Cochlear Implant—Update


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Abstract: In recent year, cochlear implant (CI), which allows the deaf to acquire hearing, is being increasingly adopted as a new medicine in Japan as well. Cochlear implant is indicated for sensorineural hearing loss due to cochlear disorder. Information by speech is converted to electric signals to stimulate the auditory nerve with electrode array in the cochlea. On an average, 70–80% of speech has been recognized by the deaf who lose hearing after the period of speech acquisition postoperatively, and favorable results have been obtained among children, who have been implanted in early age of life. The advances in cochlear implant include miniaturization of the implantable part and improvement in a speech processor to the wearable type behind his/her ear(s). The coding strategy of speech signals also diversifies. In addition, the lowering of age for indication was also conducted in 1998 in Japan: children more than 2 years of age were included as candidates for the implantation. In Japan as well, auditory brainstem implant (ABI) was initiated for the treatment of hearing loss due to surgery for bilateral acoustic neurinoma. In the future, indications of CI will increase considerably by improvement in the device and contribution of speech auditory therapist to the medical care of CI users.

Key words: Cochlear implant; Indication; Advance in device; Postoperative result; Brainstem implant

Introduction

Multi-channel cochlear implant is being increasingly adopted in recent years, as a therapeutic method for patients with severe sensorineural hearing loss. Even the deaf become to understand speech via CI. At present the new medical treatment is globally being adopted, and it has been introduced to Japan for more than 10 years, and at least 1,400 cases at more than 50 approved institutes have been conducted.

In this article, general concept of the new medicine is briefly introduced, with reference to the recent advances in CI device, change of criteria for indications and future of CI.

The Principles of Cochlear Implant

Most cases of sensorineural hearing loss may be caused by a disorder of Corti’s organ in the cochlear where sounds are converted
to nervous impulses. Therefore the spiral ganglion of cochlear is directly stimulated with the electrode of CI to produce auditory sensations at the auditory cortex. Several devices developed in Australia, United States, France, and Austria have common principles as follows.

Cochlear implant is composed of extracorporeal and intracorporeal parts. The intracorporeal part includes an antenna for receipt of extracorporeally processed information, the transmitter linked with the antenna, and the electrode to be placed in the cochlear at the end of the transmitter. On the other hand, the extracorporeal part to convert speech sound into electric signals and transmit it to the intracorporeal part is composed of a microphone for signal receipt, a speech processor and a coil to transmit signals to the intracorporeal antenna (Fig. 1). The speech processor which is regarded as “the heart” of CI decides the way how and which electrode is turned on electrically. There are systems of coding strategies, as will be described later.

**Postoperative Results**

The outcome in speech understanding after the surgery depends on the age of hearing loss. The postoperative results in the people who lost hearing before speech acquisition (prelingual deaf) are much different from those in the people who lost hearing after speech acquisition (postlingual deaf). In case of prelingual deaf, the results vary with the time when the implantation is conducted; the people treated before school age, which is believed to be the critical period of neural plasticity, show much better speech understanding than those treated after adolescence. In general, postlingual deaf people can understand approximately 80–100% of vowel and approximately 40–60% of consonant syllables after the operation, and overall understanding of speech reaches 70–80%. The prelingual deaf people treated after adolescence, however, show poor discrimination of consonant syllables and speech understanding is generally poor, although they can understand vowel relatively well. On the other hand, the prelingual deaf people treated in their childhood, show improvement in understanding of speech with time. The postoperative speech understanding in children aged 2–3 years may be favorable, although they develop speech slightly retarded than that in normal children.

**Advances in Cochlear Implant Device**

Representative CI which are currently used over the world include Nucleus CI (Cochlea Inc., Australia), Clarion CI (Advanced Bionic Inc., USA), Combi 40 CI (Medel Inc., Austria), and so on. In Japan, only the CI with 22 channels (Cochlea Inc.) has been conventionally used. Its improved type, Nucleus 24 and Clarion (Advanced Bionic Inc.) are going to be used in Japan as well in the near future.
A dvances in CI include improvement in the device and the widening in the indications for implantation. Cochlear implant device has also advanced both in terms of hardware and of software as follows.

