REVIEW ARTICLE

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Pre-Operative Workup of Cochlear Implant

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Abstract

Hearing loss, an increasing problem across the globe, results in an important solution in the form of cochlear implants, highlighting the critical need for effective interventions. This review involves analyzing 46 relevant publications via databases such as PubMed and Google Scholar, providing current insights into pre-operative issues. Studies through databases such as PubMed and Google Scholar, ensuring contemporary insights into the pre-operative considerations. The pre-operative evaluation encompasses medical history, covering prenatal events and immediate post-natal health, along with physical examinations and complete audiometric assessments. High-Resolution Computed Tomography (HRCT) and Magnetic Resonance Imaging (MRI) emerge as crucial imaging techniques, guiding surgical planning and electrode placement. Brainstem Evoked Response Audiometry (BERA) supplements inconclusive MRI data, while vestibular screening aids in candidate selection. Cochlear duct length determination, often assessed through imaging techniques, contributes to optimal electrode array selection. Models in cochlear implant research, spanning computational, animal, tissue engineering, and physical models, further enhance our understanding and refinement of cochlear implant designs. In conclusion, this comprehensive pre-operative workup plays a significant role in assessing patient health, identifying causes of deafness, and contributing to the overall success of cochlear implantation, a transformative solution for profound hearing impairment.

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Introduction

Hearing loss occurs when part of the auditory system doesn't function in the normal way and causes difficulty in an individual's ability to perceive sound. It is assessed by pure tone audiometry to test hearing thresholds at frequencies of 0.5 kHz, 1 kHz, 2 kHz, and 4 kHz (1). Cochlear implants are small medical devices that can help an individual with severe hearing loss to hear again, distinguish sounds and understand speech. Currently, it is the only treatment available to restore hearing partially in patients with profound to severe sensorineural hearing loss. Unlike hearing aid devices which aim to amplify the sound to make it audible to an ear, a cochlear implant directly stimulates the auditory nerve by passing the damaged hair cells in the cochlea (2). According to A. Martini et al. the implant consists of an external portion that sits behind the ear and a second internal portion surgically placed under the skin. It consists of a microphone to collect sound from the environment, a speech processor that processes the sounds the microphone captures, a transmitter and a receiver/stimulator that converts speech processor signals into electrical impulses (Figures 1 and 2). A group of electrodes known as an electrode array collects stimulator impulses and sends them to various

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regions of the auditory nerve (3). According to World Health Organization (WHO), more than 1.5 billion people are currently affected by hearing loss in at least one ear and around 430 million require rehabilitation for disabling hearing loss (4). It is predicted by WHO that the number could rise to more than 2 billion by 2050 with around 1 billion young people (12-35 years) at risk of hearing loss by 2050 and at least 700 million people will require some form of hearing aid or surgery.

Figure 1. External component of a cochlear implant: (1) behind the ear sound processor; (2) antenna with a magnet (Taken from open access article) (5).

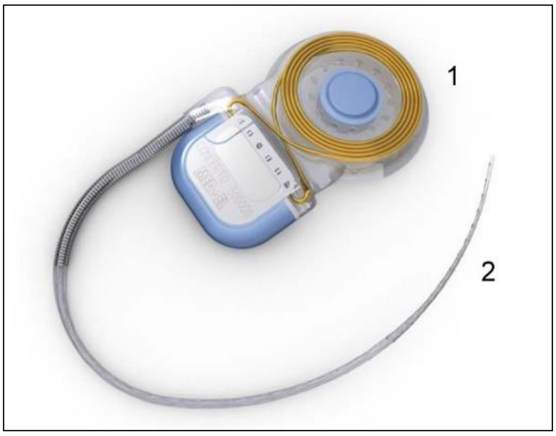

Figure 2. The internal component of a cochlear implant: (1) receiver-stimulator with coil and magnet; (2) intracochlear electrode array (Taken from open access article) (5).

This study aims to provide an overview of the various factors and methods involved in the pre-operative evaluation and preparation of cochlear implant candidates, such as medical history, physical examination, audiometric assessment, imaging techniques, cochlear duct length measurement, and research models. The study also aims to highlight the importance and impact of these pre-operative factors on the outcome and effectiveness of cochlear implantation.

Methods

This review article contains an analysis of published studies discussing the pre-operative workup of cochlear implants. Multiple databases including PubMed and Google Scholar were utilized to collect the relevant articles on this topic. The search terms include preoperative evaluation of cochlear implant, cochlear implantation, hearing loss, and hearing aid. We included all English studies that addressed cochlear implants and its pre-operative workup. Studies with insufficient data or outdated data were excluded. The initial screening contains 325 studies. After implementing our inclusion criteria, the most relevant articles were selected and included in this review. This review article involves 46 papers on this subject.

