MANSOURA MEDICAL JOURNAL

ISSN - Print: 1110-211X - Online: 2735-3990

journal homepage: mmj.mans.edu.eg

Volume 52 | Issue 1 Article 8

Long-term stability of electrical stapedial reflex and electrodes impedance in children with MED-EL cochlear implants

Maram Mohamed Rashad Ghoniem

Audiology specialist- Mansoura International Hospital, Ministry of Health, Egypt

Ayman El-Saeed Elsharabasy

Professor of Audiology- ENT Department Faculty of Medicine, Mansoura University, Egypt

Yousef Kamel Shabana

Professor of ENT, ENT Department Faculty of Medicine, Mansoura University, Egypt

Elshahat Ibrahem Ismail

Assistant professor of Audiology-ENT Department Faculty of Medicine, Mansoura University, Egypt,

drshahat@yahoo.com

ORIGINAL STUDY

Long-Term Stability of Electrical Stapedial Reflex and Electrodes Impedance in Children with MED-EL Cochlear Implants

Maram M.R. Ghoniem [a], Ayman E.-S. Elsharabasy [b], Yousef K. Shabana [c], Elshahat I. Ismail [b,*]

[a] Mansoura International Hospital, Ministry of Health, Mansoura, Egypt
[b] Audiology Unit, Department of ENT, Faculty of Medicine, Mansoura University, Mansoura, Egypt
[c] Department of ENT, Faculty of Medicine, Mansoura University, Mansoura, Egypt

Abstract

Background: **The purpose of this study was to investigate changes in electrical evoked stapedial reflex thresholds (ESRTs) and electrodes impedance over time in children with MED-EL cochlear implants.**

Methods: **In this study, 60 kids were included, while 15 kids were excluded because their cases did not fit the requirements. Patients who received MED-EL cochlear implants were monitored postoperatively over 5 years to determine whether or not their electrical evoked stapedial reflex thresholds (ESRT) and electrode impedance remained stable.**

Results: **At the initial fitting, electrodes 4, 5, 6, 8, and 9 showed significantly different impedances, while electrodes 1, 2, 3, 7, 10, 11, and 12 showed no significantly different impedances. Excluding electrode 12, all electrodes showed a statistically significant difference in ESRT at three and 6 months. All electrodes, except electrodes 7 and 8, showed no difference between ESRT and the behaviorally based MAP most comfortable level (MCL). After three months, there was a highly significant difference between ESRT and the behavioral MAP for the audiometric frequencies 500, 1000, 2000, and 4000 Hz.**

Conclusion: **Particularly at 3 and 6 months, there was a considerable decrease in electrode impedance, which stabilized throughout the course of the remaining follow-up period. Nearly all the electrodes showed a significant variation in ESRT between 3 and 6 months, but over the subsequent 5 years, ESRT essentially stabilized. Additionally, there was no difference between behavioral-based MAP and ESRT MCL; nevertheless, after 3 months, there was a highly significant difference between ESRT and the behavioral MAP at the 500, 1000, 2000, and 4000 Hz audiometric frequencies.**

Keywords: Cochlear implant, Electrical stapedial reflex threshold, Electrode impedance

1. Introduction

Improving audiological outcomes following cochlear implantation in young children or patients with poor conformance necessitates using objective fitting procedures (Weiss et al., 2021). Now that newborns are being examined for hearing disabilities, children with hearing loss can receive a diagnosis and potentially obtain cochlear implants at a much tender age than in the past. The need for objective devices to program these kids has increased since the average age of a kid receiving implantation has decreased and the candidacy criterion has broadened to include babies at a tender age and children with multiple disabilities (Çiprut and Adõgül, 2020).

The resistance to the flow of electric current via cables, electrodes, and living tissue is estimated using electrode impedance recording (Finley et al., 2008). The resistive properties of the fluid, the surrounding tissues, and the size of the electrodes all contribute to the impedance of

Received 8 March 2023; accepted 7 April 2023.
Available online 1 June 2023

* Corresponding author at: Audiology Unit, Department of ENT, Faculty of Medicine, El-Gomhoria St., 35516, Mansoura, Egypt.
E-mail address: drshahat@yahoo.com (E.I. Ismail).

https://doi.org/10.58775/2735-3990.1381

the electrodes. It is one of the most essential aspects in determining energy consumption, making it crucial in creating new arrays (Swanson et al., 1995).

