Chapter 11

Paediatric Amplification: Implantable Hearing Devices

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'Every day, with appropriate technology and intervention, children with hearing loss are learning to listen, talk and thrive'

~Hearing First, 2025

Introduction

Advances in implantable hearing solutions, including bone conduction implants (BCIs), cochlear implants (CIs), auditory brainstem implants (ABIs) and middle ear implants (MEIs), offer effective options for managing HL, especially when traditional air-conduction hearing aids (HA) are insufficient. Implantable hearing devices provide direct stimulation to different parts of the auditory system, allowing better sound perception when HAs fail to meet the child's needs (McCreery 2014). Throughout this chapter, we reference several devices currently offered by various companies, including links to their respective websites. Please note that as technology rapidly evolves, device names and specifications may change, and some links may become outdated or may no longer be functional.

When choosing amplification, the following factors need to be considered (Bagatto and Scollie 2023):

- Age and timing: Early intervention is critical to maximise spoken language and auditory outcomes. Children with congenital HL should be treated as soon as possible — the sooner the intervention, the better the potential hearing outcome.
- Family-centred care: Involvement of parents and caregivers is essential for success (Chapter 15).
- Site of lesion and type of HL: For different types and sites of HL, different implantable solutions are available. In choosing an implantable hearing device, it is important to understand that the choice of the appropriate device depends on the site of the lesion.
- Long-term sustainability and upkeep of chosen hearing technology: Especially within resource-constrained environments, it is important to consider whether the family has access to the necessary resources to maintain the device and provide the necessary support. Implantable hearing devices are a costly intervention, and so is their maintenance, as well as auditory rehabilitation (Chapter 12) and other services like occupational therapy and educational support (Chapter 13).

Bone Conduction Hearing Devices (BCHDs)

BCHDs are used for children with conductive (CHL) or mixed hearing loss (MHL) or with limited usable hearing unilaterally (LUHU). BHDs transmit sound vibrations through the skull bone directly to the inner ear, bypassing the sound conductive mechanism of the outer and middle ear, and transmitting sound directly to the cochlea by creating vibrations in the bone of the skull (Reinfeldt et al. 2015). The device typically consists of an internally implanted component and an external sound processor that captures and converts sound into vibrations that are transmitted to the skull.

Category 1: Non-implantable BCHDs

The first category is non-implantable BCHDs, which can include traditional body-worn devices, soft band BCHDs and adhesive BCHDs (Table 11.1). Figure 11.1 shows an example of a soft band BCHD.



Figure 11.1: Child with a BCHD on a soft band. Source: Alder Hey Children's NHS Foundation Trust (2026)

Table 11.1: Non-implantable BCHD options

Non-implantable BCHD options	Description	Example
Traditional BCHDs	Body-worn devices or bone-conduction spectacles	Body-worn devices/ spectacles: *www.heartronix.co.za*
Soft-band BCHDs	Devices mounted on a soft headband that transmit vibrations through the skin	Cochlear BCHDs on a soft band/SoundArc: *www.cochlear.com/us/en/professionals/products-and-candidacy/baha-start*; Oticon soft band: *www.oticonmedical.com/solutions/bone-conduction/softband*; MED-EL soft band: ADHEAR can be worn on a soft band.
Adhesive BCHDs	Adhesive devices that stick to the skin and transmit sound vibrations	ADHEAR™ by MED-EL: *www.medel.pro/products/adhear*

Category 2: Implantable BCHD options

The second category is implantable BCHDs. There are currently two main types of BCHD implants available on the market: active BCHDs and passive BCHDs (Table 11.2). Passive BCHDs are further categorised into transcutaneous and percutaneous devices.

Table 11.2: Implantable BCHD options

Category	Description	Examples
Active BCHDs	The implanted device actively vibrates within the bone, stimulated by the external sound processor, which is held in place by a magnet.	MED-EL Bonebridge: *www.medel.com/hearing-solutions/bonebridge* Cochlear Osia: *www.cochlear.com/us/en/home/products-and-accessories/cochlear-osia-system* Oticon Sentio: *www.sentio.oticonmedical.com*
Passive BCHDs: Percutaneous	A titanium abutment is implanted into the skull and protrudes through the skin; the sound processor clips onto the abutment.	Cochlear Baha System: *www.cochlear.com/us/en/home/products-and-accessories/cochlear-baha-system/baha-implant* Oticon Ponto: *www.oticonmedical.com/solutions/bone-conduction/ponto-system*

Category	Description	Examples
Passive BCHDs: Transcutaneous	This is a fully implanted disc under the skin; the external sound processor is held in place by a magnet over the skin.	Cochlear Attract: *www.cochlear.com/au/en/home/products-and-accessories/cochlear-baha-system/baha-implant*

Active BCHDs

An active BCHD (Figure 11.2) is an implantable hearing solution designed to directly stimulate the bone, bypassing the outer and middle ear to deliver sound to the inner ear (Reinfeldt et al. 2015). Unlike passive systems, active BCHDs contain an implanted transducer that vibrates within the bone itself, improving sound quality and reducing energy loss. All active bone conduction devices are transcutaneous because they incorporate a built-in actuator that actively generates vibrations (Reinfeldt et al. 2015). They are designed to provide a more robust sound output by converting electrical signals into mechanical vibrations directly stimulating the bone. Many manufacturers offer this type of device (Table 11.3). The introduction of active transcutaneous devices (BONEBRIDGE™ and Osia™) offers electronic signal transmission to optimise audiologic gain.

Table 11.3: Active BCHDs

Device	Manufacturer	Implant technology	*Key Features*	*Coupling*
Bonebridge™	MED-EL	Bone Conduction Floating Mass Transducer (BC FMT)	The implanted transducer vibrates the bone directly; excellent sound transmission; cosmetically appealing.	External sound processor held by a magnet
Osia System™	Cochlear	Piezoelectric Actuator	Offers a powerful and stable performance; designed for conductive/ mixed HL; fully implanted transducer.	External sound processor held by a magnet
Sentio™	Oticon Medical	Skin-friendly transcutaneous design with an implanted vibrator	Ensures effective bone conduction while preserving skin integrity; discreet and reliable.	External sound processor held by a magnet.



Figure 11.2: Illustration of an active BCHD. Source: Hearing Loss Association of America (2026)

Passive BCHDs

In passive BCHDs, a portion of the implant embedded in the skull 'passively' receives the vibrations from an externally worn vibrating device – the sound processor (Reinfeldt et al. 2015). Table 11.4 details the key differences between transcutaneous and percutaneous passive BCHDs.

a) Transcutaneous BCHDs

These devices have an external sound processor placed against the skin, typically held in place by a magnetic or adhesive mechanism, with no part of the device passing through the skin. Sound vibrations are transferred through the skin to the underlying bone, stimulating the cochlea. The implanted portion of the device is entirely buried under the skin, with nothing penetrating through the skin to connect to the exterior component (Reinfeldt et al. 2015). Active devices are all transcutaneous, while some passive devices are transcutaneous with the external and internal components held in communication with magnets. In passive devices, some sound attenuation occurs because of the intervening skin. Figure 11.3a below illustrates a transcutaneous and percutaneous passive BCHD.

