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Hearing Rehabilitation Using Bone Conduction Implants in Patients With Single-Sided Deafness After Vestibular Schwannoma Removal

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청각신경종양 제거술 후 발생한 일측 청력저하 환자들에서 골전도 임플란트를 이용한 청각재활 효과

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Background and Objectives Vestibular schwannoma (VS) itself or treatment of VS can cause single-sided deafness (SSD), a unilateral sensorineural hearing loss. Patients of SSD experience communication problems, which can be frustrating. For decades, many types of bone conduction implants (BCIs) have been developed and used to treat such hearing problems. In this study, we evaluated the effectiveness of BAHD surgery to treat SSD patients' hearing impairment and analysed the complications patients suffer.

Subjects and Method A retrospective chart review was conducted on 12 patients who had undergone BCIs, such as Baha Attract, Bonebridge, and Sophono implantation, after removal of VS. From 2016 to 2021, one senior surgeon at a single tertiary hospital performed surgery for SSD rehabilitation. The authors analysed the clinical features, radiologic findings (CT and MRI), hearing tests (pure tone audiogram [PTA], speech audiogram [SA], and Korea hearing in noise test), subjective satisfaction scores (abbreviated profile of hearing aid benefit), and surgical outcomes of the patients.

Results All patients underwent temporal MRI, temporal bone CT scan, PTA, and SA at least 3 years after VS removal and confirmed no residual tumour or serviceable contralateral hearing at the last follow-up. Among the patients (12), eight received Baha Attract implantation, three received Bonebridge implantation, and one received Sophono implantation. On the average, patients' ipsilateral hearing outcomes improved by 82.7 dB (from 115.8±9.8 dB to 33.1±9.5 dB).

Conclusion There are many methods of hearing rehabilitation in SSD that are used after VS, but BCI seemed to be the most useful treatment.

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Keywords Hearing loss, unilateral; Vestibular schwannoma.

Introduction

Ipsilateral hearing loss is the most frequent complaint of patients with vestibular schwannoma (VS) and it usually continues or worsens after treatment, such as surgical removal or Gamma Knife radiosurgery.[1,2] Single-sided deafness (SSD) is defined as unilateral sensorineural hearing loss of the worse ear. It has been proved that patients with unresolved SSD ex-

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perience significant problems using only monoaural hearing.[3,4] They have problems understanding speech, discrimminating language from noisy condition, and sound localization. One of the most common choices is simply to do nothing.

The bone-anchored hearing device (BAHD) was first introduced 30 years ago for the treatment of conductive or mixed hearing loss.[4-7] The first BAHD was Baha (Cochlear, Sydney, Australia), which is a percutaneous type, in which the external skin processor sends an external signal to the internal pin directly through the subcutaneous tissue. It is associated with problems such as inflammation, infection, skin overgrowth, and cosmetic issues. Therefore, the newly developed transcutaneous implants, Baha Attract (Cochlear), Bonebridge (MEDEL, Innsbruck, Austria), and Sophono (Sophono Inc., Boulder, CO, USA), have various advantages compared to the previous type (Fig. 1).

In this study, we planned to study SSD patients' hearing impairment can be improved after BAHD surgeries and complications patients suffer. We treated 12 patients who underwent surgical removal of VS and received transcutaneous bone conduction implantation and analysed the outcomes.

Subjects and Methods

This retrospective study included 12 patients. We defined SSD as patients who had ipsilateral hearing impairment (over 41 dB threshold in six-frequency average) in pure tone audiogram (PTA). Patients experienced single-sided hearing loss after VS removal. Through at least 2 years of follow-up after tumour removal, no residual tumour or contralateral serviceable hearing was confirmed. Patients underwent ipsilateral bone conduction implant (BCI) surgeries, such as Baha Attract, Bonebridge, and Sophono, by one senior surgeon (M.I.S) at a single tertiary hospital from January, 2016 to February, 2022. Among the 12 patients, 8 received Baha Attract implantation, 3 received Bonebridge implantation, and 1 received Sophono implantation.

We analysed the patients' clinical features, radiologic findings (CT and MRI), hearing tests (PTA, speech audiogram [SA], and Korea hearing in noise test [K-HINT]), subjective satisfaction scores (abbreviated profile of hearing aid benefit [APHAB]), and surgical outcomes. This study was approved by the Institutional Review Board (No. 4-2022-0427).

