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Review Article

Advancements in cochlear implant technology: A comprehensive overview

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Abstract

A surgically implanted device known as a cochlear implant (CI) is used to treat severe to profound sensorineural hearing loss in both children and adults. It functions by converting sonic energy into an electrical signal, which is then utilized to stimulate the auditory nerve's remaining spiral ganglion cells. In the last two decades, there has been a sharp increase in the number of CI operations carried out. The safety and effectiveness of CI surgery have been proven by ongoing advancements in programming techniques, device design, and minimally traumatic surgical procedures. Due to advances in technology, the eligibility criteria for cochlear implants (CI) have expanded to include individuals with higher levels of residual hearing and children less than one year old who are deaf. This article discusses the current designs of CI and their future prospects. To illustrate the progress of these medical CI technology over the years, acknowledging key figures in the fields of otology and Cochlear Implant designers.

It is essential to understand the advancements in clinical and surgical anatomy, physiology, treatment methods, and the key figures involved in order to progress medical science. Cochlear Implants has a rich history, with significant pioneers and collaborators in designing. Cochlear Implants have experienced significant advancements in recent years, incorporating technologies beneficial for patients.

Keywords: Cochlear implant, Future designs, Deafness, Hearing Rehabilitation; Neubio bold

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1. Introduction

The cochlear implant is one of the recent medical innovations that best exemplifies success, that can be attained by congruent technology and surgical innovations (CI).[1] The first cochlear Implants were used to provide post linguistically deafened adults with increased awareness of environmental sound and the suprasegmental features of speech to aid lipreading. Rapid development in the field resulted in audition-alone speech understanding for adults with acquired loss. Following these early successes with adults, interest shifted to the pediatric population who obtained little or no benefit from existing hearing aids.[1] Early prototype designs were successful thanks to steadfast collaboration between pioneering surgeons, clinical scientists, and engineers, despite initial criticism from the scientific community. Today, cochlear implantation has become the gold standard care for patients with severe to profound sensorineural hearing loss, children and adults who are deaf or severely hard-of-hearing can be fitted for cochlear implants.[3] National Institute on deafness & other communication disorders reported, as of December 2019, approximately 736,900 registered devices have been implanted worldwide.

Even though we've come a long way in the last 25 years, there's still an opportunity for improvement. Future devices should simulate natural hearing in both quiet and complicated noise environments, show safe long-term performance. In this article, the authors give a brief overview of the history of the CI's development, talk about the state of currently

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available technologies, and explore probable long- and short-term future directions.

1.1. Incidence of hearing impairment in world

Worldwide perspective According to the WHO (2017) reported untreated HL costs nations between $750 and $790 billion a year in direct medical expenses and lost productivity3 According to the World Burden of Disease survey, HL prevalence increased from 1.2 billion people (17.2%) in 2008 to 1.4 billion people (18.7%) in 2017.[6]Hearing impairment, which contributed more than 39.5 million years of healthy life lost since 2000, has been ranked by the World Health Organization as the third most common cause of loss of time due to disability, with an increase from 27 million in 2000. WHO projected that Disabled Hearing Loss affected 466 million people worldwide in 2018 (or 6.12% of the world's population). This estimate is projected to rise to 630 million by 2030 and to over 900 million by 2050.

