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Original Article

Preoperative Hearing Aids Improve Outcomes of Cochlear Implantation

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Objectives. We aimed to investigate the effects of preoperative auditory rehabilitation using hearing aids in patients with prolonged hearing deprivation.

Methods. We retrospectively enrolled 204 patients who underwent cochlear implantation surgery at age >60 years using a single university hospital database. In total, 135 patients with a duration of deafness (DoD) >10 years were divided into three groups according to perioperative hearing aid use: unaided (n=22, 16.3%), aided (n=92, 68.1%; comprising 22 ipsilateral hearing aid users and 70 bilateral hearing aid users), and contralateral-only aided (n=21, 15.5%). We identified the highest postoperative sentence recognition score (Max_S) and compared this measure across groups.

Results. Max_S was significantly higher in the DoD <10 years group than in the DoD ≥10 years group (72.38±25.74 vs. 64.09±32.29, P=0.048). Among patients with DoD ≥10 years, the aided group had significantly better Max_S than the unaided group (69.84±28.72 vs. 47.86±37.14, P=0.015). After one-to-two propensity score matching, Max_S remained significantly better in the aided group than in the unaided group (73.64±29.10 vs. 47.86±37.14, P=0.007).

Conclusion. Our study demonstrated the need for hearing rehabilitation during the period of hearing deprivation, including on the ear to be implanted, regardless of whether it produced immediate improvement in hearing levels.

Keywords. *Cochlear Implant; Hearing Aids; Auditory Rehabilitation*

INTRODUCTION

As life expectancy increases in aging societies, interest in hearing loss and auditory rehabilitation is also increasing. Auditory rehabilitation in patients with moderate to moderately severe sensorineural hearing loss (SNHL) is usually performed using hearing aids (HAs). However, patients with severe-to-profound SNHL (hearing loss with hearing thresholds >70 dB) often derive limited benefit from HAs because of poor speech recognition [1]. Accordingly, cochlear implantation (CI) is the standard treatment for these patients [2].

Auditory outcomes after CI in adults with postlingual deafness are reportedly influenced by preoperative factors such as duration of deafness (DoD), age at CI surgery (ageCI), duration of HA use (DoHA), and preoperative residual hearing [3-6]. However, there is ongoing debate regarding which factor has the greatest impact on postoperative speech comprehension. A recent study used a machine learning model to predict CI outcomes and reported that DoD was the most influential factor, followed by ageCI and DoHA. That research also indicated significantly better word recognition scores (WRS) (P<0.01) after CI in patients with DoD <10 years than in those with longer DoD [7].

In this study, we aimed to investigate the effects of auditory rehabilitation using HAs before CI in patients with longer DoD.

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Because previous studies have reported better CI outcomes in patients with DoD <10 years, we focused on patients with DoD ≥10 years to control for the confounding effect of DoD. Furthermore, we analyzed subgroups based on the HA-aided side to determine whether the side of HA use affected CI outcomes.

MATERIALS AND METHODS

The study protocol was approved by the Institutional Review Board of Severance Hospital (No. 4-2022-1081). The requirement for consent was waived owing to the retrospective design of the study.

Participants

A total of 229 patients who underwent CI surgery between January 1, 2007 and October 31, 2022 and whose age at surgery was >60 years were screened from the xxx Hospital database. The following patients were excluded: (1) one patient with prelingual deafness (hearing loss since childhood, under 10 years of age), (2) one patient with vestibular schwannoma who underwent combined translabyrinthectomy surgery, (3) two uneducated patients who were unable to perform the sentence recognition test, and (4) 21 patients with unilateral deafness (contralateral hearing level >70 dB). Consequently, 204 patients who were expected to have postlingual deafness, underwent fully inserted CI surgery, and followed up for >1 year were included. For patients with bilateral CIs, only the outcomes for the first implanted ear were analyzed.

Preoperative information and hearing tests

We collected the following preoperative data: ageCI, DoD, DoHA, residual hearing, WRS of ipsilateral and contralateral ears to the CI, and sentence recognition score (Pre_S). DoD was defined as the duration from when the patient reported being unable to converse without HA in the medical records. Residual hearing was analyzed by measuring the pure tone average (PTA) and average air conduction thresholds at 500, 1,000, 2,000, and 4,000 Hz. When no response to the presented tone within the audiometer limits was observed, a level of 120 dB was assigned. The WRS was analyzed by conventional speech audiometry using open-set mono/disyllabic words. Sentence recognition scores were measured in the auditory-only listening conditions. The tests were performed with samples of words or sentences from everyday life in a noiseless sound field environment. The test was scored based on the percentage of words that were correctly repeated. The PTA reflected the state of no HA use, whereas the WRS and Pre_S were performed under HA conditions.

