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Can preoperative CT scans be used to predict facial nerve stimulation following CI?

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Abstract

Objectives—1) Determine the ability of pre-operative CT to predict facial nerve stimulation (FNS) after cochlear implantation (CI). 2) Recognize the limitations of CT in predicting FNS.

Study Design—Case control study

Setting—Tertiary care academic medical center.

Subjects—Adult patients with CI from 2003–2015

Methods—Patients with severe FNS (n=4) were compared with randomly selected CI patients (n=28). Three blinded reviewers evaluated preoperative temporal bone CT scans to measure the distance from the labyrinthine segment of the facial nerve (LSOFN) to the basal turn of the cochlea (BTOC) and attempted to predict whether or not the subject had FNS after CI.

Results—In total 32 CT scans were evaluated representing 49 ears that underwent cochlear implantation. The distance (mm) measured from the LSOFN to the BTOC in both the axial (0.3 ± 0.3 vs. 0.6 ± 0.3) and coronal (0.4 ± 0.2 vs. 0.6 ± 0.2) orientation were significantly different between the two groups ($p=0.0001$ and $p=0.0034$) respectively. The intra-class correlation coefficient demonstrated good ($K > 0.7$) reviewer correlation in both the reviewers' measurements and predictions. The sensitivity, specificity, positive predictive value, and negative predictive value for pre-operative CT scans to predict FNS were 38.5%, 85.1%, 19.2%, and 93.8% respectively. The reviewers were 23% accurate in predicting FNS.

Conclusion—Based on a blinded retrospective case-control study, CT scan measurements show a significantly reduced distance between the labyrinthine facial nerve and the basal turn of the cochlea in patients with FNS. However, it is difficult to predict who will have FNS based on these measurements.

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Keywords

cochlear implant; facial nerve stimulation; temporal bone imaging; cochlear implant complications

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Introduction

Cochlear implant surgery is overall a safe procedure with infrequent complications.¹ Facial nerve stimulation (FNS) following cochlear implantation (CI) has been reported to occur in 5%–15% of cases.^{2,3,4} In certain conditions including otosclerosis, temporal bone fractures and cochlear ossificans the incidence is much higher.^{5,6,7} Facial nerve stimulation symptoms may range from mild facial motion to more severe facial spasms that are often painful or debilitating. Severe stimulation often necessitates changing strategies for programming, reducing current levels, or deactivating electrodes. This can lead to suboptimal hearing results or non-use of the device. In some situations, the device may need to be explanted and possibly reimplanted.⁸

A few theories exist as to why FNS following CI takes place. In cases of otosclerosis the electrical impedance of the otic capsule bone is reduced and thereby current from the CI can more easily spread and stimulate the facial nerve.^{9,10} Other studies have also shown that a narrow distance from the basal turn of the cochlea (BTOC) to the labyrinthine segment of the facial (LSOFN) nerve may result in FNS.¹¹ However, data on the use of preoperative CT scans to predict FNS are lacking. The aim of this study was to evaluate the ability of the preoperative CT scans to predict severe FNS in a case control analysis in patients without predisposing risk for FNS.

Materials and Methods

Approval was obtained from the Institutional Review Board (IRB #52730) of the Medical University of South Carolina (MUSC).

Group Selection

We conducted a retrospective review from 2003–2015 using our institution's CI database to identify patients who developed severe FNS following CI for the study group. Severe FNS was defined as requiring multiple programming changes, deactivation of multiple electrodes, or discontinuation of the device. Inclusion criteria were a dedicated preoperative CT scan of the temporal bones that included axial and coronal sections, and audiological documentation of FNS along with activated electrodes and mapping strategies. Exclusion criteria were prior skull base surgery, anomalous facial nerve course, temporal bone trauma, otosclerosis, cochlear malformation or cochlear ossificans. The control group was obtained from the same database. The inclusion and exclusion criteria were the same for both groups aside from FNS. Four (n=4) were included in the FNS group and seven randomly selected control patients were selected from the MUSC CI database. The total number of patients for the control group was 28. Demographic data and CI information were also collected for each patient.

Imaging and Hardware

The analyzed temporal bone CT scans were all obtained with a standard collimation of 0.625 mm. Images were reconstructed in axial and coronal sections. The scans were obtained at our institution on either a Siemens Somatom Sensation 16 or a Siemens Definition 128 (Siemens Medical Solutions, Malvern, Pennsylvania). Spatial resolution was rated as accurate to 0.1 to 0.2 mm per protocol.¹² Software-reformatted images were analyzed via the proprietary digital radiology imaging system AGFA Impax 6 (AGFA Impax, Mortsel, Belgium). The images were viewed on ThinkVision™ monitors with the resolution of 1920 by 1080 pixels. Distance between the LSOFN and the BTOC was measured via the partial volume averaging formula in this software. Accuracy was rated to be 0.1 mm. However, owing to the limitation of the measuring calipers, the minimum measurable limit was at 0.3 mm. A distance of 0.0 mm was used as the minimum when no obvious bone was seen between the LSOFN and the BTOC.