1.2. Incidence of the hearing impairment in Indian context

According to the Census of India (2011), 1.98 million people in the population have various of speech impairments, while 5.07 million people have hearing impairment.[4] In underdeveloped nations, there are more than 10 newborns born alive with bilateral severe to profound hearing loss for every 1000 live births, according to Pasolini and Smith (2009).[11] As per NSSO survey, currently there are 291 persons per one lakh population who are suffering from severe to profound hearing loss (NSSO, 2001). Of these, a large percentage is children between the ages of 0 to 14 years. With such a large number of hearing-impaired young Indians, it amounts to a severe loss of productivity, both physical and economic. An even larger percentage of our population suffers from milder degrees of hearing loss and unilateral (one sided) hearing loss. In a hospital-based survey, Niskar et al. in 1998 discovered 14.9% of kids had either low-frequency or high-frequency hearing loss.[12] According to Norman et al., (2016) 30.9% of schoolchildren (aged 8 to 14) in the villages of Vadamavanthal, Tamil Nadu, have hearing impairment. According to the Census of India (2011), one out of every 100 children between the ages of 0 and 6 have a disability. There are 2.42 million (20.42 lakh) impaired children in this age group, and 23% of them have hearing impairment[13] Moreover, 20% of the 7.87 million disabled people in the 0–19 age range have hearing impairments. The age range 10 to 19 years has the biggest number of impaired people (4.62 million)14 Just 61% of impaired children aged 5 to 19 are observed to be enrolled in educational institutions. Children aged 0 to 14 made up 25.9% of the population in 2018, according to data from India's sample registration survey (Sample Registration Survey of India, 2018).[15] India has the highest school-age child population with hearing impairments given the prevalence rate of hearing impairment in this age group. These kids can be easily located in schools for hearing tests, as well as for the proper rehabilitation, speech therapy, and educational facilities for their best development. The Right to Person with Disabilities Act of 2016 and the Right to Education Act of 2009 both guarantee rehabilitative and educational assistance for children who have hearing impairments.[15] Hence for the treatment and management of the hearing impairment who do not benefit from other medical treatments, various devices like Cochlear Implants were introduced.

1.3. History of cochlear implant development

Allesandro Volta in the year 1800 did an experiment on himself and discovered that electrical stimulation of the auditory system could produce sound. After initiating a w50-V circuit, he felt "une recousse dans la tete" ("a boom within the brain") and heard a sound like boiling thick paste. In the early 1900s, researchers discovered that electrical current directly stimulates the cochlear nerve to create auditory perceptions.16 French otologist Djourno and physicist Eyrie described the consequences of directly stimulating the auditory nerve in a deaf patient in (1957).[18] Radical excision for severe bilateral cholesteatomas sacrificed the right cochlear and facial nerves. The proximal auditory nerve stump was electroded before grafting the facial nerve. After applying a current, the patient was able to distinguish intensity and frequency, appreciate environmental sounds, and recognize many short words.[19] Volta’s first report of auditory percepts elicited with electrical stimulation, although it is not certain if the experiment was produced with direct electrical activation of auditory neurons or via electro-mechanical effects, such as those underlying electrophonic hearing. While his experiment was the first, Volta’s observation sparked sporadic attempts to investigate the phenomenon over the next 50 years in Paris, Amsterdam, London, and Berlin. Wilson & Dorman (2008) present that the sensation described by patients was always momentary and lacked tonal quality. Since sound is an alternating disturbance in an elastic medium, it was soon realized that stimulating the auditory system with a direct current could not reproduce a satisfactory hearing sensation.

Several US groups implanted prototype CIs in the early 1960s. Blair Simmons from Stanford University implanted 6 stainless-steel electrodes into the auditory nerve through the modiolus in 1964.[19] One of his patients gave William House in Los Angeles an article on Djourno and Eyrie's earlier work. Motivated by this narrative, House implanted numerous gold electrodes in 1961 and worked with engineer Jack Urban to build long-term devices in 1965. House began clinical testing in 1973 with a commercial implant containing a wearable signal processor, platinum electrodes, and an induction coil system.