Figure 11.3: (a)

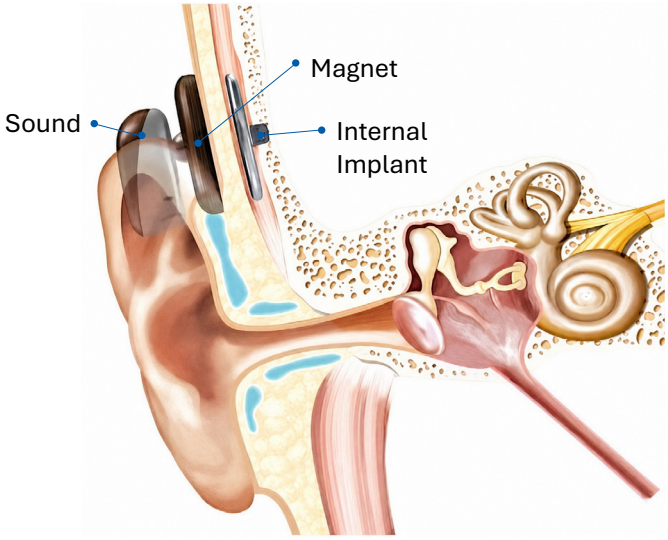


Figure 11.3: (b)

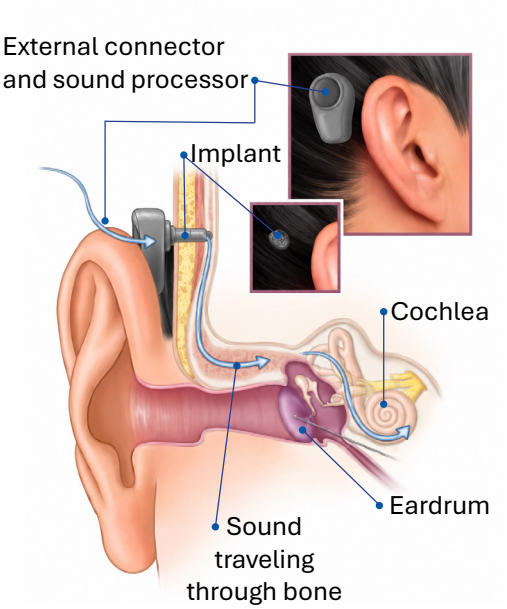


Figure 11.3: (a) Transcutaneous passive BCHD. Source: Questions and Answers in MRI (2026).
Figure 11.3: (b) Percutaneous passive BCHD. Source: Cleveland Clinic (2023).

b) Percutaneous BCHDs

A small titanium implant (an 'abutment') is surgically placed in the skull bone. The external processor connects/clips onto the abutment where it protrudes through the skin. This avoids sound attenuation, but the abutment traversing the skin may give rise to infections and requires good care. Sound vibrations from the external processor are transmitted directly through the abutment to the bone, providing efficient sound conduction (Reinfeldt et al. 2015). Figure 11.3b illustrates a percutaneous passive BCHD.

Table 11.4: Summary of key differences between transcutaneous and percutaneous BCHDs

Feature	Transcutaneous devices	Percutaneous devices
Skin Penetration	External processor placed on the skin	Through an abutment
Sound Transmission	Through the skin to the bone	Directly to the bone
Active or Passive	Primarily active	Primarily passive
Risk of Complications	Lower risk due to no skin penetration	Higher risk of skin infections
Maintenance	Generally easier maintenance	Requires care of the abutment area

Indications for BCHDs

Children with CHL can be treated through surgery that addresses the cause of the CHL (Chapter 9). Where the CHL cannot be corrected with reconstructive middle ear surgery, or the outcome of middle ear surgery is poor or unsatisfactory, conventional HAs or BCHDs can be a solution to provide a child with access to sound. BCHDs are considered in the following cases:

- Congenital microtia and/or atresia (absent or narrow ear canal).
- Ear canal stenosis.
- Syndromes including Down, Treacher-Collins and Goldenhar.
- Chronic or recurrent otorrhoea with chronically draining ears preventing use of traditional HAs.
- Chronic suppurative otitis media not (yet) resolved by surgery.
- Mastoid cavity problems where feedback and dizziness occur using HAs.
- Severe skin conditions preventing the use of traditional HAs.
- LUHU: Profound sensorineural hearing loss (SNHL) and/or poor word recognition in one ear, with normal or near-normal hearing in the other ear.

Additional considerations

- Age of the child: Younger children may benefit from non-surgical options (for example, soft band) until they are old enough for surgery.
- Children with Down Syndrome who often have fluctuating CHL and very narrow ear canals must be considered for BCHDs on a soft band.
- Medical contraindications to surgery: In some cases, BCHDs are the best alternative to traditional air conduction aids, especially when occluding the ear with a conventional air conduction HA might exacerbate the occurrence of middle ear infections.

Contraindications to BCHDs

These include:

- Scalp dermatologic problems due to the propensity for skin infection or skin breakdown related to the device.
- Patients with bony anatomy not amenable to osseointegration.

- The need for ongoing MRI evaluation, especially of the ipsilateral temporal lobe.

Assessment candidacy

Comprehensive audiological and medical evaluations are required to determine BCHD candidacy. The assessment process typically involves:

a) Audiological assessment (Chapter 5):

- Pure-tone audiometry to measure hearing thresholds.
- Masked and unmasked bone conduction testing to confirm conductive or mixed HL.
- Speech recognition testing in quiet and noise to evaluate speech perception.
- Bone conduction ABR testing to confirm CHL in young children (Chapter 6).

b) Medical assessment:

- Otoscopic examination will be needed to evaluate outer and middle ear status (Chapter 5 and 9).
- Imaging (for example, CT or MRI) may be necessary to assess anatomical structures. In a passive percutaneous BCHDs routine, a preoperative CT scan is not essential. It might be helpful in children, patients with congenital aural atresia or in patients with an irradiated bone to determine the ideal location for implant placement. In contrast, in active BCHDs, a preoperative CT scan is obtained routinely to determine if the patient's anatomy is adequate for placement of the device and for suitable device positioning.
- Consultation with an ENT specialist is necessary to determine if surgical implantation is appropriate.

As sound vibrations can easily travel through the skull, the BCHD will stimulate the cochlea (inner ear) with the best hearing, whether it is on the same side as the device or the opposite side (Samra 2018). This means that when fitting a BCHD, it should be based on the masked bone-conduction hearing levels or the hearing levels measured with the device in place (in situ thresholds). Each manufacturer of BCHDs has their own bone conduction fitting range. It is thus important to consult the different fitting ranges to select the ideal implant for the patient's HL. The specification sheets can be obtained directly from the manufacturer. Figure 11.4 provides the maximum bone conduction thresholds that can be fitted with an implantable bone conduction device (65 dB HL).

