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Impact of Intrascalar Electrode Location, Electrode Type, and Angular Insertion Depth on Residual Hearing in Cochlear Implant Patients: Preliminary Results

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Abstract

Objective: To evaluate the relationship between intrascalar electrode location, electrode type (lateral wall, perimodiolar, and midscala), and angular insertion depth on residual hearing in cochlear implant (CI) recipients.

Setting: Tertiary academic hospital.

Patients: Adult CI patients with functional preoperative residual hearing with preoperative and postoperative CT scans.

Intervention: Audiological assessment after CI.

Main Outcome Measures: Electrode location, angular insertion depth, residual hearing post-CI, and word scores with CI (consonant-nucleus-consonant [CNC]).

Results: Forty-five implants in 36 patients (9 bilateral) were studied. Thirty-eight electrode arrays (84.4%) were fully inserted in scala tympani (ST), 6 (13.3%) crossed from ST to scala vestibuli (SV), and 1 (2.2%) was completely in SV. Twenty-two of the 38 (57.9%) with full ST insertion maintained residual hearing at 1 month compared with 0 of the 7 (0%) with non-full ST insertion ($p = 0.005$). Three surgical approaches were used: cochleostomy (C) 6/44, extended round window (ERW) 8/44, and round window (RW) 30/44. C and ERW were small group to

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Conflict of Interest:
G.B.W. is a consultant for Advance Bionics, MED-EL, Cochlear, and Oticon Medical. A.R. is a consultant for Advance Bionics, MED-EL, Cochlear, Grace Medical, and Carestream. R.F.L. is a consultant for Advance Bionics and Medtronics.

compare with RW approaches. However if we combine C + ERW, then RW has higher chance of full ST insertion ($p = 0.014$). Looking at the full ST group, neither age, sex, nor electrode type demonstrated statistically significant associations with hearing preservation ($p = 0.646$, $p = 0.4$, and $p = 0.929$, respectively). The median angular insertion depth was 429°(range, 373°–512°) with no significant difference between the hearing and nonhearing preserved groups ($p = 0.287$).

Conclusion: Scalar excursion is a strong predictor of losing residual hearing. However, neither age, sex, electrode type, nor angular insertion depth was correlated with hearing preservation in the full ST group. Techniques to decrease the risk of electrode excursion from ST are likely to result in improved residual hearing and CI performance.

Keywords

Angular insertion depth; Cochlear implant; Electrode location; Residual hearing

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Electroacoustic stimulation (EAS) in cochlear implant (CI) recipients has been shown to provide hearing benefits useful for both communication in complex listening environments and spatial hearing. CI recipients with hearing preservation generally have binaural acoustic hearing in the low-frequency range, which allows access to interaural time difference (ITD) cues (1–5). Research has shown that such patients exhibit significantly better horizontal plane localization when using the residual acoustic hearing in the implanted ear (4–6). Preserving low-frequency hearing in the implanted ear allows the patients to better differentiate the signal from noise by using binaural timing cues—a phenomenon commonly referred to as squelch or binaural unmasking of speech. Interaural level differences (ILDs)—dominant for higher frequency sounds—may not be readily available to hearing preservation patients with a single cochlear implant; however, bilaterally implanted patients with bilateral hearing preservation (BiBi) may, in fact, have access to both ITDs and ILDs (7). However, even for unilaterally implanted patients with hearing preservation, ITDs can improve speech understanding in daily life environments, such as restaurants and other complex noise (2,4,5,8–10), and reverberant environments (2).

Despite the known advantages of hearing preservation in CI recipients, there are many variables that can influence the outcome of successful hearing preservation surgery (9,11–16). Some variables can be improved upon, such as surgical trauma, implant size, and surgical approach. There are other factors, however, that, at present, cannot be clinically modified for human subjects such as individual inflammatory response and cellular apoptosis (11,15,16).

Some factors are under the control of the surgical team and may be related to hearing preservation outcomes including surgical approach, intrascalar electrode location, electrode type, and angular insertion depth. Thus, the purpose of this paper was to investigate the potential relationship between intrascalar electrode location, electrode type, surgical approach, and angular insertion depth on residual acoustic hearing preservation in adult CI recipients.

Our hypothesis was that CI with minimally traumatic surgical techniques and atraumatic electrodes results in significant preservation of acoustic hearing and that scalar excursion would be associated with loss of residual hearing.

