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Implementation of Image-Guided Cochlear Implant Programming at a Distant Site

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Abstract

Our objective was to prospectively evaluate implementation of a new cochlear implant (CI) mapping technique, image-guided cochlear implant programming (IGCIP), at a site distant to the site of development. IGCIP consists of identifying the geometric relationship between CI electrodes and the modiolus and deactivating electrodes which interfere with neighboring electrodes. IGCIP maps for 17 ears of 15 adult CI patients were developed at a central image-processing center, Vanderbilt, and implemented at a distant tertiary care center, House Ear Institute (HEI). Before IGCIP and again 4 weeks after, qualitative and quantitative measures were made. While there were no statistically significant group-wise differences detected between baseline and IGCIP qualitative or quantitative measures, 11 of the 17 (64.7%) elected to keep the IGCIP map. CT image quality appears to be crucial for successful IGCIP with 100% of those with high resolution CT scans keeping their maps compared to 53.8% without.

Introduction

Cochlear implantation (CI) is standard of care for patients with severe-to-profound sensorineural hearing loss. While the vast majority of patients perform well, great variability in outcomes exist. Post-operative programming represents an area where improvements

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Conflicts of interest: EPW (Grant support from Cochlear Americas and MED-EL), RHG (Audiology Advisory Board for Cochlear Americas, Advanced Bionics, and Frequency Therapeutics), RFL (Consultant for Advanced Bionics, Cochlear and Ototronix)

Level of evidence: 2C

could be realized if the location of electrodes in relationship to the modiolus were known. Image-processing techniques to achieve this have recently been introduced by a research group at Vanderbilt and clinically used to program CI recipients via a process known as image guided CI programming (IGCIP).¹ Clinical implementation at the primary clinical site has demonstrated significant performance improvement using IGCIP^{1,2} and we report herein implementation of the technology at a distant site.

Material and Methods

Institutional Review Board approval was obtained, and patients who were at least 18 years old and had 6 months of use of a traditional CI map programmed by an expert audiologist were recruited. Post-CI temporal bone CT scans were obtained with minimum 0.4–0.5mm slices non-overlapping or 0.6–0.8mm slices with 0.3–0.4mm overlapping cuts in the axial plane. CT scans were de-identified and sent to Vanderbilt for evaluation. If pre-operative CTs were available, analysis was done as previously reported.¹ First, a high resolution statistical shape model of the cochlea and its sub-compartments was registered to the patient's CT to accurately identify the borders of the modiolus.³ Next, the positions of individual CI electrodes were found using graph-based electrode localization techniques.^{4,5} Next, the two CT images were registered to quantify the position of the electrodes relative to the modiolus. Patients for whom no pre-operative CT was available were also enrolled noting that the image processing is more difficult secondary to the metallic artifact caused by the implant. To overcome this, different processes are used.^{6,7} Finally, based on the position of the electrodes relative to the modiolus, electrodes that are predicted to have a high probability of interfering with neighboring electrodes were deactivated from the patient's map.¹

Each patient underwent hearing and speech recognitions test (Minimum Speech Test Battery and Bamford-Kowal-Bench Speech-in-Noise (BKB-SIN)); qualitative testing (Abbreviated Profile of Hearing Aid Benefit (APHAB) and Speech, Spatial and Qualities of Hearing Scale (SSQ)); and quick spectral modulation detection (QSMD) task, a non-speech-based hearing performance metric that provides a psychoacoustic estimate of spectral resolution. After baseline testing, the participant's CI was reprogrammed according to the IGCIP strategy and returned 4 weeks later for repeat testing. Participants were only provided the IGCIP map to ensure compliance. Statistical analyses was done using SPSS (version 23) with appropriate tests (e.g. logistic regression to assess whether the amount of change in speech increased or decreased the likelihood of keeping the map after controlling for the respective pre-IGCIP value).

Results

Seventeen ears in 15 post-lingually deafened CI users were enrolled (see Table 1: patient information). On average, patients had 6.8 years of CI use prior to enrollment. With IGCIP patients with Cochlear devices had, on average, 12.3 electrodes active and Advanced Bionics had 10. At the end of the four week trial, 11 patients (64.7%) chose to keep their IGCIP map. No patient factors were statistically associated with keeping the IGCIP map (all $p>0.05$). Figure 1 displays the individual patient data for the qualitative and quantitative

metrics (note APHAB and BKB-SIN axes are reversed because decreased score denotes improvement). Hearing outcomes for the group prior to and after implementing the study map are displayed in Table 2. As a group, there were no statistically significant changes in hearing outcomes or qualitative measures when comparing IGCIP performance to baseline (all $p>0.05$). All patients who had a pre-operative CT kept their IGCIP.

