European Archives of Oto-Rhino-Laryngology (2021) 278:3789–3794
https://doi.org/10.1007/s00405-020-06486-7

OTOLOGY

Evaluation of computed tomography parameters in patients with facial nerve stimulation post-cochlear implantation

Isra Ali Aljazeeri[1] · Tawfiq Khurayzi[1] · Mariam Al-Amro[1] · Farid Alzhrani[1] · Abdulrahman Alsanosi[1]

Received: 18 August 2020 / Accepted: 10 November 2020 / Published online: 26 November 2020

Abstract

Purpose To compare the preoperative computed tomography (CT) parameters, including the thickness and density of the bone separating the upper basal turn of the cochlea (UBTC) and the labyrinthine segment of the facial nerve (LSFN), in patients with and without facial nerve stimulation (FNS) in post-cochlear implants (CI).

Methods A retrospective case review of 1700 CI recipients in a tertiary referral center between January 2010 and January 2020 was performed; out of the 35 recipients who were found to have FNS, 29 were included in the study. The control group comprised the same number of randomly selected patients. CT parameters of the patients were measured independently by three fellowship-trained neuro-otologists blinded to the postoperative status of the patients. Thickness in axial and coronal views and density of the bone separating the UBTC and the LSFN were measured.

Result There was satisfactory agreement between the readings of the three reviewers. The distances (in mm) between the UBTC and LSFN obtained from the coronal (0.43 ± 0.24 vs. 0.63 ± 0.2) and axial (0.42 ± 0.25 vs. 0.6 ± 0.18) views were statistically lower in the FNS group ($p = 0.001$ and 0.005, respectively). The density (in HU) of the bony partition was also statistically lower in the FNS group (1038 ± 821 vs. 1409 ± 519; $p = 0.029$).

Conclusion Patients who experienced FNS postoperatively had significantly lower distance and bone density between the UBTC and the LSFN. This finding can help surgeons in preoperative planning in an attempt to decrease the occurrence of FNS.

Keywords Facial nerve stimulation · Cochlear implant · Complication · Radiology · Otolaryngology

Introduction

Cochlear implants (CIs) are among the most effective treatments for patients with severe to profound hearing loss. CI surgery is considered a relatively safe procedure with rare major complications [1]. Facial nerve stimulation (FNS) after CI surgery is a problem. An incidence of 0.9–15% has been reported [2–5]. Patients with temporal bone fracture, prior surgery of the lateral base of the skull, congenital cochlear malformation, facial nerve course anomalies, cochlear ossificans, and otosclerosis are at a higher risk for FNS [6–8].

✉ Isra Ali Aljazeeri
ialjazeeri@moh.gov.sa

1 King Abdullah Ear Specialist Center (KAESC), College of Medicine, King Saud University Medical City (KSUMC), King Saud University, PO Box 245, Riyadh 11411, Saudi Arabia

Managing patients with FNS necessitates the modification of CI fitting parameters, which can affect hearing and speech outcomes or may necessitate ex-plantation and re-implantation with a more appropriate type of electrode in severe cases [9, 10].

A higher incidence of FNS has been associated with cochlear implantation using lateral wall type electrodes rather than perimodiolar electrodes [4, 8, 9, 11, 12]. In theory, this is attributed to the closeness of the perimodiolar electrodes to the modiolus, which decreases the current flow needed to stimulate the Cochlea and, at the same time, increases their distance from the facial nerve [9]. For this reason, perimodiolar electrodes are recommended for use in patients who are anticipated to have FNS based on their CT findings [11, 12]. However, up to our knowledge, the technology to measure this current flow from the electrode to the facial nerve is not yet available, which makes it difficult to prove this theory. Several approaches, to control FNS in the patients implanted with lateral wall electrodes have been effectively used during programming sessions. These approaches include but not limited to: changing the maximum comfort level and thresholds, changing the phase duration, changing the sensitivity, and deactivating the responsible electrodes [13]. Recently, triphasic, instead of biphasic pulse stimulation has been reported as an efficient treatment for FNS, which does not present with significant worsening of hearing and speech [14, 15].

A leakage of electrical current from the electrode at the UBTC to the LSFN may underlie this complication, as the distance between the electrode and the facial nerve is the shortest at this point [16, 17]. Another explanation for FNS is the low bone density between the electrode and the LSFN. The extreme version of this scenario may present in cases of otosclerosis [18, 19].