CT Measurements

The measurements were performed in a blinded fashion by three fellowship-trained neurotologists who regularly perform CIs as part of their clinical practice. Prior to obtaining the measurements the blinded reviewers were given a tutorial regarding radiology software and how to use the measuring calipers. The reviewers then obtained the distance from the LSOFN and BTOC where it appeared to be the narrowest (figure 1) for the axial and coronal sections for each side. Based upon those measurements the reviewers were then asked to predict whether FNS would occur on that side. Further, bone density estimates were obtained by outlining the otic capsule surrounding the cochlea on axial imaging. The average Hounsfield units (HU) for the area were calculated as a surrogate measurement for bone density.

Audiologic Assessments

Prior to implantation all patients were evaluated with appropriately fit amplification on Maryland CNC words and AzBio sentences to determine CI candidacy.^{13, 14} All the patients met candidacy criteria prior to implantation. For patients in the control group who were bilaterally implanted, only audiologic data from the ear that was implanted first was included. Postoperative data were included for the same tests from any interval 12 months post activation or greater.

Statistics

Statistical analysis was performed using MedCalc Software Version 16.4.3 (MedCalc Software, Oostende, Belgium) and SigmaPlot 12.5 (Systat Software, Chicago, Illinois). Axial and coronal measurements were described by mean±standard deviation. Continuous variables were tested for normal distribution as determined by the D'Agostino and Pearson omnibus normality test. For continuous variables, comparisons between groups were made with an independent t-test or a Mann-Whitney test. Calculation of sensitivity, specificity, positive predictive value, and negative predictive value were performed. A value of $P < 0.05$ was considered indicative of statistical significance. In addition, an intraclass correlation coefficient (ICC) was done to determine consistency among the three raters. The ICC is an

index for the reliability of different raters averaged together. Intraclass correlation coefficients, K , which are a measurement of the homogeneity of the reviewers' measurements were also performed.¹⁵ The K values correlate with the strength of agreements and are rated as: <0.20 poor, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 good, and 0.81–1.0 very good.

Results

A total of four (n=4) patients were identified for the FNS study group (2 females and 2 males). The average age of the patients was 72 years (61–83). Of these patients, 3 underwent bilateral implantation and one unilateral (n=7). Two patients had left FNS and two had right FNS. All four patients had lateral wall orientated electrodes implanted with three implanted with a Med El® (Innsbruck, Austria) Flex 28 device and one patient with a Cochlear® (Sydney, Australia) CI422 device. Seven age-matched controls were selected for each patient with FNS (n=28) from the CI database and used for the control group. There were 10 females and 18 males with the average age of 67.2 (35–92). Of these, 14 had bilateral implants, 7 had left sided implants, and 7 had right sided implants. In the control group, 10 patients had perimodiolar or mid-scalar electrodes and 18 patients had lateral wall electrodes. In the control group 5 patients had Advanced Bionics® (Valencia, CA, United States), 13 had Cochlear®, and 10 had Med El® devices. In total 49 implanted ears were used to measure the median distance from the LSOFN to the BTOC.

The average distance (mm) was 0.28 (STD± 0.29) in the axial plane and 0.37 (± 0.24) in the coronal plane in the FNS group. The control group measurements were 0.59 (± 0.33) in the axial and 0.56 (± 0.29) in the coronal planes. (Figure 2) These distances between the LSOFN and the BTOC in the control group versus the FNS cohort were statistically significant ($p < 0.001$, axial; $p = 0.0034$ coronal). The results are summarized in table 1.

A separate analysis was also performed by excluding all the patients in the control that did not have a lateral orientated electrode array (n=10). This was done because all the patients in the FNS group had lateral wall electrodes. The remaining 18 patients were compared to the FNS group with similar results in that the FNS group had statistically significant less distance (mm) from BTOC and LSOFN in both the axial (0.28 ± 0.3 vs. 0.58 ± 0.34 , $p = 0.0001$) and coronal (0.38 ± 0.24 vs. 0.56 ± 0.29 , $p = 0.004$) measurements compared to this control group.

In regards to bone density measurements (HU), there was no difference between the FNS group (1755.8 ± 40) and the control group (1772.3 ± 61 ; $p = 0.23$).