MATERIALS AND METHODS

After obtaining institutional review board approval, we completed a prospective investigation of postlingually deafened adult patients with functional/aidable preoperative acoustic hearing. Preoperative functional/aidable acoustic hearing was defined as having audiometric thresholds of 80 dB HL or less at 250 Hz and below for the audiogram most closely preceding surgery; 250 Hz is considered highly relevant for speech understanding as having acoustic audibility at 250 Hz would afford the listener with information regarding fundamental frequency (F0) or voice pitch for most adult male and female talkers (17–19). Research has shown that audibility of voice pitch can allow a listener to extract the target speech stimulus in the presence of background noise (20–24). The 80 dBHL limit for preoperative functional hearing was chosen based on the typical 40-dB gain limits of low-frequency amplification and the 1/2 gain rule on which most prescriptive fitting formulae are based (25–27).

Once we had identified those adults in our CI database meeting the preoperative audiometric inclusion criteria, only those who also had preoperative CT scans of the temporal bone at the authors' institution were offered enrollment in the study. After consent was obtained, postoperative temporal bone CT scans were obtained via either flat panel, volumetric computerized tomography (fpVCT) using a Xoran XCAT scanner (Xoran Industries, Ann Arbor, MI) or a traditional multi-slice CT scanner. Patient demographics, type of implant, surgical approach, and postoperative audiometric performance were recorded. Three types of insertion techniques were used: traditional cochleostomy (C), extended round window (ERW) defined as opening the round window membrane and enlarging it by drilling its anterior-inferior margin, and round window (RW) defined as removing the round window bony overhang when necessary and opening the RW membrane directly without enlargement. Implants from all 3 FDA-approved device manufacturers (MED-EL [ME] GmbH Innsbruck Austria, Cochlear Americas [CA] Corporation Centennial, Colorado, and Advanced Bionics [AB] Corporation Valencia, California) were used. Electrode models were designated as perimodiolar (PM), lateral wall (LW), or Mid Scala (MS) according to manufacturer specifications. All patients received a 10 milligram (mg) intravenous (IV) dose of decadron before the surgical incision.

To determine the location of the electrodes in relation to the ST and SV, an automated, highly accurate algorithm was used. This technique uses a nonrigid, atlas-based registration (28,29) that has been previously validated using cadaveric models (30). Using these algorithms, electrodes were noted at ST only, SV only, or ST-SV indicating crossing of the intrascalar septum separating ST from SV.

SPSS Version 22 was used to conduct statistical analyses. Frequency distributions were used to summarize the nominal and ordinal data. Mean and standard deviation summarized age at implant and depth of insertion in millimeters. With the exception of the association of electrode location, Pearson chi-square statistics tested the associations of the nominal data with preservation of hearing at 1 month postactivation (~6 weeks after implantation). Given the small sample of non-full scala tympani (ST), Fisher exact tests were used for that association. Mann–Whitney tests were used for those respective comparisons of age at implant and depth of insertion. A maximum alpha of 0.05 was used for determining statistical significance.

RESULTS

Forty-five implants in 36 patients (9 bilateral) were studied. Five experienced cochlear implant surgeons were involved in performing the surgeries. Mean age of the patients at implant was 65.1 years (SD = 12.2 years); 58% (21 of 36) were male. Summaries of the characteristics of the groups of implants with (n = 22) and without (n = 23) hearing preservation are summarized in Table 1. Surgical approach was 13.6 % for C, 18.2% for ERW, and 68.2% for RW. The small number of C and ERW did not allow for comparison. However if we combined C and ERW, RW had a higher probability of full ST insertion. (p = 0.014; technique C or ERW, 35.7% crossed; technique RW, 6.7% crossed). Table 2 summarizes the electrodes locations and surgical approaches. Seven electrodes crossed from ST to SV. Table 3 summarizes the characteristics of this group. There was a statistically significant association of non-full scala tympani (ST) insertion location with residual hearing 1 month postactivation ($\chi^2 = 10.63$, $df = 1$, $p = 0.005$). Twenty-two (57.9%) of the 38 with full ST insertion maintained residual hearing compared with 0 of the 7 (0.0%) with non-full ST insertion. Although not reaching statistical significance, there was a tendency for the insertion depths of those with residual hearing to be greater than those without residual hearing (median = 453.5 vs. 380.0, respectively; $p = 0.63$; Table 1). However, there was also a confound of insertion depth with full ST insertion in this sample. The 7 implants not fully inserted in the ST were of shallower insertion depth than the 38 fully inserted (non-full ST: median = 357, min = 206, max = 425; full ST: median = 429, min = 277, max = 710; $p = 0.042$). The sample size was too small to allow for multivariate attempts to tease out the relative effect of each variable.

None of the other demographic or electrode or surgical characteristics demonstrated statistically significant associations with hearing preservation (p > 9 0.05; Table 1). Furthermore, within the group of implants with full ST insertion, none of the demographic or surgical characteristics were statistically significantly associated with residual hearing at 1 month postactivation (p > 9 0.05, Table 4).