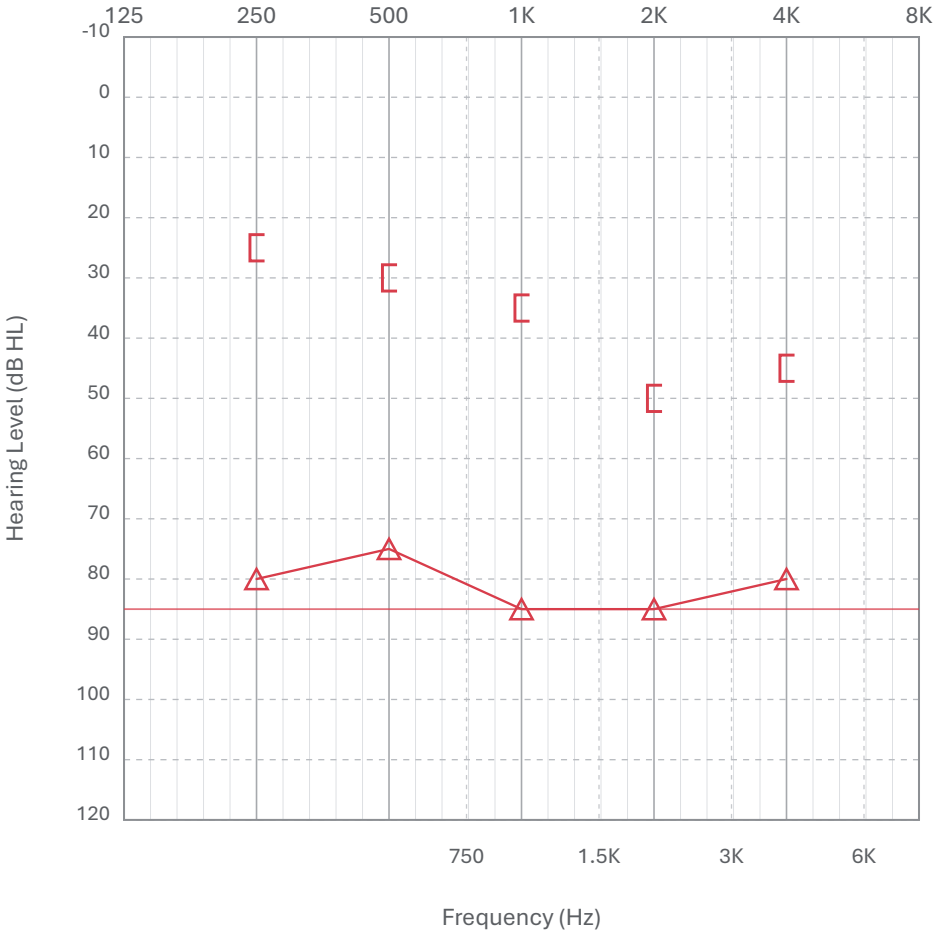


Figure 11.4: Maximum bone conduction thresholds considered for BCI selection for the right ear ([= masked bone conduction thresholds; Δ = masked air conduction thresholds)

Trial with BCHD

The child's family should be informed about the different types of BCDHs available, and the selected device should be explained in terms of its function and effectiveness in addressing the child's HL (Cleveland Clinic 2023). The longevity, reliability, upgrade options and MRI compatibility should be included in the discussion. The advantages and disadvantages of the different systems available on the market should also be included. Written information about the devices should be made available to the family.

A trial with a bone conduction soft band or sound processor allows the clinician to assess the benefits and the family to assess the suitability of a BCHD. Both aided pure tone testing and speech perception testing should be conducted to determine the benefit. It is important when choosing a device to consult the different bone conduction fitting ranges of devices available on the market. It should also be determined whether the child needs a BCHD on a soft band or if surgical implantation must be done. Children under the age of five years may not qualify for bone conduction implantation (Roman et al. 2011). These children should be fitted with a device on a soft band until they are old enough to receive an implant. Children with temporary CHL that will improve in the future either with surgery or medical management should be fitted with a BCHD on a soft band.

Surgical technique

The principle of the surgery is the suitable and secure placement of the implanted portion in the skull/mastoid bone where it is fixed and can achieve integration into the bone ('osseo-integration') (Wazen et al. 2007). The surgery is carried out under general anaesthetic and takes between forty minutes and one hour. The standard surgical approach consists of a postauricular incision with placement of the implanted component in or around the mastoid bone. The location and size of the incision will vary based on the device chosen, anatomic structures, planned implantation location and considerations of external ear reconstruction.

The ENT surgeon considers multiple factors before deciding on a surgery plan. In children with microtia who are planning or may be candidates for otoplasty in the future, the abutment should be positioned carefully in co-operation with the otoplasty surgeons to allow for microtia repair without compromising blood supply (McKay-Davies et al. 2024). Failure of osseointegration is more likely to occur when bone quality is immature or abnormal. Paediatric bone has lower mineral content and is softer and thinner than mature adult bone. To compensate for these factors, younger children may need to undergo two-stage surgery. Some devices are also not suitable for young children because thicker bone density is required.

Depending on the device chosen and surgeon preferences, the skin flap over the device may be thinned. The bony area immediately surrounding the implant location will need to be flat or drilled until it is flat to facilitate the firm placement of a passive transcutaneous device

(McKay-Davies et al. 2024). Active transcutaneous devices might require the drilling of a recess, depending on the particular device.

Post-operative care and complications

Patients are monitored postoperatively for wound care and soft tissue healing. Intraoperative complications of bone conduction implant (BCI) surgery are rare but can include damage to nearby structures such as the dura or sigmoid sinus, with associated risks of cerebrospinal fluid (CSF) leak or bleeding, respectively (McKay-Davies et al. 2024). If these complications occur, CSF leaks are typically managed with careful intraoperative repair and postoperative bed rest, whereas significant bleeding requires immediate hemostasis and, in rare cases, surgical revision.

Postoperative complications are most commonly soft tissue-related and include local skin numbness or pain, infection, excess granulation tissue, and hypertrophic scarring. Management strategies include:

- Local skin numbness or pain: Usually resolves spontaneously; symptomatic management may involve topical analgesics or short-term oral pain medication.
- Infection: Mild infections are treated with topical or systemic antibiotics; more severe infections may require debridement or, rarely, temporary removal of the implant.
- Excess granulation tissue: This can be treated with topical corticosteroids, silver nitrate cauterisation or surgical removal.
- Excess scarring: Excess scarring is managed conservatively or with minor surgical revision if it interferes with device function or skin integrity.

Late complications such as skin breakdown over the implant or chronic infection may necessitate more extensive intervention, including revision surgery or, in severe cases, explantation of the device.

Bone-related complications, though infrequent, include failure of osseointegration, technical fractures or issues related to trauma, chronic soft tissue infection or inadequate bony recipient sites. Management may involve surgical revision, removal and re-implantation,

depending on the severity and underlying cause. Osteomyelitis is exceedingly rare and if it occurs, it requires systemic antibiotic therapy and surgical debridement.