HIGHLIGHTS

- Preoperative hearing aid use significantly improves cochlear implant outcomes in older adults with prolonged hearing deprivation; this finding emphasizes the importance of auditory stimulation before implantation, even in cases of long-term deafness.
- Patients with deafness duration ≥10 years who used hearing aids displayed better postoperative sentence recognition scores than unaided patients; this result suggests that hearing aids may help maintain auditory pathways, potentially improving cochlear implant performance.
- Auditory rehabilitation, including for the ear to be implanted, is crucial during the period of hearing deprivation, regardless of immediate hearing improvement; this highlights the need for comprehensive preoperative auditory management in cochlear implant candidates.

Evaluation of CI surgery outcome

Although follow-up compliance was not perfect in some patients, sentence recognition tests in the auditory-only listening condition were conducted at 3, 6, 9, 12, and 24 months after CI surgery. For patients who underwent follow-up tests >2 years after surgery, only the results up to 2 years postoperatively were collected. Postoperative tests were performed in the CI-alone condition, and the contralateral HA was consistently turned off during testing. Among the 3-, 6-, 12-, and 24-month postoperative results, the highest score was designated as Max_S and was analyzed as the primary outcome of CI surgery in this study.

Study design and patient classification

We conducted a stepwise multiple linear regression analysis to identify the preoperative predictors of Max_S. The independent variables included ageCI, DoD, DoHA, ipsilateral and contralateral PTA and WRS and Pre_S. Among these, DoD and Pre_S emerged as the most significant predictors of Max_S ($P<0.001$), and the following regression equation was obtained: $\text{Max\_S}=72.815-0.616\times\text{DoD}+0.551\times\text{Pre\_S}$.

To further explore an optimal DoD threshold, we conducted subgroup analyses by dichotomizing patients at various DoD cutoffs: 5, 7, 10, 12, and 15 years. Among these, only the 10-year cutoff yielded a statistically significant difference in Max_S between groups ($P<0.05$), while Pre_S did not significantly differ across any of the thresholds (Supplementary Table 1). Based on these findings and prior studies by Kim et al. [7], we adopted a DoD of 10 years as the criterion for grouping.

Among the patients, 135 older patients with a DOD ≥10 years were divided into 3 groups according to perioperative HA use: unaided, aided (including the ipsilateral side and ipsilateral side plus both sides), and aided on the contralateral side (contra). Patients were included in the aided group only if they had been aided for >1 year.

Statistical methods

All groups in this study passed the normality test performed using the Kolmogorov–Smirnov test ($P>0.05$); thus, parametric tests were used. Analysis of variance (ANOVA) and post-hoc (Dunnett's T3) tests were used to analyze the differences among multiple groups, and a Student *t*-test was used to compare the two groups. Categorical variables, such as sex and operation site, were analyzed using the chi-squared test. One-to-two propensity score matching was performed with a caliper width of 0.1 of the standard deviation of the logit of the propensity score, and the matching covariates were as follows: ageCI, DoD, PTA_Ipsi, PTA_Contra, WRS_Ipsi, WRS_Contra, and Pre_S. The DoHA was not included in the final analysis due to its lack of significant association with the outcome, and as it was conceptually redundant with the group categorization based on preoperative auditory rehabilitation via HAs. All statistical analyses were conducted using IBM SPSS software version 23 (IBM Corp.), and $P<0.05$ was considered statistically significant.

RESULTS

Effect of DoD on CI outcomes

First, CI outcomes were evaluated by DoD to confirm the importance of DoD in this cohort (Table 1). Overall, 135 patients had DoD ≥10 years, while 69 had DoD <10 years; Max_S was significantly higher in the DoD <10 years group (72.38±25.74 vs. 64.09±32.29, $P=0.048$). To control for the confounding effect of DoD, we included only patients with DoD ≥10 years (n=135) in subsequent analyses to evaluate the effect of preoperative HA use on CI outcomes.

