Bilateral Cochlear Implantation for Children in Nagasaki, Japan

Yukihiko Kanda, MD1,2 · Hidetaka Kumagami, MD2 · Minoru Hara, MD2 · Yuzuru Sainoo, MD2 · Chisei Sato, MD2
Tomomi Yamamoto-Fukuda, MD2 · Haruo Yoshida, MD2 · Akiko Ito1 · Chiharu Tanaka1 · Kyoko Baba1 · Ayaka Nakata1
Hideo Tanaka1 · Haruo Takahashi, MD2

1Kanda ENT Clinic, Nagasaki Bell Hearing Center, Nagasaki; 2Department of Otolaryngology and Head and Neck Surgery, Nagasaki University Graduate School of Biomedical Sciences, Nagasaki, Japan

INTRODUCTION

The clinical effects of both unilateral and bilateral cochlear implantation (CI) in children is well established internationally (1-15), but there are only a few reported cases of bilateral CI in Japan. The number of patients with bilateral CI has gradually increased as patients and/or parents recognize its effectiveness. The following are some of the bilateral CI cases in children that we have experienced. This is a review of bilateral CI in 169 pediatric CI users, who received auditory-verbal/oral habilitation at our hearing center.

Methods. We evaluated the audiological abilities 29 Japanese children with bilateral CIs including wearing threshold, word recognition score, speech discrimination score at 1 m from front speaker (SP), 1 m from second CI side SP, speech discrimination score under the noise (S/N ratio = 80 dB sound pressure level [SPL]/70 dB SPL, 10 dB) at 1 m from front SP, word recognition score under the noise (S/N ratio = 80 dB SPL/70 dB SPL, 10 dB) at 1 m from front SP.

Results. Binaural hearing using bilateral CI is better than first CI in all speech understanding tests. Especially, there were significant differences between the results of first CI and bilateral CI on SDS at 70 dB SPL (P=0.02), SDS at 1 m from second CI side SP at 60 dB SPL (P=0.02), word recognition score (WRS) at 1 m from second CI side SP at 60 dB SPL (P=0.02), speech discrimination score (SDS) at 1 m from front SP under the noise (S/N=80/70; P=0.01) and WRS at 1 m from front SP under the noise (S/N=80/70; P=0.002). At every age, a second CI is very effective. However, the results of under 9 years old were better than of over 9 years old on the mean SDS under the noise (S/N=80/70) on second CI (P=0.04). About use of a hearing aid (HA) in their opposite side of first CI, on the WRS and SDS under the noise, there were significant differences between the group of over 3 years and the group of under 10 months of HA non user before second CI.

Conclusion. These results may show important binaural effectiveness such as binaural summation and head shadow effect. Bilateral CI is very useful medical intervention for many children with severe-to-profound hearing loss in Japan as well as elsewhere.

Key Words: Cochlear implant, Children, Bilateral, Binaural, Binaural summation, Head shadow effect, Japan
results after second CI? 3) Is there any critical time span between the first and second CI for their progress in language perception? 4) What is the advantage of bilateral CI over unilateral CI?

MATERIALS AND METHODS

Subjects
Since we started CI surgery in 1997, out of 169 children undergoing CI rehabilitation in our clinic, 29 children (17%) had bilateral CI for at least half a year before May 2011. The age of the children at the first CI operation ranged from 1 year 4 months to 15 years 5 months, whereas the age of children at the second CI operation ranged from 2 year 1 month to 15 years 10 months (Fig. 1). The most common age for the first CI was 1 or 2 years. The interval between first and second CI fitting ranged from 5 months to 10 years 1 month. This can be considered a relatively wide range, but the most frequent interval between the two CIs was under 1 year (Fig. 2). The period on non-use of their HA before the second CI is also valuable: it ranges from 0 month to

---

Fig. 1. Age at operation of first cochlear implantation (CI) and second CI (year).

Fig. 2. Interval between first and second cochlear implantation (month).
108 months (9 years). Twelve cases did not remove their HA before the second CI (Fig. 3). Causes for deafness were described in Fig. 4. The devices used are described in Fig. 5.

We examined 19 children who acquired language with either CI or HA using various audiological tests. Children with severe anomaly or late development were not included. The children were divided into 2 groups to evaluate the amount of habilitation time after the second CI. The first group (group A) consisted of 11 children who had their second CI for at least a year. The second group (group B) included 8 children who had their second CI between 6 and 12 months.

**Methods**

We evaluated audiological abilities including 1) wearing threshold (WTH); 2) word recognition score (WRS, TY-89; Japanese-3 syllabic word-CD, at 60 dB sound pressure level [SPL], at 70 dB SPL); 3) speech discrimination score (SDS, 67-S; Japanese-mono-syllabic word-CD, at 60 dB SPL, at 70 dB SPL) at 1 m from front speaker (SP), 1 m from second CI side SP; 4) SDS under noise (67-S; Japanese-mono-syllabic word-CD, S/N ratio=80 dB SPL/70 dB SPL, 10 dB) at 1 m from front SP; 5) WRS under noise (TY-89; Japanese-3 syllabic word-CD, S/N ratio=80 dB SPL/70 dB SPL, 10 dB) at 1 m from front SP (noise: speech noise). We conducted all tests in a shielded room. Statistical analysis was done using the Student’s t-test and paired t-test.