Activation, programming and (Re)habilitation post-surgery

a) Activation and initial fitting:

- Once the BCHD is surgically implanted or the soft band is fitted, the device is activated.
- During the activation, the clinician adjusts the sound processor's settings to meet the child's hearing needs.
- Aided sound field warble pure tone thresholds are obtained with the BCHD.
- Speech perception testing is carried out with the device, and if possible, speech perception in noise testing.

b) Programming:

- The device must be programmed to the child's audiogram, ensuring appropriate amplification across different frequencies.
- Some companies' BCHDs offer in-situ measurement or direct hearing thresholds of bone conduction thresholds. This means that when the processor is placed on the implant or soft band, the clinician can perform bone conduction threshold testing through the processor (Samra 2018). This is valuable for ensuring that accurate bone conduction thresholds are used to set the gain settings of the device across the frequency spectrum.
- Fine-tuning may be required in subsequent visits based on feedback from the child and caregivers.

c) (Re)habilitation:

- Following activation, auditory rehabilitation is crucial to maximise the benefits of the BCHD.
- Speech-language therapy and auditory training help children develop listening and communication skills.

- Ongoing audiological monitoring ensures that the device continues to meet the child's hearing needs.

Outcomes

The success of BCHDs in paediatric patients largely depends on early intervention, consistent device use and access to auditory rehabilitation services. Some reported outcomes include:

- Minimal surgical complications: BCHD surgery has demonstrated low rates of surgical complications, with successful healing in most patients and minimal postoperative issues.
- Improved speech perception in quiet and noise: BCHDs significantly improve speech understanding, especially in noisy environments. This is particularly beneficial for individuals with conductive or mixed HL and LUHU, helping them perform better in challenging listening situations.
- Improved sound localisation/spatial awareness: Children with CHL will experience improved sound localisation, although the accuracy will be lower than children with normal hearing. In children with LUHU, it will not be true sound localisation but rather improved spatial awareness.
- Improved hearing thresholds: BCHDs help close the air-bone gap, particularly in conductive and mixed HL, improving overall hearing thresholds.
- Better quality of life: Users of BCHDs report significant improvements in quality of life, citing enhanced social interactions, communication abilities and reduced listening effort, all of which are particularly important for children in educational settings.
- Effective treatment for LUHU: For individuals with LUHU, BCHDs provide significant auditory benefit by transmitting sound from the deaf side to the better-hearing ear, improving spatial awareness and overall hearing ability.

Cochlear Implants (CIs)

CIs are a well-established and effective treatment for children with severe to profound SNHL. By providing a child with access to sound, a CI enables the potential for the acquisition of spoken language.

CI team

A CI programme is made up of a dedicated, specialist, multidisciplinary team that functions within the context of a CI Programme (Dettman et al. 2016). The team consists of the following core hearing healthcare practitioners (HHPs): audiologists, otologists, radiologists and specialists in rehabilitation (speech and language therapists and/or auditory verbal therapists) (Warner-Czyz et al. 2022). At a minimum it should consist of an ENT surgeon with specialist experience in Otology and training in CI surgery, an audiologist and a speech-language therapist. Audiologists in the team should have received specialist training in CI MAPping. The speech-language therapist should be trained to work with children who have HL and are learning spoken language through technology. The team should have specialist knowledge and skills to work in the field of CI to manage, assess and work with children and adults with a range of complex needs, additional to their HL. The specialist CI team must be able to service all future needs of the child. CI involves a lifelong commitment by the family and the CI team. The teams should develop partnerships with local services where appropriate (Warner-Czyz et al. 2022). In South Africa there are thirteen CI programmes, details of which can be found here: https://www.sacig.org.za/patients-corner/implant-programs/. CI team members should belong to their local CI organisation that should have a set of guidelines to ensure the highest realistically possible standards of care for patients.

CI functioning

The principle of the CI system is that it bypasses the dysfunctional hair cells in the cochlea to directly stimulate the cochlear nerve with electrical current (Figure 11.5) (Carlyon and Goehring 2021). The auditory nerve, which is still functional, then takes these signals to the brain where they are interpreted as sounds and speech.

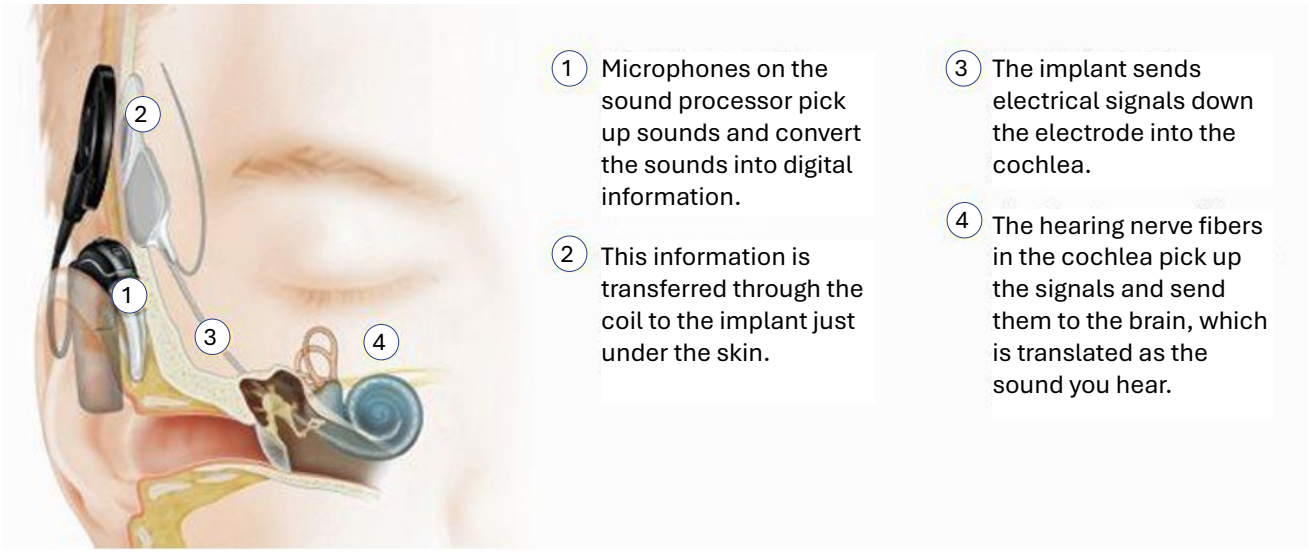


Figure 11.5: The components and functions of a CI. Source: ENT & Audiology Associates (2026).

A CI device consists of two primary components: an externally worn sound processor and an implanted receiver-stimulator and electrode array (Carlyon and Goehring 2021). The sound processor consists of a microphone and transmitter. The microphones on the processor pick up (acoustic) sounds from outside the ear. The speech processor converts the sounds into digital signals which it sends through a coil to the internal receiver that has been placed under the skin behind the ear. The signal is sent through the skin via a radio frequency signal. The receiver-stimulator sends the electrical signals to the multi-channel electrode array that has been inserted into the cochlea. The electrical signals activate the spiral ganglion cells to stimulate the cochlear nerve, which sends the signals to the brain. The brain interprets the electrical signals as sounds.

