International Journal of Otorhinolaryngology and Head and Neck Surgery
*Swain SK. Int J Otorhinolaryngol Head Neck Surg. 2025 Feb;11(1):95-100*
http://www.ijorl.com
pISSN 2454-5929 | eISSN 2454-5937

DOI: https://dx.doi.org/10.18203/issn.2454-5929.ijohns20250127

**Review Article**

# Hybrid cochlear implant:a scoping review

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**Received:** 14 October 2024
**Accepted:** 10 December 2024

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## ABSTRACT

Cochlear implants (CIs) restore the perception of sound for individuals with severe to profound hearing loss by employing electrical stimulation to directly activate the remaining auditory neurons. Post-implantation ipsilateral hearing loss has been observed in every patient series involving hearing preservation cochlear implantation. Patients with residual hearing in the low-pitched area of the cochlea but severe to profound hearing loss in the middle and high-frequency range can be inserted with a shorter electrode array which preserves the residual hearing. The Hybrid CI, also referred to as electro-acoustic stimulation (EAS), is a type of cochlear implant designed to preserve residual acoustic hearing. It allows for the simultaneous use of a cochlear implant and a hearing aid in the same ear. Expanding electrical speech processing to individuals with more remaining acoustic hearing using a less invasive and shorter cochlear implant marks a significant milestone in cochlear implant technology. In Hybrid CI, the integration of electrical and acoustic hearing often leads to notable improvements in word recognition for the majority of cases. There is a distinct advantage of combining acoustic and electric hearing over relying solely on electrical stimulation, particularly in understanding speech in noisy environments and appreciating music. In general, patients who undergo Hybrid CI express high levels of satisfaction with their outcomes. This review's goal is to discuss Hybrid CI with its history, principles, design, candidacy, advantages, and limitations.

**Keywords:** Hybrid cochlear implant, Low-frequency hearing loss, Short electrode

## INTRODUCTION

Cochlear implantation is a well-established and effective method for restoring hearing and verbal communication among post-lingually deaf children with severe to profound hearing loss.[1] Individuals with post-lingual deafness and children who are prelingual and implanted early get successful outcomes by restoring their hearing.[2] If cochlear damage involves a significant number of missing inner hair cells, electrical stimulation of the auditory nerve is the sole method to deliver sound stimulation.[3] This is the most successful neural prosthesis that improves speech recognition in quiet for most of the CI recipients. However, speech recognition in noisy environments has remained poor.[4] As cochlear implantation is usually implanted fully into the cochlea, the process of the implantation often damages the remaining position of auditory structures and thus the residual acoustic hearing.[4] Low-frequency hearing is crucial for understanding the first formants of speech and enjoying music.[5] Patients with severe hearing loss above 750 to 1,000 Hz are more likely to benefit from preserving low-frequency hearing combined with a hybrid CI.[5] A traditional full-length cochlear implant (CI) cannot deliver all this information. Therefore, it's suitable to try preserving hearing with a short electrode and complement it with assisted natural hearing for the low frequencies.[5]

## REVIEW

Various methods were used to find research articles on the Hybrid cochlear implant. Initially, an online search was performed across databases such as Scopus,

PubMed, Medline, and Google Scholar. The search strategy was designed according to PRISMA (preferred reporting items for systematic reviews and meta-analyses) criteria to ensure a systematic and thorough review of relevant literature. In addition to manually sourcing research publications from citations, our search methodology included screening the abstracts of published works.

The eligibility criteria covered randomized controlled trials, observational studies, comparative studies, case series, and case reports that offered adequate evaluation of the Hybrid cochlear implant. A total of 56 papers were included, 14 case reports, 17 case series, and 25 research articles (Figure 1). This article covers the history, principles, design, candidacy, and advantages of Hybrid cochlear implants. It serves as a starting point for future prospective trials and could act as a catalyst for further investigation into Hybrid cochlear implants, an area with currently limited studies.

***History***

Cochlear implants have been utilized by otorhinolaryngologists worldwide since the late 1960s, following approval by the Food and Drug Administration of the USA (USFDA) in 1985.[3] In 1995, cochlear Americas designed the concept of the Hybrid cochlear implant, which involved implanting an electrode into the base of the cochlea while preserving low-frequency hearing in individuals with mild to moderate residual hearing.[6]

The development of the Hybrid S or short-electrode cochlear implant was subsequently undertaken at the University of Iowa in collaboration with cochlear corporation in 1996, specifically targeting a particular patient population for treatment.[7]

In 1999, an FDA feasibility clinical trial began with the Hybrid S implant. Instead of a full-length cochlear implant, a shorter version was inserted into the basal turn of the cochlea using soft surgery techniques to preserve the architecture of the apical cochlea. This approach aims to maintain the residual apical structures and associated low-frequency hearing. The electrode was extended to 10 mm, with the six electrode contacts positioned closer to the apex of the electrode array.

