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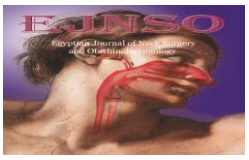

# Correlation between auditory response telemetry (ART) and computerized tomography measurements in detection of cochlear implant electrode position

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## Abstract:

**Introduction:** Cochlear implant (CI) has been widely used in cases with severe to profound sensorineural hearing loss. The integrity of the internal CI part after implantation could be objectively assessed by measuring the auditory response telemetry (ART) based on each individual electrode's ECAP threshold, and by postoperative imaging which provides detailed information on the position of individual electrodes especially with measurement of the electrode- modiolus distance (EMD).

**Objective:** We aimed to correlate between the auditory response telemetry (ART) measurements and radiological position of the electrode arrays (Electrode-Modiolus distance) inside the cochlea.

**Patients and methods:** Twenty-five children with severe to profound sensorineural hearing loss who had implanted unilaterally with MED-EL SONATA FLEX 28 were enrolled. Intraoperative ART results for each array were obtained. Postoperative imaging by means of a128-Multidetector CT scanner with sagittal and oblique multiplanar reconstructions (MPRs) were obtained. Images were analyzed to measure the electrode modiolus distance (EMD) and results were correlated with ART measurements.

Results: The mean ART threshold for each electrode ranged between 15.97±4.69 qu and 20.61±6.64 qu. While, the mean electrode-modiolus distance for each electrode fluctuated from 1.72±0.38 mm to 4.53± 1.27 mm. Pearson test showed a statistically significant positive correlation between the electrode- modiolus distance and the auditory response telemetry (ART) measurements.

**Conclusion:** Postoperative computerized tomography scanning could provide a valuable tool to assess the outcome of cochlear implant through measuring the electrode modiolus distance (EMD).

**Key words:** Auditory response telemetry, Electrode modiolus distance, Cochlear implant.

## Introduction

Cochlear implantation (CI) has been an established treatment option for patients with profound sensory neural hearing loss to achieve near normal hearing. [1] A great need for assessment of the location of electrodes has become very important to improve the functional outcomes. Full insertion of the CI electrode array and insertion in scala tympani usually provide the most favorable outcome. Electrode array translocation from scala tympani to

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scala vestibuli may result in poor response. [2]

There are many intraoperative and postoperative tools to detect the intracochlear electrode array position such as computed tomography and auditory response telemetry.[3] Also, electrode-modiolus distance has a great impact on the auditory nerve stimulation.[4] The Auditory Response Telemetry (ART) is an electrophysiological technique based on each individual electrode's ECAP threshold which is dependent on the distance between the electrodes and the spiral ganglion cells and can identify the intracochlear electrode array position. [5]

## Patients and methods:

We enrolled 25 children aged < 5 years who had bilateral profound sensorineural hearing loss. All children have fulfilled the following criteria; All had got a minimum of 6 months phoniatrics and audiological follow-up in our department. None had any congenital anomalies, syndromic hearing loss, meningitis, jaundice or history of major head trauma.

All have received unilateral cochlear implantation with MED-EL SONATA FLEX28 (MED-EL GmbH, Innsbruck, Austria) through round window approach during the period from 2017 to 2019 at Assuit University Hospital. The results of intraoperative Auditory Response Telemetry (ART) measurements and postoperative CT scanning were obtained.

**Intraoperative evaluation:**

Auditory nerve response telemetry (ART) was recorded intraoperatively using MED-EL software and hardware interface system. ART was recorded in all 12 electrodes using MED-EL Maestro system software 2014 version 6.0.1 (Insbruke, Austria) (Fig1).

All intraoperative auditory response telemetry (ART) measurements were collected. Then, the mean ECAP threshold for each electrode was calculated. According to the electrode number, the stimulated area was divided into three regions. In participants with 12 active electrodes, electrodes 9 to 12 were referred to as the basal region, electrodes 5 to 8 as the intermediate region, and electrodes 1 to 4 as the apical region. The mapping was moved by one electrode if the most basal electrode (electrode 12) was not active, resulting in an apical region with electrodes 1 to 3.

Similarly, if electrodes 11 and 12 were deactivated, the ranges were moved by two electrodes, resulting in the apical region consisting of only electrodes 1 and 2. Out of the 25 patients, 12 electrodes were active in 16 patients (64%), 11 electrodes were active in 5 patients (20%), and 10 electrodes (16%) were active in 4 patients (16%).