Hearing test

We conducted a PTA and SA immediately before and at least 3 months after implantation surgery using a 6 frequencies average method ([500 Hz+2*1 kHz+2*2 kHz+4 kHz]/6), which is the most common calculation method. We used the warble tone-sound field test in both 45° angle-distant speakers. We used an ear plug or headphone in contralateral ear to mask real noise, which is globally used. We also implemented speech tests, such as the word recognition score (WRS) and Most Comfortable Level tests.

In addition, 4 patients underwent K-HINT 3 months after implantation surgeries. K-HINT evaluates patients' hearing levels not only in noisy conditions from the front, left, right, rear, and all directions, but also in quiet conditions, using signal-to-noise ratio (SNR) in general studies. We used all directions of the surrounding speakers for patients; normal data was localization: 98%, frontal noise: -3.5 SNR, right direction noise: -9.3 SNR, left direction noise: -8.9 SNR, and circumferential noise: -7.3 SNR. However, in our study, we calculated the difference score gap between the unaided and aided hear-

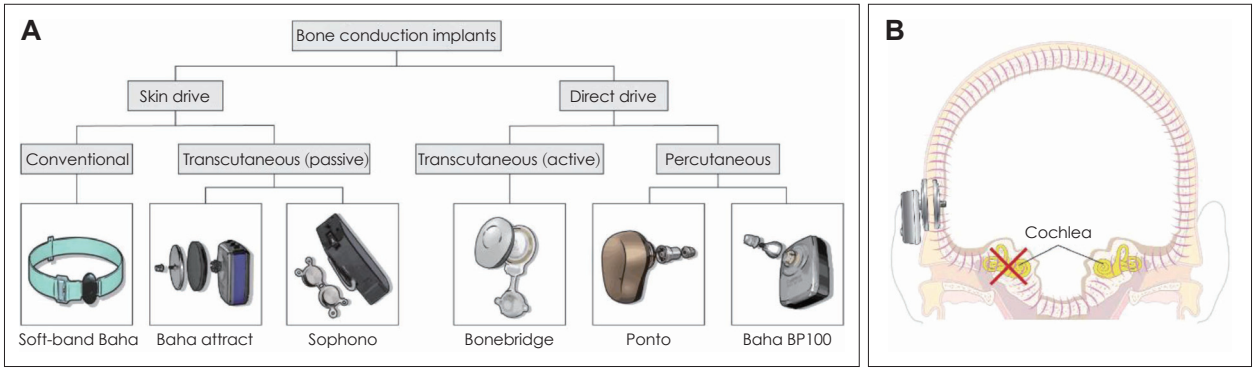

Fig. 1. Classification and working principle of bone conduction implants. A: Classifications of bone conduction implants. There 2 types of bone conduction implants (BCIs), direct-drive system and skin-drive system, Baha attract are Sophono are passive transcutaneous type in skin-drive system, Bonebridge is active transcutaneous type in direct-drive system. B: BCIs basically transmit external sounds to opposite portion of cochlea (contralateral side) through skin, skull and connective tissue.

ing levels in each BCI to compare each of the 3 BCI devices' difference. If patients receive better hearing, the resulting gap value is less than 0 (minus), and if they receive worse hearing, the gap value is more than 0 (plus).

We also performed the APHAB for 10 patients 3−6 months after BCI surgeries to evaluate subjective hearing satisfaction. The APHAB is a reliable tool for quantifying satisfaction with hearing aids. It consists of 4 categories: ease of communication (EC), reverberation (RV), background noise (BN), and aversiveness (AV). Each category has 6 questions; a total of 24 patients can be scored from 0 (good) to 10 (bad) before and after wearing their devices. When the device is worn, the score is lowered, which indicates that it is effective and satisfactory.

Surgical procedures

The average BCI surgery time ranged from 30 to 50 min, including wound closing. All surgeries were performed under local anaesthesia. The surgical position was supine and the head rotated to the contralateral side. An epinephrine-mixed lidocaine solution was injected on the ipsilateral side. After skin incision, skin and subcutaneous tissue dissection were performed, and the internal device was implanted according to the implantation guidelines of each device.[8] Internal devices were confirmed by postoperative radiologic tests (Fig. 2).

