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Bilateral Cochlear Implantation Versus Bimodal Hearing in Patients With Functional Residual Hearing: A Within-subjects Comparison of Audiologic Performance and Quality of Life

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Abstract

Objective—Evaluate performance and quality of life changes after sequential bilateral cochlear implantation in patients with preoperative residual hearing functioning in a bimodal hearing configuration.

Study Design—Retrospective analysis using within-subjects repeated measures design.

Setting—Tertiary otologic center.

Patients—Twenty-two adult patients with bilateral sensorineural hearing loss who used bimodal hearing before second cochlear implant (CI) meeting the following criteria: 1) preoperative residual hearing (≤ 80 dB HL at 250 Hz) in the ear to be implanted, 2) implantation with current CI technology (2013–2016), 3) consonant-nucleus-consonant (CNC) speech recognition testing in the bimodal condition preoperatively and bilateral CI condition postoperatively.

Intervention—Cochlear implantation.

Main Outcome Measures—CNC and AzBio sentence scores in quiet and noise (+5 SNR). Subjective measures of communication difficulty and sound quality were also administered.

Results—Twenty-two patients (mean 64 yr, 68% men) were included. At an average follow-up of 11.8 months, CNC scores in the bilateral CI condition (mean 63%, standard deviation [SD] = 22) were significantly better than preoperative bimodal scores with repeated measures analysis (mean 55%, SD = 22) ($p = 0.03$). AzBio scores in quiet were also higher with bilateral CI (mean 76%, SD = 24) compared with bimodal listening (mean 69%, SD = 29) ($p = 0.0007$). Global abbreviated profile of hearing aid benefit (APHAB) and overall speech, spatial, and qualities of hearing (SSQ) scores exhibited significant improvement following bilateral implantation ($p = 0.006$ for both analyses).

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Conclusions—For patients using a bimodal hearing configuration with substantial residual hearing in the non-CI ear, bilateral cochlear implantation yields improved audiologic performance and better subjective quality of life, irrespective of the ability to preserve acoustic hearing during the second sided implantation.

Keywords

Acoustic; Bilateral; Bimodal; Cochlear implant; Hearing aids; Hearing loss; Sensorineural

For patients with bilateral profound sensorineural hearing loss, bilateral cochlear implantation is considered the standard of care for hearing rehabilitation. In recent years, the indications for cochlear implantation have expanded to include patients with greater degrees of residual low-frequency hearing for hybrid/electric and acoustic stimulation (EAS) systems. These expanded indications are relevant to bilateral cochlear implantation as an increasing number of bimodal listeners (unilateral CI and hearing aid [HA] in the contralateral ear) are pursuing a second implant. If residual hearing is lost or rendered non-functional after second sided cochlear implantation, patients lose access to certain speech perception benefits afforded by bimodal listening—these include finer spectral resolution afforded by acoustic hearing, greater access to temporal fine structure cues, natural sound quality, and improved music perception (1,2). Given the above, the decision to pursue second sided cochlear implantation in bimodal patients, particularly those who have substantial residual hearing, is not straightforward. Additionally, previous studies report conflicting data on speech understanding for bilateral cochlear implant (CI) recipients and bimodal listeners. While some studies demonstrate significantly higher outcomes for bilateral CI users on standard clinical measures of speech understanding (3), others have documented no difference between these groups (4). Using a within-subjects, repeated measures design, Gifford et al. (1) documented no change in speech understanding for clinical measures of speech understanding but significant improvement resulting from bilateral implantation for speech understanding in diffuse noise.

In assessing current evidence, whether the bilateral cochlear implantation confers speech perception benefit over a bimodal listening configuration in patients with functional residual hearing in the non-CI ear, remains unclear. This is an inherently difficult problem to study as between-study comparisons of bimodal patients and bilateral patients have to be large and heterogeneous to overcome biases. A prospective, longitudinal investigation involving randomization of intervention (bimodal versus bilateral CI) would afford the level of clinical evidence needed to determine second implant criteria, but randomizing patients to a surgical treatment arm can be ethically complicated. That being said, a within-subjects, repeated-measures design allows for comparison of patient performance in the bimodal condition against their own performance in the bilateral CI condition after sequential implantation, thereby eliminating variability introduced by comparing different patient populations.

