Audiological Rehabilitation After Cochlear Implantation: A New Model Developed Based on the International Classification of Functioning, Disability and Health (ICF)

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Technical advance

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Abstract

**Background:** There is a need for a more holistic approach to treating hearing impairment, as it affects many aspects of a person's life, not just their hearing. This article describes how The International Classification of Functioning, Disability and Health (ICF), particularly the ICF core sets for hearing loss, can be used to plan and evaluate the audiological (re)habilitation of cochlear implant (CI) recipients. Using the ICF core sets should help clinicians better address not only hearing impairment but also its consequences.

**Methods:** The opinions of experts were gathered on their clinical experience about the most relevant ICF categories and codes to describe audiological rehabilitation after cochlear implantation. For the relevant ICF categories, the most commonly used audiological assessment tools and methods were identified.

**Results:** The most relevant codes for Body Functions and Structures, Activity, and Participation were identified. These include: structure of the inner ear (s260), auditory nerve (s260), brainstem (s1105), midbrain (s1101), diencephalon (s1102), and cortical lobe (s110); sound detection (b2300); sound discrimination (b2301); localization of sound source (b2302); lateralization of sound (b2303); speech discrimination (b2304); listening (d115); communicating with – receiving – spoken messages (d310); handling stress and other psychological demands (d240); using communication devices and techniques (d360); conversation (d350); family relationships (d760); school education (d820); remunerative employment (d850); and community life (d910). The appropriate questionnaires as assessment tools were proposed.

**Conclusions:** Using the ICF can help target the holistic (re)habilitation of CI recipients and reduce hearing loss-induced deficits in function, activity, and participation.

1. **Background**

Hearing is a very important function in the human body [1]. The acoustic energy, i.e. sound, that an individual perceives is transformed into neuronal impulses by hair cells in the inner ear. This transformation is essential for generating an auditory sensation (which is a biological function). Damage to these cells disrupts inner ear function and thus, as a deviation from the biological norm, is considered a pathological state called sensorineural hearing loss [2]. Depending on the extent and type of damage, the severity of an individual's hearing loss or impairment can vary. In most cases, hair cell damage is irreversible [2]. Sensorineural hearing loss is, according to the Medical Model of Disability, a functional deficit of the inner ear which leads to a sensory impairment. This model links a disability diagnosis to an individual's physical body. The medical model sees disabilities as a pathological state requiring appropriate treatment [3]. If no effective treatment methods exist, the model recommends that the individual with hearing loss undertake rehabilitation activities that aim to reduce the functional deficit (e.g. hearing impairment) caused by the pathological state [4].
Currently, it is not possible to regenerate hair cells, and therefore, the only medical intervention available is to use a medical device or hearing prosthesis, e.g. hearing aids or cochlear implants (CIs) [2]. Hearing aids are generally used in cases of mild to severe hearing loss; CIs are generally used in cases of severe to profound hearing loss, for people with ski-slope audiograms (electric-acoustic stimulation or “EAS”), and single-sided deafness (SSD).

As this paper is concerned with CIs and not hearing aids, CIs will be the sole focus. CIs restore the process of transforming sound into neuronal impulses by electrically stimulating the surviving nerve fibres thereby, in essence, replacing the defective hair cells. In short, a CI can partially compensate for hearing impairment, and to some extent mitigate the negative consequences of hearing disability via surgical intervention with a CI and postoperative rehabilitation. In any case, there is a need for a more holistic approach to treating hearing impairment.

2. Functional Model Of Disability

Recent technological progress has brought about the rapid development of rehabilitation science, which is rooted in the medical model of disability. According to the American Institute of Medicine, rehabilitation combined with biomedical engineering should take advantage of the newest achievements in medical, social, and technical sciences related to their capacity to restore lost biological and body functions as well as their capacity to improve the quality and range of an individual's interactions with their environment [5].