Statistical analysis

We used Wilcoxon signed-rank test to compare difference each 12 patient's preoperative and postoperative PTA hearing levels and 10 patient's each 4 categories of APHAB scores. Each *p*-value of 0.05 or less was considered to reflect statistical significance. All analyses were conducted using SPSS software (version 29.0; IBM Corp., Armonk, NY, USA).

Results

Patients' features

The 12 patients were aged 59.1±11.5 years old from 41.0 to 71.0 years old. Male and female were 5 (63.2±10.5 years old) and 7 (56.1±11.3 years old). All patients had a single-sided VS and got surgeries. The translabyrinthine, retrosigmoid, middle cranial fossa, and modified exclusive endoscopic transcanal transpromontorial approaches (mEETTA) were used. The approaches were decided based on the tumour size, location, and hearing levels (Table 1 and Fig. 3).

Hearing outcomes

None of the patients had remnant tumours in the ipsilateral operation site on follow-up MRI scans over 2 years.

The preoperative and postoperative hearing levels of all 12 patients were 115.8±9.8/33.1±9.5 dB in PTA, and 0.8%±2.8%/87.1%±7.3% in WRS respectively. On average, all patients' ipsilateral hearing outcomes improved by 82.7 dB (p=0.002). Analysis of the 3 types of implants showed that the results were good for every device. Baha Attract showed an 82.6 dB improvement in hearing (from 113.6±11.4 to 31.0±10.4 dB) (p=0.012), Bonebridge showed an 84.7 dB improvement in hearing (from 120.0±0 to 35.3±4.9 dB)(p=0.109), and Sophono showed a 77.0 dB improvement in hearing (from 120.0±0 to 43.0±0 dB) (Table 1 and Fig. 4).

We also performed the K-HINT test 3 months after BCI surgery (Table 2). Each of the 3 devices showed an average -2.1±2.0 SNR unaided-aided gap in quiet conditions, and -0.6±0.7 (front), -1.0±0.4 (right), -2.9±3.0 (left), -1.1±0.7 (circumference) SNR, respectively.

There were no differences among patients' subjective satisfaction when applying each of the three devices and the oc-

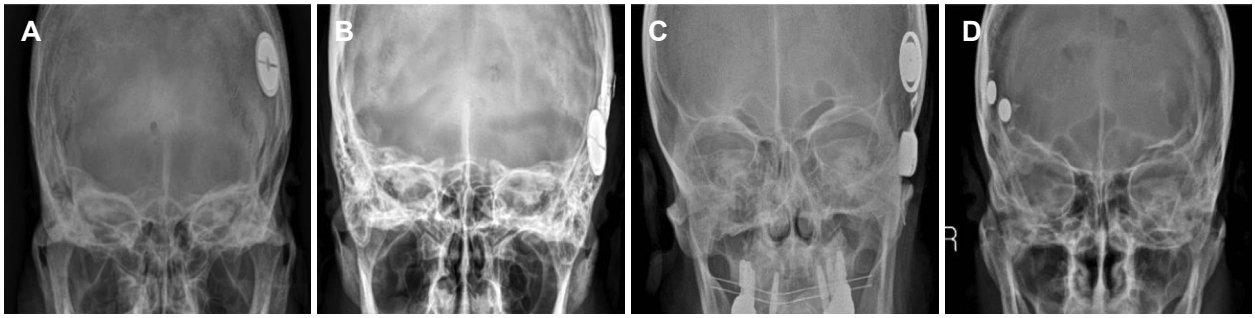

Fig. 2. Postoperative skull X-rays. After BCIs surgeries, we conducted skull X-rays to confirm devices' proper location. A: Patient who received BAHA attract after mEETTA . B: Patient who received BAHA attract after TLA. C: Patient who received Bonebridge after MCFA. D: Patient who received Sophono after TLA. BCI, bone conduction implant; BAHA, bone anchoring hearing aid; mEETTA, modified exclusive endoscopic transcanal transpromontory approach; MCFA, middle-cranial fossa approach; TLA, translabyrinthine approach.