Preoperative CT is routinely performed in some centers, including our center, for patients scheduled to undergo CI surgeries, and using it to assess the possibility of FNS helps in choosing the appropriate electrode and side of implantation.

Several studies have compared CT parameters in CI patients with and without FNS. However, the number of subjects in these studies was very limited; it included four cases [20, 21]. Moreover, one of these studies evaluated only the distances between the UBTC and the LSFN obtained from the axial view, while another evaluated the distance in both axial and coronal views. This calls for a new evaluation of the subjects. The primary goal of this study was to evaluate the distances and bone densities of the bony partition between the UBTC and LSFN in both axial and coronal views in a large number of patients.

Materials and methods

This was a retrospective study performed on patients who underwent cochlear implantation in a tertiary referral ear center. This study was approved by the institutional review board of the University Hospital.

Group selection

The included patients underwent a high-resolution, thin-cut CT followed by cochlear implantation if accepted by the CI Committee. All included patients had normal anatomy of the cochlea and the labyrinthine segment of the facial nerve.

FNS was defined as any repeatable facial movement that is clinically appreciable and detectable by the physician, audiologist, or the patient at or below the maximum comfortable level on any electrode that happens after activation of the device for any duration [22, 23].

As all the patients with FNS were implanted with the lateral wall type of electrode, their controls were chosen with lateral wall type of electrode as well, but they did not experience postoperative FNS.

Patients were excluded if they had a history of otic capsule fracture, prior lateral skull base surgery, anomalous facial nerve course, cochlear ossificans, cochlear anomalies, otosclerosis, and low-resolution CT scans.

Imaging and measurements

The images were obtained using a 512-slice multidetector row CT scanner (General Electric Healthcare, Milwaukee, WI, USA). The following scanning parameters were used: axial plane, 0.625-mm slice thickness, 230 mAs, 140 kV, rotation time 1 s with 0.3-mm reconstruction in axial and coronal views.

The thickness and the least distance between the UBTC and the LSFN were measured in both coronal and axial views. The density was measured in Hounsfield units (HU), and the thickness and distances were measured in millimeters (mm).

The Universal Viewer software, version 6.0 SP10.2 (General Electric, Healthcare Centricity, GE Co, Barrington, IL, USA), was used to load patients' preoperative images for measurements. The measurements were made by three fellowship-trained neuro-otologists who performed cochlear implantation weekly. The neuro-otologists were blinded to the postoperative status of the patients (Fig. 1).

A distance of 0.0 mm and thickness of 0 HU was used as the minimum when no obvious bone was seen between the UBTC and the LSFN.

Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS Inc., Chicago, IL, USA) version 23. The statistician was blinded to the allocation of patients in the groups.

Cronbach's alpha is a measure of internal consistency and was used to evaluate the homogeneity and reliability of the reviewers' measurements. The Cronbach's alpha values correlate the agreement between the reviewers' measurements, and they are rated as: <0.20 = poor; 0.21–0.40 = fair; 0.41–0.60 = moderate; 0.61–0.80 = good; 0.81–1.0 = very good. Statistical significance, confidence interval, and study power were set at $p<0.05$, 95%, and 80%, respectively.

The mean values for thickness and density in both views, which were measured by the three reviewers independently, were used for further analysis. According to the normality test, our data were not normally distributed, and non-parametric statistical analyses were applied.