This configuration is known as the nucleus hybrid S8 implant and has been referred to as the Iowa/nucleus 10 mm hybrid implant or short electrode in various publications.[8,9] This is helpful for a bimodal mode of hearing where the low-frequency information is provided acoustically via a hearing aid, and high-frequency information is provided electrically through the implant. The S8 Hybrid CI, a 10 mm long version of the original 24 mm cochlear implant, was developed and validated through an FDA trial conducted from 1999 to 2009.[10]

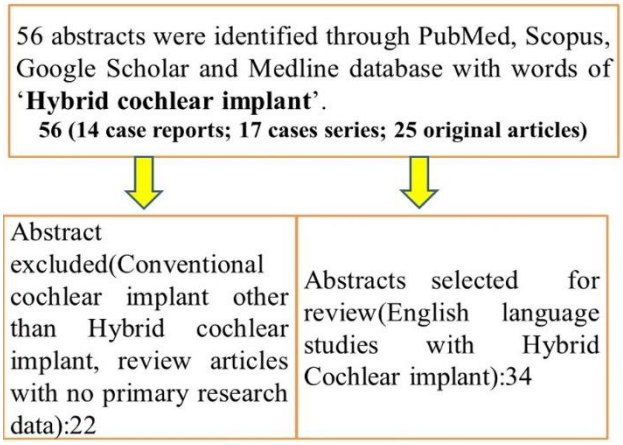


**Figure 1: Recurrent laryngeal nerve and parathyroid complications.**

***Principle of hybrid CI***

A subset of cochlear implant recipients who have undergone hearing preservation may experience increased hearing loss after the initiation of electrical stimulation.[11] The increased hearing loss observed in some hearing preservation cochlear implant recipients may be linked to high levels of electrical stimulation, which can potentially damage the afferent neural processes that innervate the organ of Corti.[12] Similarly, noise-induced trauma significantly damages the afferent cochlear innervation.[13] Exacerbation of existing damage to the afferent neural structures by electrical stimulation may contribute to the increased risk of post-implantation hearing loss in patients with noise-induced hearing loss.

The residual hearing status in the implanted ear does not strongly correlate with bilateral measures of speech comprehension. Various studies have shown that scores such as nucleus-consonant (CNC) and hearing in noise test (HINT) scores improve in both listening conditions regardless of postoperative hearing impairment in the implanted ear.[14] The hybrid device combines acoustic and electric stimulation within the same ear.

By shallowly inserting a shorter array at the cochlear base, functional cochlear structures at the apex are preserved. This approach allows for the preservation of low-frequency or apical residual hearing, while the impaired high-frequency or basal region of the cochlea receives electrical stimulation from the device.

Patients with residual low-frequency hearing loss, such as those with age-related hearing loss (presbycusis), can benefit from hybrid devices that utilize both acoustic and electrical modes of hearing simultaneously. This combined approach holds significant potential as it enhances speech understanding in quiet environments as well as in situations with background noise from competing talkers.[15]

### *Candidacy for hybrid cochlear implant*

Until recently, individuals with residual hearing were not considered candidates for standard CIs because implanting the device could potentially damage their most useful remaining hearing.[16] Typically, preimplant residual hearing in individuals often resides in the low-frequency apical area of the cochlea. Hearing in this apical region enables listeners to utilize fine timing and spectral cues, which are crucial for tasks such as understanding speech in noise, localizing sound, and appreciating music.[17] In contrast, CI speech processing usually does not provide fine spectral information of residual low-frequency hearing individuals.[17]

Therefore, candidates for cochlear implants are typically selected based on their potential to benefit from stimulation of the damaged high-frequency area of the cochlea, while also aiming to preserve their low-frequency hearing. Candidates for hybrid CI range from normal to moderate hearing loss in the low frequencies (threshold better than 60-decibel hearing loss up to and including 500Hz). Severe to profound mid to high-frequency hearing loss (threshold average of 2000,3000, and 4000 Hz≥ 75-decibel hearing loss) in the ear to be implanted.[17] Electroacoustic stimulation offers a promising treatment option for individuals who have too much residual hearing to qualify for a traditional cochlear implant, yet insufficient hearing to benefit adequately from a hearing aid alone. Ideal candidates typically have low-frequency aidable hearing ranging from 250 to 1,000 Hz, coupled with severe to profound hearing loss beyond these frequencies. These individuals are suitable candidates for combined electroacoustic hearing solutions or hybrid cochlear implants.[18]