Table 1. Characteristics of the patients

Patient No.	Age	Sex	Pre-tumor removal symptoms			Tumor size (mm)	Excision approach	Type	Pre/post-BCI hearing (dB HL)	Pre/post contralateral BC (dB HL)	Pre/post-BCI WRS (%)	Pre/post-BCI MCL (dB)	Follow up period (months)
			Tinnitus	Dizziness	Hearing (dB HL)								
Pt. 1	53	F	+	+	55	14×10	TLA	Baha	120/20	40/34	0/100	120/50	8
Pt. 2	68	M	-	+	48	10×6	TLA	Baha	120/20	5/5	0/92	120/58	4
Pt. 3	43	M	-	-	64	11×11	TLA	Baha	120/22	10/10	0/92	120/54	11
Pt. 4	71	M	+	+	108	26×19	TLA	Baha	120/44	33/33	0/88	120/57	4.5
Pt. 5	71	F	-	-	52	17×13	TLA	Baha	120/32	20/15	0/90	120/56	8
Pt. 6	71	M	-	+	120	38×35	RSA	Baha	100/35	25/25	0/82	100/60	6
Pt. 7	44	F	+	-	58	5×4	MCFA	Baha	89/49	36/33	10/73	90/64	6
Pt. 8	41	F	++	-	52	6×6	mEETTA	Baha	120/26	15/15	0/92	120/50	7
Pt. 9	64	F	+	-	117	26×20	TLA	BB	120/29	28/29	0/90	120/56	65
Pt. 10	70	F	-	-	120	11×13	TLA	BB	120/41	31/25	0/88	120/58	63
Pt. 11	63	M	++	-	70	3×3	mEETTA	BB	120/36	24/24	0/83	120/60	16
Pt. 12	50	F	+	-	120	25×18	TLA	SPH	120/43	22/19	0/75	120/62	54

Used six-frequency average. BCI, bone conduction implant; BC, bone conduction; WRS, word reception score; MCL, Most Comfortable Level; TLA, translabyrinthine approach; RSA, retrosigmoid approach; MCFA, middle-cranial fossa approach; mEETTA, modified exclusive endoscopic transcanal transpromontory approach; Baha, Baha Attract; BB, Bonebridge; SPH, Sophono

currence rate of complications among the types of 3 devices in our study, such as inflammation, infection, and wound dehiscence.

Finally, we used the APHAB score for 10 of 12 patients, (Baha attract 7, Bonebridge 2, Sophono 1) (Table 3). The APHAB is a quantifying tool that expresses satisfaction before and after wearing each device. We calculated the gap (pre-fit–postfit) of each of the 4 categories of the APHAB and expressed the average of each patient's device. The Baha Attract pre-fit and postfit gap average scores were 30.1±16.4 (EC) (p=0.018), 31.4±8.5 (RV) (p=0.018), 36.0±7.5 (BN) (p=0.018), and 6.0±9.6 (AV) (p=0.18). The Bonebridge average gap scores were 19.0±3.0 (EC) (p=0.18), 17.5±3.5 (RV) (p=0.18), 21.5±8.5 (BN) (p=0.18), and 0 (AV). The Sophono average gap scores were 16.0 (EC), 14.0 (RV), 13.0 (BN), and 0 (AV). Patient satisfaction was better and the gap score was high.

Discussion

To date, several treatment options for hearing impairment patients have been developed, including Cochlear Implantation (CI), Ossiculoplasty, Stapes Surgery, and hearing aids. In 2019, Zeitle and Dorman[9] analysed 29 patients with SSD and normal or near-normal hearing in the contralateral ear who underwent CI surgery. Although there was some variability in objective outcomes, 13 out of 19 (68%) demonstrated improved WRS (mean improvement, 28%) after CI, and 14/19 (74%) demonstrated improvements in sentence recognition scores. In a single centre study by Arndt, et al.,[10] 45 patients with SSD and 40 patients with asymmetric hearing loss were treated with CI, BCI, or bilateral contralateral routing of signals hearing aids (CROS). They concluded that patients who received CI treatment showed superiority in speech recognition after 12 months.

As mentioned above, many studies have shown that CI is appropriate for patients with SSD, but in patients with VS who undergo tumour removal surgery, it is difficult to prove whether patients' cochlear nerves are intact, which is necessary for CI indication, so the success of CI cannot be guaranteed. Another treatment for SSD, contralateral routing of signals was introduced in 1965.[4] However, CROS also has disadvantages, such as wearing in both sides of the ears, causing infection in the external ear and not improving hearing competency.