DISCUSSION

More than 3 decades have passed since FDA approved the use of CI in adults. The goal of the surgery has progressed from relying solely only on electrical stimulation to preserving, and then taking advantage of, residual acoustic hearing via combined EAS.

There are many benefits of hearing preservation and EAS particularly with respect to speech recognition in complex environments (2–5,8–10), music perception (31–34), spatial hearing (4–6), and overall quality of life (35,36).

Avoiding cochlear trauma is a crucial ingredient for preserving residual hearing. Insertion trauma can cause a wide spectrum of injury to the cochlea including trauma to the lateral wall, basilar membrane, osseous spiral lamina, osseous spiral ligament, and generalized modiolar injury—all of which hold potential to negatively impact hearing preservation (35). Additionally, vascular injury to the blood vessels of scala tympani can contribute to hearing loss (37). The importance of hearing preservation has pushed CI manufacturers to design reliable and atraumatic electrodes and encourage surgeons to use atraumatic technique such as is used during stapes surgery (34,38).

In the current study, we investigated scalar excursion as a possible negative predictive factor for hearing loss resulting from CI surgery. Indeed, we found that none of our patients with scalar excursion had preserved hearing when tested 1 month postactivation.

For those recipients without electrode excursion, neither age, sex, nor electrode type were significantly related with hearing preservation. These findings are early, and longer follow-up is warranted. It is well documented that patients with preserved hearing at 1 month can still lose their hearing overtime. In a recent study by Kopelovich and colleagues (39), age and male sex were negatively associated with hearing preservation at 1-year follow-up.

Another important point to make is that 43% of our patients with full ST insertion lost their residual hearing. This could be due to a myriad of reasons including intracochlear vascular injury (37) or inflammation (11,40). More research on the role of drug therapy and mode of delivery is warranted as it is an area that could ultimately play a major role in hearing preservation.

Our findings are especially applicable to the angular depth of electrode insertion that has been investigated extensively recently. Skarzynski et al. (34) found no significant difference between angular insertion depth and hearing preservation rate. Another study found no correlation between depth of insertion and hearing loss (41). When we look at the depth of angular insertion in our group—after excluding those with scalar excursion given its negative predictor factor—there was no significant difference between the hearing and nonhearing preserved groups. It is noteworthy to mention that the median angular insertion depth was 429.0 degrees (range, 373–512). Another major finding to report is that patients with scalar excursion have a shallower angular insertion depth and this may bias findings. Thus, electrodes location must be controlled especially when comparing angular depth of insertion. Although none of the Med El electrodes crossed ST to SV. In the current study, hearing preservation was possible with any brand of cochlear implant, as long as the electrodes stayed fully in ST. The sample size was too small to allow for multivariate analysis to tease out the relative effect of each variable.

In previous work by Holden et al (42), the importance of full ST insertion and its potential impact upon audiological outcome was analyzed. Previous work by our group built on this concept and found in a larger sample that lateral wall implants were associated with greater rates of full ST insertion as compared with perimodiolar electrodes (43). Given the results of the current and past studies (43), prevention of scalar excursion should be a priority for better audiological outcomes and for any chance of hearing preservation. When it comes to surgical approaches, RW has a statistically significant higher probability as is reported both herein and in our previous work (43). Although more study is needed to investigate factors affecting long-term hearing preservation and individual inflammatory responses; future studies should consider electrode location specifically scalar excursion before completing data analysis.

It is very important to mention that previous studies that showed residual hearing loss to be associated with other factors have overlooked electrodes position (38), and we posit that the hearing loss reported may be due to an underlying cause of scalar translocation. Thus, grouping individuals with full ST insertion along with those who have scala excursion can result in confounding errors. Trans-scalar excursion can have an immediate impact on residual hearing and should be evaluated in cochlear implant studies and hearing outcomes. Advances in technology in electrode designs that are slimmer and atraumatic combined with advances in image guidance surgery may help dramatically decrease the incidence of trans-scalar excursion by allowing a more customized cochlear implant surgery based on the individual size of the cochlea and the implant type. Should this occur, the remaining challenge will be identifying and treating factors that affect residual hearing in full ST implanted patients in the short and long term.

The strength of our study is it has shown in vivo the negative impact of transscalar excursion on preserving functional residual hearing in cochlear implant patients. Also, it delineates the importance of controlling for electrodes location for future studies especially when angular depth of insertion is evaluated. However, it is important to note that these are early findings, and as has been done for other factors, longer follow-up will be needed before any definitive conclusions can be drawn as to the hearing preservation. What is clear, even at early postoperative follow-up time, is that scalar excursion likely results in loss of residual hearing.