Despite these early successes, other specialists in the area were skeptical, and electrical stimulation for meaningful audiologic rehabilitation in deaf individuals was denounced by the scientific community.20 A National Institutes of Health-commissioned investigatory team reviewed the first thirteen single-channel electrode implantees in 1977, legitimizing cochlear implantation. Robert Bilger reported that CI technology could increase hearing, lipreading, environmental sound detection, and voice modulation with minimal patient risk.[22]

In 1978, Graeme Clark in Sydney, Australia implanted his first patient with a multichannel banded electrode for limited open-set speech recognition. The University of Melbourne, the Australian government, and Nucleus Ltd., a medical equipment company, founded Cochlear Ltd. after early success.[21]

Computer microcircuit and implanted pacemaker technologies aided early CI commercial device development. The FDA approved the first single-channel CI (House/3 M) for adult profound post lingual deafness patients on November 26, 1984. 3M/Vienna single channel cochlear implant provided sufficient information both in intracochlear and extracochlear stimulation to result in open-set word recognition without lipreading. These results corroborated the previous findings of Hochmair-Desoyer et al.[40] In the last 10 years, speech recognition performance in quiet has plateaued, thus our focus has switched to more demanding listening tasks including background noise, sound localization, and music enjoyment to better simulate normal hearing.

1.4. Cochlear implant function and design

Separate external and internal components make up the behind the ear Cochlear Implant system (**Figure 1**). The transmitter antenna, external magnet, speech processor, battery, and microphone are among the external components. The electrode array, antenna, receiver-stimulator, and internal magnet are among the internal components. An ear-worn microphone picks up sound, which is then transformed into an electrical signal. The external sound processor receives this signal and converts it into digital electrical code using one of its numerous processing schemes. Via the skin, a transmitting coil that is held externally above the receiver-stimulator by a magnet transmits this digital signal through radiofrequency. The receiver-stimulator ultimately decodes this signal into quick electrical impulses that are sent to a number of electrodes specific for particular frequency on an array implanted within the cochlea (specifically, the Scala tympani). The auditory nerve axons and spiral ganglion cells are then electrically stimulated by the electrodes and proceed to the brain for additional processing with digital signal. You may communicate the frequency, and intensity of sound by using these signals to carefully control the firing of intracochlear electrodes not in the continuous time domain. Currently, there are four CI manufacturers: Advanced Bionics Company (Valencia, CA, USA), Cochlear Corporation (Lane Cove, Australia), MED-EL GmbH. (Innsbruck, Austria) & Nurotron (Zhejiang Hangzhou, China). All four implant manufacturers' devices are largely comparable in terms of performance and dependability. Electrode arrays have been developed over the past ten years to be thinner, softer, and more flexible in order to reduce trauma during insertion and protect the fragile neuroepithelial structures within the cochlea.

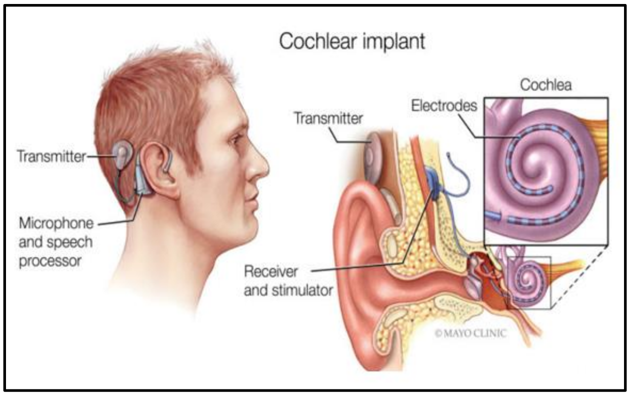

Figure 1: Components of the behind the ear cochlear implant system. (Adapted from Deep NL, Dowling EM, Jethanamest D, Carlson ML. Cochlear Implantation: An Overview. *J Neurol Surg B Skull Base*. 2019;80(2):169-177. doi:10.1055/s-0038-1669411).

1.5. Minimizing trauma

Early Cochlear Implant systems were thought to cause considerable intracochlear trauma during electrode insertion, which would then irreversibly lose any remaining hearing. The adoption of altered surgical methods and electrode design, however, has resulted in increased rates of hearing preservation following implantation during the past 20 years.

In the past ten years, there has been a paradigm change toward the creation of soft surgical procedures and less invasive electrode designs in order to enhance performance.