CI outcome differences based on preoperative ipsilateral HA use

Among the 135 patients with DoD ≥10 years, we compared the unaided group (n=22) and the aided group (n=92; compris-

Table 1. Differences based on DoD

	DoD ≥10 yr (n=135)	DoD <10 yr (n=69)	Mean difference (95% confidence interval)	*P*-value
Sex (male)	54 (40.0)	39 (56.5)	-	0.025*
Operation site (right)	75 (55.6)	42 (60.9)	-	0.468
ageCI (yr)	67.59±6.43	69.20±6.25	1.62 (–0.24 to 3.48)	0.088
DoD (yr)	26.53±14.64	3.97±2.46	–22.56 (–25.11 to –19.99)	0.000***
PTA_Ipsi (dB)	99.09±15.91	96.28±15.57	–2.81 (–7.40 to 1.77)	0.228
PTA_Contra (dB)	91.19±17.05	88.09±19.01	–3.09 (–8.27 to 2.07)	0.257
WRS_Ipsi (%)	8.92±12.81	9.54±11.33	0.62 (–2.98 to 4.22)	0.725
WRS_Contra (%)	20.16±19.04	16.32±17.89	–3.84 (–9.28 to 1.60)	0.158
Pre_S	9.56±16.49	11.96±16.33	2.40 (–2.39 to 7.18)	0.325
Max_S	64.09±32.29	72.38±25.74	8.29 (0.07 to 16.51)	0.048*

Values are presented as number (%) or mean±standard deviation.
DoD, duration of deafness; CI, cochlear implantation; ageCI, age at CI surgery; PTA, pure tone average; Ipsi, ear ipsilateral to CI surgery; Contra, ear contralateral to CI surgery; WRS, word recognition score; Pre_S, preoperative sentence recognition score; Max_S, maximum postoperative sentence recognition score.
*$P<0.05$, ***$P<0.001$.

Table 2. Differences based on preoperative auditory rehabilitation

	Aided HA (n=92)	Unaided HA (n=22)	Mean difference (95% confidence interval)	*P*-value
Sex (male)	35 (38.0)	10 (45.5)	-	0.523
Operation site (right)	53 (57.6)	13 (59.1)	-	0.899
ageCI (yr)	68.39±7.10	64.55±3.88	3.84 (1.62 to 6.07)	0.001*
DoD (yr)	25.48±13.29	30.14±19.38	–4.65 (–13.62 to 4.30)	0.295
PTA_Ipsi (dB)	97.61±15.67	100.14±17.01	–2.52 (–10.02 to 4.96)	0.505
PTA_Contra (dB)	91.88±16.78	95.45±18.88	–3.57 (–11.92 to 4.51)	0.383
WRS_Ipsi (%)	9.13±12.79	10.36±13.89	–1.23 (–7.35 to 4.88)	0.690
WRS_Contra (%)	19.35±18.49	14.64±15.95	4.71 (–3.77 to 13.19)	0.274
Pre_S	9.93±17.04	9.82±13.20	0.11 (–7.59 to 7.82)	0.976
Max_S	69.84±28.72	47.86±37.14	21.97 (4.61 to 39.33)	0.015*

Values are presented as number (%) or mean±standard deviation.
HA, hearing aid; CI, cochlear implantation; ageCI, age at CI surgery; DoD, duration of deafness; PTA, pure tone average; Ipsi, ear ipsilateral to CI surgery; Contra, ear contralateral to CI surgery; WRS, word recognition score; Pre_S, preoperative sentence recognition score; Max_S, maximum postoperative sentence recognition score.
*$P<0.05$.

Table 3. Propensity score-matching data (1:2 matching)

	PSM_aided HA (n=44)	PSM_unaided HA (n=22)	Mean difference (95% confidence interval)	*P*-value
ageCI (yr)	64.98±4.83	64.55±3.88	0.43 (−1.93 to 2.80)	0.717
DoD (yr)	28.39±13.41	30.14±19.38	−1.75 (−11.13 to 7.63)	0.706
PTA_Ipsi (dB)	100.18±15.12	100.14±17.01	0.04 (−8.18 to 8.27)	0.991
PTA_Contra (dB)	96.68±16.28	95.45±18.88	1.22 (−7.73 to 10.18)	0.785
WRS_Ipsi (%)	8.59±13.63	10.36±13.89	−1.77 (−8.92 to 5.38)	0.622
WRS_Contra (%)	13.09±18.02	14.64±15.95	−1.54 (−10.60 to 7.51)	0.734
Pre_S	6.59±13.31	9.82±13.20	−3.22 (−10.15 to 3.70)	0.355
Max_S	73.64±29.10	47.86±37.14	25.77 (7.38 to 44.16)	0.007*

Values are presented as mean±standard deviation. Covariates; AgeCI, DoD, PTA_Ipsi, PTA_Contra, WRS_Ipsi, WRS_Contra, Pre_S.
PSM, propensity score matching; HA, hearing aid; CI, cochlear implantation; ageCI, age at CI surgery; DoD, duration of deafness; PTA, pure tone average; Ipsi, ear ipsilateral to CI surgery; Contra, ear contralateral to CI surgery; WRS, word recognition score; Pre_S, preoperative sentence recognition score; Max_S, maximum postoperative sentence recognition score.
*$P<0.05$.

