Acta Oto-Laryngologica. 2015; 135: 147–153

informa
healthcare

ORIGINAL ARTICLE

The advantages of sound localization and speech perception of bilateral electric acoustic stimulation

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Abstract

Conclusion: Bilateral electric acoustic stimulation (EAS) effectively improved speech perception in noise and sound localization in patients with high-frequency hearing loss. *Objective:* To evaluate bilateral EAS efficacy of sound localization detection and speech perception in noise in two cases of high-frequency hearing loss. *Methods:* Two female patients, aged 38 and 45 years, respectively, received bilateral EAS sequentially. Pure-tone audiometry was performed preoperatively and postoperatively to evaluate the hearing preservation in the lower frequencies. Speech perception outcomes in quiet and noise and sound localization were assessed with unilateral and bilateral EAS. *Results:* Residual hearing in the lower frequencies was well preserved after insertion of a FLEX^{24} electrode (24 mm) using the round window approach. After bilateral EAS, speech perception improved in quiet and even more so in noise. In addition, the sound localization ability of both cases with bilateral EAS improved remarkably.

Keywords: *High frequency, hearing loss, residual hearing, cochlear implant*

Introduction

The cochlear implant (CI) has been recognized as a standard treatment for patients who do not have sufficient improvement in hearing level with hearing aids, and it is widely accepted as a safe procedure even in infants and very young children. Recently, the development of new electrode designs has enabled the preservation of residual hearing at the lower frequencies and this new concept of minimally invasive cochlear implantation surgery has extended the indications for CI [1–3]. Preserved residual acoustic hearing combined with electrical stimulation in high frequencies by electrode has provided significant improvement of speech perception in noise and quality of natural hearing as compared with electrical stimulation alone [4–6]. This electric acoustic stimulation (EAS) system improves hearing ability for patients with high-frequency hearing loss in whom standard hearing aids are ineffective, through preservation of residual hearing at the lower frequencies.

Meanwhile, bilateral CIs are known to be more effective for children with bilateral deafness compared with unilateral implantation because hearing, sound localization, speech perception in noise, and normal auditory processing are improved through binaural hearing [7]. Also, bilateral CIs have been shown to have several advantages over a unilateral CI in improving hearing performance for adults as well [8]. Naturally, normal-hearing listeners use two ears for processing sound, defining directions, and understanding spoken language even in noisy conditions. However, the potential risks of vestibular dysfunction and taste disorder should be considered before deciding on a second implantation; moreover, the risk is higher with a second implantation [9]. Thus, the surgical approach and the design of electrode of the implant are important factors for

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(Received 2 May 2014; accepted 23 July 2014)

ISSN 0001-6489 print/ISSN 1651-2251 online
DOI: 10.3109/00016489.2014.951453

the patient's safety. These factors are also crucial for the preservation of residual hearing [10].

Since 2009, we have applied EAS for adult Japanese patients with bilateral high-frequency hearing loss as a clinical trial, and have found that EAS provides substantial improvement in hearing ability in these patients. Some participants, after receiving a unilateral EAS and experiencing the resulting improvement in their quality of life, wished to also receive a contralateral EAS. To date, only a single report on bilateral EAS has been published [11]. Here, we report our results for two cases of adults with bilateral EAS implanted sequentially, the benefits they obtained using conventional speech recognition, sound localization testing, and the safety of the procedure.

Material and methods

Case 1

This case was a 38-year-old woman. She had hearing loss detected by hearing screening in primary school at the age of 10. It appeared to slowly progress as she grew up, and by age 25 years she experienced difficulties in hearing and communication. She wore hearing aids in both ears; however, their efficacy was limited in her noisy workplace. There were no inner ear abnormalities and no complications in her general status. Her elder brother had hearing loss as well, and nearly the same symptoms of hearing deterioration. It was suspected that this early-onset and slowly progressive hearing loss was due to some genetic causes. She presented with bilateral mid-high frequency steeply sloping hearing loss and was implanted on December 21, 2009 in her left ear (first EAS). Nearly 2 years later, a second CI surgery was performed in her right ear on August 10, 2011 (second EAS). Postoperatively low-frequency hearing in both ears was preserved and she could hear sounds through combined electrical and acoustical stimulation using bilateral DUET2 EAS systems.