Within-study models have been used previously to address this specific clinical situation; Potts and Litovsky (5) described four patients that transitioned from the bimodal condition to bilateral CI condition. Two of the four patients had improved speech recognition, and all patients had improved sound localization. Perhaps more importantly, all patients preferred

the bilateral CI condition to the bimodal condition. Luntz et al. (6) also used a within-study design to evaluate 10 adult bimodal users that transitioned to the bilateral CI condition. Patients in the bilateral CI condition showed improved speech processing and localization in complex listening environments, but lost low-frequency speech cues that they previously used in the bimodal condition. Interestingly, patient satisfaction as measured by the speech, spatial, and qualities of hearing (SSQ) questionnaire was higher in the bilateral condition than the bimodal condition. Given the relatively limited body of literature regarding speech perception benefits associated with bilateral CI when compared with bimodal hearing, further research is warranted particularly given the high clinical relevance. In addition, subjective outcomes and quality of life measures should be examined to determine whether differences in objective speech scores reflect patient-based outcomes.

The following study is, therefore, designed to evaluate a patient population that transitioned from bimodal hearing to the bilateral CI condition with a within-study design to minimize confounding variables. Furthermore, subjective quality of life measures assessed with the SSQ questionnaire and the abbreviated profile of hearing aid benefit questionnaire (APHAB) will be assessed (7,8). The authors hypothesized that patients in the bilateral CI condition would demonstrate better speech recognition and improved APHAB/SSQ scores when compared with their preoperative bimodal condition.

METHODS

Patient Selection and Clinical Information

Institutional review board approval was obtained before initiation of the study. Postlingually deafened adults undergoing CI were eligible for inclusion. Prospectively collected data from our CI database were retrospectively reviewed, and patients undergoing second sided cochlear implantation were identified. Inclusion criteria were as follows: 1) preoperative residual hearing (≤ 80 dB HL at 250 Hz) in the second ear to be implanted, 2) implantation with current CI technology (2013–2016), and 3) availability of consonant-nucleus-consonant (CNC) speech perception testing in the bimodal condition preoperatively and bilateral CI condition postoperatively. Only patients with post-lingual progressive sensorineural hearing loss with normal cochlear anatomy on magnetic resonance imaging (MRI) were included. Patients were excluded if the time between the first implant and second implant was less than 6 months, such that short duration of bimodal hearing did not confound results.

As above, residual hearing in the ear to be implanted was defined as an unaided air-conduction threshold less than or equal to 80 dB HL at 250 Hz. Similarly, preservation of postoperative residual hearing was defined as less than or equal to 80 dB HL at 250 Hz, and was examined with unaided air-conduction thresholds measured at least 6 months after surgery. This threshold was chosen since the target gain with acoustic amplification is theoretically achievable when figuring a half-gain rule for acoustic amplification and typical low-frequency gain limits for conventional hearing aids (range, 40–45 dB). Two hundred fifty Hertz (250 Hz) was chosen for the following reasons: 1) it is the lowest frequency for which clinicians can verify hearing aid output for various prescriptive fitting targets, thus serves as a marker for whether or not residual hearing is functionally useful, and 2) acoustic

hearing low-pass filtered at 250 Hz is the minimum bandwidth for which significant additive benefit can be derived from EAS in CI recipients (9–12).

Assessment of Speech Understanding

Before bilateral implantation, CNC scores in the first CI, unilateral HA, and bimodal conditions were recorded (13). When available, AzBio sentence recognition in the bimodal condition, in both quiet and noise (+5 signal-to-noise [SNR] ration), were recorded. Postoperatively, the primary outcome of interest was the CNC score in the bilateral CI condition assessed between 6 and 18 months after surgery. When available, postoperative AzBio sentence scores in the bilateral CI condition in quiet and noise were also recorded (14).

Subjective Measures of Communication Difficulty and Speech Quality

Subjective assessments of communication difficulty and overall sound quality were obtained using the SSQ (7), and the APHAB (8). The SSQ measures three domains: speech understanding, spatial hearing, and quality of sound. The total score is the mean of the three domain scores with a higher score representing better subjective outcomes. The APHAB generates an overall score, in percent of problems, based on four domains: ease of communication, background noise, reverberation, and aversiveness. Because the APHAB reports scores in percent of problems experienced, a lower score represents better subjective outcomes. When available, postoperative data were collected between 6 and 18 months after the second sided CI surgery.

