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Cochlear Implant in Children

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Abstract

With the introduction of the cochlear implant (CI) device, hearing sensation has been restored to many profoundly deaf children. In this article, we will review new issues in cochlear implantation including candidacy, bimodal and bilateral cochlear implant, music and speech perception, and vestibular system involvement in cochlear implant.

Abbreviations: IT-MAIS: Infant-Toddler version of the Meaningful Auditory Integration Scale; CI: Cochlear Implant; MAIS: Meaningful Auditory Integration Scale; FAPCI: functioning after Pediatric Cochlear Implantation; PBK: Phonetically Balanced Kindergarten; HINT-C: Hearing in Noise Test sentences for children; ITD: Interaural Time Differences; IID: Interaural Intensity Differences

Introduction

Approximately 1-3 out of 1000 newborns has some degree of hearing impairment [1,2]. With the introduction of the cochlear implant (CI) device, hearing sensation has been restored to many profoundly deaf children [3]. A cochlear implant is a small, complex electronic device. The implant consists of an external portion that sits behind the ear and an internal part that is surgically placed under the skin behind the ear and inside the cochlea. In December 2012, approximately 324,200 cochlear implant devices have been implanted worldwide [4].

The external parts of CI device include a microphone, a speech processor, and a transmitter. The microphone looks like a behind-the-ear hearing aid. It picks up sounds and sends them to the speech processor. The speech processor may be housed with the microphone behind the ear, or it may be a small box-like unit typically worn in a chest pocket. The speech processor is a computer that analyzes and digitizes the sound signals (based on a strategy) and sends them to a transmitter worn behind the ear. The transmitter sends the coded signals to an implanted receiver under the skin (via wireless connection).The receiver takes the coded electrical signals from the transmitter and delivers them to the array of electrodes that have been surgically inserted in the cochlea. The electrodes stimulate the fibers of the auditory nerve, and sound sensations are perceived [5].

Candidacy criteria

Cochlear implant candidacy criteria have changed since first approval by the FDA in 1985 for adults and in 1990 for children. Initially, only individuals with bilateral profound sensorineural hearing loss with no open set speech recognition were considered candidates for cochlear implantation. Over time, however, these criteria have become less strict and we are now implanting individuals with greater amounts of residual hearing and pre-implant speech recognition scores. Due to advancements in technology of the internal and external device, advancements in speech coding strategies, implanting children with more residual hearing and implanting children in younger age, speech recognition outcomes after cochlear implantation have been improves significantly overtime [6].

In cochlear implant candidacy several factors are important including audiometric threshold, speech recognition performance, age, auditory progress with hearing aids, and other factors. There are three approved cochlear implant companies in Iran market and many countries: Advanced Bionics, Cochlear, and Med El. There is a slight difference among them in terms of implantation candidacy criteria [7]. In terms of audiometric threshold, for children aged 12 to 24 months, children with bilateral profound sensorineural hearing loss with limited benefit from binaural amplification (trial period of 3 to 6 months with full time device usage and intervention) are candidates of CI [8,9]. It is important to note that this indication does not mean that children with less severe hearing loss do not benefit from cochlear implants. During the hearing aid trial, children should have at least month-to-month auditory progress and speech and language developmental progress. If it is not happening for a child even with full-time use of amplification and appropriate intervention, then a cochlear implant should be considered [7].

Auditory skills are generally assessed by using parental history and validated questionnaires designed to search for auditory-based reaction and response to speech and sounds in a child's environment. One of the most frequently administered questionnaires used for children from birth to 3 years is the Infant-Toddler version of the Meaningful Auditory Integration Scale (IT-MAIS). All three cochlear implant manufacturers reference the MAIS and/or IT-MAIS for use in determining auditory progress with amplification [7,10-12]. There are also a number of other parental questionnaires that can be used to assess infants and toddlers' responses to auditory stimuli, including LittlEars auditory questionnaire, Functioning after Pediatric Cochlear Implantation (FAPCI) questionnaire, Functional Auditory Performance Indicators and the Early Listening Function questionnaire [12]. Of course, implant candidacy cannot be based only on the results of auditory questionnaires. Speech and language evaluations by speech/language pathologists are critical, as well. In addition, regular therapy (auditory training) should be considered a part of the hearing aid trial for all children being seen for implant evaluations [7,13].