**Postoperative radiological evaluation:**

All cases had postoperative 128-multidetector CT scanning of the temporal bones (Phillips Medical Systems, Netherlands). Images were captured with a 200 mm scan field of view (FOV), 1 mm slice thickness, 0.5-1 pitch factor, 140 KV tube voltage,0.5 s rotation time, 512 × 512 matrix, 160 mA tube current, window level of 600, and window width of 4000.

Slices were 0.6 mm thick when the images were reconstructed. The scan field involved the area from the jugular foramen to the superior margin of the petrous pyramid. The petrous bone was displayed in the axial plane, parallel to the infraorbito-meatal line.

For illustrating the anatomy of cochlear turns, cochlear aperture, and modiolus, two-dimensional reformatted images were obtained through a multiplanar reformatted images (MPR) procedure. Images were reconstructed in a sagittal oblique plane with the long axis of both vestibular aqueduct and round window, and parallel to the cochlear axis. The cochlear turns were then visualized using 3D

reconstructions created through a maximum intensity projection (MIP) so the electrodes inside and outside of the cochlea could be counted.

Inter-observer agreement was determined between the surgeon and the neuro-radiologist for axial and coronal images, as well as oblique reformations within the plane of the cochlear basal turn. Finally, electrode modiolus distance was measured from the center of the electrode to the center of the modiolus (Fig 2), and the mean EMD distance for each electrode was calculated.

## Statistical analysis

Data were analyzed using SPSS (Statistical Package for the Social Science, version 20, IBM, Armonk, New York). Continuous data were expressed in the form of mean ± SD or median (range), while nominal data were expressed in the form of number and percentage.

The level of confidence was kept at 95%, hence a P value <0.05 indicated a significant association.

## Results

Data from 25 children implanted with a MED-EL CI were collected; seven were males and eighteen were females. Their age ranged between 2-5 years olds with a mean age of 3.24 ± 1.31. The duration of hearing loss among these patients varied from 2 to 5 years with a mean of 3.24 ± 1.31 years (table 1).

All children had received implantation unilaterally in their left ear, except four patients, who had received an implant in their right ear. The ECAP thresholds and electrode modiolus distances were analyzed for all electrode channels.

The mean ECAP threshold for each electrode ranged between 15.97±4.69 qu and 20.61±6.64 qu, while the mean EMD distance for each electrode fluctuated from 1.72±0.38 mm to 4.53± 1.27 mm (Table 2).

A Pearson 2 tailed correlation of Pearson r = 0.835 was applied to the ANOVA. The ANOVA revealed a significant strong positive correlation between the electrode- modiolus distance and the ECAP threshold with 95% probability (P value< 0.001) as shown in (Figure 3).

| Variables | Result |
|---|---|
| Sex | 7 Males (28%) |
| | 18 Females (72%) |
| Age (years) | Mean ± SD (3.24 ± 1.31) |
| | Range (2-5) |
| Duration of hearing loss | Mean ± SD (3.24 ± 1.31) |
| | Range (2-5) |

**Table 1:** Patients' demographic data.

**Table 2:** Correlation between ECAP threshold and electrode modiolus distance in each electrode.

| Electrode | Mean ART (ECAP threshold) | Mean EMD |
|---|---|---|
| 1 | 15.97 ± 4.69 | 1.72 ± 0.38 |
| 2 | 17.45 ± 5.73 | 2.11 ± 0.47 |
| 3 | 17.63 ± 5.59 | 2.37 ± 0.50 |
| 4 | 16.04 ± 5.27 | 2.62 ± 0.53 |
| 5 | 16.24 ± 5.84 | 2.95 ± 0.41 |
| 6 | 17.91 ± 5.66 | 3.06 ± 0.55 |
| 7 | 19.25 ± 4.65 | 3.14 ± 0.54 |
| 8 | 19.67 ± 4.93 | 3.25 ± 0.53 |
| 9 | 19.14 ± 5.79 | 3.62 ± 0.58 |
| 10 | 20.34 ± 5.00 | 3.92 ± 0.92 |
| 11 | 20.61 ± 6.64 | 4.37 ± 1.43 |
| 12 | 19.89 ± 6.71 | 4.53 ± 1.27 |
| P values | 0.021* | <0.0001*** |