Reviewer Agreement & Predictive Ability

The intraclass correlation coefficient (K) for our reviewers' measurements were 0.8 for the axial and 0.7 for the coronal planes. The combined predictions from both the FNS group and the control group also demonstrated good correlation ($K = 0.7$). There was disagreement among the reviewers if only the FNS group is included in a separate analysis. The reviewers could predict FNS with only fair correlation ($K = 0.4$). Further, the reviewers did not independently agree on a single individual from the FNS group that would have FN

stimulation after CI. The reviewers' predictions for FNS after CI based on CT were found to be 38.5% sensitive (CI 13.9–68.4%), 85.1% specific (CI 78.1% to 90.6%), 19.2% positive predictive value (CI 6.6% to 39.3%), and 93.75% negative predictive value (CI 88.1% to 97.2%.) (Table 2).

Treatment for patients with FNS

The managing audiologists made various programming changes to address the FNS including electrode deactivation, pulse width lengthening, level reduction, and change in processing strategy. During device programming, specific electrodes were identified as the cause of the FNS for all cases. One patient with FNS had electrodes in the middle of the array deactivated (electrode 5). Another patient had one apical and two (adjacent) mid array electrodes deactivated (electrodes 4–6). The two other patients had electrodes in both the apical and basal regions deactivated. One patient, with a Cochlear device, had 7 apical and 3 basal electrodes deactivated. This did not however completely resolve the FNS. The other patient, with a MedEl device, had 1 apical and 2 basal electrodes deactivated. For all patients, only monopolar strategies could be used due to the limits of the equipment. Processing strategy changes were only made to accommodate for the reduced number of active electrodes. Two patients achieved normal aided thresholds without FNS following programming adjustments while two did not. For the latter patients, one had pervasive FNS after above changes were made and elected to terminate use of the device. The other subject had electrodes deactivated, pulse width increased and stimulation levels reduced. Afterward, the subject did not achieve open set word understanding with this implant but does demonstrate some bilateral benefit and prefers sound quality when using bilateral implants.

Discussion

In the present study of patients without predisposing risk factors for FNS following CI, we found that preoperative CT was poorly predictive to accurately identify which patients had FNS. This finding was surprising given that our reviewers, albeit blinded, knew that there were patients in the cohort that had FNS. Even with this knowledge, there was only fair agreement ($k=0.04$) amongst the reviewers in their predications when looking exclusively at the FNS group. Interestingly, the measurements were statistically significant different when comparing the actual distance of the LSOFN to BTOC between the FNS and control groups which one could argue that the reviewers would have been better at predicting FNS. Thus, the sensitivity and positive predictive values were low for the ability of preop CT to identify patients at risk for FNS. Conversely, preoperative CT scans are effective in predicting the absence of FNS as evidenced by the high specificity and negative predictive values.

In our study, we identified 4 patients that had severe FNS following CI. Unfortunately, despite multiple attempts to address the FNS through the above-mentioned alterations, two of these patients continued to do poorly in regards to audiologic functioning and persistent FNS. In the single patient that stopped wearing his device altogether because of FNS, had a post-operative CT scan showed an obvious cochlear dehiscence. There was discussion amongst our cochlear implant team about revision CI with a perimodiolar electrode array. However, the patient was unable to obtain medical clearance to undergo the procedure.

A few theories have been proposed as to why FNS occurs. For example, in otosclerosis and temporal bone fractures the electrical current can more easily spread outside the confines of the cochlea because of damage to the otic capsule.^{11,16,17,18} The 4 patients in this current study were included because they did not have any known risk factors for FNS. To account for potential causes of FNS stimulation we measured otic capsule density using CT scans and found no difference between the groups. The distance from the LSOFN and the BTOC has also been shown to be a factor. This distance from the BTOC to the LSOFN has been previously measured and found to be 0.4mm in cadavers and < 1.0 mm in radiological images.¹⁹ Other studies also demonstrate similar findings in cadaveric measurements.^{11, 20} In the current study, radiographic measurements in the axial plane were significantly lower in the FNS cohort than the control group (0.3mm vs 0.6mm). We also found our FNS cohort had a significantly smaller distance between the cochlea and FN than the control group (0.4mm vs. 0.6mm) in the coronal plane. Prior studies have not described coronal plane findings in CT based measurements. By measuring in both the axial and coronal planes, our study is the first look at both measurements in the setting of potential FNS patients following CI. This suggests that if the distance from the BTOC to the LSOFN is approximately 0.6 mm in otherwise normal temporal bones then the risk of FNS would be low. Further, the reviewers demonstrated good intra-class correlation which means that the measurements were homogeneous. Our study supports the theory that inadvertent electrical stimulation of the facial nerve is more likely to occur the closer the facial nerve is to the cochlea. However, the predictive ability of this measurement is poor