Therefore, we chose another treatment option using various types of BCI surgeries for patients with SSD. One of the most important advantages of BCIs is ipsilateral hearing improvement. Regardless of the implant type, all 12 patients had improved hearing outcomes by 82.7 dB (from 115.8±9.8 dB to 33.1±9.5 dB). This is notable when compared to a study by Seigert and Kanderske[11] where 21 patients who received Sophono implantations had their hearing level improved only by 31±8 dB.[7,11,12]

According to the PTA results, all BCI devices seemed effective for hearing improvement on the ipsilateral side of patients with SSD. Unfortunately, no study has compared hear-

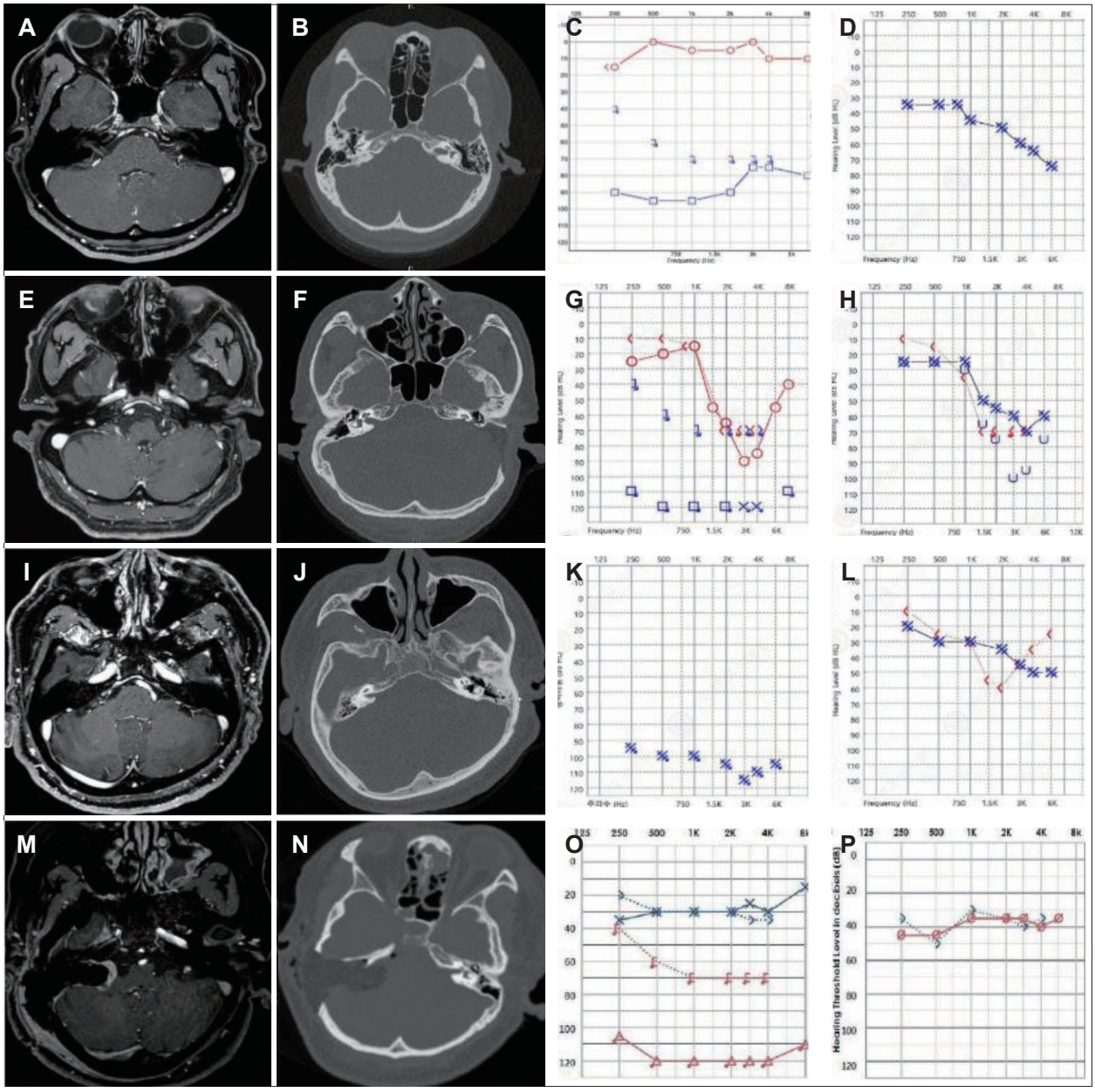

Fig. 3. Patients description. Figures showed pre implantation (and post VS removal images), preimplantation and post-implantation PTA of the patient who received BAHA attract after mEETTA and (A-D), of the patient who received BAHA attract after TLA (E-H), of the patient who received Bonebridge after MCFA (I-L), and of the patient Sophono after TLA. Above images are for each patient's preoperative and postoperative findings. Each line left side 2 pictures (A, B, E, F, I, J, M, N) are temporal MRI and temporal bone CT which were taken right before BCIs surgeries, and right side 2 pictures (C, D, G, H, K, L, O, P) are