When electrodes are inserted, there are at least three primary processes that might cause an acute mechanical inner ear injury. The electrode can also be implanted through the membrane of the round window or by a cochleostomy established anterior to the round window. It is possible to fracture the osseous spiral lamina or spiral ligament during electrode insertion since the round window membrane is situated close to the vertically oriented osseous spiral lamina. Traumatic abutment of the lateral scalar structures at the first basal turn of the cochlea and beyond is a second frequent cause of harm. The majority of electrodes show a very straight mid-scalar route along the cochlea's basal turn. The majority of electrodes, on the other hand, are compelled to go toward the basilar membrane once they reach their first turn. If enough force is exerted, the electrode may fracture the interscalar partition or dislodge the basilar membrane, which would allow the electrode to extend into the Scala media or perhaps the Scala vestibuli. Finally, there seems to be a limit to how deep an electrode can go without causing significant harm with today's designs. During implantation, reducing electrode-related trauma has a number of positive effects, including:

1. Limiting damage can preserve natural hearing in patients with residual low-frequency hearing, enabling concurrent electric-acoustic stimulation (EAS) strategies.
2. Revision surgery may be less difficult if intracochlear damage is reduced as this may reduce the amount of intracochlear fibrosis and ossification.

A smaller cochleostomy can be achieved with a thinner, shorter electrode since it is less likely to harm the sensitive scalar structures. On the other hand, a deeper insertion in case of bipolar stimulation would potentially allow for better frequency coverage as the electric field is created in a smaller region limits the stimulation of frequencies. Therefore, it is necessary to stimulate more populations of surviving nerve fibres or spiral ganglion cells to activate in that case. Length of insertion depends on the type and size of electric field generated by ground and active electrode. The subject of the appropriate depth of insertion is therefore brought up by this factor, which is one of the most significant in terms of current CI electrode design when stimulation is bipolar electric field. Canfarotta et.al, reported in his article, cochlear implant recipients implanted with a 31.5-mm array experienced better speech recognition than those with a 28-mm array at 12 months post activation. Deeper insertion of a lateral wall array appears to confer speech recognition. What is too deep, considering the other end of the spectrum? Contrastively Van de Marel et al. found no correlation between angular insertion depth and postoperative CVC word scores, while correcting for age at implantation, duration of deafness, preoperative phoneme score, and preoperative word score (p=0.89). In their analysis, Van de Marel et al. did not correct for electrode scalar location and electrode-to-modiolus proximity. All participants were implanted with the same type of electrode (HiFocus I/IJ) and with the same surgical technique (extended round window approach). This homogeneity in implantation characteristics prevented bias of results caused by differences in CI systems and by differences in electrode designs which is a strength of this study. Spiral ganglion frequency mapping indicates that an electrode must be placed deeper to stimulate low tone frequencies (1000 Hz); according to place theory. The place theory for normal hearing suggests that neurons closer to the base of the basilar membrane are optimized for encoding high frequency signals (up to 20khz), while neurons near the apex encode low frequency signals (down to 20hz). Nevertheless, it appears that with the current electrode models, such as depth of insertion would result in unacceptable harm. The place theory fails to account for human frequency discrimination below 1000hz (Mannell, Robert Theories of Hearing Macquarie University, 2008). This relatively low electrode count compared to the estimated 32,000 sensory hairs. The sound processing unit typically groups, compresses, and delivers frequencies to localized electrodes in trains of pulses limiting the frequency range and sample rate which is less than ideal for tonal languages. (Plack, Chris earing Pitch Right Place, Wrong time He Psychologist, Vol. 25, NO, 12, PG. 892, December 2012). Longer implant stems are needed to accommodate more electrodes increasing risk of surgical trauma. (MD et al., 2016 in his article importance of electrode location in cochlear Implantation Laryngoscope Investigation Otolaryngology.

2. Bilateral Cochlear Implantation

The use of bilateral implants is one emerging method for working around several of the drawbacks of conventional unilateral cochlear implantation. Compared to unilateral implantation, simultaneous binaural electrical stimulation has ascertained increased speech perception (both in quiet and in noise) and enhanced sound localization. Bilateral implantation is thought to restore this arrangement and allow many bilateral users to have directional awareness at least partially. Normal-hearing subjects can distinguish sound location when off-midline in the horizontal plane (left-right discrimination) by using interaural timing and level differences (Dunn et al., 2008).