Children between 2-17 years old with bilateral severe-to-profound sensorineural hearing loss are candidates for CI. Again, if a child has less severe sensorineural hearing loss and shows no auditory progress with full-time use of well-fitted hearing aids and appropriate intervention, referral for a cochlear implant evaluation is appropriate [7]. As is the case with infants and toddlers, assessment of auditory skills for preschool-aged children cannot always be well predicted by the audiogram. Behavioral assessment of auditory skills, including speech recognition skills, is necessary. Due to a number of potential factors, speech recognition testing may not be possible; therefore, there are also a number of validated auditory questionnaires for preschool children. Some of the more popular questionnaires include the MAIS, PEACH (Parents' Evaluation of Aural/Oral Performance in Children), and the FAPCI [7,14].

The determination of cochlear implant candidacy for older children is generally based upon either mono- or multi-syllabic word recognition. The speech recognition materials that are specifically used include the Multisyllabic Lexical Neighborhood test and the Lexical Neighborhood Test, the Phonetically Balanced Kindergarten (PBK) word recognition test, and Hearing in Noise Test sentences for children (HINT-C) [15,16].

The device selected for an individual patient depends on several factors including the center at which the patient is followed and the preference of the surgeon and recipient. Some centers offer cochlear implant candidates a choice of devices from all three major manufacturers whereas other centers may offer only one or two different cochlear implant systems. Typically, device selection is made by the patient in consultation with the surgeon. With current cochlear implant technology, cochlear implant outcomes are similar across devices from all three manufacturers [17].

No significant differences in performance are evident for children implanted before age 5 compared to children implanted after age 5 on closed-set tests of speech perception ability. All children demonstrated an improvement in performance compared to the pre-operative condition. Open-set word recognition performance is significantly better for children implanted before age 5 compared to children implanted after age 5 at the 36-month test interval and the 48-month test interval [18]. Children who receive a cochlear implant before the age of 5 show greater benefit in their speech production skills than children who are older, at least after a minimum of 2 years of using CI [19].

Speech perception in noise

CI users report problems in understanding speech in noise and working on this problem is an important step toward improving CI users' performance in noisy listening conditions. Even with the latest technology, the speech recognition of CI listeners is more susceptible to background noise than that of normal-hearing listeners, especially when the interfering sound is competing speech or temporally modulated noise [3,20]. Regardless of the type of noise (e.g., steady-state or modulated), CI users' speech recognition in noise is negatively affected by the loss of spectro-temporal fine structure caused by the limited number of electrodes and spectral channels in the speech processing strategy. Fewer numbers of channels degrade the spectral resolution, and speech recognition becomes difficult in noise [3].

Severely-to-profoundly hearing impaired adults may benefit from combined fitting of implants and conventional hearing aids in opposite ears [21]. A cochlear implant in one ear and a hearing aid in the other ear can provide binaural advantage [22]. Furthermore, results of the Cueing the Listener test suggest that listeners with two cochlear implants are better able to quickly identify where a sound is coming from in comparison to a listener with only one implant. This could be due to a greater ability to take advantage of localization. The results of the Cognitive Load test suggest that listeners with two cochlear implants are

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presumably better at processing speech while attending to other simultaneous tasks, perhaps because they are able to segregate the signal from the background noise [23,24].