Candidacy is typically defined as having severe hearing loss at 1500 Hz and beyond. Before undergoing surgery, patients should ideally demonstrate aided speech perception scores ranging from 10% to 60% on consonant-nucleus-consonant (CNC) words in the ear that will receive the implant.[19] The opposite ear is better than or equal to the ear to be implanted but scored no greater than 80% on nucleus-consonant (CNC) words. Patients with noise-induced hearing loss (NIHL) often experience further hearing loss after cochlear implantation and typically demonstrate poorer performance on clinical measures of cochlear implant (CI) effectiveness, such as CNC (consonant-nucleus-consonant) and HINT (Hearing in Noise Test). This increased vulnerability is linked to noise exposure triggering elevated production of free radicals within the cochlea, subsequently reducing cochlear blood flow and leading to cell death in the organ of Corti.[20]

A recent study on mice indicates that even reversible noise-induced threshold shifts can lead to ongoing degeneration of afferent neurons.[21] So, patients with NIHL are susceptible to post-implantation hearing loss. The cochlear nucleus hybrid system consists of a nucleus hybrid L24 implant and the Nucleus sound processor, which integrates acoustic amplification for low frequencies with electric stimulation for high frequencies. This system is recommended for unilateral use in patients aged 18 years and older who have residual low-frequency hearing sensitivity and severe to profound sensorineural hearing loss in the high frequencies. It is also suitable for individuals who receive limited benefit from appropriately fitted bilateral hearing aids.

### *Design of hybrid cochlea implant*

Hybrid CI represents a novel form of cochlear implantation that retains residual hearing, allowing individuals to continue using a hearing aid in the same ear following the surgery.[22] The hybrid CI is a streamlined version of the traditional cochlear implant, featuring a shorter electrode that is implanted exclusively into the basal region of the cochlea. This placement targets high-frequency sounds while preserving low-frequency hearing capabilities.[23] This procedure is minimally invasive, involving the insertion of a 10 mm Iowa/nucleus hybrid electrode, which is significantly shorter than the conventional cochlear implant electrode. Unlike traditional implants that reach depths of 22-30 mm into the scala tympani of the cochlea, this approach targets a much shallower depth within the cochlea.[24]

Inserting a longer electrode into the cochlea can potentially damage more auditory neurons, leading to a loss of low-frequency hearing. In contrast, using a shorter and thinner cochlear implant (CI) electrode array reduces trauma in the low-frequency region of the cochlea. This approach involves inserting the array only into the basal to middle parts of the cochlea, thus preserving the integrity of the apical cochlea where low-frequency sounds are processed. Most patients present significant high-frequency hearing impairment with preservation of low-frequency acoustic hearing (ski slope hearing loss).

The hybrid cochlear implant is designed to be of shorter length, sitting only within the basal turn of the cochlea and giving electric signals to the portions tuned to higher characteristic frequencies, and at the same time avoiding injury to the cochlea.[22] It may come with increased angled insertion depth and larger electrodes. This design allows patients to use electric acoustic stimulation in the form of both a cochlear implant and a hearing aid in the same ear. Hybrid cochlear implantation needs a speech battery test score of 10 to 60% in the planned ear and less than 80% in the non-implanted ear.[25]

### *HOW does hybrid CI work*

The Hybrid device integrates both a hearing aid and a cochlear implant. The hearing aid component is utilized to optimize any remaining low-frequency hearing of the patient, while the cochlear implant directly stimulates the auditory nerve in the mid to high-frequency ranges, where there may be little or no residual hearing. This

device amplifies low frequencies and electronically stimulates middle and high frequencies. Known as electric-acoustic speech processing, it has proven successful in emphasizing the critical role of articulation information in consonant recognition for individuals with profound high-frequency hearing loss.

The Hybrid CI is designed primarily for patients who have relatively good low-frequency hearing but poor high-frequency hearing. Electroacoustic hearing, achieved through intracochlear implantation with both short and long electrodes, has been available as a treatment option.[26] Short electrodes provide the benefit of minimizing damage to intracochlear structures while still effectively stimulating the neural structures essential for hearing using electrical signals.[27] A 10 mm electrode with six channels in a cochlear implant significantly improves word understanding in both quiet and noisy environments. It also helps maintain stability in residual hearing following the device's initial activation. Hybrid cochlear implants combine acoustic and electric processing, further enhancing monosyllabic word scores in quiet and noisy conditions.

