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SPECIAL TOPIC

Cochlear Implant Innovations

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ABSTRACT

Extensive research has improved cochlear implant technology in a number of aspects. New coding strategies are important for better speech understanding and music appreciation. Devices can be implanted in obstructed cochleas due to specially designed electrodes. Hybrid devices permit hearing preservation at the low frequencies which can be amplified with the use of a hearing aid. Criteria for cochlear implant candidacy have been expanded from profound to severe sensorineural hearing loss. It is important for Otolaryngologists to be apprised of these advances in cochlear implant technology in order to provide patients with the best options for hearing loss rehabilitation.

KEY WORDS: *cochlear implants; deafness; hearing loss; hearing aid; aided hearing*

List of abbreviations

ABI = auditory brainstem implant
dB = decibels
HRCT = high resolution computed tomography
MRI = magnetic resonance imaging
NF 2 = neurofibromatosis type 2

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INTRODUCTION

Cochlear implants, as we know them now, are the result of extensive research over the last four decades. The first attempt to stimulate the auditory system electrically began in the late 18th century by Alexandro Volta but it was not until 1957 that Djourno and Eyries provided the first detailed description of the effects of directly stimulating the auditory nerve in deafness. Since then there has been great progress in cochlear implant technology, triggering the acceptance of implants. Over 100,000 people who had profound or severe hearing impairment can now hear thanks to this technological marvel.[1]

In normal individuals sound waves are transmitted through the ear canal to the ear drum which in turn vibrates the ossicular chain, consisting of the hammer, the anvil and the stapes. When the latter vibrates, sound is transmitted through the oval window to the fluids of the cochlea. Sound waves start the motion of the hair cells of the basilar membrane which triggers electrical responses in the auditory nerve. Electrical impulses travel through the auditory nerve to auditory areas of the brainstem and auditory cortex. Sensorineural hearing loss occurs when the sensory cells of the cochlea or the auditory nerve fibers are dysfunctional. With a cochlear implant, sound is transmitted directly to the auditory nerve, bypassing the sensory cells of the cochlea.

COCHLEAR IMPLANT FUNCTION

The cochlear implant provides a direct stimulation of the residual spiral ganglion cells of the cochlear nerve by bypassing the destroyed hair cells. It consists of numerous parts, the knowledge of which is essential for understanding this complex device. The speech processor, a microphone placed behind the ear and worn like a hearing aid and a transducer coil, which transfers the acoustic signal form the external part of the cochlear implant. The internally implanted component includes the receiver coil and an electrode array into the cochlear lumen (Fig. 1 & 2). The sound waves received by the external microphone are transformed into electric signals, which are encoded by the speech processor and then transmitted as electromagnetic waves across the skin to the receiver. These radio waves are converted into electric signals to stimulate the electrodes of the implant which excite spiral ganglion cells or axons within the cochlea.

Cochlear implant technology has developed rapidly since devices with multiple electrodes first came into widespread use 20 years ago. Advances are continuing to occur in many aspects of implant design and application.

CANDIDACY CRITERIA

Not all individuals with sensorineural hearing loss are eligible for cochlear implantation. Only those who cannot benefit from hearing aids are considered appropriate candidates. They must also fulfill a number of criteria such as bilateral hearing loss, high motivation and realistic expectations (Table 1).[2-4] The US Food & Drug Administration (FDA) granted approval of multichannel cochlear implants for adult patients in 1985 and for pediatric patients in 1990.[3]

Many factors influence the outcome of cochlear implantation. Selecting patients who are appropriate candidates for cochlear implantation is one of the most important steps. Patients being considered for implantation have to go through extensive preoperative assessment, in order to ensure that they will benefit from it (Fig. 3). In recent years we encountered new challenges when implant candidacy expanded from profound (>90 dB) to severe hearing loss (70-90 dB). Patients who are now widely considered good candidates are adults with severe hearing impairment and open sentence discrimination, that is less or equal to 30 percent in the best aided condition.[2] These new criteria have given patients the opportunity to improve speech perception by substituting residual natural hearing for a cochlear implant. Gifford et al, in a study on postoperative speech perception performance, support that a reassessment of audiologic candidacy criteria for adults is warranted, to allow more hearing impaired individuals to benefit from cochlear implantation.[3]

HEARING PRESERVATION

Hybrid devices are a combination of a cochlear implant and a hearing aid. They give the opportunity to preserve hearing at the low frequencies, which can be amplified using a hearing aid in the same or the opposite ear.[5] Electrode arrays from 10 to 20 mm are inserted in the scala tympani without damaging the apical cochlear structures. Following a short electrode array insertion there is a mean hearing loss ranging from 10 to 20 dB.[6] Outcomes using bimodal stimulation have shown improved results regarding music comprehension. Benefit of bimodal stimulation has yet to be established, but up to the present time it appears possible to preserve low frequency hearing with short electrode implantation.[7]

Photo courtesy of Cochlear, Ltd.