1. Advances in hardware of cochlear implant

The implantable part of CI is needed to be miniaturized, because the device must be kept in the thin temporal bone of child without compression to the dura. In several types of CI, as well as Nucleus 24, the part has already been miniaturized to 1/3 or 1/2 in size of the conventional one. Electrode has also been improved; it is divided into two, and one of them can be placed in the second turn of cochlear. In Clarion device self curling electrode array in the scala tympani will become closer to the spiral ganglion, with a silicone positioner, placed outside the electrode. These improvements in CI are believed to lead to improvement of speech understanding via CI. Miniaturization of speech processor to the wearable type behind his/her ear(s), have already become to practical use. In the future, CI is to be improved to the ear-insertion type or the type in which all parts of device are implanted (whole implantable type).

2. Advances in the software of cochlear implant

Audio signals input into CI are encoded by speech processor as follows. At present, however, there have been no marked differences in the outcome of speech understanding among them.

(1) SPEAK method

The 22-channel CI (Cochlea Inc.) was improved to SPEAK in 1995; on an average, 6 signal components with high energy are extracted from the speech sound. The CI is being changed to CI 24 system that can be operated by the continuous interleaved sampling (CIS), which will be described in the following. In the future, the CI is to take a coding strategy called advanced combination encoders (ACE), which has both characteristics of SPEAK and CIS method.

(2) CIS

In this method, any characteristic of speech sound is not extracted, but audio waveforms are reproduced and input by click processions. Speech signals are separated with a filter of about 8 bands and converted to square waves. Thus, audio waveforms become biphasic click processions, to be transmitted without interference among electrodes. In this method frequent stimulation more than 1,000 times/sec is possible. The method is being adopted to Combi 40 and Clarion.

(3) Analogue stimulation method

In the Clarion system, the analogue stimulation method as well as CIS, can also be selected. In this method, signals input are divided into several frequency bands through the filter, and stimulated by compressing the dynamic range, so that the auditory nerve will be able to react. Interference between the electrodes has been minimized, allowing the simultaneous input of analogue waveforms.

Increase in the Indications for Cochlear Implant

1. Pediatric cases

The indications for CI in Japan were restricted to postlingual adults more than 18 years of age. In April 1998, however, the new criteria for indication including pediatric cases, were established; children more than 2 years of age were included as candidate for the implantation (Table 1). In the pediatric case, however, the hearing threshold is more restricted than in adults; severe hearing loss more than 100 dB, and non-effectiveness of hearing aid observed for a certain period. Contraindications for the implantation include no space for the electrode in the cochlear on any CT or MRI image, and severe mental retardation. The number of operation in the world using the Nucleus CI has been reached...
to 21,067 cases as of February 1999, and 9,925 (ca. 47%) of them were pediatric case (Fig. 2). The proportion of pediatric cases in Japan, however, still remains low, ca. 14%.

The lower limit of age for the indications is 12 months in the U.S., while 6 months in Germany. As a result, it has been confirmed that the case, which receives the CI at low ages, showed significant development of normal speech as compared with other cases. In Japan as well, the age for the operation may tend to be younger in the future. On this occasion, it is important to establish the system of early hearing screening and evaluation of the accurate threshold of hearing loss. The project of mass screening for deafness in neonates has started in Japan as well. In the near future, selection of an appropriate method to acquire hearing including CI will be conducted. In Germany, along with the project of younger implantation, bilateral implantation has been confirmed to improve understanding of speech considerably.

