Impedance changes in cochlear implant electrodes one year after switch on: A cohort study at a tertiary referral hospital in Jakarta, Indonesia

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ABSTRACT

Introduction: Monitoring of impedance field telemetry is crucial to maintaining optimal function of cochlear implants. This study aims to investigate impedance changes in cochlear implant electrodes one year after switch on.

Materials and Methods: A retrospective repeated cross-sectional study was conducted by recruiting patients with cochlear implants presenting to the Dr. Cipto Mangunkusumo National General Hospital, Jakarta, Indonesia between 2017 and 2021. Basal (b1, b2) and apical (a1, a2) electrodes, representing the outermost and innermost parts of the cochlear implant electrodes, were measured at switch on and at 1 year post-implantation.

Results: A total of 123 patients, with a total of 123 cochlear implant samples, were included in the analysis. We found a substantial change in electrical impedance between switch on and follow-up periods, where the impedance levels of basal electrodes decreased (b1: mean difference (MD) −1.13 [95% confidence interval (CI): −1.71, −0.54], *p*<0.001; b2: MD −0.60 [95%CI: −1.17, −0.03], *p*=0.041) and those of apical electrodes increased (a1: MD 0.48 [95%CI: −0.28, 0.99], *p*=0.064; a2: MD 0.67 [95%CI: 0.12, 1.22], *p*=0.017). We also found that the choice of surgical approaches for implant insertion may affect the electrode impedance. Cochleostomy approach resulted in a higher impedance than round window in basal (b1) and apical (a2) electrodes both at switch on and follow-up (b1 at switch on and at follow-up: *p*=0.019 and *p*=0.004; a2 at follow-up: *p*=0.012). Extended round window approach also resulted in a higher impedance than round window in basal (b1) and apical (a2) electrodes at follow-up (*p*=0.013 and *p*=0.003, respectively).

Conclusion: Electrical impedance of cochlear implant electrodes may change over time, highlighting the importance of regular impedance assessments for cochlear implant users to ensure optimal device function. The round window approach resulted in better initial and long-term impedance levels compared to cochleostomy, and better long-term impedance levels than extended round window. Extended round window approach also gives better impedance level than cochleostomy. Further research should investigate the potential interplay between surgical approach and other factors that may impact impedance levels to confirm our findings.

KEYWORDS:
Cochlear implant, cross-sectional, electrical impedance, follow-up studies, surgical approach

INTRODUCTION

Cochlear implants are widely used for the habilitation and rehabilitation of patients with profound sensorineural hearing loss (SNHL). Such implants use a software connecting an external component, i.e., speech processor, to an internal component consisting of an array of electrodes surgically implanted into the cochlea. The electrodes play a crucial role in aural habilitation by stimulating the auditory nerve fibers in the cochlea, enabling the brain to receive auditory input and perceive sound, thereby improving hearing and speech development especially in children with congenital SNHL.

To maintain an optimal function, it is essential to regularly examine the electrode impedance in cochlear implants. Electrical impedance, a parameter measuring the resistance or opposition of electrodes to the flow of electrical current, is evaluated both intraoperatively and during mapping sessions to describe the integrity of the electrodes and the electrical current between the electrodes and the surrounding cochlear tissues.[1,2] Any changes in impedance levels may indicate issues with the electrodes and/or cochlear implants, such as short circuits, open circuits, or damaged devices.[1,3]

Electrical impedance of a cochlear implant may be affected by several factors including electrode placement, tissue changes (e.g., inflammation or damage), electrode corrosion, and the duration of use. Long-term use of the device may lead to a reduction in its efficiency in delivering electrical current to the surrounding cochlear tissues, resulting in an increase in impedance and decreased implant effectiveness.[2-4] Therefore, it is saliently important to perform follow-up examinations post-implantation to investigate potential changes in the electrical impedance of cochlear implants over time. This study aims to investigate changes in impedance levels in patients with cochlear implants one year after implantation at a tertiary referral hospital in Jakarta, Indonesia.