The basic model of disability used by rehabilitation science is a functional model which originally comes from the social sciences [6]. In this model, the loss of auditory capacity is understood as a dynamic model composed of four sub-processes: 1) a pathological process occurring on a molecular level in the hair cells, 2) damage manifested as a sensory deficit, 3) functional disability (inability to perform a task, e.g. understanding spoken communication), and 4) difficulties encountered in his/her social life, e.g. difficulties in fulfilling social expectations [5, 6].

2.1. The International Classification of Functioning, Disability and Health (ICF)

Following the newest recommendations of audiological organizations, postsurgical care after CI provision should be based on the functional model of disability developed by the International Classification of Functioning, Disability and Health (ICF) [e.g. 7]. In this model, disability is a comprehensive term involving impairment, activity limitations, and participation restrictions [1]. Impairment is a problem with a body function or structure (e.g. hearing loss); activity limitations are difficulties an individual may have in executing activities or tasks (e.g. cannot hear well enough to understand conversations); and participation restrictions are problems an individual may experience in involvement in everyday situations that would otherwise be accessible (e.g. poor hearing causes someone to stop using a telephone) [1]. Moreover, the ICF defines an individual’s functioning (and their
limitations) as an effect of a dynamic interaction between health condition(s) and the environment (i.e. contextual factors) [1]. Relations between components of the ICF are shown in Fig. 1. (Fig. 1 here)

The ICF model of disability identifies five spheres of human functioning [1]:

1. Body functions and structures – physiological functions of body structures and all anatomical body parts. Any (pathological) changes at this level are called damages / impairments.
2. Activity – the execution of an action/task/undertaking or beginning some action by an individual. Activity limitations are difficulties that an individual may have in executing such activities.
3. Participation – involvement in life situations. Participation restrictions are problems an individual may experience in becoming involved in life situations. This can involve environmental contextual factors and/or personal contextual factors.

The ICF includes lists of particular body functions and structures, names of actions and forms of participation, and a list of external (environmental) factors affecting each element of functioning and disability. ‘Personal factors’ are another element of contextual factors but are not classified in the ICF because they could potentially cover the entirety of human social and cultural diversity. The ICF classification describes situations related to an individual’s functioning and its limitations as well as a tool to organize this information. Further, the ICF classification establishes a structure for ordering this information in a logical and easily accessible way.

2.2. ICF core sets for hearing loss

The ICF was developed for use in different disciplines and sectors, especially those related to health care [1]. This classification is increasingly being used as a clinical tool to evaluate health-related needs, to select appropriate management of specific health conditions, and to professionally evaluate and assess rehabilitation and its effects [8]. The level of complexity of the ICF (it has 1424 assessment categories) makes its application to general medicine difficult [9]. Several studies have been performed to facilitate the use of the ICF in caring for people with hearing loss. The results of these studies have led to the creation of core sets for hearing loss, which are lists of particular body functions and structures, forms of activity and participation, and external factors related to hearing impairment [10]. The ICF core sets for hearing loss can be found online [11].

In this paper, these core sets are used to describe audiological rehabilitation for CI users. The term ‘audiological rehabilitation’ is here defined as a problem-solving exercise aimed at reducing the negative effects of hearing loss by creating conditions conducive to activity and the restoration of full participation in everyday life situations [12]. A priority of audiological intervention is the provision of an appropriate hearing prosthesis to compensate for auditory function lost due to hearing loss [12]. Audiological rehabilitation must, however, also take advantage of other strategies that aim to increase an individual’s scope of activities and participation, e.g. perceptual training, counselling, and education. This understanding of audiological rehabilitation seems to be the most convergent with the functional model
of disability developed for the ICF. This paper describes the model of audiological rehabilitation for CI users based on the ICF classification.