FIGURE 1. Receiver coil and electrode array.

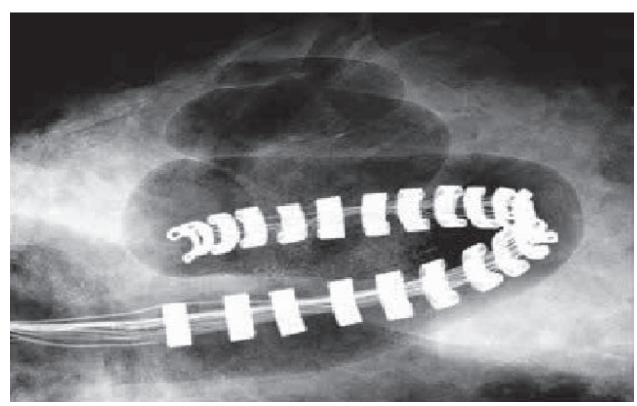

FIGURE 2. Electrode array inside the cochlear lumen.

TABLE 1. Candidacy Criteria for a Cochlear Implant

Postlingual adults
• Severe sensorineural hearing loss >70 dB
• Speech discrimination <40% /
• No benefit from hearing aids
Prelingual adults
• The same as with postlingual adults, but also development of
• Oral communication and
• Lip reading
Prelingual children
• Severe to profound sensorineural hearing loss
• Cochlear nerve present
• No benefit from hearing aid trial for 3 months
• Adequate family support
• Motivation with realistic expectations

Sensorineural hearing loss >70 dB
Speech discrimination with hearing aids <40%

↓

Hearing aid trial 3-6 months

↓

No benefit

↓

CT/MRI (patent cochlea, normal VIII nerve)

↓

Speech therapist assessment

↓

Phsychiatric assessment

↓

Cochlear implantation

FIGURE 3. Approach to cochlear implantation; CT = computed tomography; MRI = magnetic resonance imaging.

PREOPERATIVE IMAGING OF THE TEMPORAL BONE

Modern radiology techniques are important in the field of cochlear implants. Preoperative assessment includes careful imaging of the temporal bone. Anatomic variations of the VIII nerve, the sigmoid sinus or the carotid artery have to be ruled out. The internal auditory meatus has to measure more than 2 mm, otherwise one has to consider the possibility of congenital aplasia or hypoplasia of the acoustic nerve. Furthermore, the presence of a cochlear nerve has to be confirmed by magnetic resonance imaging (MRI).[8] High resolution computed tomography (HRCT) can also demonstrate obliteration of the cochlear lumen. In the event of an occluded cochlea, insertion of the electrodes may not be feasible, or special techniques may be necessary. Therefore, it is important for the surgeon to be aware, preoperatively, of any such structural abnormality.

Recent developments in imaging techniques that use submillimeter HRCT are of great importance in preoperative assessment of cochlear implant candidates. Sections of 0.5-1 mm thickness are important for accuracy of cochlear patency assessment. Equally important is the experience of the radiologist regarding the specific issues that arise from cochlear duct occlusion.[9] Magnetic resonance imaging is considered more sensitive and specific in diagnosing soft tissue abnormalities in a cochlea in comparison with HRCT.[10]

COCHLEAR OBSTRUCTION

With improving surgical techniques and specially designed electrodes many more patients have become acceptable candidates for implantation despite cochlear obstruction. The Nucleus® double array (Cochlear AG, Basel, Switzerland) is a cochlear implant that was designed for the obstructed cochlea, in which two different electrode arrays are being placed through a cochleostomy at the basal turn and at the second turn,[11,12] based on the belief that speech recognition is correlated with the number of activated electrodes. MED-EL (Durham, NC, USA) also marketed a split electrode array for obstructed cochleas. Surgical techniques that can allow the insertion of the electrodes in an obstructed cochlea include: i) drill out of the basal turn, ii) scala vestibuli insertion, and iii) double array. Results in auditory performance are below average after drill-out of the basal turn and remain to be evaluated as far as double array is concerned.[13]