The software should be easily operated and reliable, giving the kid access to all speech sounds. Due to high patient volumes, CI clinics must find ways to reduce the amount of time spent on the program's modelling. Objective fitting methods are typically required to meet these criteria (Kosaner, 2010). Methods that are precise but do not necessitate a patient reaction were frequently adopted. One of the most adopted diagnostic methods is the electrical Stapedius reflex test (Çiprut and Adõgül, 2020). When configuring a cochlear implant, electrically evoked stapedial reflex thresholds (ESRT) can be a helpful objective measure of the upper stimulus levels (Brickley et al., 2005).

Both adult and pediatric implant patients can benefit from ESRTs objective nature as their implants can be programmed using ESRT. As early as the late 1980s, studies on the correlation between ESRT thresholds and C levels were published. Current research has revealed a strong correlation between postoperative ESRT thresholds and map most comfortable levels (MCLs). It is possible to forecast map C/MCLs by recording postoperative ESRT thresholds. The measurement is easy to take when fitting children with cochlear implants and adults who cannot provide valid behavioral assessments (Andrade et al., 2014; Wolfe and Schafer, 2015).

Only Pitt et al., 2021 reported long-term ESRT stability in adults and children; the majority of investigations concerning ESRT stability were conducted during the first six months after fitting. In light of this, the current study sought to a) examine changes in ESRTs and electrode impedance over time in CI children; and b) ascertain the connection between ESRTs and behavioral MCLs.

2. Methods

The anticipated study was carried out in the Audiology unit at the Otorhinolaryngology Department at Mansoura University. It involved 75 children aged three to five with congenital prelingual idiopathic significant sensorineural hearing loss (SNHL) and enlisted in the cochlear implant program. Initially, they were trained via behavioral programming. The researchers gathered data from October 2015 through January 2023. Parental written informed consent was obtained from all parents. The ORL Department's ethical review board authorized this study.

2.1. Equipment

a) Computer-based programming Software and a programming unit for MED-EL (MAESTRO) cochlear implant device versions 7.1and 9.3; b) Impedance audiometer, Madsen model Zodiac 901 middle ear analyzer (Denmark); c) Two-channel pure tone diagnostic audiometer model (ORBITTER 922) (Denmark); and d) Locally made sound-treated room.

The device was initially activated by two teams: one in charge of the conventional behavioral maximum comfort levels (MCLs), and the other in order of our research study's ESRT-based programming.

Each patient got an otoscopic assessment examining the tympanic membrane and the external auditory meatus.

2.2. The initial activation of the devices

After three or four weeks postoperative, the device was activated for the first time. The impedances were recorded, behavioral MCLs were established by monitoring the children's auro-palpebral responses (MCLs were programmed at 2—4 steps below this level). The threshold was established at 10% of the MCL. After three months, patients' progress was verified via aided free field audiometry using either the conditioning play approach or the visual reinforcement method, based on their ages.

2.3. ESRT procedure

Both ears underwent tympanometry to measure the pressure in the middle ear and rule out the possibility of any external or middle ear influences. The study included only children with a normal tympanogram. We programmed the Middle Ear Analyzer to reflex decay mode to assess any contralateral electrical reflex threshold. The MED-EL DIB, diagnostic interface box was the link between the computer and the speech processor, while the MED-EL fitting software was the controlling unit.

A 500 ms burst of biphasic pulses was transmitted to the chosen electrode while the measure mode was initiated. The default pulse duration on each electrode was initially used to calculate the ESRT. Next, current levels were steadily increased until a reflex was recorded constantly. Each child was closely monitored for indications of traumatic stress. If the child expressed any form of traumatic stress, the search for a reflex was terminated. A distinct, minimally repeatable deflection of at least 0.5 ml from the baseline value was required to be considered a reflex. An ascending-descending method was used to ascertain ESRT, starting at the MCL level of the most recent program of the child. Should a reflex be detected, the stimulus was gradually lowered by 3% until no deflection was observed. Where no reflex was detected, the stimulus was steadily raised by 3% pending the observance of a reflex. When three separate, non-adjacent electrodes failed to elicit a reflex before reaching an intolerable loudness level, testing was stopped. In light of the fact that a charge may vary from one electrode to another, reflexes were measured on all active electrodes (beginning with the electrode in the middle). To achieve a balance amongst MCLs and ensure that the sizes of the reflexes were similar, this magnitude of the stimulus was maintained across all electrodes. By programming MCL and programming the threshold level at 10% of the MCL, an objective program was obtained.

Electrodes were turned off when ESRTs could not be elicited, or the charge level was much higher than at neighboring electrodes. This was done during the initial device activation; the collected data was stored on the device when activation was yet to be done, and ESRT data was used to readjust the behavioral MCLs' programming again three months later. Aided free field audiometry was used to verify the results one week after the last ESRT treatment was administered. Then, at 6 months, 1 year, 2 years, 3 years, 4 years, and 5 years of follow-up, the ESRT and electrode impedance was measured in all electrodes for each child. Typically, measurements would take around 30 min.