3. Electroacoustic Technologies

For the majority of CI users, electric-only stimulation offers satisfactory levels of speech comprehension in peaceful environments; nevertheless, it currently has limitations regarding its capacity to give enough frequency resolution, which appears to be crucial for speech recognition in background noise. Bimodal stimulation has been shown to improve speech comprehension in both calm and noisy environments, as well as to improve musical appreciation. Also, patients benefit from a binaural advantage that makes it easier to locate sounds when ipsilateral EAS increases are combined with contralateral hearing-aid amplification. (Gantz et al., 2010)

3.1. Recent advancements

3.1.1. Indigenous innovative device

Recently a novel device – “NEUBIO” has been introduced in India that applies the “Transfer of the technology” initiative. It is ergonomically designed. The NEUBIO BOLD Sound processors utilize new electronics technology that digitally processes the signal in digital signal Processing chip and converts these into an electric analog waveform to transmit it to the implant continuously. The processor uses full-spectrum-continuous-stimulation (FSCS) coding strategy which mimics the original sound input while preserving most signal information. It has the ability to change the pulsatile digital signal into an electrical analog signal (sinusoidal wave) through proprietary signal modulation techniques preserving most signal information stimulating at a continuous rate in an instantaneous time domain. This potentially can address current challenges like speech understanding in noisy environments, music perception as the present technology's stimulator has speed limitations.

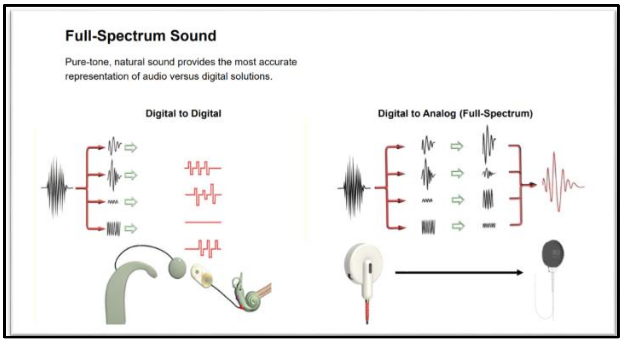

Figure 2: Sound processing pathway (Digital to digital, digital to electric analog full spectrum)

As the mammalian brain naturally encodes for the analog signal, it is assumed that the device sending the continuous electric analog signal is being coded by the auditory cortex spontaneously in the time domain. The NEUBIO device offers the following advantages: - The implant is an inert or passive device, with all electronics located in the external processor; - The implant employs an exceptionally low alternating current (AC) current using full spectrum continuous stimulation compared to Direct current. The primary cause of explanting Implants has been the electronic failure of internal receiving unit (IRU) and the hermeticity leaking issue that led to recalls. (Bhadania et al., 2018). The BOLD implant from Neubio has all of its electronics in an external processor, which increases the inside device's safety (**Figure 3).**

3.1.2. The implant is currently the lightest, smallest, and thinnest in the market.

The Neubio BOLD cochlear implant system is the only one that continually codes in the frequency and time domain because it employs a full-spectrum-continuous-stimulation (FSCS) coding approach. It creates monopolar electric field covering the entire spiral ganglion, enabling it to naturally decode and capture full-spectrum frequencies on the basis of energy to transmit them to the auditory nerve. Robin L. Davis (2015) reported that the first neural component of the auditory pathway is made up of type I spiral ganglion neurons. These unique primary afferents, unlike other sensory afferents, have their cell bodies directly positioned in the pathway for transmitting electrical signals and exhibit varying morphological properties. They also exhibit specialized electrical activity, as seen in the diverse voltage-gated ionic currents conducted by different ion channel subunits, which likely play a role in fine-tuning the neurons' firing patterns. The distribution of these ion channel subunits and their densities is not uniform within the ganglion but instead follows specific patterns, some of which are related to the frequency-specific contour of the cochlear end organ. Furthermore, these properties can be regulated by neurotrophins, resulting in primary afferents innervating high-frequency regions displaying faster firing patterns, while those innervating low-frequency regions exhibit slower firing patterns.[41]

