Chapter 8

Cochlear Implants: An Excursus into the Technologies and Clinical Applications

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Abstract

Hearing loss causes severe alterations in social function and daily communications. Cochlear device implantation (CDI) is the only beneficiary method for auditory rehabilitation in patients with severe to profound sensorineural hearing loss (SNHL). Regarding a report in 2014, over 300,000 people had received cochlear implants throughout the world since December 2012 among which about 60,000 were adults and 40,000 were children in the United States. In this chapter, we discuss the history, origin, mechanism of action, and type of cochlear implants, as well as method of surgery and complications.

Keywords: cochlear implantation, hearing loss, complications, clinical applications, surgical technique, epidemiology

1. History and introduction

Most of the patients with significant social dysfunction due to hearing loss can be treated by nonsurgical interventions. Many ways such as selective seating closer or with the better ear near important sound sources or using hearing aids can be utilized for these situations [1].

Cochlear device implantation (CDI) is the only beneficiary method for auditory rehabilitation in patients with severe to profound sensorineural hearing loss (SNHL). Regarding a report in 2014, over 300,000 people had received cochlear implants throughout the world since December 2012, among which about 60,000 were adults and 40,000 were children in the United States [2].

A 60-year-old history protects cochlear implantation technology, which has experienced multiple changes in devices and speech processing strategies. It was about 200 years ago when Alessandro Volta described the early auditory percepts induced by applying a large voltage between his own ears in 1790 [3–6]. Further investigations by Weaver and Bray were focused and resulted in this concept that it might be possible to generate electrical signals mimicking auditory input stimulus [7].

In 1957, an electrode with receiver coil was successfully implanted for a patient with resected cochlear nerve due to cholesteatoma, which was able to stimulate the apparatus for months, and shockingly, the patient had sound awareness and simple word recognition [8–10]. Following Djourno and Eyries, House started his work in the early 1960s who implanted simple wires, wires with ball electrodes, and even simple arrays into the scala tympani, which finally led into production of implantable device in 1972; this was a beginning point for clinical trials [3, 11].

At the beginning, there was a resistance from scientific community especially neurophysiologists and otologists against CI; however, the national institute of health (NIH) approved the use of electrical stimulation of auditory nerves as a rehabilitation method in 1977, while evaluating the outcome in patients with single channel implants [3, 4, 12, 13].

Multichannel CIs were produced in greater numbers due to the food and drug administration (FDA) approval because of their ability of open-set word recognition and better frequency spectrum percepts [3, 6, 14]. Another remarkable progress was occurred in 1991, while continuous interleaved sampling (CIS) strategy was introduced, which developed improved open-set word recognition in comparison with previous analogue methods, so that all currently available strategies are based on CIS [15].

2. Structure and mechanism of action

Sensory hair cells within the cochlea have the responsibility for transforming sound vibration to neural signal in healthy individuals; then, the signal continues its way to auditory cortex through cochlear nerve. Cochlear implants take the place of these cells using electrodes which stimulate the nerve fiber electrically. **Figure 1** illustrates a cochlear implant device. Common cochlear implants have two parts: external component as a hearing aid and internal component which is surgically inserted in mastoid [16].

The external part is consisted of three parts: a microphone for gathering sounds, a speech processor analyzing and encoding sound into a digital code, and a magnetic headpiece which transmits coded signals by a transcutaneous radiofrequency link to the internal part.

The internal part has a receiver stimulator which receives and decodes the data and conducts decoded signal to the electrode array. In the next step, there is a flexible silicone carrier, which has variable number of electrodes. The remaining cochlear nerve fibers are stimulated by the electrode array, which is surgically implanted in scala tympani of the cochlea.