2.4. Aided warble tone response

The patient's reaction to sounds was tested through various methods, involving either a trial of visual reinforcement or conditioned play audiometry. We performed in a sound-field environment using warble tones at 0.5, 1, 2, and 4 kHz. Loudspeakers were positioned at a 45-degree angle, one meter from the child, and used to the experiment.

2.5. Statistical analysis

SPSS version 21 was used for the statistical analysis. Shapiro–Wilk was used to initially assess the data normality. Numbers and percentages were used to describe the qualitative data. Continuous variables were reported as means ± SD (standard deviation). The unpaired t-test was employed to compare the two data sets, while paired t-tests were utilized to compare paired data. The level of statistical significance for all the above-mentioned tests is 5%. (*P* value).

In this study, results were deemed insignificant if the probability of error was higher than 5% ($P > 0.05$). The results are considered significant when the probability of error is lower than 5% ($P \leq 0.05$). Highly significant when the probability of error is lower than 0.01% ($P \leq 0.001$). As the p-value decreases, the significance of the findings increases.

3. Results

Fifteen children (20%) were not included for various reasons (Table 1), and sixty children (80%) went on to complete the research. Everyone who had severe SNHL participated in the cochlear implant study. There was a total of 26 males (43%) and 34 females (57%). The age range was 3–5 years (mean 4.04 ± 0.67 years). All the children had MED-EL implants. Fifty-two children (88%) were implanted on the right side, and eight children (12%) were on the left side. They were programmed initially using behavioral programs.

At the initial time of fitting, 3 months, and 6 months after, there was a statistically significant difference in impedance between electrodes 4, 5, 6, 8, and 9, whereas no such difference existed between electrodes 1, 2, 3, 7, 10, 11, and 12 at the initial fitting, 3 and 6 months later; and then no changes was recorded during the remainder of the follow-up period (Table 2). Across all time periods, the impedance at the apex of the electrodes was greater than that at the base and middle of the electrodes (Fig. 1).

All electrodes except electrode 12 showed a statistically significant difference in ESRT after three and six months. After 6 months, ESRT became relatively stabilized (Table 3). Considering all the electrodes, only electrodes 7 and 8 showed statistically significant differences between ESRT and behaviorally based MAP MCL (Table 4). After three months, there was a highly statistically significant

Table 1. The causes of exclusion of the 15 children in the study.

Number of cases	Cause	Side of implant
1	Device failure due to head trauma	Right
1	Facial twitch	Right
1	Travelling outside country	Right
2	OME	Right
10	Absent ESRT	8 right and 2 left

Table 2. Electrode impedance (KOhms) changes over 5 years duration of the study.

Electrode	Electrode impedance at the follow-up period								Significance	
	Initial fitting	3 months	6 months	1 year	2 years	3 years	4 years	5 years	F test	*P* value
1	7.59 ± 1.86	7.51 ± 2.11	7.45 ± 2.06	7.42 ± 1.96	7.41 ± 1.89	7.40 ± 1.88	7.41 ± 1.86	7.41 ± 1.86	0.58	0.553
2	7.68 ± 1.94	7.63 ± 2.14	7.56 ± 2.11	7.52 ± 2.08	7.52 ± 1.99	7.51 ± 2.01	7.51 ± 1.98	7.51 ± 1.97	0.81	0.411
3	7.26 ± 2.47	7.03 ± 2.51	6.85 ± 2.24	6.81 ± 2.22	6.74 ± 2.14	6.72 ± 2.21	6.73 ± 2.12	6.72 ± 2.15	1.82	0.082
4	6.95 ± 2.13^{bc}	6.35 ± 2.15^{a}	6.19 ± 2.05^{a}	6.16 ± 2.08^{a}	6.15 ± 2.1^{a}	6.15 ± 1.89^{a}	6.15 ± 1.86^{a}	6.15 ± 1.85^{a}	2.46	**0.022***
5	6.63 ± 1.76^{c}	6.01 ± 1.81	5.95 ± 1.79^{a}	5.78 ± 1.77^{a}	5.76 ± 1.76^{a}	5.75 ± 1.75^{a}	5.74 ± 1.74^{a}	5.74 ± 1.75^{a}	2.69	**0.014***
6	5.74 ± 1.35^{c}	5.52 ± 1.32	4.92 ± 1.19^{ab}	4.83 ± 1.14^{ab}	4.81 ± 1.11^{ab}	4.81 ± 1.12^{ab}	4.80 ± 1.09^{ab}	4.80 ± 1.09^{ab}	3.31	**0.003***
7	6.78 ± 6.65^{bc}	5.32 ± 5.14^{a}	5.19 ± 4.48^{a}	4.91 ± 2.32^{ab}	4.90 ± 1.88^{ab}	4.90 ± 1.55^{ab}	4.89 ± 1.51^{ab}	4.89 ± 1.42^{ab}	2.42	**0.052***
8	5.64 ± 1.05^{bc}	5.24 ± 1.16^{a}	5.11 ± 1.23^{a}	5.02 ± 1.28^{a}	5.01 ± 1.31^{a}	5.01 ± 1.32^{a}	5.00 ± 1.34^{a}	5.00 ± 1.33^{a}	2.28	**0.033***
9	5.91 ± 1.15	5.62 ± 1.36	5.53 ± 1.48^{a}	5.36 ± 1.47^{a}	5.34 ± 1.46^{a}	5.32 ± 1.45^{a}	5.31 ± 1.44^{a}	5.31 ± 1.44^{a}	2.49	**0.023***
10	5.76 ± 1.23	5.71 ± 1.64	5.69 ± 1.59	5.65 ± 1.49	5.64 ± 1.50	5.66 ± 1.52	5.64 ± 1.51	5.64 ± 1.50	0.54	0.595
11	6.32 ± 1.76	6.33 ± 1.68	6.32 ± 1.66	6.29 ± 1.64	6.29 ± 1.61	6.28 ± 1.62	6.28 ± 1.63	6.27 ± 1.63	0.69	0.518
12	6.59 ± 3.40	6.52 ± 3.84	6.49 ± 4.04	6.46 ± 3.91	6.48 ± 3.88	6.47 ± 3.91	6.46 ± 4.06	6.47 ± 3.93	1.54	0.138