The coils of the external sound processor and internal receiver are held in apposition to send and receive the electrical signal by an external and internal magnet respectively. The sound processor is worn either behind the ear (Figure 11.6) or off the ear. The behind-the-ear processor includes a cable that connects the processor to the external coil and magnet directly over the magnet of the internal coil. The off-the-ear processor contains the magnet, the processor and the coil and is therefore placed directly over the internal coil.

There are three FDA (USA Conformity) and CE (European Conformity) approved manufacturers of CIs:

- Cochlear: www.cochlear.com
- Medel: www.medel.com
- Advanced bionics: www.advancedbionics.com



Figure 11.6: Behind-the-ear speech processor

Referrals for CI evaluation

Referral for CI by the HHP is based on both physiological and behavioural audiological information, within the context of access to sound with optimally fitted HA technology for each ear (Bagatto and Scollie 2023). The foundation of optimal outcomes is primarily based on early and appropriate intervention during the period of cortical plasticity (Ching et al. 2018). Should the family desire a spoken language outcome for their child, the recommendation is made for evaluation for candidacy and the child should be referred to a local (or accessible) CI team.

When making a CI referral, consideration should be given to each ear as well as the degree and configuration of the HL to determine whether a child is receiving appropriate access to sound through technology. Sixty-six per cent of speech sounds are heard above 1 kHz. To hear the softer sounds of speech (for example, /s/, /th/, /k/, /p/), which is necessary for acquiring spoken language, HAs should provide adequate access to sounds across the frequency spectrum (Figure 11.7).

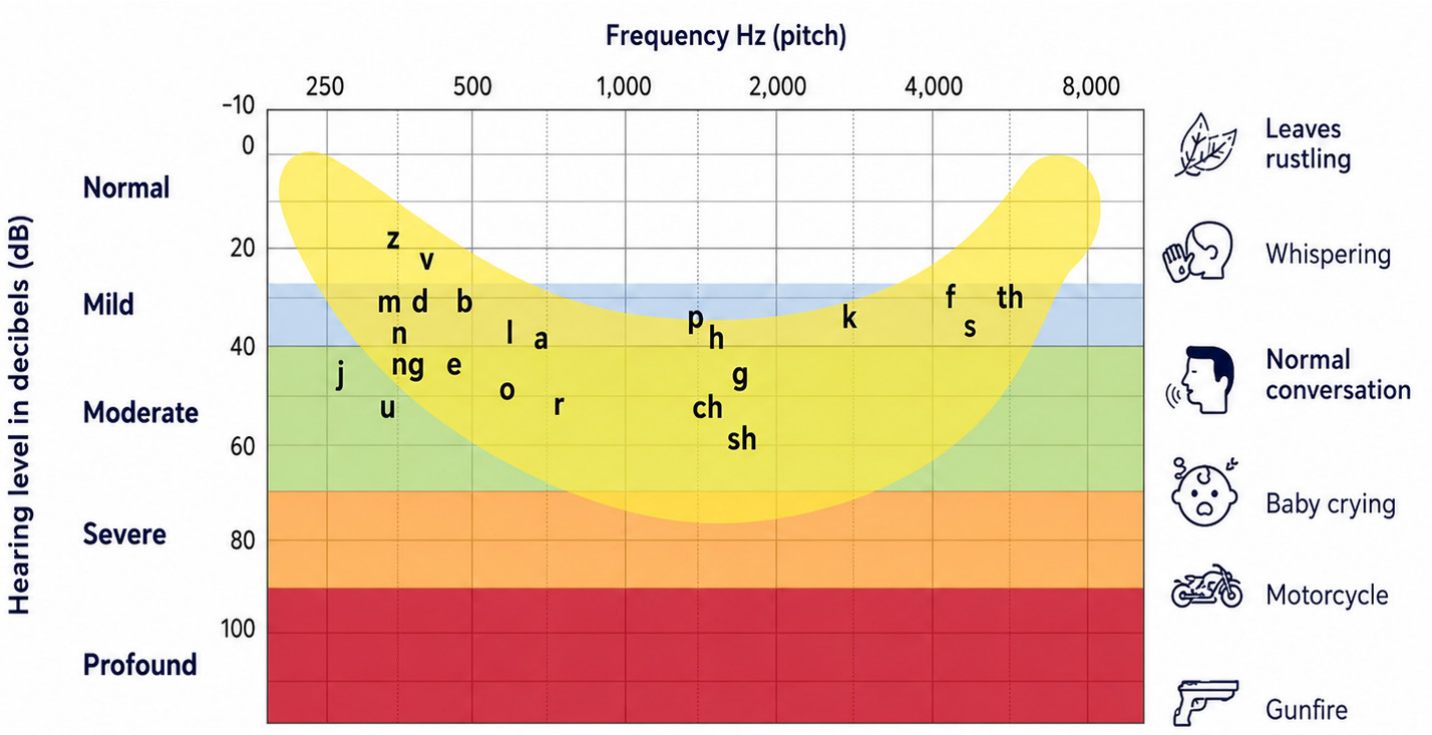


Figure 11.7: The 'speech banana' shows where speech sounds occur across the hearing range for pitch and loudness

The Speech Intelligibility Index (SII) is a standardised measure designed to evaluate speech audibility across different frequencies during the HA verification process (Bagatto and Scollie 2023). Information about the aided audibility of sounds for the child can be obtained from an aided audiogram or through the SII obtained from the HA verification. McCreery (2014) recommends that children who have an aided SII of less than 0.65 should be considered for CI regardless of (unaided) pure tone thresholds. If aided audibility is 0.65 or less for average conversation in quiet, it is likely to be much lower across realistic listening situations where there is noise and reverberation, and/or the talker is more than one meter away. Even sloping configurations with three Frequency Pure Tone Threshold (FPTA) as low as 43 dB HL can result in an aided SII of less than 0.65 (Leal, Marriage and Vickers 2016). About 90% of what children learn is through incidental hearing and learning (Madell, 2016). This means they need to be able to access soft speech easily through their technology.

Recommendations for evaluation for CI (Figure 11.8) should maintain flexibility and consider a child's skill progression (month-by-month progress in speech, language and auditory development) and quality of life with appropriately fitted HAs and under the management of an appropriately trained speech-language therapist. Children with HL should be carefully monitored on at least an annual basis to ensure their hearing levels and HA benefit remain stable. Should hearing deteriorate in either ear, referral for CI evaluation should be guided by their SII, aided thresholds, speech perception benefit or functional performance in that ear. This should ensure configuration of appropriate technology for each ear. Assessing functional outcomes based on parent and clinician feedback on a child's auditory awareness, auditory responsiveness and progress in acquiring language skills should become fundamental considerations for implant candidacy. Children with confirmed Auditory Neuropathy Spectrum Disorder (ANSD) should be considered as potential candidates for CI due to their disproportionately poor speech perception in relation to their audiogram.