The limitations of the current study are the relatively small sample size and short-term follow-up. Also, electrode types were very variable, and multiple surgeons were involved. To overcome this effect, a randomized controlled study will be needed, and a larger cohort with longer term follow-up is warranted to better understand other factors that may affect hearing preservation over time. As we prospectively enroll more patients and exclude those with trans-scalar excursion, our goal is to have a longer follow-up and a larger sample on which we can perform powerful multivariant analysis to study the relative effect of each separate variable.

CONCLUSION

The results of the current study suggest that scalar excursion is a strong predictor of lost residual hearing. However, neither age, sex, electrode type, nor angular insertion depth were correlated with hearing preservation in the full ST group. Techniques to decrease the risk of electrode excursion from ST are likely to result in improved residual hearing and CI performance.

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TABLE 1.

All implants

Characteristic	Overall (n = 45)	Residual hearing 1 month No (n = 23)	Residual hearing 1 month Yes (n = 22)	*P*
		Median (IQR[a])		
Age at implant	66.6 (55–73)	60.8 (52–72)	67.9 (57–75)	0.235
Depth of insertion	408.0 (362–466)	380.0 (343–436)	453.5 (375–517)	0.063
	n	n (%)[b]		
Side				0.300
Left	21	9 (42.9)	12 (57.1)	
Right	24	14 (58.3)	10 (41.7)	
Model				0.537
LW	27	12 (44.4)	15 (55.6)	
MS	3	2 (66.7)	1 (33.3)	
PM	15	9 (60.0)	6 (40.0)	
Procedure				0.257
Cochleostomy	6	5 (83.3)	1 (16.7)	
ERW	8	4 (50.0)	4 (50.0)	
RW	30	14 (46.7)	16 (53.3)	
Crossed				
No	38	16 (42.1)	22 (57.9)	0.005
Yes	7	7 (100.0)	0 (0.0)	
Sex[c]				
Male	17	11 (64.7)	6 (35.3)	0.687
Female	10	5 (50.0)	5 (50.0)	

[a] 25th to 75th interquartile range.

[b] Note that the values in the cells are row n (%).

[c] Single ear implants only.

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TABLE 2.

Electrode location and surgical approach

	Insertion technique (collapsed)		
Electrode location	**C or ERW**	**RW**	**Total**
Crossed			
No			
Count	9	28	37
% Within insertion technique (collapsed)	64.3	93.3	84.1
Yes			
Count	5	2	7
% Within insertion technique (collapsed)	35.7	6.7	15.9
Total			
Count	14	30	44
% Within insertion technique (collapsed)	100	100	100

TABLE 3.

Implants with trans-scalar electrode arrays

Case	Electrode brand	Electrode type	Electrode position	Approach	Angular depth of insertion
Trans-scalar implant 1	Cochlear Straight (CI422)	LW	ST → SV	ERW	425
Trans-scalar implant 2	Cochlear Contour Advance	PM	ST → SV	Cochleostomy	342
Trans-scalar implant 3	Cochlear Contour Advance	PM	ST → SV	Cochleostomy	357
Trans-scalar implant 4	Cochlear Contour Advance	PM	ST → SV	RW	384
Trans-scalar implant 5	Cochlear Contour Advance	PM	SV	ERW	387
Trans-scalar implant 6	Advanced Bionics 1 J	LW	ST → SV	ERW	347
Trans-scalar implant 7	Advanced Bionics Mid-Scala	MS	ST → SV	RW	206

TABLE 4.

Implants fully inserted in ST

Characteristic	Overall (n = 38)	Residual hearing 1 month		*P*
		No (n = 16)	Yes (n = 22)	
		Median (IQR[a])		
Age at implant	67.9 (57–74)	67.3 (56–73)	67.9 (57–75)	0.646
Depth of insertion	429.0(373–512)	394.0 (347–497)	453.5 (375–517)	0.287
	n	n (%)		
Side				0.511
Left	19	7 (36.8)	12 (63.2)	
Right	19	9 (47.4)	10 (52.6)	
Model				0.929
LW	25	10 (40.0)	15 (60.0)	
MS	2	1 (50.0)	1 (50.0)	
PM	11	5 (45.5)	6 (54.5)	
Procedure				0.253
Cochleostomy	4	3 (75.0)	1 (25.0)	
ERW	5	1 (20.0)	4 (80.0)	
RW	28	12 (42.9)	16 (57.1)	
Sex[b]				
Male	15	9 (60.0)	6 (40.0)	0.400
Female	8	3 (37.5)	5 (62.5)	

[a] 25th to 75th interquartile range.

[b] Single ear implants only.