*$P < 0.05$: statistically significant by F: Friedman test in comparison between initial fitting and the other follow-up periods.
Paired t-test: (a) statistically significant in comparison with the initial fitting, (b) significant compared to 3 months, (c) significant compared to 6 months.

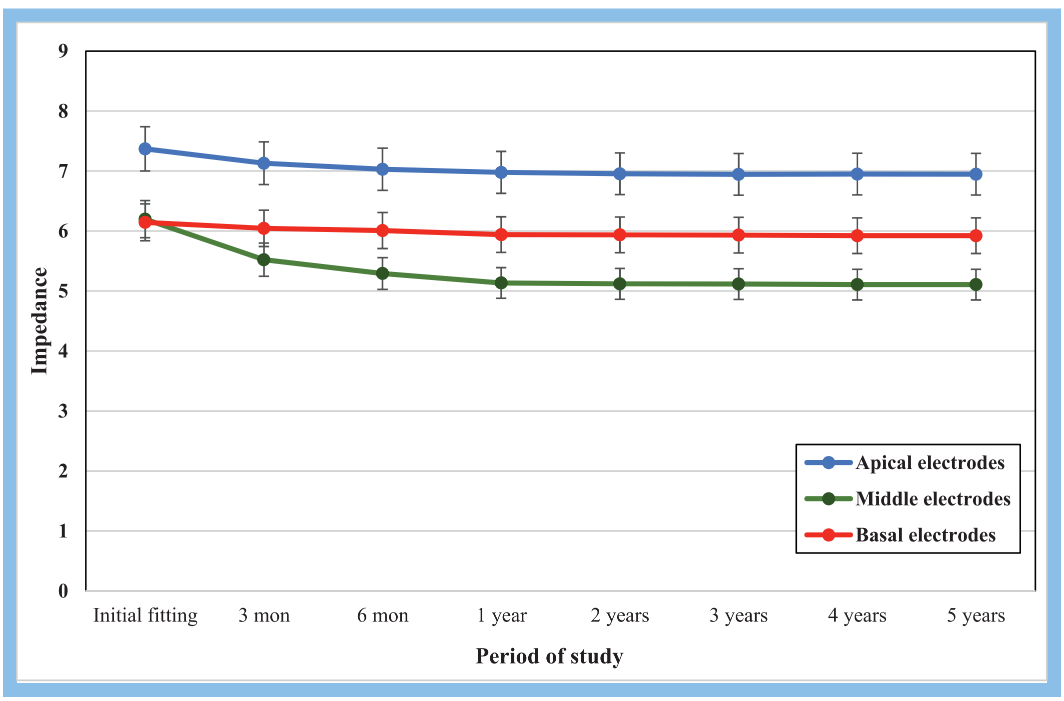

Fig. 1. Changes of electrode impedance region during 5 years of the study.

difference between ESRT and behavioral MAP at the 500, 1000, 2000, and 4000 Hz audiometric frequencies (Table 5).

