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Changes in Intraoperative and Postoperative Neural Response Telemetry in Cochlear Implant Users

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ABSTRACT

Introduction: The cochlear implant directly stimulates the auditory nerve in deaf patients. Neural Response Telemetry (NRT) is used to record the response of the auditory nerve through the feedback of the electrical signal. NRT does not need behavioral responses from very young children for thresholds and comfort levels. This study was conducted to detect the changes in intraoperative and postoperative neural response telemetry in cochlear implant users.

Patients and Methods: Thirty patients were implanted with a MED-EL device, Sonata II, at Sohag University hospital. The neural responses of electrodes 2, 4, 6, 8, 9, 10, 11 and 12 were investigated intraoperatively, one month and 3 months postoperativly. Threshold of the neuronal response is calculated using linear equation function.

Results: There is significant improvement in thresholds of NRT response postoperatively which were elevated or absent in intraoperative measurement. NRT threshold increases again in 3 months postoperative follow up in comparison with first postoperative measurement but this increase is not statistically significant.

Conclusion: Absence or elevation of NRT response in some electrodes intraoperative does not mean that electrode must be out of function or outside the cochlea, and improvement usually happens postoperatively.

INTRODUCTION:

Cochlear implantation provides the single most effective form of hearing rehabilitation in patients with bilateral severe to profound sensorineural hearing loss that is no longer responsive to conventional amplification. Cochlear implantation plays a critical role in hearing restoration for those patients who are either born with sensorineural hearing loss (congenital) or in those who develop a significant sensorineural hearing loss throughout childhood.[1]

Clark (2003) [2] described the cochlear implant as a device that electrically stimulates the auditory nerve, bypassing the nonfunctional inner ear of children and adults with severe-to-profound hearing loss. Current cochlear implant systems consist of: a multichannel electrode array that is

surgically implanted and an external sound-processing unit, usually worn behind the ear, which controls the implant over a transcutaneous link.

Grolman et al. (2009) [3] reported that during the implantation, various parameters could be utilized in order to show that the CI is functioning properly and examine the integrity of the electrode. In addition to measurement of ECAP signals through auditory nerve response telemetry (ART) or neural response telemetry (NRT), the excitation threshold of the stapedius muscle (ESRT) is also used in many cases. The most commonly used tool to examine CI function is impedance field telemetry (IFT).

According to **Cosetti et al. (2010)** [4] neural response telemetry is routinely measured at the time of implantation. This gives us information regarding the electrical output of the implant, the response of the auditory system to electrical stimulation and preliminary device programming data. However, in some cases the NRT is noticed to be absent in all or some electrodes intraoperative while the radiological shows complete insertion of the electrode array in the cochlea. This questioned the sensitivity of the NRT intraoperatively and if there is change in this response postoperatively.

Aim of the work:

This study is conducted to examine the changes in neural response telemetry postoperative compared to that measured intraoperative.

Subjects and Methods

Subjects:

Thirty patients (17 females, 13 males) were included in this study. The age of patients ranged between 2 and 16 years (mean 6.2 ± 3.5 years). All subjects were implanted with a MED-EL device, Sonata II (Med-El, Innsbruck, Austria) at Sohag University hospital. They all suffered from bilateral severe to profound sensorineural hearing loss.

Methods:

-Procedure:

Informed written consent was taken from the parents before the surgery and this study was approved by the research ethics committee at Sohag University.

-ECAP recording:

The cochlear implant device used in this study consists of: internal receiver-stimulator and 12 intracochlear electrodes. The receiver-stimulator features a bi-directional telemetry system, which allows communication of data between the programming hardware and the implant using transcutaneous radio-frequency code.

1-Intra-operative recording of NRT:

Whole-nerve action potentials were evoked by electrical stimulation intraoperatively while stimulating over electrodes within the intracochlear array. The stimulus current limit was estimated at each electrode, and 9 steps (100 current levels each) from 200 to 1000 were performed as stimulation applied on a given intracochlear electrode.

The neuronal responses were recorded using the MEDEL telemetric system. In this system, the implant records those potentials arising from nerve fibers local to the stimulation site from a

neighboring recording electrode, amplifies them and encodes them for radio frequency (RF) transmission back to the speech processor.

ECAP is extracted from the stimulus artifact using a subtraction method. ECAP recordings were obtained in operating room. The recordings were obtained at the end of the implant operation after the surgeon placed the skin flap over the implanted device. The surgeon positioned a transmitting coil over the internal device, using commercial Maestro 6.0.1 Build 5456.33222 software which allows in-situ measurements of the ECAP by implementing the forward masking paradigm by using MAX coil.