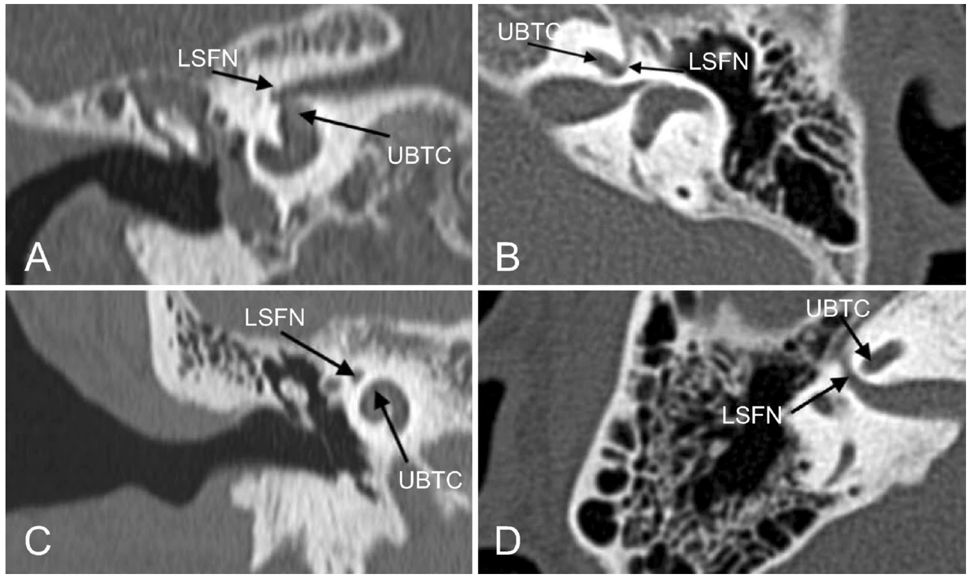

Fig. 1 CT images in coronal (**a**) and axial (**b**) views showing no distance between the upper basal turn of the cochlea (UBTC) and the labyrinthine segment of the facial nerve (LSFN). CT images in coronal (**c**) and axial (**d**) views showing a thick bony partition between the UBTC and the LSFN

Results

Twenty-nine out of 35 patients who were diagnosed with FNS were included in this study. A control group of 29 patients was matched for age and sex. The age of the subjects ranged from 2 to 56 years with a mean of 16.7 years. The subjects had a male-to-female ratio of 1.23:1. The left-to-right ear implant ratio was 1.9:1 in the control group and 1:1.23 in the FNS group. All the cases were found to have a lateral wall type of electrode. The controls were selected from patients who underwent lateral type electrode to match the FNS cases. The onset of the FNS was immediate for nine subjects and occurred in up to 16 months after the implantation for the remaining subjects.

The inter-rater reliability using Cronbach's alpha was higher than 0.8 for all the three groups of readings, the distances measured in the axial and coronal views, and bone density (Table 1).

Generally, the means of the distances between the UBTC and the LSFN in the axial and coronal views and the bone densities in this segment were higher in the control group than in the FNS group (Figs. 2, 3) using a Mann–Whitney *U* test (which was used because of the non-parametric nature of the data) (Table 1).

No bony partition could be appreciated in the CTs of 41% of patients in the FNS group compared to 13% in the control group ($p = 0.019$ for the Chi-square test, with a continuity correction of 0.04). The positive and negative predictive values for finding no bony partition in the CT were 75% and 59%, respectively. Finding a bony partition can rule out the possibility of developing postoperative FNS with 86% specificity; however, it has a low sensitivity of 41%.

Using the Pearson correlation test, a positive correlation was found between the distances in the axial and coronal views as well as each of them and the bone density, with a *p* value of 0.00. However, no correlation was found between these readings and the age at implantation (Fig. 4).

There was no statistical difference, using a Mann–Whitney *U* test, between the distances in the axial and coronal views and the bone densities of different genders (*p* values: 0.86, 1.00 and 0.53, respectively) as well as the location of implantation (*p* values: 0.80, 0.56, and 0.67).

Discussion

In this study, a high degree of internal consistency was found across all measurements of the three reviewers. This homogeneity suggests that CT measurements are reliable indicators.

The results of this study suggest that in the absence of any known predisposing factors, the distance from the UBTC to the LSFN and the density of the bony partition is significantly lower in patients who develop FNS after CI. The difference in the distance from UBTC to LSFN was demonstrated in previous studies [20, 21]. However, they were not able to demonstrate a significant difference between the bone densities. This could be due to the very small size of the FNS group ($n = 4$) that they used, which was not enough to demonstrate this difference [21].

Our data suggested that a distance of less than 43 mm and 42 mm in the coronal and axial views, respectively, and a bone density of less than 890 HU increases the risk of developing FNS post-CI.

To emphasize the effect of the distance between the UBTC and the LSFN, we assessed patients with no visible bony partition. Although FNS is not common, we found that the positive predictive value of finding no bony partition was

Table 1 Reliability test and statistical comparison between the mean values of control and study groups