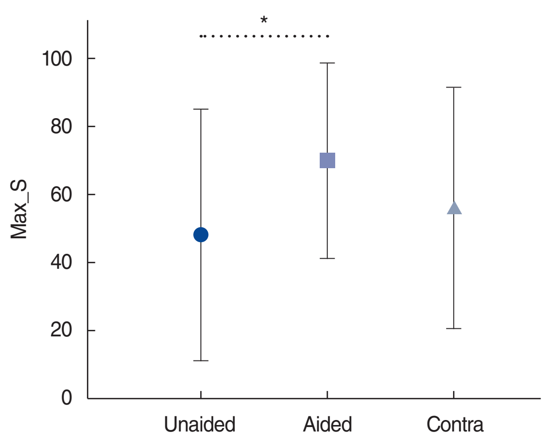

Fig. 1. Group analysis of hearing aid application. The graph presents the mean±standard deviation of maximum postoperative sentence recognition score (Max_S) in each group. The circle, square, and triangle indicate the group mean for the unaided (n=22, 47.86±37.14), aided (n=92, 69.84±28.73), and contra (n=21, 55.90±35.63) groups, respectively (analysis of variance, $P=0.007$). Post hoc analysis using the Dunnett T3 test showed a significant difference only between the unaided and aided groups ($P=0.044$); no significant difference was observed between the unaided and contra groups ($P=0.850$) or between the aided and contra groups ($P=0.280$). *$P<0.05$.

ing 22 patients with ipsilateral HA use and 70 patients with bilateral HA use) to evaluate the effect of ipsilateral HA use on CI outcomes (Table 2). Most preoperative variables did not differ between groups, except for ageCI ($P=0.001$). The aided group had significantly higher Max_S than the unaided group (69.84±28.72 vs. 47.86±37.14, $P=0.015$).

When we compared the 22 patients in the unaided group with 44 best-matched patients in the aided group, Max_S remained significantly higher in the aided group (73.64±29.10 vs. 47.86±37.14, $P=0.007$) (Table 3, Supplementary Table 2).

Group analysis by HA application

Patients were divided into three groups based on perioperative HA use: unaided (n=22, 16.3%), aided (n=92, 68.1%), and contralateral-only aided ("contra") (n=21, 15.5%). In this group analysis, Max_S differed significantly across groups (ANOVA, $P=0.007$), and Max_S was significantly higher in the aided group than in the unaided group ($P=0.044$) (Fig. 1). Although differences between the unaided and contra groups ($P=0.850$) and between the aided and contra groups ($P=0.280$) were not statistically significant, the contra group had a lower mean Max_S than the aided group.

DISCUSSION

The most noteworthy finding of this study was that preoperative hearing rehabilitation using HAs was associated with better speech comprehension after CI. The aided group, which included patients using ipsilateral or bilateral HAs, had significantly higher Max_S than the unaided group, which comprised patients who had never used HAs or had used them for <1 year. This finding remained consistent after propensity score matching to control for potential confounders. In contrast, the contra group did not differ significantly from the unaided group.

Previous reports have indicated that DoD is the most important predictor of CI outcomes and that longer DoD is associated with poorer outcomes after CI surgery [7-11]. Long-term hearing loss may limit auditory system plasticity and lead to degeneration of spiral ganglion neurons that are stimulated by cochlear implants [12-15]. In our study, patients with DoD ≥10 years had worse postoperative speech comprehension than those with DoD <10 years.

The potential benefit of preoperative HA use may be explained by the preservation of central auditory pathway function through sustained afferent auditory stimulation. Prolonged auditory deprivation has been shown to induce maladaptive neuroplastic changes, including cortical reorganization, reduced neural synchrony, and cross-modal plasticity, which are associated with poorer CI outcomes [15,16]. In addition, long-standing auditory deprivation has been linked to degeneration of spiral ganglion neurons and reduced effectiveness of electrical stimulation after CI [12-14].