The signal was processed by the subtraction method to differentiate between the stimulus artifact and the neuronal response. The relationship between the amplitude of the neuronal response and the stimulus levels was calculated.

A linear regression line was fitted to these data. Using the equation of this linear function, the current level was calculated at which just no recordable neuronal response occurs ('zero amplitude'). This parameter is called tNRT (threshold of the neuronal response telemetry).

The stimulus used in the measurements was a biphasic current pulse, 30 μs/phase Minimum amplitude 200cu and maximum amplitude 1000 cu, of alteration: 25, measurement gap: 1ms, measurement delay 125ms.ECAP recordings were made at eight stimulation sites (electrodes no.2, no.4, no.6, no.8, no.9, no.10, no.11 and no.12).The corresponding recording site was one electrodes apical to the stimulation site (i.e., the neural response to stimulation on electrode (n) was recorded from electrode n+1 except electrode 12 was recorded from electrode11).

2-Post-operative recording of NRT:

ECAP recordings were obtained again on the first fitting of the device after the operation in the Sohag Cochlear Implant Unite while the patient was awake. ECAP was done at the same electrodes (no.2, no.4, no.6, no.8, no.9, no.10, no.11 and no.12), phase duration 30μs, begin by amplitude 200cu increasing in steps each 100cu till get response or reached the uncomfortable level of the child. Threshold of the neuronal response is calculated using linear equation function.

Two months later (three months postoperatively), neural response threshold of the same electrodes were measured with the same parameters starting with 200cu amplitude with 100 cu increments till get response or the uncomfortable level of the patient.

Results

Comparison of NRT response rate intraoperative, one month and three months postoperative.

1-NRT results in apical and mid electrodes number 2, 4, 6 and 8:

On comparison of the NRT response rate (presence or absence) intraoperative versus one month and three months post-operative for the apical and basal electrodes no. 2, 4, 6, and 8 (table 1), there was no statistically significant differences in all electrodes except for electrode 6 (El.6) only when comparing the response among the three groups (p-value) and in comparing the response between intraoperative and one month

postoperative (p1), this means that there was significant improvement in the response of NRT of El.6 between the three groups and between intraoperative and one month postoperative. While other comparisons for El.6 also showed no significant difference neither between intraoperative and three months post-operative (p2), nor between one month and three months after implantation (p3).

Trying to predict expressive language age, t-score of the multiple linear regression test is not significant in total I.Q, verbal reasoning and short-term memory but it shows significant scores in abstract/visual reasoning and Quantitative reasoning (t= 0.036, t=0.037 respectively) (table 5).

2-**NRT results in basal electrodes number 9, 10, 11 and 12:**

On comparing NRT response rate for between intraoperative and one month after implantation and between intraoperative and three months after implantation, there was statistically significant difference at all basal electrodes (except for El.12 there was no significant differences between response rate intraoperative versus one-month post-operative). This means that there is significant improvement in the NRT response rate for the basal electrodes one month and three months post operatively compared to intraoperative response. In addition, results showed statistically significant difference when comparing the response among the three groups for all electrodes (table 2).

Comparison between NRT threshold intraoperative, one month and three months postoperatively:

For the apical and mid electrodes, the comparison between the intraoperative NRT threshold versus one month after implantation (P1 in table 3) showed significant decrease in thresholds for all electrodes except El.4. However, the NRT threshold elevated again in the three months post-operative follow and there was no statistically significant change compared to intraoperative threshold (P2 in table 3). Results also showed no statistically significant change between the NRT threshold one month versus three months postoperative for the all apical and mid electrodes examined in this study.

For the four basal electrodes (El.9 to El 12), results showed significant decrease in NRT threshold for both one month and three months postoperative measures compared to the intraoperative one for electrodes El.9 and El. 10. However, no statistically significant difference was found for the most apical electrodes El.11 and El.12.

Finally, On Comparing the NRT threshold one versus three months postoperatively, there was increase in electrodes El.2, El.4, El.6, El.8 and El.12. However, this increase was not statistically significant except at El.8 (P3 in table 3).

Table (1): Comparison of the (NRT) response rate measured by electrodes no. 2, 4, 6 and 8 intraoperative, one month and three months after implantation (N=30).