4. Discussion

In the present investigation, we found that the electrode impedance was significantly lowered in certain electrodes (4–6, 8, 9). For the rest, a comparison of electrode impedance between the initial fitting, 3 months later, and 6 months later shows a decrease that is not statistically significant, and then the impedance practically remained stable for the rest of the research period. It has been reported that electrode impedance dropped significantly in the postoperative period, before balancing a few months later (Fayed et al., 2020; Henkin et al., 2003; Sarathy et al., 2018). However, Hughes et al. (2001) found that after activation, the impedance of the electrodes dropped initially due to the formation of a hybrid layer, but then increased respectably within the period of 1–12 months after activating the device due to the presence of intracochlear fibrous tissue and osteogenesis in the cochlea. The

Table 3. Comparison between Electrical Evoked Stapedial Reflex Thresholds (current units) at the initial fitting and the follow-up period of the study.

Electrode	Electrical Evoked Stapedial Reflex Thresholds after								Significance	
	Initial fitting	3 months	6 months	1 year	2 years	3 years	4 years	5 years	F	P value
1	17.28 ± 5.03^{bc}	18.94 ± 5.11^{ac}	19.45 ± 4.36^{ab}	19.43 ± 4.36^{ab}	19.44 ± 4.28^{ab}	19.43 ± 4.18^{ab}	19.43 ± 3.28 ^{ab}	19.44 ± 3.31^{ab}	2.09	0.045*
2	16.53 ± 3.74^{bc}	17.89 ± 3.38^{ac}	18.29 ± 3.17^{ab}	18.31 ± 3.17^{ab}	18.29 ± 3.13^{ab}	18.30 ± 3.09^{ab}	18.31 ± 2.80^{ab}	18.32 ± 2.83^{ab}	2.61	0.017*
3	16.45 ± 4.42^{bc}	18.09 ± 4.33^{a}	18.19 ± 4.28^{a}	18.28 ± 4.28^{a}	18.29 ± 4.23^{a}	18.29 ± 4.21^{a}	18.28 ± 3.37^{a}	18.29 ± 3.38^{a}	2.15	0.035*
4	15.62 ± 4.23^{bc}	18.11 ± 4.48^{a}	18.64 ± 4.18^{a}	18.65 ± 4.18^{a}	18.66 ± 4.14^{a}	18.67 ± 4.11^{a}	18.66 ± 4.12^{a}	18.68 ± 4.09^{a}	2.68	0.013*
5	17.49 ± 5.97^{bc}	19.95 ± 5.91^{ac}	21.09 ± 5.81^{ab}	21.10 ± 5.81^{ab}	21.11 ± 4.86^{ab}	21.09 ± 4.95^{ab}	21.15 ± 4.79^{ab}	21.17 ± 4.82^{ab}	2.58	0.019*
6	18.40 ± 4.97^{bc}	20.25 ± 4.88^{ac}	22.29 ± 4.87^{ab}	22.28 ± 4.85^{ab}	22.27 ± 4.78^{ab}	22.29 ± 4.77^{ab}	22.30 ± 4.53^{ab}	22.31 ± 4.54^{ab}	3.31	0.003*
7	18.88 ± 5.41^{bc}	19.78 ± 5.47^{ac}	21.02 ± 5.50^{ab}	21.06 ± 5.52^{ab}	21.08 ± 5.49^{ab}	21.07 ± 5.50^{ab}	21.09 ± 5.51^{ab}	21.08 ± 5.53^{ab}	2.28	0.033*
8	19.41 ± 5.46^{bc}	21.17 ± 5.35^{a}	22.05 ± 5.16^{a}	22.07 ± 5.05^{a}	22.08 ± 5.03^{a}	22.09 ± 5.01^{a}	22.08 ± 4.31^{a}	22.11 ± 4.13^{a}	2.51	0.021*
9	20.23 ± 7.82^{bc}	20.83 ± 6.23^{a}	20.94 ± 6.62^{a}	20.97 ± 5.82^{a}	20.98 ± 5.68^{a}	21.01 ± 5.62^{a}	21.05 ± 5.44^{a}	21.06 ± 5.42^{a}	2.59	0.019*
10	20.64 ± 8.01^{bc}	23.54 ± 7.75^{ac}	24.23 ± 7.86^{ab}	24.26 ± 7.98^{ab}	24.27 ± 7.72^{ab}	24.28 ± 7.79^{ab}	24.29 ± 7.75^{ab}	24.31 ± 7.76^{ab}	2.48	0.020*
11	21.31 ± 9.13^{bc}	26.23 ± 9.09^{ac}	27.05 ± 9.07^{ab}	27.07 ± 9.03^{ab}	27.08 ± 9.00^{ab}	27.08 ± 8.98^{ab}	27.09 ± 8.82^{ab}	27.10 ± 8.83^{ab}	3.14	0.004*
12	19.89 ± 13.21^{bc}	24.15 ± 11.1^{a}	25.42 ± 10.19^{a}	25.45 ± 10.1^{a}	25.46 ± 9.96^{a}	25.47 ± 9.85^{a}	25.48 ± 9.89^{a}	25.48 ± 9.91^{a}	2.56	0.018*