MATERIALS AND METHODS

A retrospective repeated cross-sectional study was conducted by including patients using cochlear implants presenting to

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the Ear, Nose, and Throat (ENT) outpatient clinic of the Department of Otorhinolaryngology and Head and Neck Surgery, Dr. Cipto Mangunkusumo National General Hospital, Jakarta, Indonesia between 2017 and 2021. All patients underwent complete electrode insertion using implants manufactured by MED-EL (PULSAR, SONATA, OR SYNCHRONY models; Innsbruck, Austria), Cochlear® (Slim Straight® (CI622) or Contour Advance® (CI612) models; Sydney, Australia), or Advanced Bionics™ implants (HiFocus™ 1J or HiFocus™ Mid-Scala models; Bangalore, India), and patients with device failures were excluded from this study. The parents or guardians of the children provided written informed consent for the children to participate in this study. The study protocol has been approved by the Research Ethics Committee, Faculty of Medicine Universitas Indonesia and Cipto Mangunkusumo National General Hospital (ethical no. 22-02-0181). This study is reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.[5]

Measurement of the impedance levels (kΩ) of the cochlear implants was performed at switch on and at 1 year post-implantation. The electrodes investigated in this study were basal electrodes (b1, b2) and apical electrodes (a1, a2; Figure 1). In addition, we also recorded data on cochlear implants (type of electrodes, hearing preservation technique, surgical approach for implant insertion) and comorbidities (inner ear malformation and obliteration of scala tympani). The round window insertion was used as the hearing preservation group, whereas extended round window and cochleostomy insertion were used as the non-hearing preservation group. The cochlear implantation procedures in this study were performed by two surgeons which can be consider as bias and a limitation to this study. The collected data were then tabulated, described narratively and analysed using paired sample t tests to compare values from consecutive fitting sessions, and one-way analysis of variance (ANOVA) followed by Tukey's HSD post hoc tests to compare impedance values between surgical approaches at each mapping session, whichever appropriate, to compare values from consecutive fitting sessions. Dichotomous data were presented in frequencies and proportions, while continuous data in mean ± standard deviation (SD) or mean difference (MD) and 95% confidence intervals (95% CI). All statistical analysis were performed using SPSS 24.0 (SPSS Inc., Chicago, IL), and a *p* value of ≤0.05 denotes statistical significance.

RESULTS

A total of 123 patients with ages ranging from 1 to 45 years old, cumulating a total of 123 samples of cochlear implantation procedures, were included in the present study. 50.4% (62/123) patients were female, and about 64.2% (79/123) received implantation on the right side. Most of the children underwent hearing preservation technique (106 patients, 86.2%) with lateral wall electrodes (114 patients, 92.7%). 71.5% (88/123) of the children underwent round window insertion, followed by an extended round window approach (18 patients, 14.6%) and cochleostomy (17 patients, 13.8%). No children presented with inner ear malformation (0/123 patients, 0.0%), and two patients (1.6%) had obliterated scala tympani (Table I).

We found a statistically significant changes in electrical impedance between switch on and 1 year post-implantation periods, where the impedance values of b1 and b2 electrodes decreased at 1 year follow-up (b1: MD –1.13 [95%CI: –1.71, –0.54], *p*<0.001; b2: MD –0.60 [95%CI: –1.17, –0.03], *p*=0.041), while those of a2 electrode slightly increased (MD 0.67 [95%CI: –0.12, 1.22], *p*=0.017; Table II). We also observed a slight increase in the impedance value of a1 electrode, although not statistically significant (MD 0.48 [95%CI: 0.28, 0.99], *p*=0.064).

We also found that the choice of surgical approaches for implant insertion contributed to the evolution of apical and basal impedance at switch on and 1-year follow-up post-implantation (Table III). In basal (b1) electrodes, cochleostomy approach resulted in a higher impedance both at switch on and follow-up compared to round window approach (*p*=0.019 and *p*=0.004, respectively), while the extended round window approach resulted in a significantly higher impedance level than round window approach only at follow-up (*p*=0.013). Meanwhile, in apical (a2) electrodes, both extended round window and cochleostomy approaches had a substantially higher/lower impedance levels than the round window approach at follow-up (*p*=0.003 and *p*=0.012, respectively), but not at switch on (*p*=0.428 and *p*>0.999, respectively).

DISCUSSION

Impedance field telemetry is a widely used parameter to assess the integrity of a cochlear implant device during implantation and mapping sessions. This enables clinicians to ensure the optimal function of cochlear implants in order to improve hearing and speech abilities of patients with severe-to-profound SNHL. This study, assessing the impedance levels of basal (b1 and b2) and apical (a1 and a2) electrodes, which represent the outermost and innermost part of the cochlear implant electrodes, found that significant changes in impedance levels occur over time, where the impedance values were decreased in basal electrodes and increased in apical electrodes at 1-year post-implantation.