Response	Intra-operative No. (%)	One month No. (%)	Three months No. (%)	P1	P2	P3	P-value
El.2 presence	25 (83.3)	29 (96.7)	28 (93.3)				
absence	5 (16.7)	1 (3.3)	2 (6.7)	0.195	0.424	0.5	0.168
El.4 presence	27(90)	30(100)	29 (96.7)				
absence	3(10)	0 (0)	1 (3.3)	0.237	0.612	0.5	0.160
El.6 presence	25 (83.3)	30(100)	29 (96.7)				
absence	5 (16.7)	0 (0)	1 (3.3)	**0.026***	0.195	0.5	**0.024***
El.8 presence	23 (76.7)	28 (93.3)	28(93.3)				
absence	7 (23.3)	2 (6.7)	2 (6.7)	0.073	0.073	1	0.075

Table (2): Comparison of the (NRT) state measured by electrode no.9, 10, 11and12 intraoperatively, one month and three months after implantation (N=30).

Response	Intra-operative No. (%)	One month No. (%)	Three months No. (%)	P1	P2	P3	P-value
El.9 presence	22(73.3)	29(96.7)	29(96.7)				
absence	8(26.7)	1(3.3)	1(3.3)	**0.02***	**0.02***	0.75	**0.004***
El.10 presence	21 (70)	28 (93.3)	30 (100)				
absence	9 (30)	2 (6.7)	0 (0.0)	**0.004***	**0.002***	0.246	**0.001***
El.11 presence	19 (63.3)	25 (83.3)	26 (86.7)				
absence	11 (36.7)	5 (16.7)	4(13.3)	**0.03***	**0.02***	0.5	**0.005***
El.12 presence	17 (56.7)	22 (70)	28 (93.3)				
absence	13 (43.3)	9 (30)	2 (6.7)	0.09	**0.001***	**0.004***	**0.04***

Table (3): Comparison of neural response telemetry threshold measured by the eight electrodes intraoperative, one month and three months after implantation.

Threshold		Intra-operative	One month	Three months	P1	P2	P3	P-value
Mean ± SD	**El.2**	370.1 ±134.8	279.8 ±133.02	305.9 ±137.3	**0.014***	0.052	0.233	**0.017***
	El.4	317.6 ± 120.9	281.2 ±131.9	316.8 ±116.4	0.205	0.973	0.138	0.298
	El.6	375 ±166.8	270.8 ±135.1	323.8 ±151.5	**0.001***	0.141	0.06	**0.004***
	El.8	380.2 ±153.9	277.7 ±121.9	340.8 ±126.02	**0.002***	0.174	**0.043***	**0.008***
	El.9	438.6 ±172.7	321.4 ±119.9	356 ±175.8	**0.002***	**0.038***	0.0142	**0.001**
	El.10	487.9 ±170.5	392.8 ±114.9	380.8 ±155.3	**0.002***	**0.015***	0.675	**0.015***
	El.11	353.6 ± 102.2	356.9 ±124.5	343.8 ±151.2	0.885	0.792	0.662	0.798
	El.12	286.2 ± 117.1	285.8 ±114.7	297 ±144.5	0.983	0.672	0.556	0.730

Discussion

All subjects in this study were evaluated for neural response telemetry 3 times, intraoperative, one month and 3 months after implantation for electrodes 2, 4, 6, 8, 9, 10, 11 and 12.

Comparison of NRT response rate (presence or absence) intraoperative, one month and three months postoperative among all electrodes under the study showed that not all the electrodes had NRT response intraoperative and; NRT response was absent in 5 children for El.2, in 3 children for El.4, in 5 children for El.6, in7 children for El.8, in 8 children for El.9, in 9 children for El.10, in 11 children for El.11 and 13 children for El.12 (table 1 &2).

The majority of the electrodes who had no response were the basal electrodes (9,10,11 and 12) which may be due to air bubbles, oedema of the tissues or due to manipulation of the implant.[4]

On follow up of the responses of the electrodes one month after the implantation; four of children who had no response in El.2 became responsive, all children had response for El.4 and El.6, only 2 children had no response for El.8 and El.10, one child had no response for El.9, 5 children had no response for El.11 and 9 children had no response for El.12 (table 1 &2). In addition, significant improvement was found at El.6, 9 and 10.

To know whether this improvement is solid or not, NRT was measured for second time, three months postoperatively and the results showed that one of children who had response one month after operation became non-responsive three months postoperatively, also one of responsive children became non-responsive three months after implantation at to electrodes only (EL.4 and El.6).

Su et al. (2008) [5] agreed with this result and attributed absence of response intraoperatively owing to interaction between surface chemistry of the electrode and electrical stimulation when implant is initially activated, this is due to the development of tissue growth around the electrode affected by protein absorption (initial increase) and electrical stimulation (dispersion of this surface layer).