Music perception

Implant users claim that music is the second most important acoustic stimulus in their lives right after speech stimuli, and most implant users find that music does not sound good on their device. One of the fundamental elements of music is pitch. A complex tone is a set of simultaneously occurring acoustic sine waves usually having a harmonic relationship with each other. The frequency of complex tones is perceived as pitch by the human ear. Pitch perception is happening by two mechanisms: place of excitation in cochlea and temporal pattern of neural activity. The processors take the acoustic input via a microphone, divide the input into a set of frequency channels, extract the temporal envelope of the acoustic wave in each channel, and deliver that temporal envelope into the cochlea with a fixed-rate sequence of biphasic electrical pulses.

The fine timing also known as the "fine-structure" of the sound waves is largely lost in the process. Typically, cochlear implant users can only hear repetition rates up to about 300 Hz. Thus, much of the fine-structure that could be used to encode pitch is absent [25]. The dynamic range in electric hearing is also highly limited. In normal hearing, the dynamic range is as much as 120 dB. In electric hearing, it can be as little as 10 or 20 dB, owing primarily to the high degree of neural synchrony created by electrical stimulation and the lack of spontaneous activity in the deaf cochlea. One aspect of music perception is rhythm. Coding of the temporal envelope in the implant will encode rhythm. This feature is quite good in CI partly because of the high degree of synchrony between the electrical impulse and the nerve firing [25].

Acoustic-electrical (bimodal) combination

Combined electrical and acoustical speech processing gain improved word understanding as compared with their preoperative hearing with bilateral hearing aids and a group of individuals receiving a standard cochlear implant [26,27]. The improvement of speech in noise and melody recognition is considered to happen because of the ability to distinguish fine pitch differences as the result of preserved residual low-frequency acoustic hearing. Preservation of low-frequency acoustic hearing is important for improving speech in noise and music appreciation for the hearing impaired subjects [27].

A simulation experiment in normal-hearing subjects demonstrated a clear advantage for preserving low-frequency residual acoustic hearing for speech recognition in a background of other talkers, but not in steady noise [28-30]. Studies provide strong preliminary support for retaining residual low-frequency acoustic hearing in cochlear implant patients. The results are consistent with the idea that better perception of voice pitch, which can aid in separating voices in a background of other talkers, was responsible for this advantage [30].

Bilateral cochlear implant

The ability of a listener to communicate and navigate successfully in everyday environments depends on his/her sensitivity to binaural information. The two primary binaural cues that make it possible to localize sound sources, and detect and/or understand speech in noise in typical listening situations are intensity differences in the signals reaching the two ears (interaural intensity differences=IID) and differences in time of arrival of signals in the two ears (interaural time differences=ITD). Patients who are not able to process these binaural cues have difficulties localizing sound sources, detecting and understanding speech in noisy situations [31].

The results of speech audiometry showed that children reached a higher word discrimination scores in quiet with both CI compared to one CI. There was a significant improvement in speech discrimination abilities in noise with the bilateral condition compared to the unilateral condition. Bilateral CI has positive effects on the children's communicative behavior. In addition to these data, the subjective evaluation of the children themselves and their parents indicated a positive effect of binaural hearing with two CIs [23,31]. Important benefits are available from bilateral implantation, both for localizing sounds (in quiet) and for listening in noise when sources of the signal and noise are spatially separated. Studies show that effects of interaural timing cues are weaker than those from interaural level cues and rely on the availability of low-rate information below a few hundred Hz [32].

Cochlear implant and Vestibular involvement

Despite the great effect of CIs on hearing, it may have some adverse effects on the vestibular system. In fact vestibular function might be impaired in some cases following CI. This may be due to damage to the vestibular receptors during traumatic insertion of the electrode into the cochlea. The saccule appears to be the most commonly affected organ [33]. Vestibular dysfunction may affect patients' ability to form an accurate environmental percept and may affect balance. It seems that cochlear implant surgery did not have any significant effect on vestibular function at least in children younger than 5 years old and it may be concluded that round window CI surgery might not have any disturbing impact on vestibular function in children. However, further studies should be performed to confirm the results [34]. There are many reports show that cochlear implant can make potential damage to vestibular system [35-37].

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