It is known that impedance levels of a cochlear implant may change over time due to various factors affecting the tissues surrounding the device. Following implantation, fibrous tissues, protein exudates, and macrophages may surround the electrodes, caused by inflammation or other tissue changes, thereby potentially altering the electrical properties of the surrounding tissues and leading to changes in impedance levels. Additionally, the metal components of the implant may gradually corrode and thus induce further changes in impedance levels of the electrodes.6 Previous studies have shown that the impedance levels of a cochlear implant electrode will increase substantially in the first week after implantation and are expected to plateau within one to two months.[7,8] In addition to wear and tear, other factors that may also affect the impedance levels of a cochlear implant include tissue changes and electrode placement. As previously stated, the environment surrounding the device may contribute to the impedance levels of the electrodes. This indicates that any tissue changes (e.g., inflammation, infection, fibrosis) and the location of the electrodes in the

Table I: Clinical characteristics of the study population (n = 123)

Sample characteristics	n (%)
Sex	
Male	61 (49.6)
Female	62 (50.4)
Side of implantation	
Right	79 (64.2)
Left	44 (35.8)
Type of electrode	
Lateral wall	114 (92.7)
Perimodiolar	9 (7.3)
Hearing preservation technique	
Yes	106 (86.2)
No	17 (13.8)
Scala tympani approach	
Round window	88 (71.5)
Extended round window	18 (14.6)
Cochleostomy	17 (13.8)
Inner ear malformation	
Yes	0 (0.0)
No	123 (100)
Scala tympani obliteration	
Yes	2 (1.6)
No	121 (98.4)

Table II: Impedance levels (kΩ) of the measured electrodes at switch on and at 1 year follow-up

Electrode		Switch on (kΩ)	Follow-up (kΩ)	Changes		
				MD	95% CI	*p* value
Basal electrodes	b1	8.94 ± 3.75	7.81 ± 3.05	−1.13	−1.71, −0.54	<0.001
	b2	±	±	−0.60	−1.17, −0.03	0.041
Apical electrodes	a1	±	±	0.48	0.28, 0.99	0.064
	a2	6.41 ± 2.80	7.09 ± 2.35	0.67	0.12, 1.22	0.017

Unless otherwise stated, data are expressed as mean ± standard deviations. p value derived from paired t tests. CI, confidence interval; MD, mean difference.

Table III: Comparison of impedance levels of the b1 and a2 cochlear implant electrodes between surgical approaches for implant insertion

Electrodes	Switch on				Follow-up			
	Approach to scala tympani	RW	ERW	C	Approach to scala tympani	RW	ERW	C
b1 electrode	RW		1.74 (p=0.203)	**2.68 (*p*=0.019)**	RW		**2.17 (*p*=0.013)**	2.49 (p=0.004)
	ERW	−1.74 (p=0.203)		−0.94 (p>0.999)	ERW	−2.17 (p=0.013)		0.32 (p>0.999)
	C	**−2.68 (*p*=0.019)**	0.94 (p>0.999)		C	−2.49 (p=0.004)	**−0.32 (*p*>0.999)**	
a2 electrode	RW		2.17 (p=0.428)	2.49 (p>0.999)	RW		**−1.95 (*p*=0.003)**	**−1.73 (*p*=0.012)**
	ERW	−2.17 (p=0.428)		0.32 (p=0.253)	ERW	**1.95 (*p*=0.003)**		0.22 (p>0.999)
	C	−2.49 (p>0.999)	−0.32 (p=0.253)		C	1.73 (p=0.012)	**−0.22 (*p*>0.999)**	

Data expressed as mean difference (p values). p values derived from Tukey's HSD post hoc ANOVA test. RW, round window; ERW, extended round window; C, cochleostomy