2. Adult cases

In the present criteria for the indications, a special note that prelingual adults have a handicap in hearing of speech, and the CI before school age was recommended. In adult cases, CI becomes a so-called boon for people who have hearing loss after acquisition of speech. In the prelingual deaf people, however, the neuron networks in the brain for recognition of speech remains undeveloped, and they can not understand speech although they feel sounds with CI. Consequently, future important tasks would be criteria for indications, including age factor, from the viewpoint of critical period of neural plasticity, and innovations in rehabilitation for

### Table 1 Criteria for the Indications for Cochlear Implant (Established by the Japanese Society of Otorhinolaryngology in April 1998)

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<tr>
<th>I. Infantile cases</th>
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<tr>
<td>1. Age: More than 2 years of age and less than 18 years of age. The operation before school age in congenital deafness (prelingual deafness) is recommended.</td>
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<td>2. Hearing level and the effectiveness of hearing aid: Bilateral severe hearing loss more than 100 dB and slight effectiveness of hearing aid. When hearing aid is little or hardly effective either in speech understanding or speech expression during the sufficient observation period, CI is indicated.</td>
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<td>3. Contraindications: The case, which has no space for CI in the cochlear on images (CT, MRI). Cochlear malformation or ossification is not necessarily included in the contraindication. Other contraindication include active otitis media, severe mental retardation, auditory central disorder, and other severe physical complications.</td>
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<td>4. Rehabilitation and educational supports: Understanding and agreement of CI by patient’s and family members are essential. Rehabilitation, special staff for education (speech auditory therapist), and facilities are also required. It is also desirable that understanding and cooperation by ambulatory facilities and facilities for auditory education are obtained.</td>
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<th>II. Adult cases</th>
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<tr>
<td>1. Age: More than 18 years of age.</td>
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<tr>
<td>2. Hearing level and the effectiveness of hearing aid: Bilateral severe hearing loss more than 90 dB, and slight effectiveness of hearing aid. The effectiveness of hearing aid should be evaluated with reference to the averaged results of speech discrimination by CI users (consonant syllable discrimination test, monosyllable test on the 57-word list, test for repetition of words and sentences, etc.).</td>
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<tr>
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<td>4. The patient’s will and the circumstance’s support: The patient’s and the family members’ will and understanding of CI are required.</td>
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Additional remarks

1. The results of promontory test is used just for reference.

2. In adult patients with congenital hearing loss, it must be necessary to make them to understand the poor effectiveness of the implantation in terms of speech understanding and the possibility to become non-user of the device. It is also necessary for the patient to have much will to use CI.
speech development.

In the aged person, indications for CI as a substitute for a hearing aid will increase. Severe sensorineural hearing loss including senile hearing loss are characterized by the lower intelligibility of speech sounds than pure tone. When hearing aid becomes useless due to progression of deafness, CI becomes a new means to improve hearing. On this occasion, there is no upper limit of age for indications, if mental faculties are within the normal range and the patient has the will to improve hearing.

3. Retrocochlear hearing loss cases

Cochlear implant is useless if the auditory nerve is not preserved in the bilateral acoustic neurinoma surgery. In such a case, auditory brainstem implant (AB1) to apply the device to the cochlear nuclei, which are located superior to the cochlear is developed. Since the cochlear nuclei have the distinct tonotopicity like the cochlear, it is highly probable for speech information to be transmitted to the central nervous system. Many cases of retrocochlear hearing loss have been treated in the U.S. and Europe using AB1, and understanding of speech as well as recognition of environmental sounds are acquired. The first case of AB1 in Japan has already been conducted, and the indications for the operation will increase in the future.

Conclusion

It is only a short time since CI was adopted as a medical treatment for the deaf. The degree of speech understanding will be increased by improvement in the device, and the indications for the operation will also be increased in the future. However, careful and accurate judgment of hearing level is particularly needed in deciding infantile indications. For this purpose as well, screening of hearing loss and the role of speech auditory therapist as a coordinator in implementing the medical care is important. It is also important for the people who are engaged in education, as well as those of medical side to tackle post-operative rehabilitation.