Key Considerations for CI Candidacy

HHPs should refer paediatric patients to a CI team for evaluation for CI if they meet any of the following criteria (in either ear):

- Appropriately selected (aided) word recognition scores ≤ 50% correct
- Unaided pure-tone thresholds ≥ 60 dB HL

- Poor functional auditory performance, limited progress in language or auditory development or poor quality of life.

Parental and clinician information on functional outcomes should guide the primary managing audiologist regarding timely referral for cochlear implant evaluation. Consideration of the family's lifestyle, goals and expectations should be considered as part of the holistic care of the child. Importantly, in cases of deafness resulting from meningitis or an inflammatory condition of the cochlea where there is radiological evidence of ossification, CI should be considered an emergency and (bilateral) implantation should be recommended (Birman, Elliot and Gibson 2012). This may need to be prior to the age of six months.

Process of implantation

Once candidacy is confirmed by the team, the steps towards implantation and longer-term management are determined (Figure 11.8).

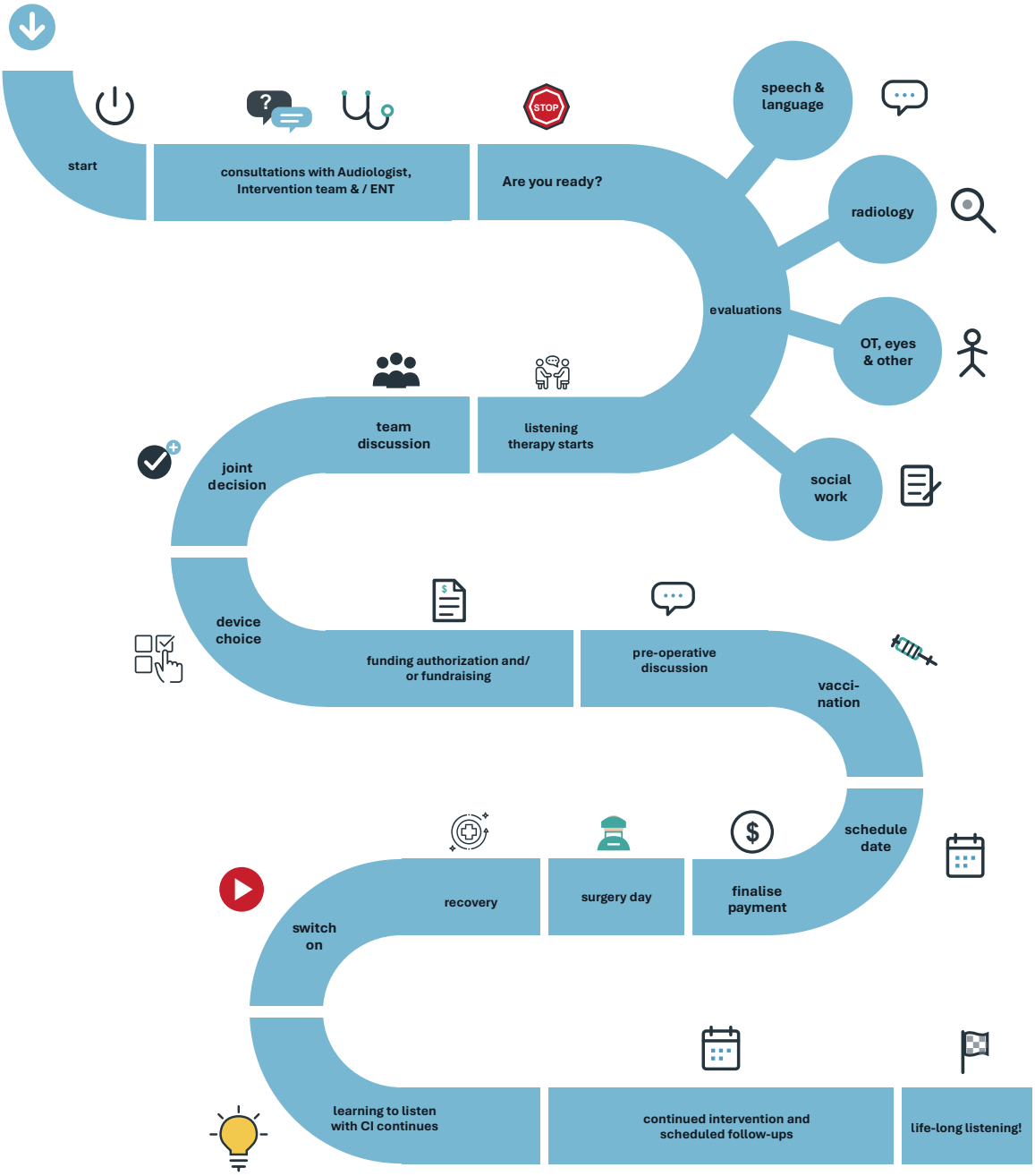


Figure 11.8: Roadmap for parents outlining steps in assessment and activation period of CI. Source: Surida Booysen

Assessment for candidacy

Assessing candidacy is an important part of the CI process. Considerations are given to the following factors to determine appropriate candidacy:

- Audiological criteria.
- Radiological criteria: The anatomy of the cochlea and auditory nerve should be suitable for insertion of the electrode array.
- Developmental factors:For example, in the case of other associated conditions, such as developmental delay, visual impairment, sensory processing disorders.
- Age: Implantation should ideally take place within the first three years of life for children with congenital bilateral severe to profound SNHL).
- Family participation.
- Financial factors: In countries with limited resources for long-term maintenance costs, consideration should be given to the ability of the family to maintain the sound processor and components, as well as to access appropriate educational support and facilities.

CI surgical implantation

After consideration and confirmation of suitable candidacy by the CI team, surgery should be scheduled. Surgery is done by the CI team's ENT surgeon and usually lasts two to three hours. Pneumococcal vaccination is given at least two weeks prior to the operation. Absolute sterility is essential to avoid the risk of infection. Implantation cannot be done on an ear that is infected or that holds risk of future infection. In such a case, preliminary subtotal petrosectomy and blind-sac closure of the ear must be considered (Hellingman and Dunnebier 2009). Infection risk following CI surgery is reduced by the use of an antibiotic that crosses the blood-brain barrier.

CI surgery comprises the following steps:

- Creation of a pocket/recess/bed for the body of the receiver-stimulator under the scalp (the periosteum) posterior-superior to the ear
- Creation of a pathway for the electrode array from this bed to the cochlea via:
- A cortical mastoidectomy

- A posterior tympanotomy exposing the round window
- Opening the cochlea
- Insertion of the electrode into the cochlea

The description provided is of the most commonly used, standard approach. Other techniques exist and anatomical variations might call for different approaches. The creation of the bed for the implant body has been much simplified in recent times. Historically a large incision was used, a deep bed drilled and ties used to hold the implant down. Currently, partly because the implants are far slimmer, a smaller incision is adequate to elevate a limited subperiosteal pocket which holds the implant in position (Carlyon and Goehring 2021). Surgeons may elect to drill a limited wedge-shaped recess at the anterior edge of the implant to prevent it from migrating anteriorly. In this case a small tunnel is made forward of this bed for the electrode array.