Pre-Operative Workup

A preoperative workup is advised in adults and pediatric patients having elective surgery to assess and identify the psychological and medical factors that require management and evaluation before surgery. The preoperative workup for cochlear implantation includes audiologic examinations, medical history, physical evaluation, HRCT (High-Resolution Computed Tomography) of the temporal bone, MRI (Magnetic Resonance Imaging) for evaluation of cochlea and auditory nerve, BERA (Brain Evoked Response Auditory) hearing test and vestibular screening. Preoperative HRCT and MRI are important planning tools for pediatric cochlear implantation particularly in academic institutions (6).

Medical History

Medical history aids the clinician in deciding on the treatment of the patient. It includes

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information from patients' medically relevant recollections, i.e., symptoms, past diseases and questioning about their concerns. Musaed A. Alzahrani et al. suggested that history is mandatory for assessing hearing loss and it contains prenatal events (such as maternal infections and medications), mode of delivery, immediate post-natal health problems (such as hypoxia, jaundice, prolonged Neonatal Intensive Care Unit admission, and neonatal infections), and other medical conditions (7). For adults, as reported by Witold Szyfter et al. history should contain bilateral post-lingual deafness, bilateral sensorineural hearing loss, and asymmetric hearing loss with severe tinnitus in the deaf ears, which cannot be treated with other hearing aids (8).

Physical Examination

According to Suat Kılıçet al., the physical exam should include a complete head and neck examination, otologic exam and inspection for dysmorphic facial features, as well as cardiac, ophthalmologic, neurologic, neck/thyroid, and extremity examinations (9). Head and neck and otological examination include craniofacial abnormalities, otomicroscopy and pneumatic otoscope examination of the ear for assessment of external acoustic meatus, tympanic membrane and middle ear and the Weber/Renne's tuning fork exam (the frequency of the tuning fork should be 256 or 512 Hertz, the most preferable is 512 Hertz).

Complete Audiometric Evaluation

Preoperative audiometric evaluation plays a pivotal role in determining the candidacy of potential cochlear implant recipients. It includes speech perception scores and pure-tone evaluation. Candidacy for cochlear implants is usually assessed by speech perception scores as a representation of hearing difficulties. Pure-tone audiometry is a behavioral test to measure hearing sensitivity. (10). Pure-tone audiometry is the standard gold method of determining the type, degree, and configuration of hearing loss due to its widespread availability, inter-test reliability, and relative ease of execution (11). Audiogram analysis supports implant candidature and electrode selection decisions, emphasising severe high-frequency sensorineural loss.

High-Resolution Computed Tomography (HRCT)

A high-resolution computed tomography scan may be conducted for a pre-operative cochlear implant to assess the anatomy and condition of the inner ear structures. The anomalies of the internal ear are well visualized and in the past HRCT has been the imaging study of choice. HRCT can provide critical information about abnormalities of the bony otic capsule and the position of the facial nerve, but, according to Seidman, up to 57% of soft tissue abnormalities of the inner ear may be missed (12). Therefore, most surgeons recommend MRI because HRCT cannot identify membranous labyrinth, endolymphatic sac, or cochlear nerve and it also requires radiation exposure (13). HRCT allows the visualisation of cochlear anatomy in detail. The cochlea is the primary organ of hearing. A normal cochlea has a scala vestibuli, scala tympani and a scala media with the modiolus in the centre. HRCT can differentiate several types of malformations which include cochlear aplasia, complete labyrinthine aplasia (total absence of internal ear structure), common cavity (cochlea and vestibule are represented in the single chamber), incomplete partition of cochlea (defect in modiolus and intercalary septa) and cochlear aperture abnormalities (narrow cochlear nerve canal) (14). Other types of anomalies that can be differentiated in HRCT is ossification. Most of the patients after post-meningitis deafness have some degree of ossification. The most prevalent regions of ossification in the cochlea are the round window and basal turn, thus the surgeon must be ready to drill to create a channel for a long multi-electrode array (15). Luxford and House reported drilling 6 to 7 mm into the scala tympani to find a good channel for insertion (16). HRCT scans are effective in predicting the potential need for further drilling of scala

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tympani in post-meningitis patients. HRCT scans performed before surgery can aid in choosing the best ear to implant (17). A study done by MICHAEL A. SEICSHNAYDRE et al. suggested that CT scans are most predictive of operative findings in patients with postmeningitic hearing loss and positive CT findings of bony overgrowth at the round window or basal turn narrowing are most likely to agree with surgical findings of ossification (15). Complete loss of hearing and vestibular function can result from a temporal bone fracture that passes through the otic capsule (18). Candidates for cochlear implantation may include patients who have bilateral temporal bone fractures. There are few reports in the English literature of successful cochlear implantation and subsequent aural rehabilitation in patients with deafness from temporal bone fractures (19; 20). A pre-operative HRCT is very crucial to choose which side to implant on in a bilateral temporal bone fracture (21) (Figure 3).