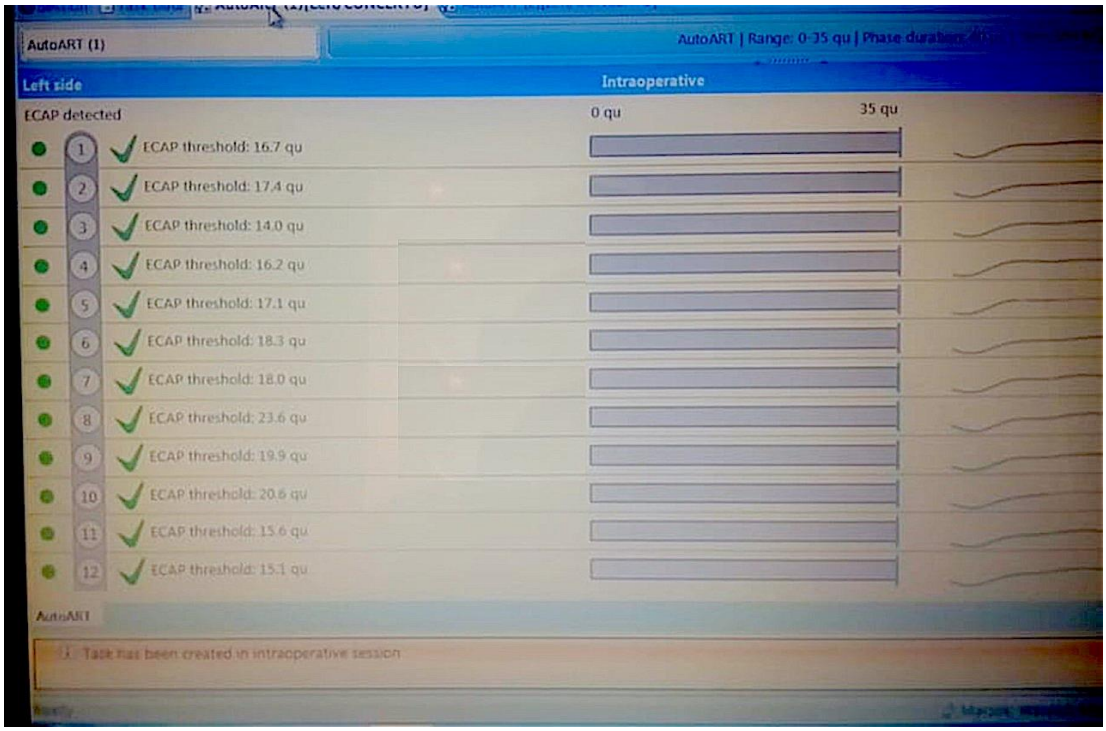


**Figure 1**: Intraoperative ART measurement showing active 12 electrodes.

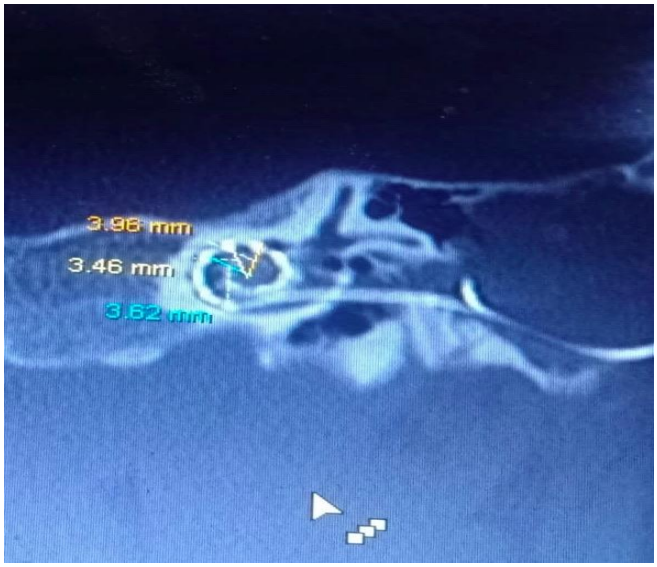


**Figure 2**: Postoperative CT scanning showing EMD measurements.

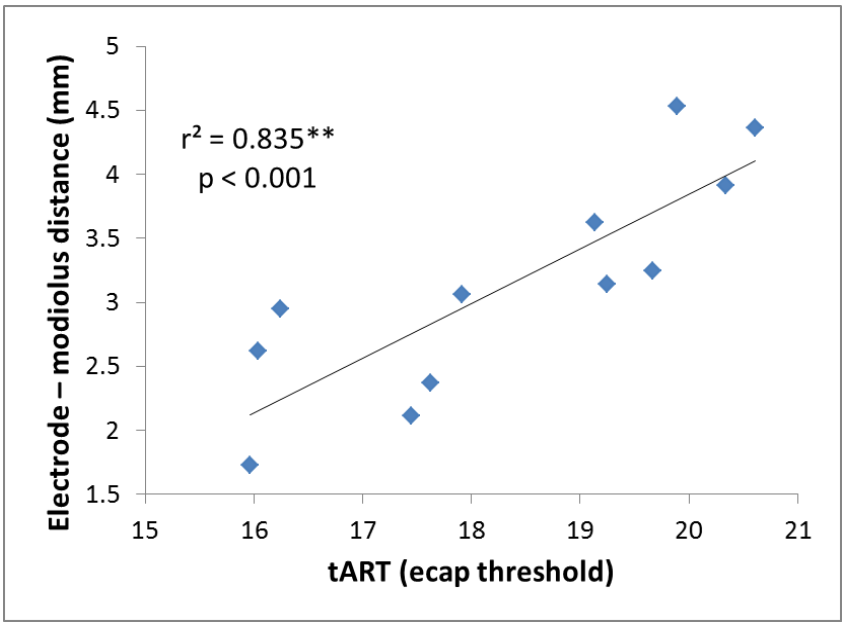


**Figure 3:** Electrode modiolus distance plotted versus ECAP threshold.

## ***Discussion :***

The outcome of cochlear implantation is variable among patients. Several studies tried to predict the factors that influence the performance of patients. [2,6,7]

Scalar location and proximity of electrode array to the modiolus were proved to have a critical effect on patients' performance. Several studies have shown that translocation of the array from scala tympani to scala vestibuli had a negative impact on audiological outcomes. [8,9] The distance between the electrode array and the modiolus, which houses the spiral ganglion cells, is also important and may influence cochlear implant users' performance. [7]

Multiple early studies showed that direct electrical excitation of auditory nerve using an electrode positioned through modiolus was more efficient in the activation of the nerve fibers than Scala tympani stimulation. [10, 11]

Our study revealed that the mean ECAP threshold has ranged between 15.97 ± 4.69 qu and 20.61 ± 6.64 qu which means that the intraoperative ECAP threshold measurements has increased from apical electrodes to basal ones. This finding was in harmony with the study of **Müller et al.,** who documented ECAP thresholds varied across the array. The array's basal end had the maximum threshold level, and ECAP thresholds decreased as one moved toward the apex. [12]

This was in concordance with Hey et al., who also reported a decline in the intraoperative ECAP thresholds at the apex which were much lower than those at the apex. [13]