3. Audiological Management After Cochlear Implantation

3.1. Body functions and structures

One of the consequences of sensorineural hearing loss is a period of sensory deprivation before cochlear implantation. This period may lead to changes in the organization of structures in the central nervous system (CNS) that are involved in processing auditory information. These changes could involve structures located in cortical structures (s110 (particularly in temporal lobe, s11001)), midbrain (s1101), diencephalon (s1102), brainstem (s1105), or vestibulocochlear nerve (s1106) [1]. While the extent of these changes is difficult to predict (because neuroplastic mechanisms are unique in each person), one should take into account that they may decrease a person's ability to process auditory information [13]. Thus, even in an ideal case of complete restoration of the biological function of hair cells via CI provision, problems with sensory information processing occurring at higher levels in the CNS could significantly limit a CI user's hearing ability/performance.

3.2. Functional assessment of auditory system structures

In order to effectively compensate lost auditory function with a CI, it is necessary to fit and optimize the parameters of electrical stimulation for each individual CI user. Stimulation parameters, such as electric charge, rate of stimulation impulses, and the position of a contact of the electrode array determine the amount and quality of sound information that is transmitted to the CNS, as well as the efficacy of auditory processing in the abovementioned CNS structures [14]. Stimulation parameters are fitted individually because the functional deficit of particular structures is different in each CI recipient [15].

3.3. Evaluation of structures of an implanted inner ear (s260)

Imaging (e.g. Stenver's X-Ray, CT-Scan, MRI, or Impedance Telemetry) can be performed to ascertain the position of the electrode array in the cochlea and the integrity of cochlear structures (s260). With computed tomography (CT) images it is possible to check if the position of the electrode array relative to the auditory nerve structures allows for effective electrical stimulation. Impedance telemetry (i.e. measuring the electric impedance of implanted electrodes) can be used to identify short circuits between the electrode contacts (low impedance) or damaged electrode-implant connections (high impedance) [16]. Analysis of impedance changes over time in the brain may provide information about pathologies which could significantly limit the ability to hear, e.g. fibrosis, cochlear ossification, or otitis interna [17].

3.4. Assessment of the auditory nerve (s260), brainstem (s1105), midbrain (s1101), diencephalon (s1102), and
Functional diagnostics of the auditory nerve are done based on the assessment of the *Electrically Evoked Compound Action Potential (EECAP).* This transmission happens by means of action potentials which are temporary changes in the neuron cell membrane potential [18]. EECAP arises as a neuronal response to an electrical impulse sent to the auditory nerve endings through the implant's electrode array.

*Electrically Evoked Auditory Potentials (EEAP)* are measured to monitor auditory information processing higher up in the brain. Potentials arising approximately 10 ms after electrical stimulation carry information about the function of brainstem and midbrain structures. Potentials arising after more than 10 ms carry information about the activity of the diencephalon and cortex [19]. In the auditory system, information is processed sequentially (information is first processed on a lower level then transmitted to a higher level), therefore an abnormal finding from a given structure may be indicative of a pathology within that structure, or of a deficit of auditory processing in preceding structures [2].

Knowledge of these features help in fitting the audio processor. Because the audio processor is a digital device, fitting of electrostimulation parameters involves appropriate programming [5]. Using a computer with specialist software and a user interface, electric stimulation parameters are programmed into the internal memory of the audio processor [16]. The set of parameters includes: current levels corresponding to the hearing threshold and comfort level of hearing sensation, the number of active electrode contacts, the speed of stimulation, the coding strategy, and the shape of the compression function. The combination of these parameters is termed a ‘programme’ [5, 16], and are used to fit audio processors. Recently, flat-based fitting methods, i.e. those which enable the audiologist to fit each channel simultaneously, have been developed (e.g. [20]); these may prove useful in fitting children.

### 4. Audiological Management After Cochlear Implantation – Helping Hearing Function

According to the ICF, hearing functions involve sound detection (b2300), sound discrimination (b2301), localization of the sound source (b2302), lateralization of sound (b2303), and speech discrimination relating to determining spoken language and distinguishing it from other sounds (b2304) [1].