Case 2

This case was a 45-year-old woman. She became aware of bilateral hearing loss and tinnitus around the age of 25 years. When she presented to us, it had been slowly progressing for 10 years. She had received a hearing aid for the left ear at the age of 35, but it was not adequately beneficial. She had no inner ear abnormalities and no other health complications, and no family history of hearing loss. Late-onset and slowly progressive hearing loss was suggested and she presented with bilateral mid- to high-frequency steeply sloping hearing loss. A CI was implanted in the left ear on November 18, 2009 (first EAS). Details of this case at that time were previously described in 2011 [3]. Nearly 3 years after the first implantation, she received a CI in the right ear on July 9, 2012 (second EAS). Postoperative low-frequency hearing in both ears was preserved, and she could hear sound through combined electrical and acoustical stimulation using bilateral DUET2 EAS systems.

Surgical procedure and implants

Both patients received the MED-EL PULSAR CI implant system with FLEX24 electrode array, which was designed to preserve low-frequency hearing. These features were previously described in the report of a multicenter study in Europe [12].

The CI surgery was performed with standard mastoidectomy by a single surgeon (S.U.). To insert the electrode array, the round window approach was applied to reduce insertion damage of the cochlea. The bony overhang of the round window was removed with a low-speed drill and the round window membrane was exposed. A small incision was made and the electrode was inserted carefully and slowly. An intraoperative infusion of dexamethasone (8 mg) was applied before electrode insertion. Also postoperative dexamethasone was administered with systemic infusion tapering down for 6 days (8, 8, 4, 4, 2, and 2 mg, respectively) [3].

EAS speech processor DUET2 fitting

Following the results of postoperative hearing assessments, electrical and acoustical components were fitted with small overlapping frequencies, with each one amplified according to the MED-EL recommended fitting procedure. The adjacent point to electrical and acoustic stimulations was defined as the patient's pure-tone audiometry (PTA) threshold of 65 dB HL.

Vestibular function testing

To evaluate the safety and conservation of postoperative vestibular function, vestibular evoked myogenic potential (VEMP) and caloric response were analyzed. In VEMP testing, the electrographic signal from the stimulated side was amplified and averaged using a Neuropack evoked potential recorder (Nihon Kohden Co. Ltd, Tokyo, Japan). Clicks lasting for 0.1 ms at 105 dB nHL were presented through a headphone. The stimulation rate was 5 Hz, the band-pass filter intensity was 20–2000 Hz, and analysis time was 50 ms. The responses to 200 stimuli were

averaged twice. In caloric testing, maximum slow eye velocity was measured by cold water irrigation (20°C, 5 ml, 20 s). Postoperative VEMP and caloric responses of the implanted ears and contralateral ears were compared.

Audiological testing

PTA was done preoperatively and postoperatively at the first fitting and 3, 6, and 12 months after activation of the first EAS. After activation of the second EAS, PTA was assessed with the same timing as fitting. Hearing threshold levels were measured using headphones with masking in a soundproof room. Speech perception tests used in this study employed Japanese plain monosyllables, words, and sentences. The monosyllable test employed 50 Japanese alphabetical sounds, with words or sentences being unpredictable from these single sounds. Speech sound was presented at 65 dB SPL in quiet or +10 dB signal-to-noise ratio (SNR) from each of the faced loudspeakers. Assessment conditions were as follows: (1) using the first