Figure 3. Coronal CT scan of left temporal bone through the level of the otic capsule (bone window). The temporal 1 bone fracture on this side(arrow) also passes through the vestibule, with evidence of pneumolabyrinth (arrowhead) (Permission taken from author/Publisher) (21).

There are two other important features assessed easily on the pre-operative CT, the position of the jugular bulb which if high and anteriorly placed may reach up almost to the round window niche and the presence of a retro- and infra-cochlear chain of air cells. These may be mistaken for the round window niche and attempts made to introduce the electrode into air cells rather than the round window niche (Peter D. Phelps) (22). HRCT scan may support the outcome of rehabilitation following cochlear implantation (23). For instance, the vestibulocochlear nerve (cranial nerve VIII) would likely be damaged by a temporal bone fracture through the internal auditory meatus, rendering the cochlear implant ineffective (19), brain stem implantation may be the sole alternative for auditory rehabilitation in these people(24). Even though cochlear implantation is a safe operation, anomalies in the facial nerve course increase the facial nerve injury risk in cochlear implant surgery (25; 26). Preoperative detection of facial nerve anomalies can reduce the risk of intraoperative nerve damage and boost the surgeon's confidence when planning cochlear implantation. Patients without abnormalities of the inner ear (visible on MRI imaging) frequently do not have abnormalities of the facial nerve (the facial nerve can only be observed on HRCT). Therefore, F B PALABIYIK et al. suggested that an MRI be performed on children with sensorineural

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hearing loss (SNHL) before cochlear implantation. In the absence of inner ear disorders, HRCT is often avoided since it uses radiation and children are more vulnerable to it (24).

Magnetic Resonance Imaging (MRI)

MRI can be utilized as a preoperative evaluation for patients with cochlear implants, as it provides detailed images of the interior compartment of the ear. Both MRI and CT scans are commonly used as principal radiological investigations for cochlear implants. MRI, without the need for CT, can detect all critical abnormalities that are considered in the preoperative decision-making process or during the surgical procedure (27). Keith Trimble et al. stated that MRI has the advantage of detecting soft tissue abnormalities such as cochlear obliteration after meningitis, cochlear nerve aplasia, and central brain lesions (28). According to Levent Sennaroglu et al. MRI is superior to CT in demonstrating nerves in the internal auditory canal and retro cochlear pathologies that result in characteristic fluid changes (29). By utilizing cutting-edge surface coils, MRI can further enhance its spatial resolution and increase its success rate. Sachiko Komatsubara et al. suggested that MRI can diagnose severe abnormalities in the cochlear nerve canal with a width of less than 1.5mm, which cannot be detected by CT scans (30). Furthermore, MRI allows for a clear analysis of the branches of the vestibulocochlear nerve in the internal auditory canal. CT scans, on the other hand, provide a good assessment of bone detail and bony malformations, which MRI may lack. However, CT scans are not suitable for analyzing neural structures, inner ear fluid, and fibrosis. According to Jan W. Casselman et al. MRI can indicate the congenital absence of the cochlear nerve, which is crucial information to consider before cochlear nerve implantation (31). In the study conducted by Arriaga MA et al. MRI successfully visualized cochlear fibrosis, vestibular schwannoma, and patency in the second turn of the cochlea in a patient with labyrinthitis ossificans and disproved suspected cochlear fibrosis observed on HRCT imaging (32). Therefore, an MRI of the temporal bone should be utilized as part of the preoperative workup before cochlear implantation. Despite its benefits, MRI does have some limitations. its ability to interact with medical implants that contain metal is frequently contraindicated. Cochlear implant users must be aware of the risks involved. In conclusion, MRI is an effective imaging technology for assessing patients with cochlear implant, cochlear anatomy, and probable contraindication.

Brainstem Evoked Response Audiometry (BERA)

When MRI data are inconclusive, brainstem evoked response audiometry (BERA) is used to check suspected problems with the vestibulocochlear nerve. Brainstem Evoked Response Audiometry (BERA) is a modern noninvasive, objective neurophysiological method for evaluation of hearing threshold. This method is applied in the complex otoneurologic diagnostic procedure (33). Auditory Brainstem Response (ABR) is a test that is comparable to BERA. The difference between the two is that ABR focuses on the auditory nerve's response to sound, while BERA evaluates the response of components in the child's nervous system responsible for hearing. This process is unobtrusive and straightforward to record. It is often advised for newborns who have a high chance of developing hearing loss. In conclusion, BERA and ABR tests are important in assessing the auditory system's reaction concerning cochlear implant stimulation, assuring the implant's appropriate operation, and helping in the improvement of hearing outcomes for people who have cochlear implants.