Even when HAs provide limited speech intelligibility, low-level auditory input may help maintain temporal processing and auditory–linguistic network engagement, thereby attenuating the negative effects of complete functional auditory deprivation [17-19]. Neuroimaging and electrophysiologic studies have demonstrated that continued auditory stimulation can modulate cortical auditory responses and support functional plasticity in adult listeners [16,20]. In this context, preoperative HA use may not restore effective hearing but may reduce the duration and extent of central auditory deprivation, thereby contributing to improved postoperative speech outcomes after CI.

The use of HAs in auditory rehabilitation remains a topic of debate. Several studies have suggested that, through trophic effects and cross-modal reorganization, auditory stimulation provided by an HA to the better-hearing ear may help preserve central auditory pathway function in adults with postlingual deafness, regardless of the side of the affected ear [5,8,11,21-23]. However, in our study, the contra group did not differ significantly from the unaided group. This finding suggests that auditory stimulation limited to the contralateral ear alone may be insufficient to preserve the auditory pathways relevant to the implanted ear, particularly in patients with prolonged bilateral hearing deprivation. This may reflect cross-modal reorganization within the auditory cortex.

Several limitations of this study should be acknowledged. First, DoD was defined as the period during which patients were unable to communicate without HAs. This definition does not allow precise differentiation between stable deaf-level hearing loss and gradually progressive hearing loss over time, which is an inherent limitation of retrospective studies relying on DoD and has been recognized in the existing CI literature. Although some degree of misclassification cannot be excluded, the same DoD definition was applied uniformly across groups. Moreover, the comparable preoperative audiometric thresholds between groups (Tables 2 and 3) provide the most objective verification feasible in this retrospective cohort and suggest that substantial differential bias related to DoD is unlikely. Nevertheless, potential biases affecting causal interpretation cannot be fully excluded.

Second, the decision to use or not use an HA may have been influenced by non-audiological factors such as socioeconomic status, educational background, cognitive function, stigma, or access to healthcare. Because this study was retrospective, these variables were not available in our database and thus could not be included in the propensity score matching process. In addition, patients who continued HA use despite advanced hearing loss may have been more motivated and more adherent to postoperative auditory rehabilitation after CI, which could have contributed to better outcomes. Although the decision to undergo CI may imply a minimum level of motivation for rehabilitation, the possibility of residual confounding cannot be completely excluded.

Third, although DoHA has been suggested as a factor influencing CI outcomes in previous studies, it was not included in the final multivariable analysis. In our correlation analysis, including Max_S, ageCI, DoHA, DoD, and preoperative audiological parameters, DoHA was not significantly associated with the outcome ($P=0.637$). Furthermore, because DoHA is inherently correlated with the grouping variable (HA use), including it could have introduced redundancy without additional explanatory value. Therefore, we excluded DoHA to maintain a parsimonious analytical model.

Fourth, follow-up compliance across postoperative time points (3, 6, 9, 12, and 24 months) was inconsistent. To address this limitation, we used the Max_S observed at these time points as the primary outcome. This approach captures the best speech performance achieved after CI and aligns with our objective of evaluating the impact of preoperative auditory rehabilitation. Lastly, postoperative CI use-time data were not available in our retrospective database. In future prospective studies, this variable should be included to better characterize the relationship between device engagement and speech outcomes.

Despite these limitations, our study demonstrated the need for hearing rehabilitation during the period of hearing deprivation and suggests that rehabilitation should include the ear on the surgical side. Clinically, even when patients with severe-to-profound hearing loss derive limited immediate benefit from HAs, continued HA use may help preserve central auditory function by reducing functional auditory deprivation. Therefore, clinicians should consider recommending HAs during the period of hearing deprivation to optimize speech outcomes after future CI.

CONFLICT OF INTEREST

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

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Conceptualization: YYA. Data curation: JSO, YYA. Formal analysis: YYA. Funding acquisition: SHB. Investigation: SHB. Methodology: YYA, SHB. Project administration: YYA. Resources: JYC. Software: YYA. Supervision: JYC. Validation: SHB. Visualization: YYA. Writing–original draft: YYA. Writing–review & editing: SHB. All authors read and agreed to the published version of the manuscript.

SUPPLEMENTARY MATERIALS

Supplementary materials can be found online at https://doi.org/10.21053/ceo.2025-00070.

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