Our study was also in good agreement with **Gordin et al.,** and **Spivak et al.,** who hypothesized that the radial distance between the electrode and the modiolar wall could be a factor. [14,15] Also, **Telmesani and Said**, and **Lathuillière et al.,** observed that intraoperative ECAP thresholds at the apical electrodes were substantially lower than those at the base [(16,17)]. **Lai and Dillier,** and **polka et al.,** reported this may be also caused by variations in the neuronal survival or density between the apex and base. [18,19]

On the other hand, we reported a significant positive correlation between the electrode-modiolus distance and the ECAP threshold with 95% probability (P value< 0.001). This is in line with

previous studies recording relation between the electrode modiolar distance and variations in ECAP levels. Saunders et al., have investigated the connection between T-Level and the electrode's estimated radial distance from the modiolus. They discovered that the Nucleus 24 Contour electrode array had a lower T- level than the conventional straight array. [20] In addition, Parkinson et al., and Cohen et al., clarified that there was a decrease in T-Level in perimodiolar placements with patients utilizing the same array. [21,22]

Meanwhile, Hughes and Abbas have examined the thresholds in 10 patients using Nucleus 24 and recorded insignificant changes between the two electrode types, straight array and the perimodiolar Contour array. [23]

Our finding unified with **Van Wermeskerken et al.,** who found a significant correlation between ECAPs and electrode-modiolar distance, through a study conducted by using five individuals and three assessed electrodes. A higher ECAP-threshold was caused by a longer distance between the electrodes and the modiolus. [4] **Brill et al.,** stated the cochlea's stimulation site had a significant impact on the ECAP threshold. [5]

Similarly, **Jolly et al.,** through physical measurements in animals and Goldwyn et al., through computational modeling studies of human cochleae stated that the voltage decreases with the distance from the electrodes. As a result, electrodes that are further from the modiolus require more current to drive neural responses. [24,25]