preoperative/postoperative BCIs surgeries' pure tone audiograms. VS, vestibular schwannoma; PTA, pure tone audiogram; BAHA, bone anchoring hearing aid; mEETTA, modified exclusive endoscopic transcanal transpromontory approach; MCFA, middle-cranial fossa approach; TLA, translabyrinthine approach; BCI, bone conduction implant.

ing improvement among various types of BCIs. In this study, we couldn't do statistic data analysis due to short of cases, only 12, so we couldn't discuss difference in hearing improvement among the 3 types of devices.

Unlike percutaneous implants, transcutaneous implants rarely have complications, such as inflammation, infection, skin overgrowth, and wound dehiscence. Although one of the patients with Baha Attract experienced skin problems, no further complications were noted in the other patients. We only used a small incision of 3 cm in Baha for cosmetic advantage; the optimal surgical site can be exposed even with a small incision[9] and a microscope was not needed. Bone-

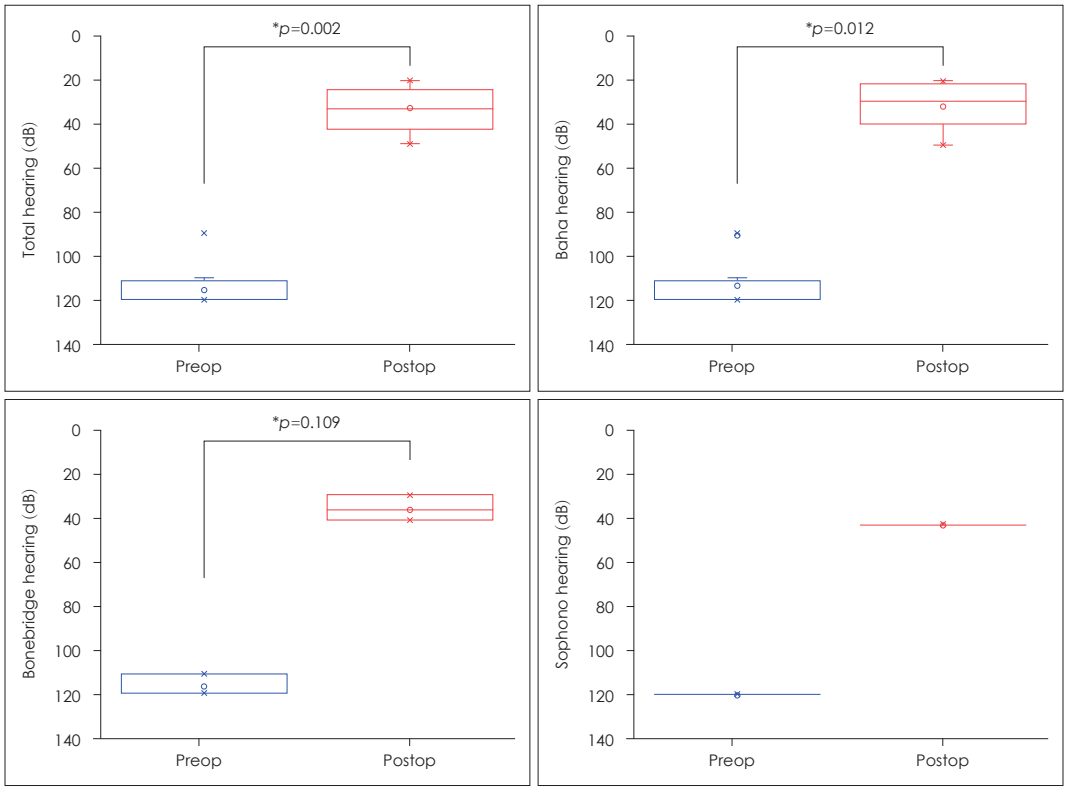

Fig. 4. Hearing levels of each implant devices (graphs). In left upper graph, all bone conduction implants' average preop and postop hearing results were expressed, and other graphs show each Baha attract, Bonebridge, Sophono's preop and postop hearing levels.