AUDITORY BRAINSTEM IMPLANTS

Patients that cannot be implanted because they do not have an intact auditory nerve, such as patients afflicted by neurofibromatosis type 2 (NF2), can alternatively have an auditory brainstem implant (ABI). This kind of implant stimulates the surface of the cochlear nucleus in the brainstem. Although the ABI provides improvement in environmental awareness and lip-reading capabilities, only a few NF 2 patients have achieved some limited open set speech perception.[14] Colletti[15] supports that improvement in cognitive parameters with ABI is due to the activation of the auditory sensory canal, which was previously absent. Speech perception is possible in ABI patients, although results are poor in NF2 patients where only a small percentage have proved capable to understand speech.[16] Surgery for ABI has a very low major complication rate, making it a safe procedure when performed by an experienced surgical team.

CODING STRATEGIES

The developments which have occurred and mostly benefit cochlear implant users are related to new coding strategies which improve speech in noise recognition and music appreciation. Cochlear implants were designed to enable good speech perception when speech is presented in quiet but are not as successful in delivering speech in noise or in understanding music.

In order to understand why cochlear implants cannot encode music well, it is important to understand how the normal auditory system encodes music. Basic elements of music are pitch, timbre and rhythm. There has been debate how pitch is being encoded, whether the encoding is spatial or temporal. The first theory supports that tones of different frequency are encoded at different places in the cochlea, whereas the temporal theory alleges that repetition rate establishes a pitch. According to Licklider[17] both theories have merit.

The encoding of complex tones relies on repetition rate of the acoustic wave. In the cochlear implant the processor takes the acoustic signal, divides it into different frequency channels, extracts the temporal envelope, and delivers it through a fixed rate of electrical impulses. In this way the fine structure is lost in the process. Cochlear implant users have a maximum repetition rate of 300 Hz, making the fine structure insufficient to encode pitch.

Other factors affecting quality of sound is that the electrodes stimulate a population of nerve fibres which is different than a specific hair cell exiting a single neuron. Timbre is perceptual quality of a sound that differentiates it from other sounds having the same pitch and loudness. Cochlear implant users have a limited capacity to discriminate different musical instrument timbre.

Another factor that limits music perception is the fact that the dynamic range in electric hearing is 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, due primarily to the high degree of neural synchrony created by electrical stimulation. Thus, increasing the dynamic range in electric hearing could improve hearing by providing better resolution of the dynamically varying range of levels in both the spectral and temporal domains.

The final aspect of music perception is rhythm. Coding of the temporal envelope in the implant, which would encode rhythm, is quite good. Shannon has found that the discrimination of timing events in cochlear implant recipients is nearly normal.[18]

Recent research is focused on improving the ability of cochlear implant users to discriminate speech in noise and to enjoy music. Different laboratories have used various approaches to improve music appreciation. These include "current steering," MP3-like processing and 100-percent amplitude modulation across channels at the fundamental (lowest) frequency (F0).[1] Current steering uses simultaneous activation of neighbouring electrodes, increasing the number of pitch percepts which improves music perception.[19] This is possible with the Advanced Bionics HiRes® Fidelity 120® cochlear implant (Advanced Bionics LLC, Valencia, CA, USA) and this could aid music appreciation, although objective clinical findings still have to be documented. Speech perception in noise can also be improved with targeted auditory training which has been shown to enhance performance gains provided by new implant devices and/or speech processing strategies.[20]

BILATERAL COCHLEAR IMPLANATION

Recent studies are evaluating benefits of bilateral cochlear implanation. For normal hearing people rely on two ears for sound localisation and speech understanding in noise, whereas cochlear implant users have difficulty locating sounds in their environment. There are accumulating data that show benefits of bilateral cochlear implanation in speech understanding both in quiet and in noise. The average score across subjects for sentence understanding was 31.1 percentage points higher with both cochlear implants compared with the cochlear implant ipsilateral to the noise.[21] Shon et al demonstrated a 4-dB gain in signal to noise ratios at the speech reception threshold in bilateral cochlear implant users.[22] Results with regards to sound localisation show significant advantages from wearing two devices compared with a single device.[23]

CONCLUSION

Developments in cochlear implant technology have been remarkable and have improved sound perception for cochlear implant users, having a highly positive impact on their lives. Still many of these innovations have to be evaluated in clinical trials in order to prove their efficacy.