Also, **Goehring et al. (2013)** [6] agreed with this result and assumed that air bubbles, edema of tissue and thickness of skin flap above electronic package may also affect initial measurement. While **Cosetti et al. (2010)** [4] refer that due to difference in the interactive electrical conduction between the tissue and the electrodes in the cochlea.

Chen et al. (2013) [7] attributed absence of the NRT response intraoperative and then appearance of the response later may be due to hematoma, infection or flap swelling. In conclusion, the appearance of response in electrodes postoperatively is with assumption of each [4-7].

However, some electrodes which had no response intraoperatively, had no response postoperatively, two children had no response for El.2, 8 and12 one children for El.4, 6 and 9, and four children had no response for El.11.

Also, some electrodes which had response became non-responsive, one child became non-responsive for El.2, one child had no response for El.4, and another one for El.6 which may be due to fibrous growth from the insertion of

the electrode into the cochlea and surface chemistry of the electrode.

On the other hand, this study examined the NRT threshold intraoperative, one month and three months postoperatively to know if there is any changes or improvement (table 3).

And the results revealed that one month postoperatively, all electrodes had improvement in their thresholds (least improvement was at El. 12) except El.11. However, statistically significant improvement of NRT threshold was found only at El.2, 6, 8, 9 and 10 (the middle electrodes).

Comparing thresholds of NRT intraoperatively and three months postoperatively thresholds of all electrodes improved even El.11; Significant improvement was found at El.9 and 10.

Comparing thresholds of NRT one and three months postoperatively there was increase in threshold of El.2, El.4, El.6, El.8, El.9 and El.12, however this increase was not statistically significant except for El.8.

Tsuprun and Santi (2001) [8] attributed this increase to the cellular layer of tympanic covering cells along the Scala tympani that adhere to the thick matrix of the basilar membrane, these cells possess phagocytic properties. It is possible that these cells react with the electrode by inducing foreign body reaction leading to the formation of a fibroblast cover encasing the CI electrode. A robust proliferation of these encasing fibroblasts could lead to increased electrode impedances that can result in lower performance.

Juiz et al. (1988) [9] had the same result, they found significant improvement in mean ECAP threshold postoperatively and attributed this to insertion of electrode caused swelling of auditory nerve fibers which could lead to decrease in the neurons sensitivity to electrical signals, and the swelling was reversible shortly after the operation.

However, this result is in disagreement with **Al Muhaimeed et al. (2010)** [10] who found that no statistically significant correlation between intraoperative NRT and postoperative NRT, while they were predicting C and T level from NRT. They found that either intraoperative or postoperative NRT can be used, but this may be due to using a different implant (Nucleus 24).

Also, **Wolf et al. (2015)** [11] result differ from this result in first measurement postoperative, they noticed increased telemetry between first- and second-week post-operative, but by ten weeks, the values had reduced, which may be due to previous onset of electrical stimulation.

Telmesani and Said (2016)[12] agreed with this result in the difference between intraoperative and postoperative changes as they concluded that intraoperative thresholds demonstrated significant improvement relative to postoperative recording times, limiting the ability to use intraoperatively recorded ECAP thresholds to predict postoperative measurements.

Also, they agree with this study result in that postoperative changes in follow up as they stated that most electrodes undergo non-significant change in ECAP thresholds over time, and therefore thresholds obtained on the day of initial stimulation can be used to estimate the patients' map levels at any time.

Brown et al. (2010) [13] agreed with this study result, they observed increase rather than decrease in the mean threshold of NRT for both pediatric and

adult CI users between an "early" visit and a" late" visit post-operatively, but this change in mean ECAP threshold was statistically significant although it was small change.

So, this study showed that NRT response may appear postoperatively while absent intraoperatively, there is significant improvement in NRT threshold postoperatively in comparison with threshold intraoperatively, mean threshold of NRT increase three months postoperatively in comparison with first postoperative measurement, however this increase was not statistically significant and therefore thresholds obtained on the day of initial stimulation can be used to estimate the patients' map levels at any time. The main objective of this study was to prove that there will be improvement in NRT in postoperative follow up.

Conclusion:

Absence of NRT response in some electrodes intraoperative does not mean that electrode must be out of function or outside the cochlea, as there is may be temporary causes of its absence such as air bubbles, edema of tissue and thickness of skin flap above electronic package may also affect initial measurement.

There is significant improvement in thresholds of NRT response postoperatively which was high intraoperatively.

There is increase in the NRT threshold at three months postoperative follow up in comparison with the first postoperative measurement, but this increase was not statistically significant.

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