Table 2. K-HINT results comparisons among BCIs

	Localization (%)	Quiet (dB)	Noise/frontal (SNR)	Noise/right (SNR)	Noise/left (SNR)	Noise/ circumferential (SNR)	Noise/ ipsilateral (SNR)	Noise/ contralateral (SNR)
Baha attract	Unaided-aided gap	-2.2	-0.9	-0.7	-1.4	-1.0	-1.5	-0.6
Bonebridge		-4.1	-1.2	-0.9	-0.1	-0.5	-0.9	-0.1
Sophono		+0.1	+0.4	-1.4	-7.1	-1.8	-7.1	-1.4
Total average		-2.1	-0.6	-1.0	-2.9	-1.1	-3.2	-0.7

Each column showed difference of SNR after aided in each devices. Unaided-aided gap means SNR change before and after use of BCIs. In quiet condition, average all BCIs' hearing level (unaided-aided gap) was -2.1 dB. In noisy condition, each SNR improved frontal (-0.6), right-side (-1.0), left-side (-2.9), all directions (-1.1) overall. BCI, bone conduction implant; SNR, signal/noise ratio

bridge usually requires a larger incision[8] and wide mastoid bone drilling, considering the device size,[13,14] and requires a microscope for mastoid bone drilling. Thus, the operation was simpler in Baha Attract.

One patient received mEETTA and CI simultaneously, but at more than 9 months follow-up after discharge showed no improvements in hearing level. There was no sign of remnant tumour in the previous lesion over 2 years; therefore, we planned CI removal and Bonebridge implantation. After 7 months of follow-up, the patient's hearing level had improved by 86 dB (from 112 to 26 dB). Each patient's subjective satisfaction was evaluated in a follow-up outpatient clinic using the APHAB questionnaire with 24 questions. Patients who participated expressed subjective satisfaction after wearing hearing devices, regardless of type, as specified in the previous section.[15]

Our study has limitation that we couldn't collect sufficient cases, only 12, because VS prevalence rate is very rare, about 10–20 per 100000 in Korea. And we did K-HINT for only 4 patients, APHAB for 10 patients. Also statistical analysis of the results of 12 PTAs and 10 APHAB scores appears to show statistical improvement, but it was not possible to compare preoperative and postoperative hearing improvment by each 3 devices due to small number of patients. It might be lack of

Table 3. APHAB results for each devices

Device	EC gap avg	RV gap avg	BN gap avg	AV gap avg
Baha Attract	30.1±16.4	31.4±8.5	36.0±7.5	6.0±9.6
Bonebridge	19.0±3.0	17.5±3.5	21.5±8.5	0
Sophono	16.0	14.0	13.0	0

10 of 12 patients conducted APHAB score (Baha attract 7, Bonebridge 2, Sophono 1). Each 4 category score was calculated by gap between prefit score and postfit score. The gap average score is higher, patients expressed more satisfaction. APHAB, abbreviated profile of hearing aid benefit; EC, ease of communication; RV, reverberation; BN, background noise; AV, aversiveness

evidence that we conclude the effectiveness of BCI in hearing rehabilitation for SSD. Unfortunately, in a study by Jansson, et al.,[16] BCIs have wide range of artifact, about 11.5 cm from the centre of the implant in Baha attract, and 5−10 cm in Sophono. As these BCIs have the disadvantage of creating interference in MRI, also methods to solve this problem should be studied.

In conclusion, there should be many further studies on the recently developed transcutaneous type of implants, which can be a useful treatment for patients with SSD to improve hearing levels.

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Author Contribution

Data curation: Jeong Gum Lee, Ju Ha Park. Investigation: Ju Ha Park. Writing—original draft: Jeong Gum Lee. Writing— review & editing: Jeong Gum Lee.

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