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Original Article

Cochlear Implantation in the Poorer-Hearing Ear Is a Reasonable Choice

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Choosing the optimal side for cochlear implantation (CI) remains a major challenge because of the lack of evidence. We investigated the choice of the surgery side for CI (*i.e.*, the better- or poorer-hearing ear) in patients with asymmetric hearing. Audiological records of 74 adults with a unilateral hearing aid who had undergone surgery at Okayama University Hospital were reviewed. The definition of 'better-hearing ear' was the aided ear, and the unaided ear was considered the poorer-hearing ear. We performed a multiple regression analysis to identify potential predictors of speech recognition performance after unilateral CI in the patients. Fifty-two patients underwent CI in the poorer-hearing ear. The post-Ci bimodal hearing rate was far higher in the poorer-ear group (77.8% vs. 22.2%). A multivariate analysis revealed that prelingual hearing loss and the patient's age at CI significantly affected the speech recognition outcome (beta coefficients: 24.6 and −0.33, 95% confidence intervals [11.75-37.45] and [−0.58 to −0.09], respectively), but the CI surgery side did not (−6.76, [−14.92-1.39]). Unilateral CI in the poorer-hearing ear may therefore be a reasonable choice for adult patients with postlingual severe hearing loss, providing a greater opportunity for postoperative bimodal hearing.

Key words: cochlear implantation, poorer hearing ear, better hearing ear, hearing aids, speech recognition

As the most successful prosthesis in the world, cochlear implantation (CI) has helped > 300,000 individuals with severe sensorineural hearing loss worldwide [1]. When the decision to perform CI has been made, several obstacles must be overcome. One of the most important problems is to choose the optimal side (ear) for implantation, but there is insufficient evidence regarding the most effective side. In many cases, adult patients have asymmetric hearing loss and different durations of hearing loss (HL) or sound deprivation in their ears. Many individuals have tried to use hearing aids in one or both sides, and they have found that the hearing aids have different effectiveness in each ear. This makes choosing the surgery side for a cochlear implant an even greater dilemma.

The duration of deafness is also a controversial factor. Some researchers showed that cochlear implants can be expected to provide better speech recognition performance in patients with a shorter duration of deafness [2-4]. Connell and Balkany suggested that implanting in the poorer ear should be avoided if the duration of deafness in that side is > 10 years [5]. However, the duration of deafness was not strictly defined in these studies. Some investigations have included patients with prelingual deafness, but others did not. In the present study, attention was paid to the prelingual versus postlingual onset of deafness, as this

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difference may have a strong effect on the results of CI.

We conducted the present study to determine whether the choice of the side of CI (*i.e.*, in the better- vs. poorer-hearing ear) significantly impacts the speech recognition score (SRS) outcome after CI. Based on our results indicating that there is no significant difference in SRS outcomes between CI to the better- versus poorer-hearing ear, we propose that CI in a poorer-hearing ear is a reasonable choice in terms of postoperative bimodal hearing and possible future intervention by gene therapy to the better-hearing ear.

Materials and Methods

This study was approved by the Ethics Committee of Okayama University Hospital (approval #2010-026). All patients were > 18 years of age at implantation. They had been diagnosed as having bilateral severe hearing loss based on a hearing test (pure-tone threshold average [500, 1,000, 2,000, 4,000 Hz] over 70 dBHL) and underwent unilateral CI. The patients' implantations had been performed at Okayama University Hospital between 2009 and 2019, and each patient underwent CI to receive a unilateral hearing aid. Participants were excluded from the study if there were surgical complications or device failures.

We defined the better-hearing ear in this study as the aided ear, and the unaided ear was considered the poorer-hearing ear, as Boisvert *et al.* described [6]. The definition of prelingual deafness was an onset earlier than 3 years of age [7]. The duration of sound deprivation was defined as: (*i*) the average pure-tone threshold was over 70 dB; and (*ii*) the onset was defined as the time when the hearing device was ineffective. The data for the second item were based on patients' self-reports. If there was no medical record of sound deprivation, the patients were excluded from the statistical analysis.

A total of 74 patients were included in this study; 52 (70%) of these patients underwent CI in the poorer-hearing ear (Table 1). There were no significant differences between the group of patients with CI in the poorer-hearing ear and the group with CI in the better-hearing ear regarding the onset of hearing loss ($p = 0.668$), age at implantation ($p = 0.468$), duration of sound deprivation ($p = 0.309$), and bilateral hearing aid use before surgery ($p = 0.411$).

The patients' speech recognition scores (SRSs) were measured after implantation using the 67S Japanese monosyllable list, using standardized audio-recorded material (67S monosyllable list) presented in free-field at 70 dB sound pressure level (SPL) which was calibrated 1 m from the front of the speaker system. The average time point of the SRS measurement was 8.17 months after implantation.