Vestibular Screening

Vestibular screening is used to identify vestibular disorders that may contraindicate the need for a cochlear implant and to help choose whether patients are candidates for

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one. respectively. Some vestibular disorders that may affect the cochlear implant candidacy or outcome include bilateral vestibular loss, unilateral vestibular loss, Meniere's disease, vestibular schwannoma, and vestibular migraine (23). These disorders may cause symptoms such as dizziness, vertigo, imbalance, and oscillopsia, which may worsen after cochlear implant surgery or interfere with auditory rehabilitation (14,34). The vestibular system provides information about body position and balance to the body. According to the study of Niels West et al. vestibular testing is an important part of clinical workup with respect to selection of candidates as 15.2% of patients of cochlear implant present with unilateral vestibulopathy (34). Certain characteristics, such as neck immobility and problems with eye tracking and communication, posed challenges for vestibular testing.

Models of Cochlea Used in Cochlear Implant

Bony labyrinth makes the cavity system of inner ear and consist of three parts cochlea, vestibule and three semicircular canals. The cochlea is a spiral-shaped structure involved in hearing and auditory transduction located in the bony labyrinth. The spirality of the cochlea allows us to perceive sound waves of different frequencies (35). The vibration produced by sound waves in the endolymph of the cochlear duct (scala media) are converted to electrical impulses by hair cells which are then carried to the auditory cortex of the brain through the vestibulocochlear nerve (C.N VIII). Models used in cochlear implants can be classified broadly into 4 categories (36) and these are briefly discussed in Table 1.

Table 1. Models used in cochlear implant

Computational models	Computational models can help researchers optimize performance of CI by simulating electrical stimulation of auditory nerve (37).
Animal models	Animal models are prevalent in Cochlear implant research for validation of cochlear implant and systemic responses to which can help prevent potential adverse effects (38,39).
Tissue Engineering Models	These are helpful to study cochlear implants effects in at tissue and cellular level (40).
Physical models	These models can be used to study the forces involved during cochlear implantation and optimize cochlear implant design to prevent hearing damage (41)

Cochlear Duct Length Determination

Cochlear duct length is a recognized parameter used in preoperative evaluation for cochlear implantation as it can help in the selection of cochlear implant electrodes. Electrode arrays are used to stimulate the auditory nerve and optimal cochlear duct length is essential for electrode array selection. An illustration of cochlea with electrode array (Figure 4). Multislice computed tomography (42) and cone beam CT (44) are commonly used in clinical practice. However, MRI can also be used reliably to determine cochlear duct length (43) especially in pediatric population as it has no radiation risk (45) as radiation exposure in children can have significant disturbances but MRI is contraindicated in patients with usage of medical devices like pacemakers (46) and it is not as effective in detecting bone anomalies in inner ear.

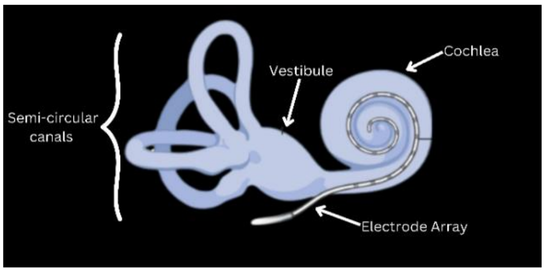

Figure 3. Inner ear with electrode array for stimulation of auditory nerve in cochlear implant

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Conclusion

In individuals who are profoundly deaf, cochlear implants have proved very successful in recovering hearing. Many people who have undergone implants can now understand speech and converse without the need for lipreading. The pre-operative examination for cochlear implants is very important in assessing the patient's health and can also identify the cause of the patient's deafness, which is very useful for surgeons when planning cochlear implantation.

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Conflicts of Interest

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Author contribution

SQH conceptualized the review, designed the methodology, and conducted the literature search. SQH contributed to the writing of the manuscript, particularly the sections related to cochlear anatomy, pre-operative workup, and the conclusion. SI contributed to the analysis of the selected publications and the extraction of relevant information. SI played a key role in synthesizing insights into cochlear implantation, particularly focusing on the medical history and physical examination aspects. SRA participated in the review process by contributing to the methodology and data analysis. SRA provided valuable insights into imaging techniques, including HRCT and MRI. ZH contributed to the interpretation of pre-operative evaluations, with a focus on BERA and vestibular screening. ZH participated in drafting sections related to vestibular disorders and the importance of pre-operative examinations in candidate selection. WAK played a crucial role in the literature review, including the identification and selection of relevant publications. WAK contributed to the sections discussing cochlear duct length determination, electrode arrays, and models in cochlear implant research. MAB provided expertise in the field of cochlear implants and contributed to the overall review design. MAB participated in critically reviewing and revising the manuscript, ensuring coherence and clarity across different sections.

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