In order to deliver audio to their custom-made FSM chip, Neubio uses an effective digital processing chip that processes audio in 32 bands consists of 10 Hz to 8KHz frequency, 96 dB input dynamic range. It reduces noise using a various noise reduction algorithms and works on dynamic range compression. 32 bands are combined by the FSM chip to continually code and stimulate electrodes.

Neubio has performed around 150 procedures in India, with exceptionally safe & effective results on the basis of evaluation of Auditory Perception post switch on of the Neubio device reported by audiologists. The feedback from various surgeons, audiologists, and therapists is included in Neubio's database of all patients utilizing their products in India.

Figure 3: Neubio bold bravo cochlear implant system

3.2. Future challenges

With Alessandro Volta's 1790 discovery of auditory stimulation to today's reliable open-set speech recognition cochlear implantation has advanced rapidly and is truly astounding. Alternative stimulation strategies (e.g., radiofrequency, optical), robotic electrode insertions with steerable arrays, minimally invasive mastoidectomy techniques, and drug-eluting electrode arrays to deliver steroids to prevent intracochlear scarring or neurotrophic factors to promote neural ingrowth for improved electrode-to-neuron coupling. Another upcoming totally implantable cochlear implant (TICI) is an innovative type of cochlear implant that is currently being developed. Unlike traditional cochlear implants, which consist of both an internal component (implant) and an external component (audio processor), all components of the TICI, including the microphone and battery, are implanted beneath the skin. This unique design ensures that the TICI is completely hidden from view. At present, the TICI is in the clinical feasibility study phase of development. In September 2020, the first patient in Europe underwent TICI implantation as part of a clinical trial, marking an important milestone in its advancement. Technology, health care delivery, and awareness campaigns are needed to expand cochlear implantation in industrialized and underdeveloped countries. Despite the safety and usefulness of CI surgery, only 6% of people who could benefit from one has improved utilization.[4] Access to CI can be achieved by raising knowledge of its benefits, training health-care professionals on the enlarged indications, providing specialized referral channels, establishing tele-audiology services, and emphasizing its cost-effectiveness.

4. Summary

Today's CIs use 9 to 22 electrodes to stimulate fewer spiral ganglion cell populations than the healthy cochlea's 3000 inner hair cells and 30,000 auditory neurons. We cannot recover normal hearing after sensorineural deafness. Difficulty understanding speech in noise, perception of music and most delicate the perception of tonal languages is still a major issue in cochlear implants. This is because the coding strategies are speech focused. There is an interleaved 'radio' silence' in between to avoid current flow on other electrodes leading to channel interactions in digital signals. Therefore, the speed at which digital signal stimulate each electrode should be very fast. However, it doesn't correspond the input sound signal speed which leads to robotic perception, raises all the major problems related to music perception, speech in noise & tonal languages. We must be heartened that even with gross stimulation tactics, a majority of patients are experiencing remarkable hearing recovery, and we continue to witness consistent development with each implant design and processing strategy. Implant users had improved speech recognition in noise, musical appreciation, and sound localization thanks to bilateral cochlear implantation. Spatial and temporal resolution and user performance variations will likely be addressed in future versions. Innovation is accelerating, and cochlear implantation's future looks bright.

5. Conclusion

In order to advance medical science, it is crucial to have a deep understanding of the developments in clinical and surgical anatomy, physiology, treatment techniques, and the influential individuals involved. The history of Cochlear Implants is marked by pioneering figures and collaborative efforts in their design. In recent years, Cochlear Implants have seen notable progress, integrating technological advancements to improve patient outcomes.