**RESULTS**

The mean WTH using first CI, second CI, and bilateral CI shows that all WTH is nearly the same ranging from 25 dB hearing level (HL) to 35 dB HL (Fig. 6). There were no significant differences between them. The mean WTH of their HA before he second CI was from 55 dB HL (for lower frequencies) to 65 dB HL (for higher frequencies). However, after operation the mean WTH using second CI ranges from almost 30 dB HL to 35 dB HL. There were significant differences ($P=0.03^*$) between HA and

---

Fig. 3. Number of months child discontinued hearing aid use before second cochlear implantation.

Fig. 4. Causes for deafness.
The mean WRS at 1 m from the front SP at 70 dB SPL is shown in Fig. 8. The mean score for the second CI in group A was similar to the mean score for the first CI. The mean score on the WRS for all cases shows that there were no significant differences between the results of the first CI and the bilateral CI at 70 dB SPL ($P = 0.13$).

The mean WRS at 1 m from the front SP at 60 dB SPL is described in Fig. 9. The mean score for the second CI in group A was similar to the mean score for the first CI. For all cases, there were no significant differences between the results of the first CI and bilateral CI at 60 dB SPL ($P = 0.05$).

The mean SDS at 1 m from the front SP at 70 dB SPL is described in Fig. 10. The mean score for the second CI in group A was similar to the mean score for the first CI. The SDS results show that there were significant differences between the results of the first CI and the bilateral CI at 70 dB SPL ($P = 0.02^*$).

The mean SDS at 1 m from the front SP at 60 dB SPL is described in Fig. 11. There were no significant differences between the results of the first CI and the bilateral CI at 60 dB SPL ($P = 0.24$).

The mean SDS at 1 m from the second CI side SP at 70 dB SPL is described in Fig. 12. The mean score for the second CI in group A was similar to the mean score for the first CI. There were no significant differences between the results of the first CI and the bilateral CI at 1 m from the second CI side SP on all cases at 70 dB SPL ($P = 0.25$).

The mean SDS at 1 m from the second CI side SP at 60 dB SPL is described in Fig. 13. The mean score for second CI in group A was superior to the mean score for first CI. There were significant differences between the results of first CI and bilateral CI at 1 m from second CI side SP on all cases at 60 dB SPL ($P = 0.02^*$).
Fig. 8. Mean word recognition score at 1 m from front speaker at 70 dB SPL (P=0.13). CI, cochlear implantation; SPL, sound pressure level.

Fig. 9. Mean word recognition score at 1 m from front speaker at 60 dB SPL (P=0.05). CI, cochlear implantation; SPL, sound pressure level.

Fig. 10. Mean speech discrimination score at 70 dB SPL (P=0.02*). CI, cochlear implantation; SPL, sound pressure level.

Fig. 11. Mean speech discrimination score at 60 dB SPL (P=0.24). CI, cochlear implantation; SPL, sound pressure level.

Fig. 12. Mean speech discrimination score at 1 m from second cochlear implantation (CI) side speaker at 70 dB SPL (P=0.25). SPL, sound pressure level.

Fig. 13. Mean speech discrimination score at 1 m from second cochlear implantation (CI) side speaker at 60 dB SPL (P=0.02*). SPL, sound pressure level.
compared the results of over 9 years old with the results of under 9 years old, analyzing the mean WRS and SDS at 70 dB SPL at 1 m from front SP, the mean SDS and WRS under the noise (S/N = 80/70) on second cochlear implantation for over and under 9 years old. SPL, sound pressure level.

We compared children that had not used their HA for over 3 years before the second CI with those that had used their HA within 10 months before the second CI using various speech understanding tests (Fig. 18). The mean WRS and SDS revealed better scores for HA usage within 10 months before the second CI than for those who stopped using their HA 3 years or more before the second CI. Especially on the WRS and SDS under the noise, there were significant differences between these two groups (P=0.01* on SDS and P=0.04* on WRS).
All speech understanding tests. Especially, there were significant differences between the results of the first CI and bilateral CI on: 1) SDS at 70 dB SPL ($P=0.02^*$); 2) SDS at 1 m from second CI side SP at 60 dB SPL ($P=0.02^*$); 3) WRS at 1 m from second CI side SP at 60 dB SPL ($P=0.02^*$); 4) SDS at 1 m from front SP under the noise ($S/N=80/70, +10$) ($P=0.01^*$); 5) WRS at 1 m from front SP under the noise ($S/N=80/70, +10$; $P=0.002^*$).

These results may show important binaural effectiveness such as binaural summation (1, 4, 5) and head shadow effect (2, 3).

Binaural summation (1, 3, 4, 7) and head shadow effect (2-5) are very likely to be important phenomena providing effective binaural advantages. Furthermore, binaural squelch (2, 4, 5) and sound localization (8, 9) are also well known to yield binaural advantages. In particular, in infancy there are many cases where the ability of hearing under the noise is very important for speech/language development.