*$P < 0.05$: statistically significant by F: Friedman test in comparison between initial fitting and the other follow-up periods.
Paired t-test: (a) statistically significant in comparison with the initial fitting, (b) significant compared to 3 months, (c) significant compared to 6 months.

Table 4. Comparison between ESRT and behaviorally based MAP MCL (current units) after 3 months.

Electrode	ESRT based MAP	Behaviorally MAP	*t*-test	P-value
Elect. 1	18.94 ± 5.11	19.19 ± 4.34	0.31	0.20
Elect. 2	17.89 ± 3.38	19.75 ± 4.51	0.72	0.07
Elect. 3	18.09 ± 4.33	20.16 ± 4.76	0.79	0.06
Elect. 4	18.11 ± 4.48	20.98 ± 5.18	0.88	0.053
Elect. 5	19.95 ± 5.91	21.95 ± 5.32	0.79	0.06
Elect. 6	20.25 ± 4.88	21.70 ± 5.94	0.89	0.07
Elect. 7	19.78 ± 5.47	24.61 ± 6.38	1.02	0.041*
Elect. 8	21.17 ± 5.35	25.40 ± 6.61	0.99	0.047*
Elect. 9	20.83 ± 6.23	23.92 ± 6.67	0.91	0.051
Elect. 10	23.54 ± 7.75	26.23 ± 6.80	0.93	0.059
Elect. 11	26.23 ± 9.09	26.69 ± 7.35	0.411	0.13
Elect. 12	24.15 ± 11.1	25.31 ± 11.25	0.679	0.07

Values in Mean ± SD, t: unpaired *t*-test, *: Statistically significant $p \leq 0.05$.

Table 5. Comparison between ESRT and behavioral based MAP regarding hearing outcome (dB) after 3 months.

Frequency	ESRT after 3 month	MAP after 3 month	Paired t test	*P* value
F.500	33.60 ± 3.95	36.60 ± 6.24	t = 2.02	0.04*
F.1000	32.00 ± 3.81	36.60 ± 4.50	t = 3.89	<0.001**
F.2000	30.20 ± 3.37	34.80 ± 4.89	t = 3.86	<0.001**
F.4000	27.60 ± 4.35	35.60 ± 5.64	t = 5.60	<0.001**

Mean ± SD, t: unpaired t test.
**Highly Statistically significant $P < 0.001$.

authors used a Cochlear Nucleus 24 M implant in their research, which may have yielded different results. The apical region of electrodes has the largest electrode impedance values, whereas the middle cochlear regions of electrodes have the lowest. This may be because the apical region of electrodes has a smaller surface area than the middle cochlear regions. Fayed et al. (2020) also published similar findings. Sarathy et al. (2018) previously published a variance in electrode impedance among cochlear regions. Nevertheless, no discernible variation in impedance values was found between cochlear regions, as reported by Henkin et al. (2003) and Hughes et al. (2001).

This study revealed that after three and six months, ESRT values increased significantly in all electrodes except for electrode (12). This is consistent with the findings of Kosaner et al. (2009), who disclosed that ESRTs levels tend to be elevated during the initial period (the first few months of device use) before stabilizing after that. These results, which showed that ESRT remained stable from six months until the conclusion of the follow-up period, are congruent with those published by Pitt et al., 2021, who measured ESRT consistently over three years. Our hypothesis is that elevated ESRT in the first few months is linked to the initial phase of decreased impedance, after which both variables stabilize. The MCL values become elevated after the first few fittings as the patient acclimates to the auditory stimulation and can tolerate louder stimulations and a larger dynamic range. Therefore, electrode impedance and ESRT follow-ups are highly recommended during the first 6 months, and thereafter on a yearly basis.