6. Ethics Approval and Consent to Participate

"Not applicable" as manuscripts does not report studies involving human participants, human data or human tissue.

7. Source of Funding

There is no funding for this research (review article).

8. Conflict of Interest

None.

References

1. Carlson ML, Driscoll CL, Gifford RH, McMenomey SO. Cochlear implantation: current and future device options. *Otolaryngol Clin North Am*. 2012;45(1):221-48.
2. Verma RR, Konkimalla A, Thakar A, Sikka K, Singh AC, Khanna T. Prevalence of hearing loss in India. *Natl Med J India.* 2021; 34:216–22.
3. Global costs of unaddressed hearing loss and cost-effectiveness of interventions: A WHO Report, 2017. Geneva: WHO; 2017. Available at https://apps.who.int/iris/bitstream/handle/10665/254659/9789241512046-eng.pdf?sequence=1.
4. GBD 2017 Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: A systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018; 392(10159):1789-858
5. Global Health Estimates 2020: Disease burden by Cause, Age, Sex, by Country and by region, 2000–2019. Geneva: WHO; 2020. Available at www.who.int/ data/gho/data/themes/mortality-and-global-health-estimates/global-healthestimates-leading-causes-of-dalys.
6. Prevention of blindness and deafness. Grades of Hearing Impairment. Geneva: WHO; 2013. Available at www.who.int/pbd/deafness/hearing_impairment_grades/en/.
7. World Health Organization. Addressing the rising prevalence of hearing loss. Geneva: WHO; 2018. Available at www.who.int/pbd/deafness/estimates/en/.
8. World Health Organization, Regional Office for South-East Asia. State of hearing and ear care. Geneva: WHO Regional Office for South-East Asia; 2005. Available at http://apps.who.int/iris/bitstream/handle/10665/205911/B1466.pdf?sequence=1&ua=1.
9. Disabled Persons in India. NSS 58th round (July–December 2002) Report No. 485 (58/26/1). National Sample Survey Organization, Ministry of Statistics and Programme Implementation, Government of India; 2003. Available at http://mospi.nic.in/sites/default/files/publication_reports/485_final.pdf
10. Chandramouli C., General R. Census of India 2011. Provisional population totals. Government of India, New Delhi, 2011; pp 409–13
11. Pascolini D, Smith A. Hearing impairment in 2008: a compilation of available epidemiological studies. *Int J Audiol. 2019* 48(7):473–85.
12. Niskar AS, Kieszak SM, Holmes A, Esteban E, Rubin C, Brody DJ. Prevalence of hearing loss among children 6 to 19 years of age: the third National Health and nutrition examination survey. *Jama.* 1998; 279(14):1071–5.
13. Norman P, Chandran M, Dhandapani T. Prevalence of hearing impairment in school children (aged 8-14 years) in the villages of Vadamavanthal, Tamil Nadu, India. *Int J Community Med Public Health.*2016; 3(12):3369–73.
14. Office of the Registrar General & Census Commissioner, Sample registration survey of India (SRS: 2018). Ministry of Home Affairs, Government of India. Available from https://censusindia.gov.in/vitalstatistics/SRS Report 2018/9.Chap 2-Population_Composition-2018.pdf
15. Ministry of Law and Justice, Government of India. The rights of persons with disabilities Act (2016) Gazette of India (extra-ordinary). Government of India, New Delhi, p 2016
16. Volta A. Electricity excited by the mere contact of conducting substances of different kinds. P*hil Tran*. 1800;90: 403-31.
17. Jones RK, Stevens SS, Lurie MH. Three mechanisms of hearing by electrical stimulation. *J Acoust Soc Am.* 1940;12:281–90.
18. Djourno A, Eyries C, Vallancien B. Electric excitation of the cochlear nerve in man by induction at a distance with the aid of micro-coil included in the fixture. *C R Seances Soc Biol Fil.* 1957; 151:(3)423–5.
19. Simmons FB, Epley JM, Lummis RC. Auditory nerve: electrical stimulation in man. *Sci*ence. 1965;148(3666):104-6.
20. House WF, Berliner KI. Safety and efficacy of the House/3M cochlear implant in profoundly deaf adults. *Otolaryngol Clin North Am.* 1986;19(2):275–86.