#### 4.1. Sound detection (b2300)

To confirm a CI recipient's ability to correctly detect sounds with their CI, free-field pure tone audiometry is performed [5, 16]. If the CI recipient is a child, the appropriate methodology of this examination is determined by their chronological/developmental age. Auditory reactions of children younger than about 5 months may be evaluated using *Behavioural Observation Audiometry (BOA)* [2]. Visual Reinforcement Audiometry (VRA) is performed for children aged 5 m to 2 years. Children older than 2 years are capable (in most cases) to be assessed with Conditioned Play Audiometry (CPA) [2].
4.2. Sound source localization and sound lateralization (b2302, b2303)

The auditory system takes advantage of small differences in intensity or time of sound reception in each ear to locate the sound source. Thus, in order to compensate for the sound localization function and sound lateralization function in persons with profound hearing loss, is it necessary to implant them bilaterally [21]. As CIs transmit only a small amount of information relating to the intensity and temporal structure of the signal, sound localisation and lateralisation functions may only be partially compensated for with CIs [14]. In the case of adults with congenital unilateral deafness who lost hearing in the contralateral ear in adulthood, bilateral cochlear implantation will not restore sound localization or sound lateralization functions. This is due to the changes in the CNS organization that took place in the period of critical development of these functions due to unilateral sensory deprivation [22].

4.3. Speech discrimination (b2304)

CI users’ abilities to detect spoken language and understand its meaning are focal points of (re)habilitation. These abilities are generally assessed using monosyllabic word tests, disyllabic word tests, and sentence tests. These tests can take place in quiet or in the presence of background noise; with an open- or closed-set of answers; and with or without the use of a contralateral hearing aid (if users wear one). The choice of which sort of assessment is used is based on the individual CI user’s experience with a CI and abilities; the targeted skill (e.g. understanding speech in noise); and clinical preference. Many validated tools exist to this end, e.g. the Hearing in Noise Test (HINT) or the Freiburg monosyllabic word test (FMS).

A variety of tests exist for young children who cannot be assessed in the same way as adults, e.g. Common Objects Token (COT) test or the LitteARS Auditory Questionnaire (LEAQ).

Regarding “other sounds”, CIs users report that being able to hear and identify the (non-speech) noises around them is a major benefit of CI use [23]. Correctly recognizing environmental sounds is, however, difficult for both adult and paediatric CI users [24] and may not significantly improve even after months of CI use [25] so at least some CI users may benefit from targeted practice.

5. Audiological Management After Cochlear Implantation – Eliminating Activity Limitations

The ICF defines an ‘activity’ as the execution of a task or the undertaking of an action by an individual [1]. Based on the core sets for hearing loss [12], the activity limitations caused by a hearing impairment most often concern listening-related activities (d115) and the reception of spoken messages (d310). Handling stress and other psychological demands (d240) and using communication devices and techniques (d360) are crucial to counteracting the negative effects of a hearing impairment. The possibility of eliminating these activity limitations via CI use and auditory (re)habilitation is dependent on both the
degree of compensation for hearing functions and on external and internal contextual factors. These contextual factors will be discussed in following sections.

5.1. Listening (d115)

Directly after the activation of a CI system, many CI users find listening difficult, particularly in complex auditory environments, because of the lack of sound detection, sound differentiation, sound source localization, and sound lateralization. Therefore, perceptual training directed at discriminating and identifying environmental and speech sounds is recommended. In CI users with partial deafness, and who were able to detect low frequency tones before implantation, restoring the detection of high frequency tones may initially cause even larger listening difficulties [26]. This happens most often in the presence of external factors related to the occurrence of high frequency interfering sounds (such as clinking of cutlery or dishes). Auditory experiences which before cochlear implantation were restricted only to low frequencies may cause pathological changes of the auditory processing in the CNS. These pathologies can cause excessive auditory effort in situations when, after CI provision, processing high frequency sounds is necessary [27]. Prolonged effort may lead to exhaustion and a sense of mental effort in everyday situations.