There was no statistically significant difference between the stimulation levels achieved during CI programming with ESRTs and the behavioral strategy for establishing MCL in the current investigation. Average ESRTs were not significantly different from those achieved by behavioral strategies. Parents of children exposed to the ESRT reported that the mapping was as good as or better than the behavioral MCL mapping. In a similar vein, Stephan and Welzl-Müller (Stephan and Welzl-Muller, 2000) found that the MCL for ESRTs was slightly lower than the MCL for behavior in adults. Our findings were also consistent with those of a study conducted on a pediatric population published by Bresnihan et al. (2001).

The ESRT program is more suitable for pediatrics as it is difficult to judge whether children accept comfortable loud sounds or too loud sounds for their behavioral program. This is simply because they may not fully understand the concept of "loud enough" and "too loud" Positive parental reports reinforce the idea of using ESRTs as a basis for CI programming. We found a large but insignificant difference between the two programs in the channel stimulating the basal end of the cochlea. Lorens et al. (2004) found a slightly larger but insignificant statistical difference in the channel stimulating the apical end of the cochlea. Bresnihan et al. (2001)'s results disagree with our study as they found a significant difference among all electrodes. This could be because of our study's small sample size thus, additional data collecting is necessary. There may also be aspects related to the different types of electrodes and the depth of implantation.

All language skills and speech development begin with a child's ability to hear. It is very important to provide a reliable speech processor program to prelingual children promptly. This is determined by testing and analyzing children's auditory perception (Kosaner et al., 2009). In this study, because children's speech abilities depend on linguistic and cognitive development without maturation, speech perception tests could not be used to assess the children's speech abilities.

Sound field measurements in our study show that the implant threshold generated by ESRTs programming is within speech range. In addition, it reflected a better threshold than the behavioral map, which was statistically significant. This indicates that children's ESRTs-based programs have better access to all speech sounds, which agrees with the study conducted by Kosaner et al. (2009). Interestingly, in the current study, our results using ESRTs-based programming produced better hearing results while requiring less stimulation than the behavioral maps.

A considerable amount of time and effort was spent on determining the optimal stimulation level for each electrode during the early stages after the switch-on (Vaerenberg et al., 2014). The sensation resulting from electrical stimulation of an auditory system that has never been deprived of adequate stimulation for a long time cannot be expected to be reported by the recipient in a realistic (similar to sensation in normal hearing people) manner when questioned on comfort. The auditory system needs to adapt to this new kind of stimulation, and recipients need to rebuild a frame of reference for loudness and comfort.

Behavioral pediatric maps will eventually result in higher stimulation levels over time, leading to what is known as overstimulation. Overstimulation using a behavioral method, usually resulting from pressure from the parent and all speech therapies, is prevented when applying ESRTs-based maps where the clinician accurately delineates the maximum stimulation levels required. However, ESRTs-based programming avoids the risk of inadequate stimulation levels during behavioral measurements, which are common in prelingual children and are typically suspected if the child is not benefiting as much as expected. Provided the device functions adequately with proper electrical impedance and a good integrity test to make every effort for a child to receive the correct information from the implant.

The result of the current study indicates that ESRTs-based measures can be useful in predicting initial stimulation levels. The use of behavioral measures alone risks providing either inadequate stimulation for an audition or a limited dynamic range of stimulation (Gordon et al., 2004).

Behavioral MCL on each electrode has been shown in other research to correlate strongly with ESRTs in adult patients. This is consistent with the findings of research by Stephan and Welzl-Muller (2000). The mean ESRT values in adults were not significantly different from those in children. Therefore, ESRTs may be used to help predict whether a child would develop MCL or not.

There are challenges with measuring ESRTs in young children, such as they must remain still, quiet, passive, and cooperative during the ESRTs measurements at each recording. Excessive swallowing, talking, and head movements could disrupt the measurement. The use of cartoon videos or the child's natural sleep has successfully helped in the measurement of ESRTs with less cooperative and very young children. The patient must exhibit a healthy middle ear status; fluid in the middle ear or dysfunction of middle ear ossicles can disrupt the accurate measurement of the ESRTs. Sometimes, a normal middle ear function patient may not exhibit a measurable reflex response (Stephan and Welzl-Muller, 2000; Hodges et al., 1997).

4.1. Conclusion

Nearly all electrodes show a significant difference in ESRT at 3 and 6 months, but throughout the 5 years of follow-up, ESRT was more or less stabilized. There is a substantial reduction in electrode impedance, especially after 3 and 6 months, which stabilized throughout the remaining follow-up period. Additionally, there was no difference between behavioral-based MAP and ESRT MCL; however, after three months, there was a highly significant difference between ESRT and behaviorally MAP at the 500, 1000, 2000, and 4000 Hz audiometric frequencies.

Conflict of interest

All the authors declare that they have not any conflict of interest.