Discussion

This study represents the first reported use of IGCIP at a distant site. Patients were recruited, underwent testing, and had IGCIP maps implemented at House Ear Institute (HEI), while the IGCIP plan was made at Vanderbilt. 64.7% of patients elected to keep their IGCIP map despite, on average, no statistically significant detectable improvement in patient word recognition. This is somewhat lower than the 78–82% previously reported by the home institution.^{1,2} We hypothesize that this may be due to one of the following three reasons.

First, with any new technology subtleties that arise during implementation that may affect outcomes. Second, the sample size at HEI was an order of magnitude smaller than at Vanderbilt. With enrollment of more patients, it is possible that similar outcomes will be seen. Third, and most interesting from a scientific standpoint, is the impact of CT scan characteristics to the sensitivity of the IGCIP image analysis as this was the first time that CT images were obtained at various ambulatory sites. Based on the findings of this study, we have undertaken phantom studies and identified that slice thickness 0.5mm (12 of 17 images acquired in this study) and those not reconstructed with extended Hounsfield unit ranges (all images acquired in this study) have less accurate IGCIP processing. Additionally, prior work has suggested that the use of post-CI CTs alone should be adequate for determining intra-cochlear CI electrode position.⁷ however, the sensitivity of this approach to post-operative CT characteristics has yet to be quantified. In the current study, it was found that all patients with pre-CI CTs kept their study maps.

Conclusion

IGCIP is a relatively new technology that can be successfully implemented at outside institutions. The data presented support continued efforts at more widespread clinical implementation. High resolution CT scanning with extended Hounsfield unit ranges appears to be critical to IGCIP.

Acknowledgments

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Figure 1.

legend: Individual subject data before and after IGCIP (subject ID are consistent throughout). Blue data points represent those who kept IGCIP and grey are those who did not.

Table 1

Patient and device information for all patients and separated based on those who kept and did not keep their IGCIP map.

Factor	All patients (N=17)	Kept Map (N=11)	Didn't keep map (N=6)	p value
	Mean (SD)	Mean (SD)	Mean (SD)	
Age	64.6 (11.7)	67.7 (8.9)	58.8 (14.7)	0.137
	N (%)	N (%)	N (%)	
Bilateral	8 (47.1)	7 (63.6)	1 (16.7)	0.088
Right sided	9 (52.9)	7 (63.6)	2 (33.3)	0.247
	Mean (SD)	Mean (SD)	Mean (SD)	
Duration of deafness (years) *	11.1 (7.8)	11.0 (7.6)	11.4 (9.1)	0.928
Length of CI use prior to experimental map (years)	6.8 (5.1)	7.6 (5.8)	5.3 (3.3)	0.327
	N (%)	N (%)	N (%)	
Had pre-op CT	4 (23.5)	4 (36.4)	0 (0.0)	0.091
Device				
AB device	3 (17.6)	1 (5.8)	2 (11.8)	0.210
Cochlear device	14 (82.4)	10 (58.8)	4 (23.5)	
	Mean (SD)	Mean (SD)	Mean (SD)	
# electrodes deactivated	9.0 (3.3)	9.1 (3.8)	8.8 (2.6)	0.885

* All patients N=16, Kept Map N=11, Didn't keep map N=5

Table 2

Speech testing outcomes for all patients and separated based on those who kept and did not keep their ICGIP map.