### *Advantages of hybrid cochlea reimplant*

The hybrid CI stimulates the impaired high-frequency regions of the cochlea while preserving low-frequency hearing, offering several advantages to recipients. The integration of acoustic and electric processing notably enhances monosyllabic word recognition scores in both quiet and noisy settings for the majority of users.[28] Preserving functional acoustic hearing with a 10 mm implant shows better outcomes compared to the Hybrid L24 (FDA Clinical Trial Hybrid L24, 2013) and the results achieved with the 20 mm or 24 mm placement of the Nucleus 422CI.[29]

A significant finding indicates that maintaining functional hearing, even with moderate to severe hearing loss, leads to substantial improvements in speech perception when combining acoustic and electric hearing in the hybrid ear, compared to ears with profound or nonfunctional acoustic hearing.[28] The effectiveness of acoustic plus electric processing relies on the preoperative pure tone audiometry results, especially in the low frequencies. For instance, if preoperative audiometry shows a 45-decibel threshold, a subsequent 30-decibel loss would still enable individuals to benefit from acoustic hearing.

Conversely, if the initial audiometry indicates a 60-decibel threshold, a further loss of 30 decibels would render the acoustic hearing nonfunctional, necessitating electric-only processing in that ear.[29] Bimodal hearing improves speech perception. However, losing functional acoustic hearing in the implanted ear can diminish the ability to localize sounds, which is crucial for safety. In Hybrid CI, preserving residual hearing is possible through a short-electrode and gentle surgical approach to implantation. Hybrid CI patients perform notably well with combined acoustic and electric stimulation compared to those with long-electrode implants, particularly in quiet environments. They often demonstrate superior performance in background noise and excel in tasks requiring detailed spectral information, such as melody and musical instrument recognition.

### *Hybrid CI and music perception*

Individuals with Hybrid CI are able to recognize familiar musical melodies and identify musical instruments comparably to normal-hearing listeners and often better than subjects with long-electrode implants.[31] In terms of recognizing melodies with lyrics, individuals with Hybrid CI show no significant difference in scores compared to the normal hearing group. However, in tasks involving melodies without lyrics, the normal hearing group performs the best, followed by the hybrid group, and then the long-electrode group performs the worst.[31] It is believed that the ability to recognize melodies without lyrics is aided by the retention of low-frequency pitch information, which is typically not transmitted through conventional signal processing methods. This preserved low-frequency residual hearing significantly contributes to the capability of individuals with hybrid CI to recognize melodies and identify musical instruments.

### *RISKS or drawbacks of hybrid CI*

The biggest concern with a hybrid CI is the risk of losing the remaining low-frequency hearing.[23] The patients of hybrid CI who lose the residual hearing still perform better with the implant than they use the hearing aids before surgery.[32] Although hybrid CI has gained widespread use in Europe, the device is still undergoing multicentric clinical trials. Potential complications associated with hybrid CI include permanent hearing loss in the implanted ear, facial nerve injury, device failure, intraoperative and postoperative bleeding, tinnitus, infections at the surgical site or flap, meningitis, otitis media, and vertigo. These risks highlight the importance of careful patient selection, surgical expertise, and post-operative management in minimizing adverse outcomes.[32,33] The primary complication of concern is the potential development of meningitis, which can result from the use of the electrode array and the extension of infection from the middle ear cleft post-operatively. Therefore, it is recommended that patients undergo routine vaccination against pneumococcal meningitis before undergoing cochlear implantation to mitigate these risks.[34]

## CONCLUSION

A hybrid CI is designed for those patients who have some residual low frequency hearing but still struggle to listen in social settings due to high frequency hearing loss. The integration of acoustic and electric speech processing offers substantial benefits for individuals with residual low-frequency hearing loss. Hybrid CI can lead to

significant improvements in speech understanding. However, predicting success with a hybrid CI, even when residual hearing is preserved and aidable, lacks definitive factors, similar to conventional CI outcomes. Results can vary widely, highlighting the need for further research to identify the factors contributing to this variability.

*Funding: No funding sources*
*Conflict of interest: None declared*
*Ethical approval: Not required*

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**Cite this article as:** Swain SK. Hybrid cochlear implant:a scoping review. Int J Otorhinolaryngol Head Neck Surg 2025;11:95-100.