Therefore, when selecting the parameters of stimulation during fitting, the audiologist must consider both compensation of hearing function and the necessity of preventing an excessive auditory effort, which could lead to serious difficulties in listening with a CI [16]. It is possible to reduce the auditory effort through proper training aimed at improving the biological function of processing auditory information in the CNS [28]. To prevent the auditory effort from restricting hearing activities, psychological counselling is also used to direct CI users towards the proper use of other body functions besides hearing, e.g. temperament and personality functions (b126), attention functions (b140), and emotional functions (b152) [12]. To optimize each CI user’s fitting and the auditory training and counselling they receive, it is necessary to monitor how their listening limitations change over time. These changes are determined using validated questionnaires for measuring listening limitations. Suitable questionnaires include the ABHAB questionnaire (the Abbreviated Profile of Hearing Aid Benefit) for adults and the LilIERS for children [29].

5.2. Receiving spoken messages (understanding) (d310)

Understanding spoken messages is one of hardest and most complicated cognition tasks related to the interpretation of sensory data for CI users. In order to accomplish this task, in addition to hearing, other psychological functions are activated: intellectual functions (b117), attention functions (b140), higher-level cognitive functions (b164), mental functions of language (b167), semantic memory of language functions (b1441), and short-term memory functions (1440) [30]. Because hearing functions are only partially compensated with a CI, the adaptation process should take proper advantage of the above-specified functions to optimise the speech understanding function [31]. The simultaneous involvement, sometimes bordering on overload, of all these functions in many situations leads to an excessive mental effort [32]. If a CI user is instructed to increase his/her awareness of why communication problems
persist even after CI provision and why it is impossible to eliminate all limitations in receiving spoken
messages, his/her participation in the rehabilitation process will be more informed and therefore more
efficient [33]. It is also necessary to provide counselling aimed at developing strategies to lower the
mental effort when receiving spoken messages [34]. Training higher level cognitive functions and short-
term memory functions is recommended to speed up and strengthen the adaptation processes directed at
utilizing the extra-auditory functions to increase speech understanding [35].

5.3. Handling stress and other psychological demands (d240)

CI users may benefit from learning strategies to manage stress, especially in first year after CI provision.
To achieve planned rehabilitation aims, it is necessity to introduce changes into CI users’ lives,
particularly regarding hearing activity and participation in verbal communication. Incomplete
compensation of hearing functions with a CI combined with old habits and communication strategies
that are inadequate to their new hearing situation may be a source of psychological burden. Another
source of psychological demands, most evident in the initial period after activation, is an excessive
listening effort. This is why it is necessary to apply different forms of psychological rehabilitation that
focus on the psychological functions and problems of a person with a disability [36].

5.4. Using communication devices and techniques (d360)

Rehabilitation includes training related to developing the ability to converse on the telephone while using
an audio processor [16]. Rehabilitation can also include training for appreciating/enjoying music [37],
singing [38], dancing [39], recognizing environmental sounds [24], and listening to audiobooks [40].

6. Audiological Management After Cochlear Implantation –
Eliminating Participation Limitations

The ICF defines ‘participation’ as involvement in everyday life situations [1]. The ICF core sets for hearing
loss include 5 life situations in which a person with a hearing impairment may encounter participation
problems: conversation (d350), family relationships (d760), school education (d820), remunerative
employment (d850), and community life (d910). Hearing impairment is the most often mentioned cause
of participation restrictions in these life situations [11]. Thus, in order to help people overcome
participation restrictions after CI provision, CI users should receive psychological and social rehabilitation
in addition to physical (medical) rehabilitation.