Statistical Analysis

Analyses were performed with GraphPad Prism 7.0 (Graph-Pad Software, La Jolla, CA). Nominal data were analyzed using a Fisher exact or χ^2 test. For continuous variables, values were determined to follow a normal distribution using a D'Agostino and Pearson omnibus normality test. When assessing the impact of various listening conditions on normally distributed speech perception scores, a paired *t* test or one-way repeated measures ANOVA was used. The latter was chosen when comparisons between more than two repeated measures were needed. If significant differences were present on ANOVA, then a post-hoc multiple comparisons test was used. When comparing nonparametric data between two repeated measures, Wilcoxon matched-pairs signed rank test was used. Means and standard deviations (SD) for outcomes reported herein are representative of all included patients, while statistical comparisons reflect repeated measures analyses for only those patients who had scores available in all the respective conditions being compared. *P* values <0.05 were considered indicative of statistical significance.

RESULTS

Twenty-two patients met criteria for inclusion. The mean age at the time of first and second CI surgery was 61 years (SD = 12) and 64 years (SD = 12); the majority of patients were men (68%). Clinical and audiometric characteristics of included patients are shown in Table 1, and detailed below. Pure-tone thresholds in the second ear before the second CI surgery are depicted graphically in Figure 1.

Speech Perception

As shown in Table 1, the mean CNC score was 47% (SD = 21) in the first CI alone condition, 16% (SD = 14) in the aided ear to be implanted, and 55% (SD = 22) in the bimodal condition. After sequential implantation, the CNC score was 51% (SD = 21) in the second sided-CI alone condition and 63% (SD = 22) in the bilateral CI condition at an average follow-up of 11.8 months (SD = 3). One-way repeated measures ANOVA revealed that CNC scores differed significantly when performance was compared between the following conditions: first CI alone, bimodal, second CI alone, and bilateral CI ($p < 0.0001$). Post-hoc repeated measures testing showed that bimodal performance was significantly better than performance with the first CI alone ($p = 0.0003$). The mean time of follow-up for speech perception testing was 12 months (SD = 3) in the bilateral condition, therefore most patients were close to 1 year of listening experience in bimodal listening before proceeding with sequential implantation. The subgroup of patients who demonstrated bimodal benefit more than 5% when compared with unilateral CI condition was analyzed independently. In these patients, mean CNC in the bilateral condition (69%) was greater than that observed in the bimodal condition (60%); the difference neared significance ($p = 0.05$). Bilateral CNC performance was also better than that observed with either CI alone ($p < 0.001$ for both analyses). Most importantly, CNC scores were on average 8% higher in the bilateral CI condition when compared with the bimodal condition ($p = 0.03$) as shown in Figure 2.

AzBio sentence recognition was also analyzed in quiet and in multi-talker babble at a SNR of +5 dB. In quiet, significantly higher scores were noted with paired testing for the postoperative bilateral CI condition 76% (SD = 24) compared with the preoperative bimodal condition 69% (SD = 29) ($p = 0.0007$) (Fig. 2). When tested in noise (+5 dB SNR), statistically significant differences between preoperative bimodal scores (mean 27%, SD = 12) and postoperative bilateral CI scores (37%, SD = 19) were not present ($p = 0.09$).

As shown in Table 1, 20 out of 22 patients had postoperative unaided air-conduction thresholds available beyond 6 months postoperatively, thus, hearing preservation could be determined. Of these, seven (35%) patients maintained functional residual hearing. There was not a statistically significant difference in CNC scores in the bilateral condition when comparing hearing preservation patients (47%, SD = 23) to those who lost functional hearing (68%, SD = 19) ($p = 0.05$).

The hearing preservation cohort was excluded in the subsequent subgroup analyses as their best listening condition would theoretically be unilateral CI + contralateral EAS; the additive benefit of preserving hearing and using EAS in the second sided surgical ear was not assessed herein.

In the 13 patients who lost functional residual hearing and were destined for the bilateral CI condition postoperatively, performance in quiet was superior in the bilateral condition compared with the bimodal condition. Specifically, the bilateral CI CNC score (mean 68%, SD = 19) was significantly higher than the bimodal score (mean 58%, SD = 20) ($p = 0.02$). Further, the bilateral CI AzBio score (mean 83%, SD = 16) was significantly higher than the preoperative bimodal score (mean 70%, SD = 28) ($p = 0.006$). For patients who lost hearing

and were tested in noise (+5 dB SNR), no difference in AzBio scores was noted when comparing bimodal (30%, SD = 10) to bilateral conditions (38%, SD = 22) ($p = 0.31$).