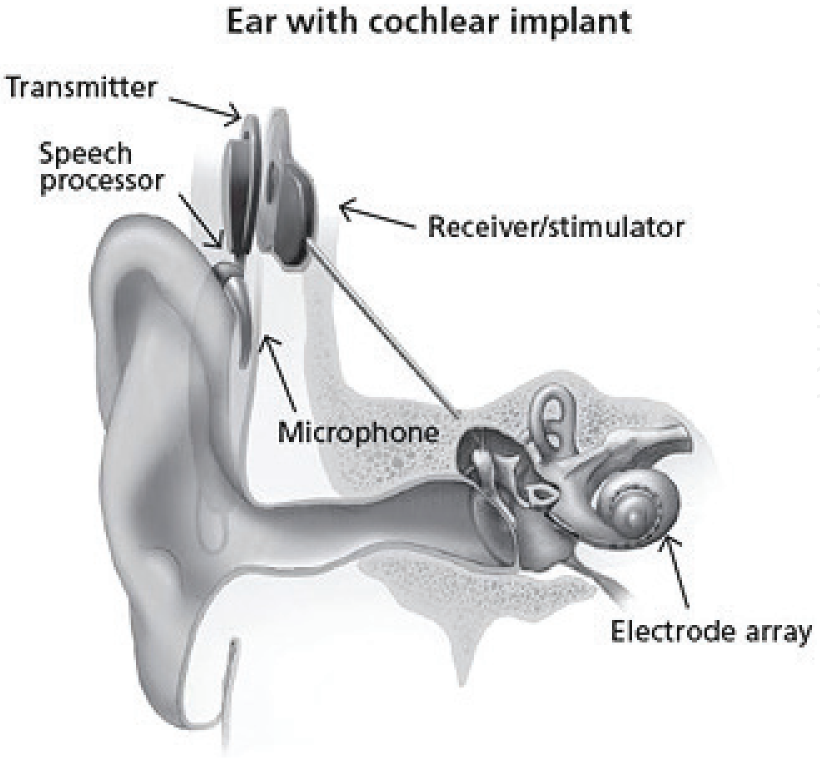

Figure 1. Different parts of cochlear implant (source: NIH/NIDCD https://www.nidcd.nih.gov/health/cochlear-implants).

3. Types of cochlear implants

3.1. Totally implantable cochlear implants

Currently available implants have an external part and need patients to wear it consisted of an external microphone, processor, and transmitting coil for empowering the electrode, which needs a dry and stable environment. Thus, development of totally implantable cochlear implants that make the whole system available underneath the skin is a new area of research. There are several challenges and requirements in the way of this progress including a tiny and sensitive microphone with ability to filter the endogenous noises, as well as a rechargeable battery with appropriate long life. There is a report of three patients with totally implantable cochlear implants [17].

3.2. Unilateral or bilateral cochlear implantation

Unilateral cochlear implantation was the only option offered at the beginning. Later, it was questioned if the patients would take more benefits from bilateral cochlear implants. Surprisingly, it was revealed that patients with bilateral cochlear implantation show better speech perception and improvement in “hearing in noise.” Also, these patients showed a significantly better sound localization in comparison with their single-side implantation condition [18, 19].

Previous studies have concluded that there is no significant difference for audiologic outcomes between unilateral and bilateral cochlear implantation regarding surgical timing, as both ears can be implanted simultaneously or sequentially. Adult studies have shown that the second ear matches the first ear performance at 6 months [20]. The story has a difference when it comes to children, as it has been concluded that patients with simultaneous bilateral cochlear implantation have improved speech recognition and language when compared to children who were implanted sequentially [21].

The cost-effectiveness of bilateral cochlear implantation has remained controversial despite evident advantages of binaural stimulation. A Canadian study has reported that cochlear implantation is cost-effective in adults compared to no implantation; however, sequential bilateral cochlear implantation has a slight superiority in comparison with unilateral implantation [22]. Other studies have approved cost effectiveness of bilateral simultaneous pediatric implantation and unilateral adult cochlear implantation, although they have not approved cost-effectiveness of bilateral sequential pediatric implantation and bilateral (sequential or simultaneous) adult implantation [23].