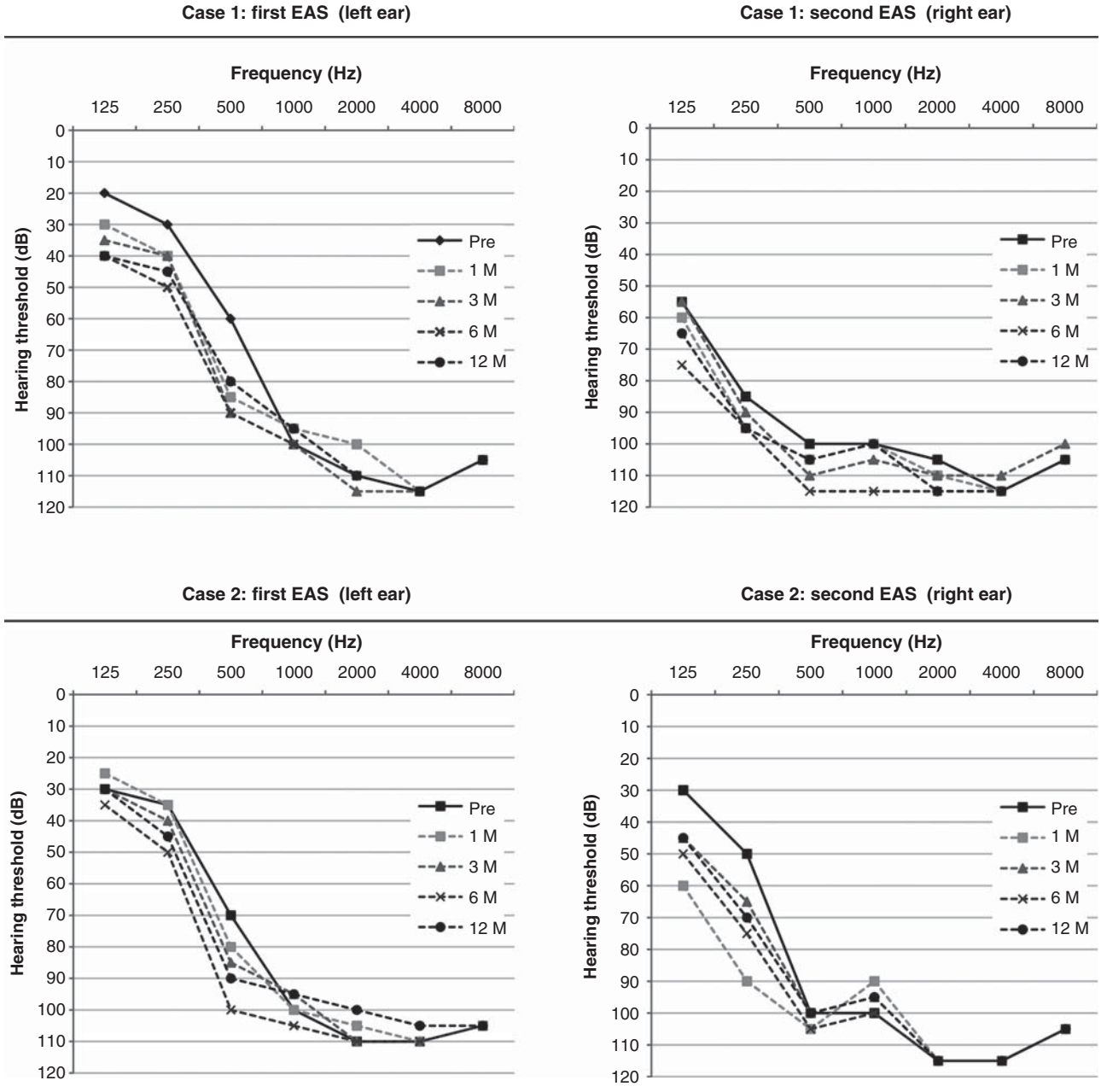

Figure 1. Pure-tone audiometry results of the two cases, first and second electric acoustic stimulation (EAS) in the left and right ear, respectively. Each hearing level threshold was determined preoperatively, and postoperatively after 1, 3, 6, and 12 months.

EAS (implanted in the left ear in both cases) in quiet and noise; (2) using the second EAS (implanted in the right ear in both cases) in quiet and noise; (3) using the bilateral EAS in quiet and noise.

Sound localization test

Testing was performed in a semi-anechoic chamber. The patient was seated in front of nine loudspeakers placed at 22.5° in a semi-circle of 1 m radius (–90° to 90° azimuth). The height of the patient's head was adjusted to the height of the loudspeakers, which were 1 m from the floor. Each loudspeaker was numbered from –90° to 90° azimuth.

The test was performed as described previously [13]. The stimulus was a 1 s speech-shaped noise (CCITT noise) burst with 100 ms rise/fall time. Stimuli levels were randomly chosen to be 60, 70, and 80 dB SPL. In the test, all stimuli levels/loudspeakers were presented 5 times, so that 135 stimuli were presented at random. The subject judged the loudspeaker from which a sound was presented and responded by a tablet device with a touch panel. During testing, there was no feedback. The MED-EL software for the localization test system, consisting of a laptop computer and tablet device, was used for stimulus presentation, data collection, data analysis, and receiving the subject's responses. The localization accuracy was quantified by using the mean deviation score (d) and the bias score (b). The mean deviation score (d) indicated the deviation between the judged azimuth and the sound presentation azimuth with and without bias adjustment, where the bias is the localization error, which is constant across loudspeakers.