The improvement of sound localization and hearing under noise that is provided in binaural hearing shows strong effectiveness in a typical infant environment and for children in a classroom setting (14). Bilateral CI is a very useful medical intervention for children with severe-to-profound hearing loss in Japan and elsewhere.

DISCUSSION

In all children, the WTH using the second CI was almost the same using the first CI ranging from 25 to 35 dB HL. Also, the WTH using the second CI recovered compared to the WTH using HA before their second CI ($P=0.03^*$). A previous report (6) also describes that aided thresholds give better performance.

At every age, a second CI is very effective. However, the results of under 9 years old were better than the results of over 9 years old on the mean SDS under noise ($S/N=80/70$) on the second CI ($P=0.04^*$). These results may be due to brain plasticity of the children for acquiring speech understanding under the noise (10, 14).

About use of a HA in their opposite side of first CI, the WRS and SDS under the noise, there were significant differences between the group of over 3 years and the group of under 10 months of HA non user before second CI ($P=0.01^*$ on SDS and $P=0.04^*$ on WRS). We recommend wearing hearing aids on the opposite side after first CI. As the Japanese language uses lower frequencies, a little wearing threshold of usable frequencies remains. Also, the input from the hearing aid is very important. It is a waste to remove the HA and let the input on the opposite side of the first CI.

Most of the speech understanding scores (WRS and SDS) for children who have undergone at least 1 year habilitation after first CI and now have been fitted with a second CI show similar results to the first CI. Though the second CI eventually caught up with the first CI, it took nearly over one year.

Binaural hearing using bilateral CI is better than the first CI in all speech understanding tests. Especially, there were significant

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Balkany T, Boggess W, Dinner B. Binaural cochlear implantation: comparison of 3M/House and Nucleus 22 devices with evidence of sensory integration. Laryngoscope. 1988 Oct;98(10):1040-3.
2. Muller J, Schon F, Helms J. Speech understanding in quiet and noise in bilateral users of the MED-EL COMBI 40+ cochlear implant system. Ear Hear. 2002 Jun;23(3):198-206.
3. Kuhn-Inacker H, Shehata-Dieler W, Muller J, Helms J. Bilateral cochlear implants: a way to optimize auditory perception abilities in deaf children? Int J Pediatr Otorhinolaryngol. 2004 Oct;68(10):1257-66.
4. Schon F, Muller J, Helms J. Speech reception thresholds obtained in a symmetrical four-loudspeaker arrangement from bilateral users of MED-EL cochlear implants. Otol Neurotol. 2002 Sep;23(5):710-4.
5. Tyler RS, Dunn CC, Witz SA, Preece JP. Update on bilateral cochlear implantation. Curr Opin Otolaryngol Head Neck Surg. 2003 Oct;11(5):388-93.
6. Vermeire K, Brocx JP, Van de Heyning PH, Cochet E, Carpentier H. Bilateral cochlear implantation in children. Int J Pediatr Otorhinolaryngol. 2003 Jan;67(1):67-70.
7. Au DK, MappStA, Hui Y, Wei WI. Superiority of bilateral cochlear implantation over unilateral cochlear implantation in tone discrimination in Chinese patients. Am J Otolaryngol. 2003 Jan-Feb;24(1):19-23.
8. Richard JM, HoesselV, Tyler RS. Speech perception, localization, and lateralization with bilateral cochlear implants. J Acoust Soc Am. 2003 Mar;113(3):1617-30.
9. Litovsky RY, Johnstone PM, Godar S, Agrawal S, Parkinson A, Peters R, et al. Bilateral cochlear implants in children: localization acuity measured with minimum audible angle. Ear Hear. 2006 Feb;27(1): 43-59.

10. Sharma A, Dorman MF, Kral A. The influence of a sensitive period on central auditory development in children with unilateral and bilateral cochlear implants. Hear Res. 2005 May;203(1-2):134-43.

11. Steffens T, Lesinski-Schiedat A, Strutz J, Aschendorff A, Klenzner T, Rühl S, et al. The benefits of sequential bilateral cochlear implantation for hearing-impaired children. Acta Otolaryngol. 2008 Feb; 128(2):164-76.

12. Brown KD, Balkany TJ. Benefits of bilateral cochlear implantation: a review. Curr Opin Otolaryngol Head Neck Surg. 2007 Oct;15(5):315-8.

13. Murphy J, O’Donoghue G. Bilateral cochlear implantation: an evidence-based medicine evaluation. Laryngoscope. 2007 Aug;117(8): 1412-8.

14. Papsin BC, Gordon KA. Bilateral cochlear implants should be the standard for children with bilateral sensorineural deafness. Curr Opin Otolaryngol Head Neck Surg. 2008 Feb;16(1):69-74.

15. Bond M, Mealing S, Anderson R, Elston J, Weiner G, Taylor RS, et al. The effectiveness and cost-effectiveness of cochlear implants for severe to profound deafness in children and adults: a systematic review and economic model. Health Technol Assess. 2009 Sep;13(44):1-330.