		Distances in coronal view (mm)			Distances in axial view (mm)			Bone density (HU)			Combined readings		
		1st reviewer	2nd reviewer	3rd reviewer	1st reviewer	2nd reviewer	3rd reviewer	1st reviewer	2nd reviewer	3rd reviewer	Distances in coronal view (mm)	Distances in axial view (mm)	Bone densities (HU)
FNS (*N* = 29)	Mean (± SD)	0.37 (± 0.23)	0.49 (± 0.33)	0.44 (± 0.25)	0.37 (± 0.24)	0.46 (± 0.35)	0.43 (± 0.26)	996 (± 772)	430 (± 956)	1086 (± 691)	0.43 (± 0.24)	0.42 (± 0.25)	1038 (± 821)
Control (*N* = 29)	Mean (± SD)	0.57 (± 0.25)	0.67 (± 0.25)	0.64 (± 0.18)	0.52 (± 0.22)	0.68 (± 0.26)	0.61 (± 0.17)	1163 (± 671)	1594(± 683)	1553 (± 481)	0.63 (± 0.20)	0.60 (± 0.18)	1409 (± 519)
Reliability	Cronbach's alpha	0.86			0.82			0.83					
Mann–Whitney *U* test	Asymp. Sig. (two-tailed *p* value)	0.004	0.014	0.002	0.041	0.012	0.011	0.422	0.003	0.006	0.001	0.005	0.029

FNS facial nerve stimulation, *HU* Hounsfield unit, *SD* standard deviation

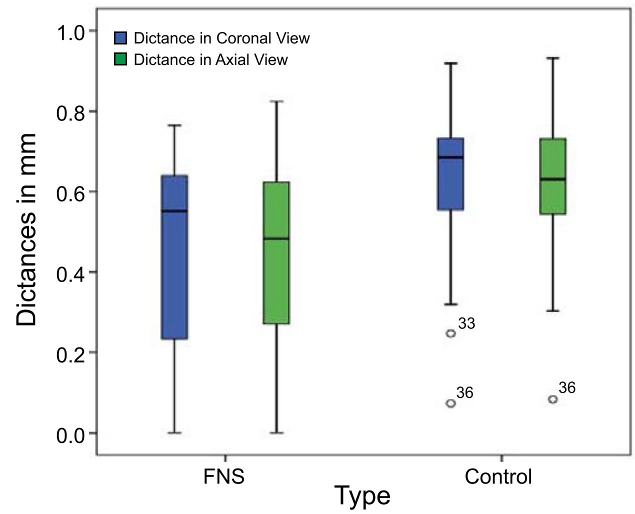

Fig. 2 Box and Whisker plot showing the difference between the distances (mm) of the control and FNS groups obtained from the coronal and axial views

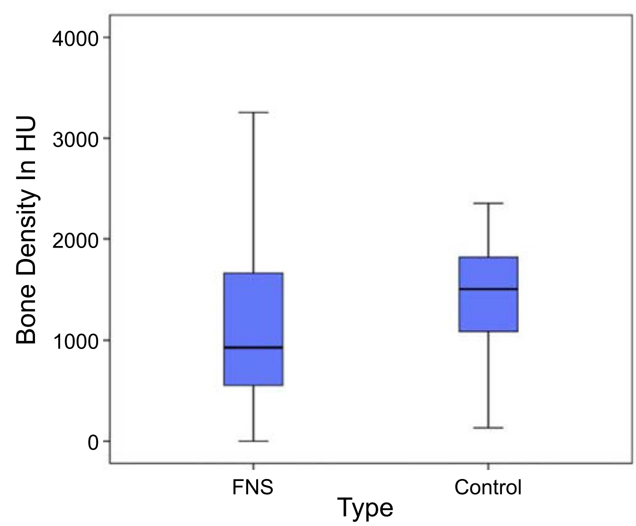

Fig. 3 Box and Whisker plot showing the difference between the bone densities (HU) of the control and FNS groups

higher than its negative predictive value. This indicates that finding no bony partition is highly predictive for developing FNS. Most importantly, this finding is not affected by measurement errors and is not reviewer dependent.

The abovementioned results support the hypothesis that electrical leakage can occur through the bony partition between the UBTC and the LSFN because the distance between the implanted electrode and the FN is the shortest at this point. This suggests that increasing the distance using a perimodiolar electrode may help to prevent FNS.