Quality of Life

Table 2 depicts subjective changes in quality of life for available subjects at an average of 12 months (SD = 3) after second sided CI surgery. Two patients had not filled out preoperative surveys, two patients had not filled out postoperative surveys, and one had neither pre- nor postoperative survey data available; these patients were excluded from these analyses. The primary reasons for lack of data points in this regard were time limitations during clinical evaluation and patient fatigue secondary to other routine testing.

As shown in Table 2, significant improvements were noted after bilateral implantation in the global and ease of communication scores for the APHAB. A small but statistically significant increase (i.e., worsening) in aversiveness score was reported by patients. In regard to the SSQ, statistically significant improvements in overall score and all subscales (speech, spatial, and qualities) were noted postoperatively.

DISCUSSION

The decision to perform second sided cochlear implantation in patients functioning in the bimodal condition with substantial hearing in the non-CI ear can be challenging. This study attempts to provide data to address this clinical scenario by examining objective audiologic performance and subjective patient quality of life outcomes after second-sided cochlear implantation. Given the nature of the study design, we were able to address what may be considered the worst-case scenario with bilateral implantation in this setting—i.e., residual hearing in the second implant ear is lost with resultant loss of all acoustic cues.

In the current study, bilateral cochlear implantation was associated with significant performance benefit for both CNC scores and AzBio sentences in quiet when compared with bimodal testing. Improvement in speech perception was also present within the subset of patients who lost residual hearing during second sided implantation. There was no statistically significant difference in AzBio performance in noise (+5 SNR) between these two conditions. This was an important metric to evaluate, as residual acoustic hearing (while not functionally useful independently) when paired with a CI is thought to give increased spectral resolution and temporal fine structure cues, both of which would potentially aid in complex listening environments (1,15–17). The fact that performance was significantly improved in quiet, and not significantly better or poorer in noise when tested in the bilateral CI condition, supports the notion that overall benefit is conferred by bilateral cochlear implantation even in a worst-case scenario when hearing is not preserved. This can also play a role in appropriately guiding patient expectations with overall performance in noisy conditions.

Subjective improvements could also be assessed using prospectively collected metrics designed to assess hearing related quality of life measures, specifically the APHAB and SSQ. This is important to examine, as improvements in audiologic performance may not always correlate with patient perceived benefit from surgical hearing interventions,

especially in the setting of lost residual acoustic hearing with cochlear implantation. In regard to the APHAB, significantly lower (i.e., better) scores were reported for the global metric and ease of communication domain following bilateral implantation. Interestingly, patients did note increased aversiveness in the bilateral condition, which could be attributed to a decrease in residual hearing in the implanted ear or even improved audibility which is known to impact aversiveness for hearing aid users (18). For the SSQ, scores overall and for each subscales (speech, spatial, quality) improved in the bilateral CI condition compared with the bimodal condition. These data suggest overall improved quality of life in patients after bilateral cochlear implantation.

The study has several limitations. Retrospective analysis has inherent flaws when compared with prospective study. Some patients had to be excluded from the quality of life analysis due to incomplete data; a common reason for lack of quality of life data was time constraints during follow-up testing. In addition, while the results demonstrated statistically significant benefits to cochlear implantation, the study size is small and conclusions should be interpreted in this context. This weakness is addressed somewhat by the “within-subjects” design that eliminates heterogeneous samples in the bilateral and bimodal groups, but larger sample sizes will be needed to confirm these findings. Lastly, some patients weren’t tested in their best listening condition after bilateral implantation for all measures of speech understanding. That being said, even better performance would likely be expected, therefore, the reported results may be an underestimation of the benefit conferred by bilateral cochlear implantation in this population.

CONCLUSION

In conclusion, bilateral cochlear implantation yields improved audiologic performance for patients previously functioning in the bimodal condition with substantial residual hearing in the second CI ear. Even in the setting of lost residual hearing, patients demonstrated significantly better performance in the bilateral condition than in the bimodal condition. Furthermore, patients’ subjective communication difficulties and quality of life as measured by the APHAB and SSQ were improved in the bilateral condition. Clinicians should consider a second implant in motivated patients in the bimodal condition.

Acknowledgments

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Pure-Tone Thresholds Prior to Second Implant

FIG. 1.

Pure-tone thresholds are demonstrated for each patient in the second ear before the second implant. Mean thresholds at each frequency are depicted in bold.

FIG. 2.

Mean CNC, AzBio, and AzBio at +5 dB SNR scores for the bimodal and bilateral CI conditions in black and grey bars, respectively. Errors bars represent the standard deviations. CI indicates cochlear implant; CNC, consonant-nucleus-consonant; HA, hearing aid; SNR, signal to noise ratio.