Test	(n when not all patients)	Pre (%)	Post (%)	Change (%)	p value
		Median [IQR]	Median [IQR]	Median [IQR]	
CNC words	Didn't keep map	51.0 [18, 85]	48.0 [7, 83]	-3.0 [-9, 7]	0.674
	Kept map	36.0 [24, 50]	38.0 [20, 56]	-2.0 [-12, 8]	
	All	36.0 [23, 64]	38.0 [18, 61]	-2.0 [-8, 7]	
CNC phonemes	Didn't keep map	70.0 [40, 93]	67.0 [15, 93]	-2.0 [-18, 6]	0.178
	Kept map	60.0 [50, 68]	64.0 [47, 69]	3.0 [-3, 8]	
	All	60.0 [48, 77]	64.0 [40, 79]	1.0 [-3, 8]	
AzBio quiet	Didn't keep map	54.5 [13, 98]	54.5 [16, 95]	-1.0 [-5, 3]	0.765
	Kept map	38.0 [21, 58]	43.0 [27, 58]	5.0 [-7, 9]	
	All	38.0 [19, 77]	43.0 [24, 79]	0.0 [-5, 9]	
AzBio +10	Didn't keep map	24.0 [3, 83]	24.0 [3, 81]	-0.5 [-5, 2]	0.348
	Kept map	7.0 [0, 15]	9.0 [7, 28]	2.0 [0, 8]	
	All	7.0 [2, 32]	9.0 [5, 30]	1.0 [-1, 6]	
AzBio +5	Didn't keep map (3)	40.0 [19, -]	31.0 [13, -]	-6.0 [-36, -]	*
	Kept map (1)	16.0 [16, 16]	17.0 [17, 17]	1.0 [1, 1]	
	All (4)	29.5 [16, 61]	24.0 [14, 43]	-5.5 [-29, 6]	
BKB-SIN	Didn't keep map	13.5 [7, 22]	14.3 [7, 24]	0 [-2, 4]	0.641
	Kept map	17.0 [15, 21]	16.5 [14, 23]	0 [-2, 2]	
	All	17.0 [13, 21]	16.5 [11, 23]	-0.5 [-2, 3]	
QSMD avg	Didn't keep map (6)	65.8 [37, 90]	44.5 [32, 55]	-21.3 [-42, -5]	0.038
	Kept map (9)	45.5 [34, 61]	48.2 [38, 75]	3.0 [-5, 9]	
	All (15)	53.6 [37, 75]	48.7 [35, 69]	-7.9 [-21, 5]	

* due to the small sample size no statistical analysis was performed

Table 3

Qualitative outcomes for all patients and separated based on those who kept and did not keep their ICGIP map.

Test	(n when not all patients)	Pre (%)	Post (%)	Change (%)	p value
		Mean (SD)	Mean (SD)	Mean (SD)	
APHAB global	Didn't keep map (5)	44.1 (18.8)	42.8 (11.4)	-1.3 (16.6)	0.709
	Kept map (11)	48.1 (21.2)	43.7 (21.4)	-4.4 (8.3)	
	All (16)	46.8 (19.9)	43.4 (18.4)	-3.5 (11.0)	
APHAB EC	Didn't keep map (5)	26.2 (20.0)	25.1 (13.2)	-1.1 (12.6)	0.797
	Kept map (11)	27.2 (27.4)	24.4 (22.8)	-2.8 (12.9)	
	All (16)	26.9 (24.4)	24.6 (19.8)	-2.3 (12.4)	
APHAB RV	Didn't keep map (5)	58.4 (26.1)	55.2 (8.3)	-3.2 (24.0)	0.865
	Kept map (11)	58.7 (21.1)	53.9 (23.5)	-4.7 (13.2)	
	All (16)	58.6 (22.3)	54.3 (19.7)	-4.3 (16.4)	
APHAB BN	Didn't keep map (5)	47.7 (20.4)	48.1 (14.1)	-0.5 (16.0)	0.594
	Kept map (11)	58.4 (20.8)	52.8 (22.5)	-5.6 (11.8)	
	All (16)	55.1 (20.2)	51.3 (19.9)	-3.7 (13.1)	
APHAB AV	Didn't keep map (5)	30.5 (20.6)	30.7 (24.1)	0.2 (13.5)	0.562
	Kept map (11)	35.4 (21.5)	30.7 (20.2)	-4.7 (12.5)	
	All (16)	33.9 (20.5)	30.7 (20.7)	-3.2 (12.6)	
SSQ speech	Didn't keep map	4.8 (1.9)	4.1 (2.0)	-0.7 (0.9)	0.074
	Kept map	4.6 (2.1)	4.9 (2.0)	0.2 (0.9)	
	All	4.7 (2.0)	4.6 (2.0)	-0.1 (1.0)	
SSQ spatial	Didn't keep map	4.3 (1.7)	3.9 (1.9)	-0.4 (1.0)	0.078
	Kept map	4.0 (2.3)	4.7 (2.7)	0.7 (1.2)	
	All	4.1 (2.0)	4.4 (2.4)	0.3 (1.2)	
SSQ qualities	Didn't keep map	5.8 (2.1)	5.2 (1.4)	-0.6 (1.3)	0.077
	Kept map	5.4 (2.5)	5.9 (2.7)	0.5 (0.9)	
	All	5.6 (2.3)	5.6 (2.3)	0.1 (1.2)	
SSQ total	Didn't keep map	4.9 (1.8)	4.5 (1.5)	-0.5 (0.4)	0.007
	Kept map	4.8 (2.2)	5.2 (2.3)	0.5 (0.6)	
	All	4.8 (2.0)	4.9 (2.1)	0.1 (0.7)	