Considering all patients with FNS in our cohort had lateral wall electrodes, device selection is worth discussing when distance between the cochlea and FN is small. Battmer et al. previously reported on 4 patients with lateral wall electrode arrays with severe FNS that required deactivation of multiple electrodes resulting in decreased use. All four underwent replacement of the lateral wall electrode array with perimodiolar arrays resulting in FNS resolution in all cases.²¹ Another study also demonstrated that in patients with otosclerosis that underwent CI found that 40% of patients implanted with a lateral wall electrode had FNS at some point in their life. While none of the patients with perimodiolar electrodes had FNS.²² These data support considering the use of perimodiolar or mid scalar electrodes and electrode arrays should be given careful consideration when there is a narrow distance between the FN and BTOC or other conditions that may predispose to FNS.

The limitations of the study include the small study size which makes statistical variations or inaccuracies which may affect the outcome possible. However, given the rare incidence of FNS after CI, this is difficult to avoid. Also, the retrospective nature of the study may bias the radiology reviewers into over calling the distance the LSOFN and BTOC. We tried to mitigate this by having a substantially larger control group and ensuring that all reviewers were blinded. Another limitation was the assumption that FNS stimulation only occurred near the BTOC. We did not review the distances at the facial recess, since this would have required a post-operative CT scan to account for introduced surgical variability.

Conclusion

Preoperative CT scans are poorly predictive of severe FNS following CI in otherwise normal ears. However, the distance between the LSOFN and BTOC is statistically less in patients with FNS and may contribute to FNS in combination with lateral wall electrodes. These data support considering the use of perimodular or mid scalar electrodes when the distance between the FN and BTOC is narrow or in patients with diagnoses that place them at higher risk for FNS.

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Figure 1.

LSOFN – labyrinthine segment of the facial nerve

BTOC- basal turn of the cochlea

HU – Hounsfield Units

- 1) Left axial preoperative CT demonstrating close proximity of LSOFN and BTOC.
- 2) Left axial post-operative CT demonstrating close proximity of the electrodes to the LSOFN in a patient with FNS
- 3) Left axial preoperative CT measuring the distance between the LSOFN and BTOC. Average density measurement (HU) of the otic capsule
- 4) Left coronal preoperative CT demonstrating close proximity of LSOFN and BTOC

Figure 2.

LSOFN – labyrinthine segment of the facial nerve

BTOC- basal turn of the cochlea

- 1) Right axial preoperative CT of a patient in the FNS group demonstrating close proximity of LSOFN and BTOC.
- 2) Right coronal preoperative CT of a patient in the FNS group demonstrating close proximity of LSOFN and BTOC.
- 3) Right axial preoperative CT of a patient in the control group demonstrating a further distance between the LSOFN and BTOC.
- 4) Right coronal preoperative CT of a patient in the control group demonstrating a further distance between the LSOFN and BTOC.

Table 1

	Demographics		Measurements								Density (HU)	Predictions
	Age	Gender (F:M)	Combined		Reviewer 1		Reviewer 2		Reviewer 3		Combined	Combined
			axial	coronal	axial	coronal	axial	coronal	axial	coronal		
FNS group	71.2	1:1	0.3 (± 0.3)	0.4 (± 0.2)	0.14 (± 0.17)	0.33 (± 0.17)	0.5 (± 0.29)	0.51 (± 0.26)	0.2 (± 0.26)	0.27 (± 0.2)	1755.8 (± 40)	
Control Group	67.2	1:1.7	0.6 (± 0.3)	0.6 (± 0.2)	0.52 (± 0.32)	0.5 (± 0.23)	0.76 (± 0.27)	0.78 (± 0.31)	0.49 (± 0.32)	0.40 (± 0.18)	1772.3 $\pm$ 61;	
<i>p</i> value	0.3	0.3	0.0001	0.0034	0.0024	0.0319	0.0122	0.0221	0.0168	0.0474	0.2334	
<i>K</i> value	-	-	0.8	0.7	-	-	-	-	-	-	-	0.7

FNS – facial nerve stimulation, F – female, M – male, mm – millimeters, SD – standard deviation, HU – Hounsfield Units, *K* – intra-class correlation coefficient (*K* values measure the homogeneity of reviewers' measurements and are rated as: <0.20 poor, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 good, and 0.81–1.0 very good).

Table 2

	Value (%)	95% CI
Sensitivity	38.5	13.9 – 68.4
Specificity	85.1	78.1 – 90.6
Positive Predictive Value	19.2	6.6 – 39.3
Negative Predictive Value	93.8	88.1 – 97.2

CI – confidence interval