REFERENCES

1. Drennan WR, Rubinstein J T. Music perception in cochlear implant users and its relationship with psychophysical capabilities. *J Rehabil Res Dev* 2008;45:779-789.

2. NIH Consensus Statement. Cochlear implants in adults and children. *NIH Consens Statement* 1995;13:1-30.
3. Gifford RH, Dorman MF, Shallop JK, Sydlowski SA. Evidence for the expansion of adult cochlear implant candidacy. *Ear Hear* 2010;31:186-194.
4. Gifford RH. Who is a cochlear implant candidate? *Hear J* 2011;64:16-22.
5. Gantz BJ, Turner C, Gfeller KE, Lowder MW. Preservation of hearing in cochlear implant surgery: advantages of combined electrical and acoustical speech processing. *Laryngoscope* 2005;115:796-802.
6. Gifford RH, Dorman MF, Spahr AJ, Bacon SP, Skarzynski H, Lorens A. Hearing preservation surgery: Psychophysical estimates of cochlear damage in recipients of a short electrode array. *J Acoust Soc Am* 2008;124:2164-2173.
7. Kong YY, Cruz R, Jones JA, Zeng FG. Music perception with temporal cues in acoustic and electrical hearing. *Ear Hear* 2004;25:173-185.
8. Marsot-Dupuch K, Meyer B. Cochlear implant assessment: Imaging issues. *Eur J Radiol* 2001;40:119-132.
9. Frau GN, Luxford WM, Lo WW, Berlineri KL, Telischi FF. High-resolution computed tomography in evaluation of cochlear patency in implant candidates: a comparison with surgical findings. *J Laryngol Otol* 1994;108:743-748.
10. Phelps PD. Fast spin echo MRI in Otology. *J Laryngol Otol* 1994;108:383-394.
11. Roland JT Jr, Coelho DH, Pantelides H, Waltzman SB. Partial and double-array implantation of the ossified cochlea. *Otol Neurotol* 2008;29:1068-1075.
12. The Nucleus double array cochlear implant: A new concept in the obliterated cochlea. *Laryngootologie* 1999;78:421-428.
13. Lenarz T, Buchner A, Tasche C, et al. The results in patients implanted with the Nucleus double array cochlear implant: pitch discrimination and auditory performance. *Ear Hear* 2002;23(1 Suppl):90S-101S.
14. Lenarz T, Lim H, Joseph G, Reuter G, Lenarz M. Central auditory prosthesis. *HNO* 2009;57:551-562.
15. Colletti L. Beneficial auditory and cognitive effects of auditory brainstem implanation in children. *Acta Otolaryngol* 2007;127:943-946.
16. Colletti V, Shannon RV. Open set speech perception with auditory brainstem implant? *Laryngoscope* 2005;115:1974-1978.
17. Licklider JC. Auditory frequency analysis. In *Cheny C (ed): Information Theory*, Academic Press, New York 1956, pp. 253-268.
18. Shannon R. Psychophysics. In *Tyler RS (ed): Cochlear implants: Audiological Foundations*. Singular Publishing Inc, San Diego (CA), 1993, pp. 357-389.
19. Firszt JB, Koch DB, Downing M, Litvak L. Current steering creates additional pitch percepts in adult cochlear implant recipients. *Otol Neurotol* 2007;28:629-636.
20. Fu QJ, Galvin JJ 3rd. Maximizing cochlear implant patients' performance with advanced speech training procedures. *Hear Res* 2008;242:198-208.
21. Müller J, Schφn F, Helms J. Speech understanding in quiet and noise in bilateral users of the MED-EL COMBI 40/40+ cochlear implant system. *Ear Hear* 2002;23:198-206.
22. Schön F, Móller J, Helms J. Speech reception thresholds obtained in a symmetrical four-loudspeaker arrangement from bilateral users of MED-EL cochlear implants. *Otol Neurotol* 2002;23:710-714.
23. Litovski RY, Johnstone PM, Godar SP. Benefits of bilateral cochlear implants and/or hearing aids in children. *Int J Audiol* 2006;45(Suppl 1):S78-S91.