Likewise, **Taha et al.,** recorded a strong positive correlation between NRT threshold and EMD, indicating that as EMD increases, so does NRT threshold, by assessment of the link between electrode array distance and modiolus using CT and NRT threshold in 25 patients and 5 electrodes (1, 6, 11, 16 and 22). [26]

On the flip side, clinical studies of **Venail et al.,** failed to demonstrate conclusively that lower ECAP thresholds correlate with electrode array position within the scala tympani. [27] **Mittman et al.,** and **Aschendorff et al.,** reported that dislocation into the scala vestibule had no effect on ECAP thresholds. [28,29]

Also, **Van Weert et al.,** assumed there was no discernible difference in ECAP answers before and after the stylet was removed through comparing intra-operatively recorded electrically evoked compound action potential (ECAP) data in 14 patients using a perimodiolar electrode array before and after the surgical stylet was removed. [30]

## ***Conclusion:***

Postoperative CT scanning could provide a valuable tool to assess the outcome of cochlear implant through measuring the electrode modiolus distance (EMD).

**Financial support:** No financial support was obtained.

**Conflicts of interest:** There is no conflict of interest.

**Ethical considerations:** This cohort observational clinical trial was approved by the Medical Ethics Committee, Assuit faculty of Medicine, and was registered in Clinical Trials.gov (No: NCT03306108).

## ***Reference:***

1. Deep, N. L., Dowling, E. M., Jethanamest, D., & Carlson, M. L.Cochlear implantation: an overview. Journal of Neurological Surgery Part B: Skull Base.2019; 80.02: 169-177.

2. Holden, L. K., Finley, C. C., Firszt, J. B., Holden, T. A., Brenner, C., Potts, L. G., ... & Skinner, M. W. Factors affecting open-set word recognition in adults with cochlear implants. Ear and hearing. 2013; 34.3: 342.
3. Mittmann, P., Todt, I., Ernst, A., Rademacher, G., Mutze, S., Göricke , S & Christov, F. Radiological and NRT-Ratio–Based Estimation of Slim Straight Cochlear Implant Electrode Positions: A Multicenter Study. Annals of Otology, Rhinology & Laryngology. 2017;126.1: 73-78.
4. Van Wermeskerken, G. K., van Olphen, A. F., & Graamans, K. Imaging of electrode position in relation to electrode functioning after cochlear implantation. European archives of oto-rhino-laryngology. 2009;266.10: 1527-1531.
5. Brill, S., Müller, J., Hagen, R., Möltner, A., Brockmeier, S.-J., Stark, T., Zierhofer, C. Site of cochlear stimulation and its effect on electrically evoked compound action potentials using the MED-EL standard electrode array. BioMedical Engineering OnLine. 2009; 8(1): 1-10.
6. Green,K. M., Bhatt, Y. M., Mawman, D. J., O'Driscoll, M. P., Saeed, S. R., Ramsden, R. T., & Green, M. W. Predictors of audiological outcome following cochlear implantation in adults. Cochlear implants international. 2007; 8 (1): 1-11.
7. Giraud,A.L., & Lee,H.J. Predicting cochlear implant outcome from brain organisation in the deaf. Restorative neurology and neuroscience.2007 ;25(3-4) :381-390.
8. Chakravorti, S., Noble, J. H., Gifford, R. H., Dawant, B. M., O'Connell, B., Wang, J., & Labadie, R. F. Further evidence of the relationship between cochlear implant electrode positioning and hearing outcomes. Otology & neurotology: official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology. 2019; 40.5: 617.
9. Finley, C. C., & Skinner, M. W. Role of electrode placement as a contributor to variability in cochlear implant outcomes. Otology & neurotology: official publication of the American Otological Society, American Neurotology Society [and] European Academy of Otology and Neurotology. 2008; 29.7: 920.
10. Van den Honert, C., & Stypulkowski, P. H. Physiological properties of the electrically stimulated auditory nerve. II. Single fiber recordings. Hearing research.1984 ;14(3) : 225-243.
11. Snyder, R. L., Bierer, J. A., & Middlebrooks, J. C.Topographic spread of inferior colliculus activation in response to acoustic and intracochlear electric stimulation. Journal of the Association for Research in Otolaryngology. 2004;5(3) : 305-322.
12. Müller, A., Hocke, T., & Mir-Salim, P. Intraoperative findings on ECAP-measurement: normal or special case ?. International Journal of Audiology.2015 ;54(4) :257-264).
13. Hey, M., Wesarg, T., Mewes, A., Helbig, S., Hornung, J., Lenarz, T., Aschendorff, A. Objective, audiological and quality of life measures with the CI532 slim modiolar electrode. Cochlear Implants Int. 2019 ;20(2) : 80-90.
14. Gordin, A., Papsin, B., James, A., & Gordon, K. Evolution of cochlear implant arrays result in changes in behavioral and physiological responses in children. Otology & Neurotology.2009;30(7) :, 908-915.
15. Spivak, L., Auerbach, C., Vambutas, A., Geshkovich, S., Wexler, L., & Popecki, B. Electrical compound action potentials recorded with automated neural response telemetry: threshold changes as a function of time and electrode position. Ear Hear. 2011;32(1) : 104-113.
16. Telmesani, L. M., & Said, N. M. Effect of cochlear implant electrode array design on auditory nerve and behavioral response in children. Int J Pediatr Otorhinolaryngol. 2015 ;79(5) : 660-665.
17. Lathuillière, M., Merklen, F., Piron, J.-P., Sicard, M., Villemus, F., de Champfleur, N. M.,Mondain, M. Cone-beam computed tomography in children with cochlear implants: the effect of