21. Kiang NY, Moxon EC. Physiological considerations in artificial stimulation of the inner ear. *Ann Otol Rhinol Laryngol* 1972; 81(5):714–30.
22. Bilger RC, Black FO. Auditory prostheses in perspective. *Ann Otol Rhinol Laryngol Suppl* 1977; 86:3–10.
23. Clark GM, Tong YC, Martin LF. A multiple-channel cochlear implant: an evaluation using open-set CID sentences. *Laryngoscope* 1981; 91:628–34.
24. Balkany TJ, Connell SS, Hodges AV. Conservation of residual acoustic hearing after cochlear implantation. *Otol Neurotol* 2006; 27:1083–8.
25. Briggs RJ, Tykocinski M, Xu J. Comparison of round window and cochleostomy approaches with a prototype hearing preservation electrode. *Audiol Neurootol* 2006;11(1):42–8.
26. Roland JT. Jr. A model for cochlear implant electrode insertion and force evaluation: results with a new electrode design and insertion technique. *Laryngoscope* 2005;115:1325–39.
27. Rebscher SJ, Hetherington A, Bonham B. Considerations for design of future cochlear implant electrode arrays: electrode array stiffness, size, and depth of insertion. *J Rehabil Res Dev.* 2008;45(5):731–47.
28. Gantz BJ, Hansen MR, Turner CW. Hybrid 10 clinical trial: preliminary results. *Audiol Neurootol* 2009;14(1):32–8.
29. Roland PS, Wright CG. Surgical aspects of cochlear implantation: mechanisms of insertional trauma. *Adv Otorhinolaryngol.* 2006;64:11–30.
30. Briggs RJ, Tykocinski M, Saunders E. Surgical implications of perimodiolar cochlear implant electrode design: avoiding intracochlear damage and scala vestibuli insertion. *Cochlear Imp Int.* 2001;2(2):135–49.
31. Cohen NL, Hirsch BE. Current status of bacterial meningitis after cochlear implantation. *Otol Neurotol.* 2010; 31(8):1325–8.
32. Dunn CC, Tyler RS, Oakley S. Comparison of speech recognition and localization performance in bilateral and unilateral cochlear implant users matched on duration of deafness and age at implantation. *Ear Hear* 2008; 29:352–9.
33. Dunn CC, Perreau A, Gantz B, et al. Benefits of localization and speech perception with multiple noise sources in listeners with a short-electrode cochlear implant. *J Am Acad Audiol* 2010; 21:44–51.
34. Häusler R. Cochlear implantation without mastoidectomy: the pericanal electrode insertion technique. *Acta Otolaryngol*. 2002;122(7):715-9
35. Kiratzidis T. 'Veria Operation': cochlear implantation without a mastoidectomy and a posterior tympan- otomy. *Adv Otorhinolaryngol* 2000; 57: 127–30.
36. Kronenberg J, Migirov L, Dagan T. Supramental approach: new surgical approach for cochlear implantation. *J Laryngol Otol* 2001; 115: 283–5.
37. It's time to be Bold! (n.d.). Neubio. https://www.neubio.in/
38. About Us - Neubio. (n.d.). Neubio. https://neubio.in/about-us
39. Deep NL, Dowling EM, Jethanamest D, Carlson ML. Cochlear Implantation: An Overview. *J Neurol Surg B Skull Base*. 2019;80(2):169-77.
40. Hochmair, E. S., Hochmair-Desoyer, I. J. Aspects of sound signal processing using the Vienna intra- and extracochlear implants. Paper presented at the 10th Anniversary Conference on Cochlear Implants, San Francisco, CA. 1983;437-42.
41. Part of the Springer Handbook of Auditory Research book series (SHAR) 52; p-1-5.

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