This study was approved by the Ethics Committee of Shinshu University School of Medicine and prior written consent was obtained from the patients after a full explanation of the study.

Results

Hearing preservation after cochlear implantation

In both cases, the residual hearing in low frequencies was well preserved at 12 months after EAS surgery in both ears (Figure 1).

Speech perception

The results are shown in Figure 2. The Japanese monosyllable test (67S, at 65 dB SPL) score in quiet slightly improved from 70% correct (first EAS only) and 65% correct (second EAS only) to 80% correct (bilateral EAS) for case 1. For case 2, the test score was 55% correct for first EAS only, 75% correct for second EAS only, and with bilateral EAS it was the same as with second EAS only at 75% correct. However, in noise (SNR +10 dB), the monosyllable perception score was improved from the first EAS only scores by bilateral EAS in both cases. The Japanese monosyllable test (67S, at 65 dB SPL) score in noise improved from 55% correct (first EAS only) and 60% correct (second EAS only) to 80% correct (bilateral EAS) in case 1 and from 45% correct (first EAS only) and 70% correct (second EAS only) to 75% correct (bilateral EAS) in case 2. These data suggest that one advantage of the bilateral EAS is improvement of speech perception, especially in noise. Similar perception improvement was also observed in the Japanese word perception test (CI2004, at 65 dB SPL in SNR +10 conditions, Figure 2).

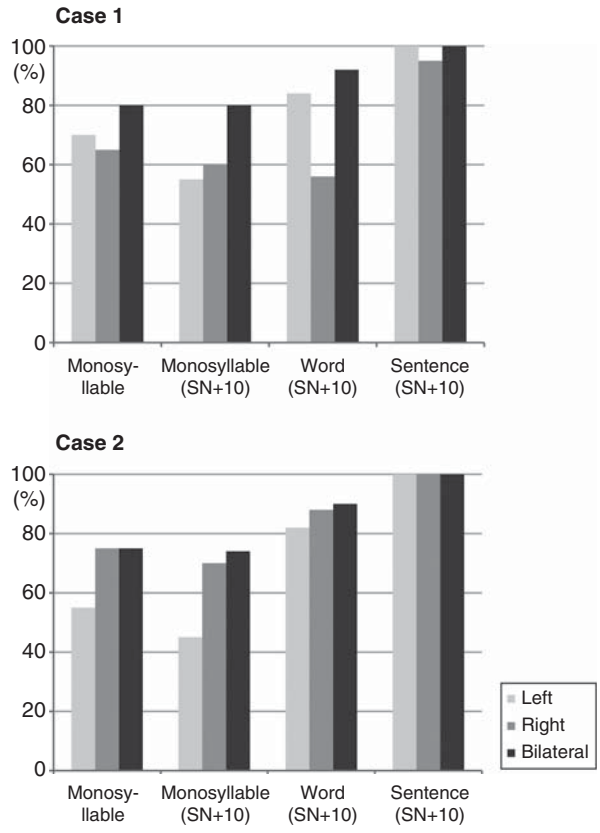

Figure 2. Japanese alphabetical monosyllable, word, and sentence scores at 1 year after fitting. Speech sound was presented at 65 dB SPL in quiet for monosyllable only and at +10 dB signal-noise ratio (SNR) for monosyllable, word, and sentence. These bar graphs show three conditions: (1) using the first electric acoustic stimulation (EAS) (implanted in the left ear in both cases), (2) using the second EAS (implanted in the right ear in both cases), and (3) using the bilateral EAS.

Sound localization

The sound localization ability of both cases improved remarkably with bilateral EAS. In case 1, the deviation

score (indicating the degree of sound localization error) improved from d = 31.83 (first EAS only), and d = 67.83 (second EAS only) to d = 15.00 (bilateral EAS). She was also able to answer the correct loudspeaker position with bilateral EAS (Figure 3). In case 2, the deviation score also improved remarkably from d = 57.83 (first EAS only), and d = 48.17 (second EAS only) to d = 20.67 (bilateral EAS) (Figure 3). These data clearly indicate the advantage of bilateral EAS for sound localization, which facilitates improvement of the quality of hearing of patients with bilateral high-frequency hearing loss.

Vestibular function

In case 1, caloric test and VEMP test results did not change after EAS surgery. In case 2, left side preoperative data were not applicable but caloric test and VEMP test results indicated normal vestibular response after EAS surgery and in the right ear, caloric test and VEMP test results were well preserved.