Statistical analyses. The impacts of potential predictors on the SRS outcome after implantation were evaluated by a multiple regression analysis. The potential predictive variables included in the model were prelingual hearing loss (vs. postlingual hearing loss), age at implantation, cochlear implantation in better- versus poorer-hearing ear, duration from the loss of the effect of hearing aids, and the side of implantation (right vs. left). The data were analyzed by a multiple regression model and the unpaired *t*-test using SPSS Statistics for Macintosh, ver. 27.0 (IBM, Armonk, NY, USA).

Table 1 Participants' Characteristics

		CI in better ear	CI in poorer ear	Significance
Number		22	52	
Sex	Female (n)	9	29	
	Male (n)	13	23	
Onset	Prelingual (n)	3	4	
	Postlingual (n)	19	48	$p = 0.668$
Age, y (mean SD)		56.0 (16.7)	60.0 (14.7)	$p = 0.468$
Duration of sound deprivation, y (mean (SD))		1.0 (4.1)	1.5 (9.4)	$p = 0.309$
Pure-tone threshold average - CI ear, dB (mean (SD))		91.3 (9.4)	99.4 (8.5)	$p = 0.008$
Pure-tone threshold average- other ear, dB (mean (SD))		101.3 (9.0)	88.1 (12.3)	$p = 0.002$
Bilateral hearing aids use before surgery (n) (%)		5 (22.7%)	19 (36.5%)	$p = 0.411$
Bimodal use after CI (n) (%)		10 (22.2%)	35 (77.8%)	$p < 0.001$

CI: cochlear implant
The data of all the patients underwent cochlear implantation in the better or poorer ear are shown.

Results

The SRSs in the implanted ear did not show a significant difference between CI in the better-hearing ears and CI in the poorer-hearing ears (unpaired *t*-test, $p = 0.23$) (Fig. 1). The mean SRS of the patients with implantation in the better ear was 75.0%, and that of the patients with implantation in the poorer ears was 69.4%.

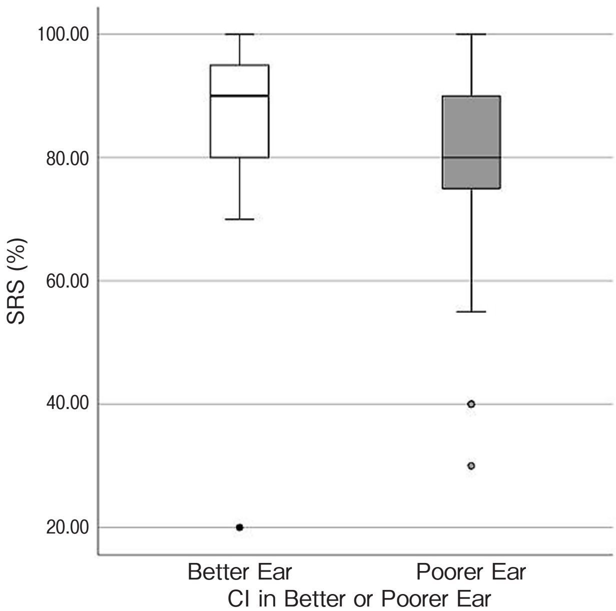

Fig. 1 There is no significant difference in the speech recognition score after cochlear implantation between the better ear and the poorer ear (unpaired *t*-test $p = 0.23$). Black line: median value, box: the middle 50% of the data, whiskers: upper and lower 25%. *P* values were determined based on the Mann-Whitney *U* test.
SRS, significant speech recognition score; CI, cochlear implant.

As shown in Table 2, the multiple regression modeling demonstrated that prelingual hearing loss and age at implantation significantly impacted the patients' SRSs after implantation: beta coefficients (β): 24.60 and −0.33, 95% confidence intervals (95%CI): 11.75-37.45 and −0.58 to −0.09, respectively. Cochlear implantation in the better- or poorer-hearing ear had no significant effect on the SRS outcome (β: −6.76, 95%CI: −14.91 to 1.39). No significant effect on the SRS outcome was also observed for the duration from the loss of effect of a hearing aid (β: −0.22, 95%CI: −0.65 to 0.22) and the CI side (right vs. left ear) (β: −3.21, 95%CI: −10.48 to 4.06) (Table 2).

Bimodal hearing is the use of a cochlear implant and a hearing aid in each ear at the same time. The rate of bimodal hearing after implantation in the poorer-ear group (77.8%) was much higher than that after implantation in the better-ear group (22.2%) (Table 1). All of the surgeons who performed the CIs always informed the patients of the benefits of bimodal use. The SRSs obtained with bimodal hearing also showed no significant difference between the poor- and better-ear groups ($p = 0.24$).