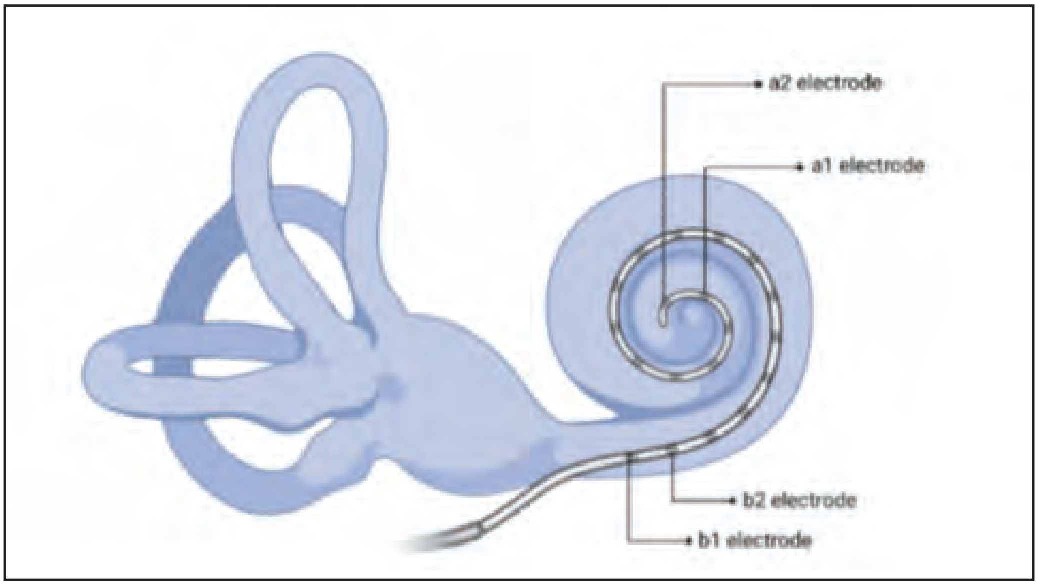

Fig. 1: Location of the basal (b1, b2) and apical (a1, a2) cochlear implant electrodes in the scala tympani.

cochlea may affect the electrical current flow and subsequently affect the impedance levels of the electrodes.[2,4] With regards to electrode placement, our findings suggest that the surgical approach to implant insertion had an effect on impedance levels of the electrodes. In this study, we recorded three surgical approaches: round window, extended round window, and cochleostomy. In brief, the round window approach is a standard method of surgery, performed by creating a small opening in the bone of the round window niche, while cochleostomy is a conventional method that involves drilling a hole in the cochlear bone to insert the electrode array.[9] On the other hand, the extended round window approach is a combination of both round window and cochleostomy approaches and is usually performed in situations where the round window is not easily visible and/or accessible.[10] To date, limited research has been conducted to compare the effect of different surgical approaches on the impedance levels of cochlear implant electrodes. A previous systematic review by Avasarala et al.[11] found that two out of three studies reported that there were no substantial differences on impedance levels between surgical approaches, while one study found that round window approach yielded a lower initial impedance value.[11] The study found that significant differences in switch on impedance were observed in the basal-middle electrodes and not in the apical region[12], which is consistent with our findings. This may be explained by the fact that traditional cochleostomy, which involves drilling a bigger hole in the cochlear bone, may induce more extensive tissue damage, resulting in higher impedance.[13,14] Previous studies foind that impedance level has a correlation to the clinical outcome of cochlear implantation. Impedance level might indirectly show the biological changes in the cochlea due to electrode insertion. Changes such as bone formation or the distance between the electrode and the modiolus will affect the impedance level at mapping. Decreased word score is correlated with an increased impedance level.[15] Nonetheless, it should be noted that the outcome of cochlear implantation surgeries is also affected by several factors such as clinical characteristics of the patients (e.g., age at implantation, comorbidities, duration of implantation, and severity of hearing loss) and surgeon's experience and available resources. This suggests that further studies are needed to confirm our findings.

The present study is limited due to its cross-sectional design, suggesting that causalities between variables were unknown. Furthermore, other potential confounding factors, such as age at intervention and characteristics of patients' hearing loss were not recorded in this study. The fact that there was no patient with inner ear anomalies and only two patients with obliterated scala tympani also limited our analysis. These suggest that future studies should also consider these potential confounding factors when assessing the impedance levels of cochlear implants over time.

CONCLUSION

This study adds to the body of evidence supporting the premise that the electrical impedance of cochlear implant electrodes may change over time, thereby highlighting the importance of regular impedance assessments for cochlear implant users to ensure the optimal function of the devices. In this cohort, the impedance level of basal electrodes decreased at one year post-implantation, while those of apical electrodes increased. The present study also suggests that the choice of surgical approach for implant insertion may play a role in the impedance levels of the electrode arrays. Further research should investigate the potential interplay between surgical approach and other factors that may impact impedance levels to confirm our findings.

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