6.1. External contextual factors

Environmental factors refer to the physical, social, and attitudinal environments in which people live [1].
Following the ICF core sets for hearing loss, the external contextual factors that most influence the
activity and participation of an individual with hearing impairment are: sounds (e250), products and
technology for communication (e125), immediate family (e310), individual attitudes of immediate family
members (e410), societal attitudes (e460), health professionals (e355), and health services, systems, and policies (e580) [12]. Modelling an environment and working to eliminate activity and participation limitations encountered by CI users are necessary, although complex and difficult, tasks [41]. Firstly, audiological rehabilitation aims to model the environment on an individual level, i.e. the environment directly surrounding a CI user [1]. Sounds are a physical characteristic of this environment which may both facilitate and inhibit activity (e580). Sound perception is largely dependent on the audio processor fitting. Fitting an audio processor enables modelling of the environment through the modification of its physical impact on the implant user. Individual environment, according to the ICF, involves direct personal contact with other people (e310). Another basic method of influencing the environmental factors used in audiological rehabilitation is instruction and expert counselling. According to the principles of Evidence Based Medicine (EBM), information about the different aspects of CI use should be grounded in the results of scientific research, particularly when concerning the possible level of compensation of hearing functions and its deficits after cochlear implantation [16]. Understanding the limitations of compensation (e.g. problems understanding speech in noise) facilitates modelling the nearest environment such as home, school, or work through the modification of the attitudes of immediate family members (e410) and societal attitudes (e460) in such way as to make activity and participation easier for an implant user.

The social-level environment in audiological rehabilitation must also be considered [1]. This level involves elements such as health services, systems and policies (e580) and health professionals (e355). At each stage and level of working with a CI user, it is necessary to exchange information, coordinate activities, and take full advantage of all available resources. Activities related to audiological rehabilitation should involve shaping the appropriate relations and attitudes of all people engaged in this process. The relationships between the CI user, his/her immediate environment, and the representatives of a multidisciplinary rehabilitation team should be in line with the principles of Patient Oriented Care. Following the definition developed by the Institute of Medicine (IOM), this model of care involves close cooperation between the therapist and the CI user (and his/her family) at all stages of the auditory rehabilitation process [42]. An important element of this model is that the CI user is knowledgeable about CIs and is involved in the entire therapy process.

6.2. Internal contextual factors

Internal factors that influence an individual’s ability to overcome activity and participation limitations after cochlear implantation include age, the presence of additional health conditions, physical fitness, lifestyle, habits, coping styles, current life experience, overall behaviour patterns, character and psychological characteristics, as well as other individual factors which (together or separately) may play a role in hearing-related activities [1].

7. Conclusions

The International Classification of Functioning, Disability and Health (ICF) is a clinical tool that is suitable for assessing the needs of people after cochlear implantation. It can also be used 1) to select methods of audiological rehabilitation, which is a comprehensive management involving different forms of medical,
psychological, and social rehabilitation, and 2) to evaluate the effectiveness of rehabilitation. The next steps in our project are to determine the necessary components of ICF for cochlear implantation and then validate the tools we use in the ICF to make sure they are clinically applicable and can easily be used in daily clinical practise.

The IFC has allowed the development of a uniform language to describe health care after cochlear implantation. This common language facilitates communication between different specialists and health professionals, e.g. physicians, speech therapists, psychologists, educators, engineers, and researchers.

8. Abbreviations

ICF: International Classification of Functioning, Disability and Health

CI: cochlear implant(s)

EAS: Electric acoustic stimulation

SSD: single-sided deafness

CNS: central nervous system

CT: computed tomography

EECAP: Electrically Evoked Compound Action Potential

EEAP: Electrically Evoked Auditory Potentials

BOA: Behavioural Observation Audiometry

VRA: Visual Reinforcement Audiometry

CPA: Conditioned Play Audiometry

HINT: Hearing in Noise Test

FMS: Freiburg monosyllabic word test

COT: Common Objects Token

LEAQ: LittlEARS auditory questionnaire

ABHAB: Abbreviated Profile of Hearing Aid Benefit

EBM: Evidence Based Medicine

IOM: Institute of Medicine
9. Declarations

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**Figures**

![Diagram](image)

**Figure 1**

Relationship between the components of the ICF [1]