Discussion

In studies in which the post-CI SRS was defined as the outcome, prelingual hearing loss (vs. postlingual hearing loss) was one of the significant predictors, whereas implantation to the better- or poorer-hearing ear was not a significant predictor [6,8]. Supporting these observations, the present data revealed that the choice of the side of CI to the better- versus poorer-hearing ear does not have a significant impact on SRS

Table 2 Results of multiple regression analysis for predictors of speech recognition performance after cochlear implantation

Variable	Beta coefficient	95% confidence interval		*P*-value
Pre- or post-lingual hearing loss	24.6	11.75	37.45	< 0.001
Age at implantation	−0.33	−0.58	−0.09	0.008
CI in better or poorer hearing ear	−6.76	−14.92	1.39	0.10
Duration of sound deprivation	−0.22	−0.65	0.22	0.32
Side of CI (right vs left)	−3.21	−10.48	4.06	0.38

CI: cochlear implant.
The multiple regression model with the dependent variable of the speech recognition performance after cochlear implantation. Pre- or Post-lingual hearing loss and age at implantation significantly impacted on the speech performance after CI, whereas CI in the better or poorer ear, duration of sound deprivation, and surgery side (right vs left) did not.

outcomes, at least in the present Japanese language users.

While the effect of the duration of hearing loss is controversial, our present findings revealed that the duration of sound deprivation was not a significant predictor of the SRS score. At the beginning of this study, we hypothesized that a brain that had received auditory stimulation through adequate hearing aids during the recent pre-operative period can react to sounds more easily after CI than a brain that had not received auditory stimulation for a long time. However, the present results showed that once a patient achieves phonologic awareness in the prelingual period, CI will work well after a longer pre-operative duration of sound deprivation than what was described in earlier studies.

The differences between the outcomes reported by Boisvert *et al.* [6] and the present results may involve the differing definitions of the duration of bilateral significant hearing loss and the duration of sound deprivation. Boisvert *et al.*'s definition is the time for which two of the following criteria were met in both ears before implantation: (*i*) the hearing loss was severe, *i.e.*, the pure-tone threshold average was ≥ 70 dBHL; (*ii*) using a telephone was not possible; and/or (*iii*) SRSs with optimally adjusted hearing aids were $\leq 30\%$ for sentences or $\leq 10\%$ for words. The definition that we used in the present study was: (*i*) the average pure-tone threshold was >70 dBHL, and (*ii*) the onset was defined as the time when the patient's hearing device was no longer effective. Our definition considers whether hearing aids are effective in the patient's daily life during the pre-operative period, whereas Boisvert's definition may not.

If auditory stimulation during the postlingual period is an important factor for the effect of CI, it is plausible to expect that the factor of the duration of sound deprivation would have shown a significant predictive effect on postoperative SRS in the present study. We suspect that the reason why the study by Boisvert *et al.* found that the duration of bilateral significant hearing loss was significant is that their study's patient group with long durations of bilateral significant hearing loss included many patients who had had significant hearing loss from the prelingual period. As reported by other researchers, the results of our present investigation demonstrated that prelingual hearing loss had a critical effect on poorer outcomes of CI [9]. This phenomenon suggests that auditory deprivation at a prelingual age and that at postlingual age have different effects on SRS outcomes post-CI.

A bimodal use of CI and hearing aids has many benefits, such as understanding speech in noisy environments, ease of listening, sound localization, music appreciation, and sound quality [10-22]. As expected, our present results showed that patients who have CI in the poorer-hearing ear tend to use bimodal hearing more frequently than patients who have their CI in the better-hearing ear. Cochlear implantation to the poorer ear thus provides more opportunity for the patients to appreciate the advantage of postoperative bimodal hearing by wearing a hearing aid in the better-hearing ear.

Moreover, CI in the poorer ear can maintain the delicate structure of the cochlea of the better-hearing ear with no surgical damage. This is an important benefit for possible gene therapy for hearing loss in the future. Gene therapy for hearing loss has been developing very quickly, and a clinical trial has begun (NCT02132130 at ClinicalTrials. gov; https://clinicaltrials. gov/ct2/show/NCT02132130) (the last access date: June 21, 2023). [23] Gene therapy for hearing loss is expected to become available soon in clinical practices that deal with hearing loss. From this perspective, CI in the poorer-hearing ear can be an important choice for patients with severe-to-profound hearing loss at this time.

Limitations of this study are that it was retrospective, and the number of cases ($n=74$) is limited. The reason(s) for selecting the surgery side were not always mentioned in the patients' medical records. In addition, the progress in the design of cochlear implants continues to advance rapidly, and our conclusions may be affected by future modifications of CI devices.

In conclusion, when the optimal side for CI in cases of severe-to-profound hearing loss is being considered, implantation to the poorer-hearing ear can be a reasonable choice, because CI to the poorer-hearing ear can provide a postoperative SRS outcome that is comparable to that provided by CI to the better-hearing ear, and it provides greater benefit of a high bimodal hearing rate after implantation. The duration of sound deprivation has little impact on the outcomes of CI for adults with asymmetric hearing loss after the postlingual period. Further studies are needed to elucidate the mechanisms that underlie these effects of CI in the auditory systems of adults and children.

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