References

Andrade, K.C., Leal Mde, C., Muniz, L.F., et al., 2014. The importance of electrically evoked stapedial reflex in cochlear implant. Braz J Otorhinolaryngol 80, 68–77. https://doi.org/10.5935/1808-8694.20140014.

Bresnihan, M., Norman, G., Scott, F., et al., 2001. Measurement of comfort levels by means of electrical stapedial reflex in children. Arch. Otolaryngol. Head Neck Surg. 127, 963.

Brickley, G., Boyd, P., Wyllie, F., et al., 2005. Investigations into electrically evoked stapedius reflex measures and subjective loudness percepts in the MED-EL COMBI 40+ cochlear implant. Cochlear Implants Int. 6, 31–42.

Çiprut, A., Adõgül, Ç., 2020. The relationship between electrical stapedius reflex thresholds and behaviorally most comfortable levels in experienced cochlear implant users. J Int Adv Otol 16, 8–12. https://doi.org/10.5152/iao.2019.6589.

Fayed, E.A., Zaghloul, H.S., Morgan, A.E., 2020. Electrode impedance changes over time in MED El cochlear implant children recipients: relation to stimulation levels and behavioral measures. Cochlear Implants Int. 21, 192–197. https://doi.org/10.1080/14670100.2020.1716464.

Finley, C.C., Holden, T.A., Holden, L.K., et al., 2008. Role of electrode placement as a contributor to variability in cochlear implant outcomes. Otol. Neurotol. 29, 920–928.

Gordon, K., Papsin, B.C., Harrison, R.V., 2004. Programming cochlear implant stimulation levels in infants and children with a combination of objective measures. Int. J. Audiol. 43 (Suppl. 1), S28–S32.

Henkin, Y., Kaplan-Neeman, R., Muchnik, C., et al., 2003. Changes over time in electrical stimulation levels and electrode impedance values in children using the Nucleus 24M cochlear implant. Int. J. Pediatr. Otorhinolaryngol. 67, 873–880. https://doi.org/10.1016/s0165-5876(03)00131-9.

Hodges, A., Balkany, T., Ruth, R., et al., 1997. Electrical middle ear muscle reflex: use in cochlear implant programming. Otolaryngol. Head Neck Surg. 117, 255–261.

Hughes, M.L., Vander Werff, K.R., Brown, C.J., et al., 2001. A longitudinal study of electrode impedance, the electrically evoked compound action potential, and behavioral measures in Nucleus 24 cochlear implant users. Ear Hear. 22, 471–486.

Kosaner, J., 2010. Generating speech processor programmes for children using ESRT measurements. Cochlear Implants Int. 11 (Suppl. 2), 20–24. https://doi.org/10.1179/146701010X12726366068535.

Kosaner, J., Anderson, I., Turan, Z., et al., 2009. The use of ESRT in fitting children with cochlear implants. J Int Adv Otol 5, 70–79.

Lorens, A., Walkowiak, A., Piotrowska, A., et al., 2004. ESRT and MCL correlations in experienced pediatric cochlear implant users. Cochlear Implants Int. 5, 28–37.

Pitt, C., Munoz, K., Schwartz, S., et al., 2021. The long-term stability of the electrical stapedial reflex threshold. Otol. Neurotol. 42, 188–196. https://doi.org/10.1097/MAO.0000000000002964.

Sarathy, K., Jaya, V., Thenmozhi, Gracia, P., Priya, B., 2018. Variation in electrode impedance in cochlear implant recipients over a period of time. JSM Pediatr Surg 2, 1007.

Stephan, K., Welzl-Muller, K., 2000. Post-operative stapedius reflex tests with simultaneous loudness scaling in patients supplied with cochlear implants. Int. J. Audiol. 39, 13–18.

Swanson, B., Seligman, P., Carter, P., Sep 1995. Impedance measurement of the Nucleus 22-electrode array in patients. Ann. Otol. Rhinol. Laryngol. Suppl 166, 141–144.

Vaerenberg, B., Smits, C., De Ceulaer, G., et al., 2014. Cochlear implant programing: a global survey on the state of the art. Sci. World J. 501738, 1–12. https://doi.org/10.1155/2014/501738.

Weiss, N.M., Óvári, A., Oberhofner, T., et al., 2021. Automated detection of electrically evoked stapedius refexes (eSR) during cochlear implantation. Eur. Arch. Oto-Rhino-Laryngol. 278, 1773–1779. https://doi.org/10.1007/s00405-020-06226-x.

Wolfe, J., Schafer, E., 2015. Basic principles of programming, second ed. Plural Publishing, San Diego CA, pp. 118–119. Programming Cochlear Implants.