translational trajectory and highlights that inner-ear gene therapy can be both safe and effective, providing important reassurance for future optogenetic applications [4].

Safety considerations for optical cochlear implants include long-term opsin expression, potential phototoxicity and immune responses to viral vectors. Preclinical studies to date show stable expression and preserved cochlear structure over extended periods. The shift toward red-light stimulation further reduces safety risks. Importantly, optical cochlear implants do not preclude conventional electrical stimulation, preserving therapeutic flexibility.

In summary, optical cochlear implants have progressed from a conceptual idea to a realistic translational technology. Advances in optogenetic actuators, implant hardware, gene delivery and quantitative evaluation tools now converge toward first-in-human applications. While challenges remain, particularly regarding large-scale device integration and regulatory pathways, optical cochlear implants hold the promise of substantially improved sound quality, especially in complex listening environments. If successful, they could represent the next major leap in hearing restoration technology.

Tobias Moser will present on this topic at BACO 2026 in Glasgow, UK, in July.
For further information visit: www.entuk.org/baco

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## References


1. Hernandez VH, Gehrt A, Reuter K, et al. Optogenetic stimulation of the auditory pathway. *J Clin Invest* 2014;124(3):1114–29.

2. Dieter A, Duque-Afonso CJ, Rankovic V, et al. Near physiological spectral selectivity of cochlear optogenetics. *Nat Commun* 2019;10(1):1962.

3. Alekseev A, Hunniford V, Zerche M, et al. Optogenetic cochlear stimulation with advanced optical implants. *Nat Biomed Eng* 2025 [ePub ahead of print].

4. Moser T et al. Gene therapy for otoferlin-related deafness: from preclinical work to clinical trials. *EMBO Mol Med* 2024;16(4):675–7.

## Further reading


- Huet A, Mager T, Gossler C, Moser T. Toward Optogenetic Hearing Restoration. *Annu Rev Neurosci* 2024;47(1):103–21.