FNS was found to be more prevalent in patients implanted with lateral electrodes in a previous study [16]; however,

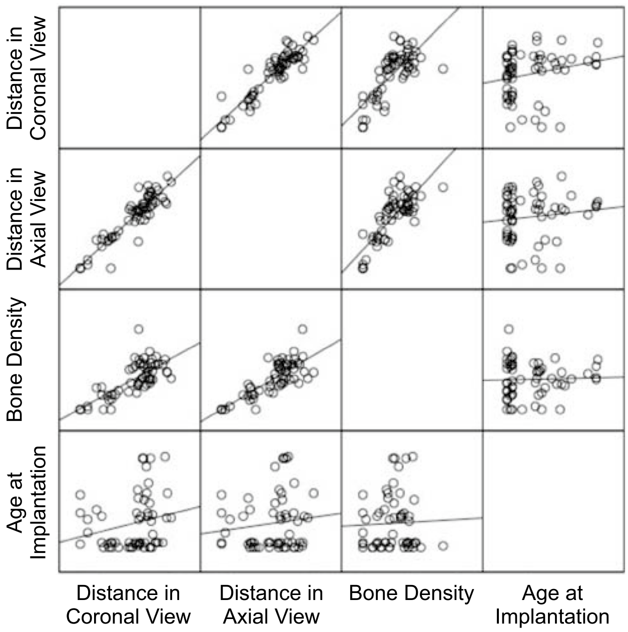

Fig. 4 Scatterplot showing the correlation between the distances in mm, bone density in HU, and age at implantation in years. The distances and bone densities in the axial and coronal views were strongly correlated. There was no growth in the distances obtained in the axial and coronal views or increase in bone density with age

another study could not replicate these findings and found no difference between lateral and perimodiolar electrode arrays [4]. In this study, all patients who developed FNS postoperatively were found to have been implanted with a lateral wall electrode. In addition, because of this finding, the relation between the type of the electrode and the presence or absence of FNS postoperatively could not be studied. Further studies should be performed to evaluate this causal relationship.

The measurements of the distances in the axial and coronal views were positively correlated, which was expected as they both measure the same distance. These measurements also correlated with the density of the bony partition between UBTC and LSFN; the wider bony partition was associated with the denser bone.

Given that the Cochlea attains its maximum size at birth and stops growing with age, we could not demonstrate any increase in any of the measurements with age due to the closeness of the bone to the cochlea [24].

Thirty-five out of 1700 CI recipients in our institute were found to have FNS. With an incidence of 2% compared to a reported incidence of 0.9–15% [2–5], this finding is on the lower side.

All patients were managed to achieve satisfactory hearing and FNS results using various programming techniques, such as targeted deactivation of FN stimulating channels, changing the phase duration, changing the coding strategy, and using triphasic pulse stimulation. None of the patients required ex-plantation or re-implantation. All these patients showed good hearing and speech results with a mean CAP-II score greater than 7, which corresponds to the ability to use a phone when talking to a known speaker [13, 25].

All our patients, control and FNS groups, routinely get fitted first with the biphasic pulse stimulation mode. Maximum comfort levels (MCL) and Thresholds (THR) were found to be higher in FNS group compared to the control group with means of 32.59 qu (± 1.27) and 4.03 qu (± 1.81) in FNS group compared to 28.59 qu (± 5.15) and 2.98 qu (± 1.27) in the control group. This difference was statistically significant using paired *T* test to compare MCL and THR between control and FNS groups. Changing the MCL and THR was attempted for all patients, and 60% of the patients, respectively. However, this changes alone could not solve the FNS problem in the subjects as they need more fitting techniques to alleviate the FNS problem. Later, and once it is available, we used the triphasic pulse stimulation to effectively manage those cases [26], in which the MCL increased again to a level of 36.62 qu (± 1.63), while the THR decreased to a level of 3.58 qu (± 1.72). Therefore, in conclusion, the fitting parameters should also be considered in evaluating FNS in CI recipients.

The limitation of this article is that the FNS cases were all found to have a lateral wall type of electrode. In addition, the effect of the type of the electrode on the development of FNS could not be studied.

Conclusion

FNS after CI can be bothersome for both the patient and the physician. The thickness of the bony partition between the UBTC and LSFN varies considerably among patients. According to the findings of this study, patients who developed FNS had a thin bony partition between the UBTC and LSFN. The preoperative evaluation of CT parameters, when available, including the thickness and density of the bony partition, can be an effective way to anticipate the occurrence of FNS post-CI. Therefore, this evaluation may help surgeons in the selection of the ear to be used for implantation and the electrode. Recently, many options could be done pre- and postoperatively to manage the FNS problem with good audiological and speech outcomes.

Funding None.

Compliance with ethical standards

Conflict of interest No conflict of interest.

Ethical approval Reference Number 20/0528/IRB.

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