The surgeon must then provide a pathway for the delicate electrode array towards the cochlea. Generally, this is done by drilling an opening through the mastoid air cells located posterior-superior to the ear canal, down to the mastoid antrum – the largest of these air cells (this procedure is called a 'cortical mastoidectomy') (McKay-Davies et al. 2024). The surgeon then exposes and identifies the lateral semicircular canal and the short process of the incus in the fossa incudis. This guides the next step – the careful drilling of a 'posterior tympanotomy'. This is a slot drilled into the posterior recess of the middle ear, deep to and behind the eardrum and the chorda tympani nerve and superficial and anterior to the facial nerve. Through this posterior tympanotomy opening the surgeon can visualise the basal turn of the cochlea and the round window (Warner-Czyz et al. 2022; Wu et al. 2023).

The surgeon is then in a position to open the cochlea and insert the electrode array. The ideal is to create, as a-traumatically as possible, an opening for insertion of the electrode into the scala tympani. Two options exist: to drill a cochleostomy into the basal turn of the cochlea, or to insert the electrode through the round window after incising its membrane (Wu et al. 2023). As electrodes have become thinner and more delicate and implants are being performed increasingly on patients with hearing to preserve, most surgeons currently practise 'soft surgical techniques' and favour round window insertion (McKay-Davies et al. 2024).

Insertion of the electrode into the cochlea should, again, be performed as a-traumatically as possible to preserve hearing and the fine structure of the cochlea. The choice of electrode

type, use of corticosteroids both systemically and locally, very slow and even insertion and correct angle of insertion to avoid damage to the basilar membrane and transposition into the scala vestibuli are some of the principles of 'soft surgery' (McKay-Davies et al. 2024). During the surgery, the CI audiologist tests the integrity of the electrode function and response of the auditory nerve to electrical simulation via CI software after the surgeon has inserted the electrode array.

The operation is completed by sealing off the opening into the cochlea with fascia, securing the electrode in the mastoidectomy to mitigate against extrusion, and using a layered closure of the skin incision.

The device is tested for function using impedance measurements and electrically evoked neural response (eCAPS) telemetry is performed. A modified Stenver's view mobile x-ray is performed to confirm that there is no misplacement or tip fold-over of the electrode (device testing may also be used to exclude this). A firm bandage is used for a few days and the patient is seen by the surgeon within a week to identify and treat possible early complications.

Activation, programming and (re)habilitation

a) Activation and MAPping

Activation of the external sound processor occurs about two to three weeks after surgery by the audiologist on the CI team. Activation involves determining both soft and comfortably loud levels of sound through electrical stimulation, a process known as 'MAPping' (Fu and Shannon 2002). This should include both behavioural and physiological measures (Electrical Compound Action Potentials [eCAPS] or Electrical Stapedial Reflex Thresholds [eSRT]) to guide the fitting process. Within or at least by three months post-activation a hearing test should be performed in the booth to confirm MAPping levels and whether appropriate access to sound levels across the frequency spectrum is obtained. Aided thresholds should be 20-30 dB HL across the frequency spectrum (Fu and Shannon 2002).

b) Family coaching

Family coaching by the speech-language therapist is essential for the development of appropriate listening and spoken language throughout the immediate and longer-term (Chapter15). The family (caregivers) play a crucial role in this process.

c) Follow-up

After an appropriate MAP is established, the intervals when the child should be seen by the audiologist are three-monthly for the first two years, then twice a year for the next two years and annually thereafter (Wu et al. 2023). Once the child starts formal schooling, the audiologist should establish and maintain contact with the educators to ensure optimal access to sound in the classroom. This should include the use of assistive listening devices (for example, RM systems) so that the child has optimal access to sound within the adverse listening conditions of a typical classroom.

Outcomes

Ongoing, holistic care involves a range of factors, including continued accurate MAPping (programming) of the CI, verification of the programme provided, multidisciplinary rehabilitation, consistent monitoring and tracking of listening and communication skills and family compliance. Feedback and teamwork among immediate core team members as well as external role players form the fundamentals of optimising the child's outcome.

Important factors influence the outcome of CI in children:

a) Age at implantation

Early fitting of hearing devices is key to achieving better speech, language and functional performance outcomes by five years of age as shown in the LOCHI study (Ching et al. 2018). Early binaural fitting of appropriate technology reduces the negative effects of deafness on the developing auditory system and captures the remarkable neuroplasticity of early brain development. This includes implantation of the deaf ear in cases of LUHU.

Implantation prior to twenty-four months of age can promote speech understanding, and ideally even before twelve months, can support speech intelligibility and language outcomes on par with normal-hearing peers (Dettman et al. 2016). Children implanted ≤ twelve months of age have better auditory outcomes than older children (Wu et al. 2023). Children who receive a cochlear implant at nine months of age have a better opportunity for reaching typical language development milestones by the time they enter school. Early CI should therefore be considered for infants with HL. The FDA (2020) has approved cochlear implantation in infants

from nine months of age. It is recommended that congenitally deaf children should receive bilateral CIs before three years of age.

b) Special populations

Sixty per cent of children with HL have a secondary disability, most commonly an intellectual disability, a learning disability or developmental delay (Birman, Elliot and Gibson 2012). These conditions may result in slower rates of skill acquisition and greater variability in communication outcomes; however, the presence of additional disabilities should not automatically preclude cochlear implantation. When considering CI in these special populations, clinicians should carefully assess:

- Overall health and medical stability: To ensure the child can safely undergo surgery and general anesthesia
- Cognitive and developmental profile: To set realistic expectations for post-implant progress and tailor rehabilitation goals
- Motivation and support systems: Family involvement and access to rehabilitation services are critical for successful outcomes.
- Communication environment and resources: Including availability of specialised therapy, assistive technology and inclusive educational settings
- Potential for auditory skill development: Even if outcomes are slower or unpredictable, early implantation may still provide meaningful benefit in receptive and expressive communication.

By systematically evaluating these factors, clinicians can provide individualised recommendations and maximise the likelihood of functional benefit from cochlear implantation, even in children with complex needs.

c) Consistent device use

As with HAs, consistent CI use has been shown to be a vital factor contributing to better outcomes (Warner-Czyz et al. 2022).

d) Resources

Financial resources, access to care and therapeutic support should be accounted for and considered in ensuring a holistic perspective on the child's outcomes.

Auditory Brainstem Implants (ABIs)

ABIs provide direct electrical stimulation to the brainstem: the electrode paddle is placed directly on the cochlear nucleus in the brainstem. ABI would be considered for children for whom CI is not possible due to radiological evidence of an absent auditory nerve or cochlear anatomy where insertion of an electrode array would not be possible. This is usually a last resort when CIs are not viable. ABIs provide meaningful auditory sensations and environmental sound awareness, often improving quality of life for affected children (Colletti et al., 2005). Outcomes vary and the ability to achieve accurate speech perception is less predictable than in the case of CIs.