4. Candidacy and patient selection

Selecting the right patient is the building block of a successful cochlear implantation. Therefore, a complete medical and audiologic workup is needed for evaluating candidacy of cochlear implantation and to make sure that the patient can tolerate anesthesia and surgical process. Patients are considered to take benefit from CI when they suffer from bilateral moderate to profound sensorineural hearing loss and when hearing aids cannot help them [24]. A combination of objective and subjective hearing tests is conducted to accurately identify the degree of hearing loss within audiometric frequencies. Currently available guidelines mention that children up to 2 years of age should have a bilateral profound sensorineural hearing loss, which is indicated by a pure tone audiometry (PTA) more than 90 dBHL for 500, 1000, and 2000 Hz frequencies, while patients older than 2 years of age should have bilateral sever to profound SNHL indicated by PTA more than 75 dBHL for 500, 1000, and 2000 Hz frequencies [25, 26]. Preoperative speech and language evaluation has the same importance for decision making regarding rehabilitation strategies and programs, as well as appropriateness of auditory performance, speech production, and mode of communication. Hearing loss is categorized to prelingual, postlingual, and perilingual types based on the time of onset. In prelingually deaf patients, hearing impairment occurs before gaining speaking skills, which is usually before 2 years of age, while it occurs after gaining complete speaking skills in postlingual patients which is usually after age of 5 years. In perilingual patients, hearing impairment occurs when some speaking skills are gained but are not completed usually between 2 and 5 years of age [16].

In addition, preoperative imaging and auditory testing are needed. Imaging modalities such as computed tomography (CT) scan, for assessing temporal bone, and magnetic resonance imaging (MRI), for evaluating brain anatomy and ruling out abnormalities of cochlear nerve, are conducted [15]. After scheduling patient for surgery, pneumococcal vaccines are administered according to FDA guidelines.

Current contraindications for cochlear implantation are two absolute and relative categories. Absence of cochlear development, deafness due to lesions of the central auditory pathway, and massive cochlear ossification that prevents electrode insertion are among absolute contraindications. Relative contraindications include aplasia of the acoustic nerve and medical conditions or developmental delays that would severely limit participation in aural rehabilitation.

5. Surgery

Cochlear implantation procedure is performed under general anesthesia associated with facial nerve monitoring. Surgeon needs to expose the mastoid, so a postauricular incision is made and soft tissue is dissected; latter, the surgeon makes a subperiosteal pocket for placement of implant magnet. A cortical mastoidectomy is performed associated with finding landmarks of temporal bone, such as incus, tegmen tympani, lateral semicircular canal, and sigmoid sinus. Then, the surgeon opens the facial recess, which is surrounded by chorda tympani, facial nerve, and incus buttress as its boundaries to identify the round window niche through the recess.

There are different methods for accessing scala tympani after finding the round window; in cochleostomy, the surgeon drills a separate hole and the anterior limit of the round window in extended cochleostomy. The implant is inserted into the cochlea, once the cochlea is opened. For making sure of the proper function of implant, an integrity test is performed by an audiologist at the end of the procedure. X-ray radiography is used to ensure proper location of cochlear implant by some surgeons. At the end, the patient is discharged the same day, and cochlear implant is usually activated 2–4 weeks postoperatively.

6. Complications

Cochlear implantation is generally a safe performed surgical procedure throughout the world with globally estimated complication rate of 16% [18]. Requiring additional surgery or cochlear explantation is categorized as major, and complications needing conservative medical management are classified as minor complications. Now, complication rates are decreasing due to improved experience, using smaller incisions and improvements in designing devices, and are generally calculated to be 11.8% for minor and 3.2% for major complications [27].

Infection is one of the most important major complications of cochlear implantation. Skin infection and acute otitis media are the most common type of implant-related infections ranging from 1 to 12% in the literature. Otitis media and soft tissue infection increase the risk of cochlear implant removal if leading to receiver stimulator infection. Also, it has been reported that cochlear implantation increases the risk of bacterial meningitis as 30-fold greater than general population; however, dawn of vaccination has made these cases sporadic [28]. Facial nerve palsy is another major complication of cochlear implantation, which is estimated to occur in 0.7% of cases due to heat induced by drill, cochleostomy, or reactivation of herpes virus as a result of surgery stress [29]. Finally, device failure is another major complication of cochlear implantation occurring in 2.5–6% of cases [18, 27]. Vestibular symptoms, such as vertigo and disequilibrium, are present in about one-third of patients postoperatively and are believed to last for more than 1 week after surgery. Most of these symptoms are resolved in weeks; however, patients over 70 years of age are more likely to have permanent vestibular weakness [30].