Discussion

Concerning the comparison between the first EAS and second EAS, the speech perception scores sometimes appeared better with the second EAS side than with the first EAS side in which more favorable residual hearing at the lower frequencies had been preserved. The reason for such an unexpected result is unclear. However, even in case 2, speech perception in EAS is better than that in electrical stimulation (ES) only (monosyllable in noise; first ear EAS 45% > ES 40%, second ear EAS 70% > ES 55%, word in noise; first ear EAS 82% > ES 76%, second ear EAS 88% > ES 80%,

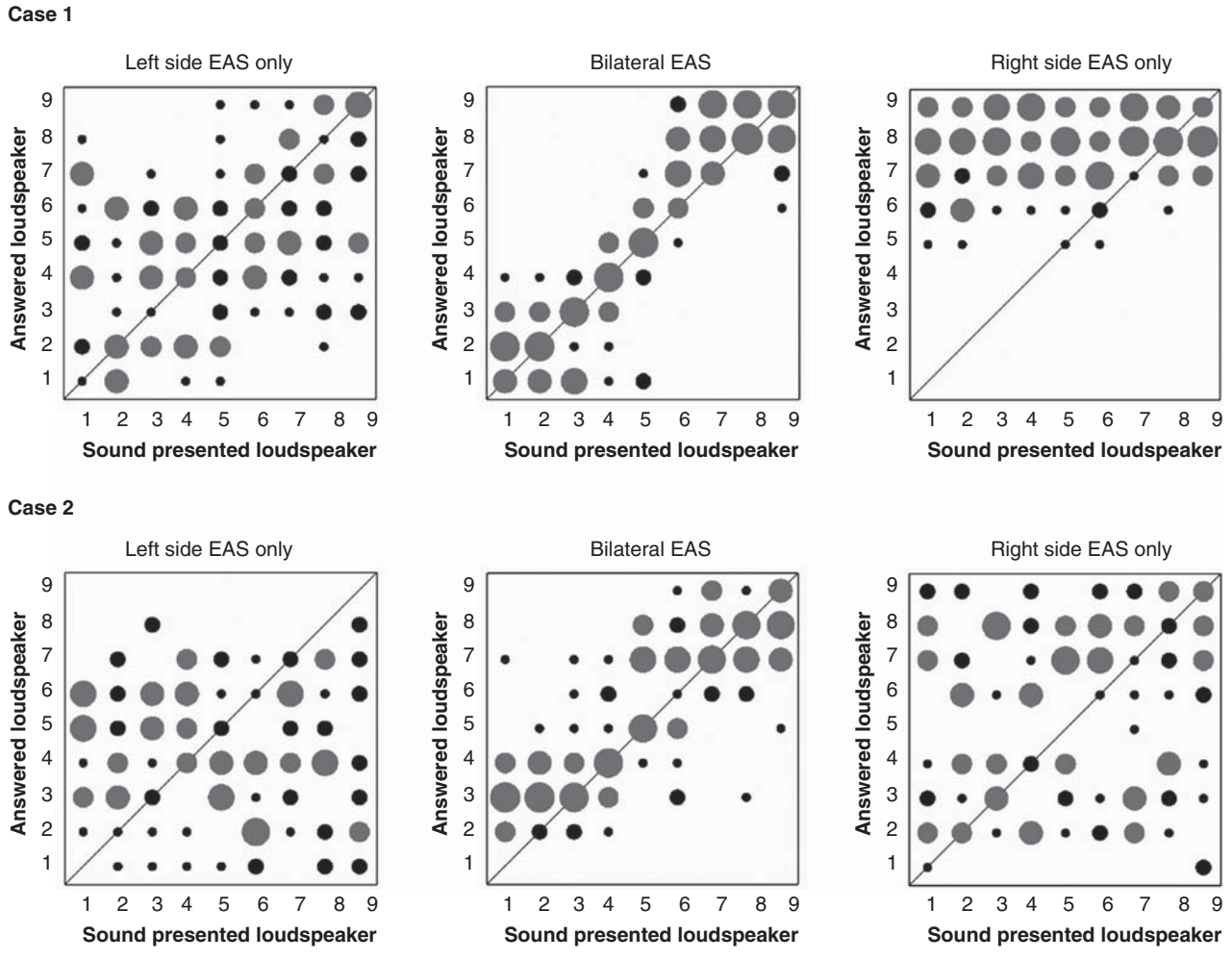

Figure 3. The scatter diagram shows the sound localization test results of the two cases. The horizontal axis shows the number of surrounding speakers from –90° to 90° azimuth, and the vertical axis shows the number of speakers that the patient answered correctly. Speaker no. 5 was directly in front of the patient. The size of each circle in the diagram indicates the number of times the patient chose each specific speaker. Larger circles show that the patient chose a speaker more frequently, while smaller circles indicate less frequently chosen speakers. The position of each circle indicates the position of the presented speaker that the patient chose.