electrode array position on ECAP. Int J Pediatr Otorhinolaryngol. 2017;92:27-31.
18. Lai, W., & Dillier, N. Neural adaptation and the ECAP response threshold: a pilot study. Cochlear Implants Int.2009 ;10(sup1) : 63-67.
19. Polak, M., Hodges, A. V., King, J. E., & Balkany, T. J. Further prospective findings with compound action potentials from Nucleus 24 cochlear implants. Hear Res. 2004;188(1-2) :104-116.
20. Saunders, E., Cohen, L., Aschendorff, A., Shapiro, W., Knight, M., Stecker, M., Cowan, R. Threshold, comfortable level and impedance changes as a function of electrode-modiolar distance. Ear Hear.2002;23(1 Suppl) :28s-40s.
21. Parkinson, A. J., Arcaroli, J., Staller, S. J., Arndt, P. L., Cosgriff, A., & Ebinger, K. The nucleus 24 contour cochlear implant system: adult clinical trial results. Ear Hear. 2002;23(1 Suppl) :41s-48s
22. Cohen, L. T., Saunders, E., Knight, M. R., & Cowan, R. S. Psychophysical measures in patients fitted with Contour and straight Nucleus electrode arrays. Hear Res.2006 ;212(1-2) :160-175.
23. Hughes, M. L., & Abbas, P. J. Electrophysiologic channel interaction, electrode pitch ranking, and behavioral threshold in straight versus perimodiolar cochlear implant electrode arrays. J Acoust Soc Am..2006;119(3) :1538-1547.
24. Jolly, C. N., Spelman, F. A., & Clopton, B. M. Quadrupolar stimulation for Cochlear prostheses: modeling and experimental data. IEEE Trans Biomed Eng.1996 ;43(8) :857-865.
25. Goldwyn, J. H., Bierer, S. M., & Bierer, J. A.Modeling the electrode-neuron interface of cochlear implants: effects of neural survival, electrode placement, and the partial tripolar configuration. Hear Res.2010 ;268(1-2) :93-104.
26. Taha, T., Sakr, H., Wahba, H., & Allam, A. Role of dual energy CT with adjusted radiation dose in accurate assessment of electrode position in pediatric cochlear implant. The Egyptian Journal of Radiology and Nuclear Medicine.2015;46(4): 1143-1148.
27. Venail, F., Mura, T., Akkari, M., Mathiolon, C., Menjot de Champfleur, S., Piron, J. P., Uziel, A. Modeling of Auditory Neuron Response Thresholds with Cochlear Implants. Biomed Res Int.2015; 2015 :394687.
28. Mittmann, P., Todt, I., Wesarg, T., Arndt, S., Ernst, A., & Hassepass, F. Electrophysiological Detection of Intracochlear Scalar Changing Perimodiolar Cochlear Implant Electrodes: A Blinded Study. Otol Neurotol.2015a; 36(7): 1166-1171.
29. Aschendorff, A., Briggs, R., Brademann, G., Helbig, S., Hornung, J., Lenarz, T., James, C. J. (2017). Clinical investigation of the Nucleus Slim Modiolar Electrode. Audiol Neurootol.2017; 22(3) : 169-179.
30. Van Weert, S., Stokroos, R. J., Rikers, M. M., & Van Dijk, P. Effect of peri-modiolar cochlear implant positioning on auditory nerve responses: a neural response telemetry study. Acta oto-laryngologica, 2005; 125.7: 725-731.