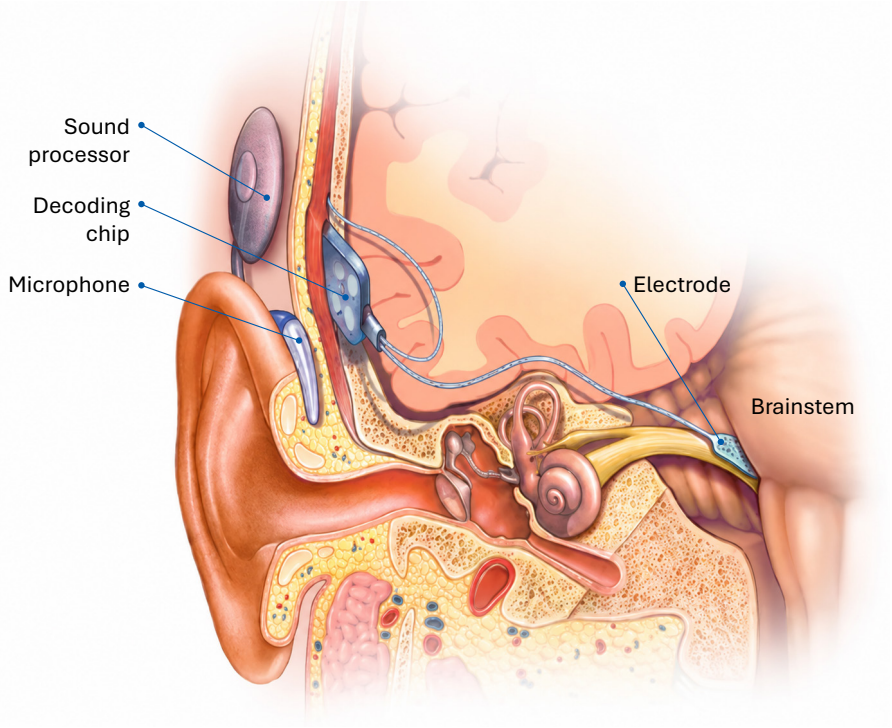


Figure 11.9: ABI components including external sound processor, cable and coil and internal receiver and electrode array. Source: Mayo Clinic (2026)

Middle Ear Implants (MEIs)

MEI are suitable for children with CHL or MHL who cannot wear traditional HAs due to chronic ear infections, ear canal issues or personal preference (Beutner and Huttenbrink 2011). These devices mechanically stimulate the ossicles (middle ear bones) to transmit sound (Figure 11.10). MEI is considered for mild to severe SNHL or MHL, chronic middle ear conditions and unilateral or bilateral HL.

This section does not cover MEI in detail, however, key factors to consider when evaluating candidacy are listed below:

- The child's age and craniofacial anatomy (suitability for implant placement)
- Middle ear status (active infection or ossicular chain abnormalities)
- Degree and type of HL
- Rehabilitation potential and family support

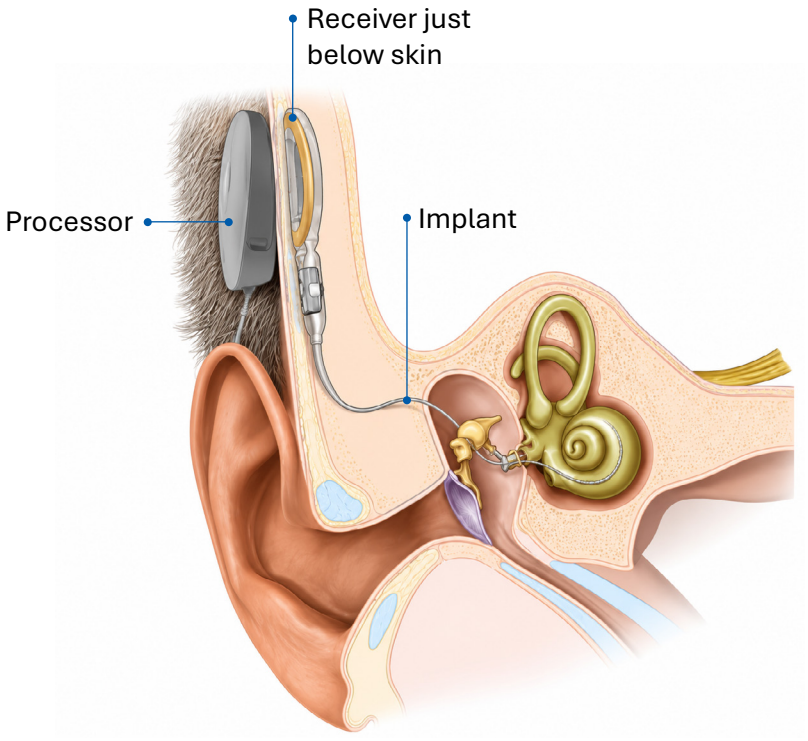


Figure 11.10: Illustration of a middle ear implant. Source: Hearing Loss Association of America (2026)

Considerations for Establishing an Auditory Implant Programme in a Low-Resourced Country

Auditory implants provide an opportunity for a child to learn spoken language, enhance educational opportunities and to ultimately be part of the hearing world. However, auditory implants in low-resourced countries come with many challenges and should be carefully considered when establishing new programmes.

Some considerations are:

- Available, appropriately trained core team members where international support is available when required
- Regular, appropriate parent coaching by suitably specialised speech-language/ Auditory-Verbal therapists within the team with the aim of developing listening and spoken language
- Sustainable programmes able to provide life-long support for auditory implant recipients
- Appropriate educational options for children once they start school-going age
- Available and sustainabley financial resources for both initial and long-term costs (including lifelong maintenance costs of the external speech processor).
- Careful device choice, considered against the critical role the company will play in lifelong support (for training, logistics and technical device support)
- Good sanitary conditions to avoid potential infections, as some auditory implants require a percutaneous connection between the implant and the processor

Considered against a backdrop of financial and infrastructure challenges in countries with limited financial, educational and professional resources, implantable hearing devices can potentially be highly cost effective for society, reducing educational and other costs (Bond et al. 2009). However, the establishment and maintenance of auditory implants in low-resourced countries should be approached in a responsible, calculated manner with careful regard to ensuring ethical, cost-effective sustainable and evidence-based standards of practice to recipients over their lifetimes.

Conclusion

Professionals working with children with HL are uniquely positioned to facilitate timely referrals for implantable hearing devices that are critical for optimal auditory brain development. This, in turn, supports the development of listening, speech and language skills — foundational abilities that significantly influence later educational achievement and employment opportunities. A team-based, multidisciplinary approach, which brings together audiologists, speech-language pathologists and ENT specialists, ensures comprehensive assessment and decision making around candidacy. With appropriate device fitting and consistent (re) habilitation, auditory implants can meaningfully enhance hearing outcomes and improve the overall quality of life for paediatric patients.

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