7. Hearing after cochlear implantation

Acoustic hearing remains preserved in more than half of the patients after cochlear implantation; however, previously, it was believed that insertion of electrode into the cochlea destroys the natural mechanism of hearing [31]. Preserving physiologic pathway of hearing has several advantages such as ability to localize the sound, recognize the speech, and hear in complex listening environments [32]. A variety of factors and approaches have been considered for improving hearing preservation after cochlear implantation. Previous studies have reported that full electrode insertion makes the hearing preservation possible; however, electrode insertion depth and length are determining factors for intracochlear trauma [24, 33].

Studies believe that the most hearing preservation achieves when the electrode is entirely located in scala tympani [34]. The most appropriate surgical approach has remained controversial; some previous studies have mentioned that there is no significant difference between round window and cochleostomy approaches regarding hearing outcomes [35, 36], while others reported that each method is superior for maximizing atraumatic scala tympani insertion. Eventually, preoperative prescription of steroids and steroid-eluting implants have been reported to improve hearing preservation up to 1 year from implantation [32].

In another retrospective analysis of cochlear implanted patients, researchers investigated the impact of related factors on hearing preservation. They reported an overall preservation likelihood of 39% for patients operated by refined soft surgery technique with a higher conservation rate at low frequencies when compared to high frequencies [37]. Age at the time of implantation, etiology of deafness, side of implant, electrode array model, and insertion technique, as well as type of cochleostomy, are investigated factors, which are considered to possibly affect hearing preservation; however, there are a variety of opinions on their effects, and further studies are required for conclusive results [36, 38–52].

8. Other applications of cochlear implant

8.1. Cochlear implantation for single-sided sensorineural hearing loss

Recently, a new topic has come up about cochlear implantation in setting of single-sided sensorineural hearing loss [53]. So far, options such as hearing aids, bone-anchored implants, and contralateral routing of signal (CROS) devices were applied for single-side deaf patients. While these options improve hearing by healthy ear, cochlear implantation restores hearing by deaf ear. Sound localization is a special challenge for patients with unilateral hearing loss.

A proper localization involves a good bilateral hearing and sound stimulation, as well as intraaural time differences, which allow complex processing of sounds. Recent studies have mentioned some advantages for cochlear implantation in unilateral hearing loss, and some has reported a better sound localization in comparison with bone-anchored implants [54]. Additionally, it has been shown that cochlear implants resolve tinnitus up to an acceptable extent in patients with single-sided deafness and may improve speech perception [34, 55].

8.2. Hybrid cochlear implants

A hybrid cochlear implant was developed by Gantz et al. with the aim of preserving residual hearing, which has only 10 mm of height [56]. This provides the possibility for stimulating the region responsible for high-frequency hearing in cochlea without stimulating regions responsible for low frequency hearing. Primary studies have revealed that hybrid implant application is associated with better hearing preservation and increased speech perception [35, 36, 57, 58]. In addition to the comparable performance of hybrid implants with conventional ones, patients with hybrid implants had improved music appreciation as a result of acoustic and electrical stimulation combination [56, 57]. Replacement of hybrid implant with full-length implant in a progressive hearing loss improves hearing and word recognition; however, it is associated with a notable additional cost [59, 60].

8.3. Cochlear implantation and Meniere’s disease

Cochlear implantation has been utilized for Meniere’s disease, a condition consisted of episodic attacks of tinnitus, hearing loss, and debilitating vertigo spells. Previous studies have shown resolution of related symptoms after cochlear implantation in Meniere’s disease patients, although the hearing outcomes are not as acceptable as patients implanted for other reasons [61, 62].

9. Prospective of cochlear implantation

So far, some in vitro and animal studies have been conducted to resolve the hearing impairment problem using regenerative medicine; nevertheless, cochlear implantation remains as the most effective current treatment method. Further efforts are being put to cochlear implantation technology field in order to improve understanding speech in noise and music appreciations.

Abbreviations

CI	cochlear implant
CROS	contralateral routing of signal
dBHL	decibels hearing level

Hz	Hertz; unit of frequency
PTA	pure tone audiometry
SNHL	sensory-neural hearing loss

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