sentence in noise; first ear EAS 100% > ES 98%, second ear EAS 100% > ES 93%). These data suggest that additional acoustic stimulation is beneficial for better speech perception. Our recent data obtained from an analysis of 32 consecutive cases also support the beneficial role of acoustic stimulation for better speech perception [14].

Concerning the benefits of bilateral hearing, bilateral EAS provided good speech perception, especially in noise, as compared with either unilateral EAS. The score of monosyllable perception in quiet with bilateral EAS was better than (case 1) or equal to (case 2) unilateral EAS. However, perception scores with bilateral EAS in noise were better than both first and second implantation scores in both cases. These data suggest that one advantage of bilateral EAS is improvement in speech perception, especially in noise. Bilateral conventional CIs are also known to be more effective in improving speech perception in noise, but the differences between first implantation and bilateral CIs are very small and sometimes these differences are only found in special conditions, such as speech signals presented from faced loudspeakers and noise presented from the first implanted side loudspeaker [8]. In this study, bilateral EAS revealed better perception performance even when both signal and noise were presented from each faced loudspeaker. Acoustic amplification of EAS is known to be beneficial for speech perception in noise compared with electric stimulation only [5,15]. As in the previous report, our current results show that bilateral EAS efficiently improved speech perception in noise, and acoustic stimulation might have played an important role in this improvement [15–17].

The other great benefit of bilateral EAS was the improvement of sound localization ability. In the present study, we employed an automated sound localization test system. In this system, stimuli levels were randomly chosen to be 60, 70, and 80 dB SPL and were randomly presented from 9 loudspeakers 5 times each, for a total of 135 stimuli presented at random, enhancing the accuracy of the test. Sound localization ability in both cases with bilateral EAS improved remarkably compared with the unilateral EAS (Figure 3). These data clearly indicate the advantage of bilateral EAS for sound localization, which facilitates improvement of the quality of hearing of patients with bilateral high-frequency hearing loss. Similar improvement of sound localization has been reported in bilateral conventional CIs [18].

In the present study, hearing preservation was achieved after bilateral EAS surgery in both cases. After full insertion of the FLEX24 electrode by the round window approach, the residual hearing in the low frequencies was well preserved to sufficient levels for acoustic stimulation bilaterally up to 12 months after the second implantation. Hearing preservation surgery and some additional treatment, for example intravenous or tympanic steroid infusion, were optimized to implant for partially deafened patients, so that there was minimal damage to the cochlear structure and influence on residual hearing [19]. This EAS surgical concept must be used for bilateral CI surgery, whether or not there is residual hearing.

The importance of conservation of vestibular function is recognized. Especially for bilateral CIs, atraumatic surgery to preserve vestibular function is very important to avoid balance problems in the future. We adopted the round window insertion approach with a flexible electrode to minimize intracochlear trauma, and vestibular function was well preserved after bilateral EAS surgery in both cases. We have recently reported that vestibular function could be preserved after a round window approach together with a flexible electrode [20].

In conclusion, bilateral EAS is beneficial in noisy conditions and improves sound localization ability. Although more cases have to be evaluated by a variety of methods to allow us to draw a final conclusion regarding the benefits of bilateral EAS, these results indicate that bilateral EAS was effective and can be a recommended treatment for patients with high-frequency hearing loss.

Acknowledgments

We thank A.C. Apple-Mathews and Nora Prachar for help in preparing the manuscript. This study was supported by a Health and Labour Sciences Research Grant for Comprehensive Research on Disability Health and Welfare from the Ministry of Health, Labour and Welfare of Japan (S.U.), and by a Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture of Japan (S.U.).

Declaration of interest: MED-EL supplied EAS systems including implants and speech processors for this clinical trial, because this cochlear implant system had not yet been approved by the Ministry of Health of Japan during the study period. The authors disclosed the above conflict of interest in this clinical research to the Ethics Committee of Shinshu University School of Medicine and received the Committee's approval.

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