TABLE 1

Clinical and audiometric characteristics of included patients

Electrode	Age at 1st CI (yr)	Age at 2nd CI (yr)	Preop Speech Perception (Before 2nd Sided CI)						Postop Speech Perception (After 2nd Sided CI)						Preop SSQ Overall	Postop APHAB Global	Postop SSQ Overall
			CNC CI	CNC HA	CNC BM	AzBio BM	AzBio+5 BM	Preop LFPTA (dB HL)	Postop Residual Hearing	CNC 2nd CI	CNC BL	AzBio BL	AzBio+5 BL				
CI24RE(CA)	47	61		0	16	4		73	No	14	24	50	13	93	33	1.2	5.6
CI422	75	78	64	12	66	89		70	No	52	72	89	39	59	58	4.2	4.7
MS	62	64	38	2	44	56		67	No	62	66	82	27	47	35	5.3	6.6
CI422	59	61	76	22	78	88	14	60	UK*	52	76	100	34	35	25		
Flex 28	75	76	48	40	56	70	24	70	No	66	70	83	62	49	45	4.3	5.1
CI422	65	67	33	4	42			62	Yes	56	68	86	32	52	50	3.2	4.6
CI522	54	57	44	24	50		34	50	Yes	36	52	82	34	56	47	3.9	5.5
Flex 24	66	67	60	42	60			40	Yes	60	74			54	24	4.0	5.9
MS	48	49	70	18	82	95	45	63	No	84	92	99	76	42	42	5.2	7.5
MS	68	68	58	18	76	81	17	57	No	71	80	98	17	43	44	4.6	3.6
CI422	56	57	62	16	78	90	38	40	No	66	76	93	32	36	28	5.0	5.7
CI422	68	70	48	0	58	60	8	72	Yes	46	56	70		89	71	1.4	1.5
Flex 24	63	64	36	18	66			78	No	26	40	82	52	53	52		3
MS	54	63	20	0	48	79	28	70	No	44	72	76	20				
CI24RE(CA)	62	63	50	14	68	88		35	No	52	84	96					
CI512	62	64	78	24	88	97		27	UK*	74	92	96					
Flex 28	70	72	0	0	6			40	Yes	4	8	14		69	68	2.8	3.6
Flex 28	67	68	38	46	46			40	Yes	36	46	50	34	61	66	2.5	2.8
Flex 28	73	74	6	28	30	35		48	No	36	48	53	20	55	49	6.4	6.7
Flex 28	75	78	38	8	28	19		43	Yes	34	28	32					
Flex 28	61	64	60	20	60		23	53	No	64	72						
CI522	21	22	54	0	72	87	38	75	No	78	84	94	64	57	65	3.8 (1.5)	5.0 (1.6)
Mean (SD)	61 (12)	64 (12)	47 (21)	16 (14)	55 (22)	69 (29)	27 (12)	56 (15)		51 (21)	63 (22)	76 (24)	37 (19)	55 (15)	47 (15)	3.8 (1.5)	5.0 (1.6)

LFPTA was calculated using the average unaided air-conduction thresholds at 125, 250, and 500 Hz.

CNC indicates consonant-nucleus-consonant; LFPTA, low frequency pure-tone average; MS, mid-scala; SD, standard deviation; Preop, preoperative; Postop, postoperative; UK*, unknown, as patient had residual hearing at activation but unaided testing was not available beyond 6 months postoperatively.

TABLE 2

Mean pre- and post-bilateral reports of communication difficulty and quality of life on the APHAB and SSQ questionnaires

QOL Instrument	Preoperative Mean (SD)	Postoperative Mean (SD)	<i>p</i>
APHAB			
Global	55 (15)	47 (15)	0.006
Ease communication	44 (23)	28 (21)	0.0003
Reverberation	61 (18)	55 (18)	0.19
Background noise	67 (13)	58 (16)	0.07
Aversiveness	41 (25)	47 (27)	0.04
SSQ			
Overall	3.8 (1.5)	5.0 (1.6)	0.006
Speech	3.7 (1.7)	4.8 (1.4)	0.004
Spatial	3.7 (1.6)	4.7 (1.9)	0.02
Qualities	3.8 (1.6)	5.4 (1.7)	0.005

Corresponding *p*-values are displayed with those exhibiting significance in bold text.

APHAB indicates abbreviated profile of hearing aid benefit; QOL, quality of life; SSQ, speech, spatial, and qualities of hearing.