# ELECTRICAL IMPEDANCES VARIATIONS VALUES IN PATIENTS WITH COCHLEAR IMPLANT

**Oana Manolache[1*], Raluca Olariu[1], Luminița Rădulescu[1,2], Sebastian Cozma[1,2]**
[1]University of Medicine and Pharmacy "Grigore T. Popa" – Iași, Romania
[2]E.N.T. Clinic, Clinical Rehabilitation Hospital
***Corresponding author:** *Oana Manolache, PhD*
*University of Medicine and Pharmacy "Grigore T. Popa"*
*16, Universității Street, 700115, Iasi, Romania*
*e-mail: oanabt@yahoo.com*

## ABSTRACT
**Introduction** Identifying the impedance values in the post-surgery care of cochlear implanted patient, provide useful information to adjust the settings of the sound processor for the best possible auditory perception. **Material and methods** We investigated changes in impedance values of the intracochlear electrodes implanted in 72 patients over a period of 3 months. The measurement was carried out using computer hardware and software interfaces from cochlear implant producers. **Results** In absence of electrical stimulation, there is an increase of impedance on all electrodes of all cochlear implant models. After activation, the impedances values variations are depending on the type of the device. **Conclusions** The intraoperatory impedance values and their fluctuations are part of the postoperative common trends for each specific brand. Besides the parameters related to the device, the individual organic features of the inner ear may play an important role in the distribution of electrical impedance profile.

**Key words:** cochlear implants, electrical impedances.

## INTRODUCTION

Technological development in cochlear implant is mainly concerned with gathering objective information that is used to assess the technical condition of the implant over time, but more than this it can be an important reference point to guide clinicians in controlling the implant especially when dealing with children.

These are the most objective electrophysiological tests which are currently available:

- Telemetric impedancemetria;
- Recording the electrically evoked compound action potential in cochlear nerve - ECAP (electrically evoked compound action potential) as characteristic of each device: Nucleus - NRT (neural response telemetry), Medel - ART (auditory response telemetry), Advanced Bionics - NRI (neural response imaging);
- Observing the Stapedian reflex by electrical evocation and measurement of electrical occurrence frequency;
- Performing auditory evoked electrical potential (recording the evoked potentials after electrical stimulation through implant (1).

These tests can be performed both intraoperatively and postoperatively; none of the methods being invasive, measurements can be repeated as many times as it is needed.

a) Telemetry is a bidirectional communication system (2). The exterior communicates with the inside allowing the system to carry out operational control, detecting failures occurring at the electrodes before, during and after implantation (3) Currently all cochlear implant devices include a telemetry system for checking the operation of the impedance of each electrode in the system and the electrical interaction between them (4). The telemetry system allows us to test the basic functions of a cochlear implant (the communication between the external and the internal components) and to detect the electrical problems in each electrode (short circuit between electrodes, open circuits due to cable cut off) (5).

The electrode impedance is a method of measuring resistance encountered by electricity passing through wires, electrodes and biological tissue (6). It is calculated as the ratio of the effective voltage applied to a particular circuit and the actual amount of electrical power intensity absorbed by the circuit. The unit of impedance is the ohm (ω). The electrodes impedance does not confirm the electrode placement and neither replace the radiographies after the implant (7).

b) Compound action potential is a synchronous response resulting from electrical stimulation of cochlear nerve fibres and it is the electric version of the I wave of the acoustically stimulated auditory potentials of the brain stem (8).

c) In the same way that early auditory evoked acoustic potentials are recorded, that is those obtained by acoustic stimulation with click or tone-burst, we can get responses of the brainstem auditory nerve and electrical stimulation of the Corti ganglion using the cochlear implant.

The latencies of these waves are 1-2 ms shorter than the latencies of the waves obtained by acoustic stimulation due to external and middle ear by pass, and due to cochlea as well, operating directly in the cell body of spiral ganglia (1).

d) The stapedian reflex is not obtained only by acoustic stimulation of the hearing subjects with normal hearing, but it can be obtained from the cochlear implanted subjects with no hearing through electrical stimulation. The response indicates the existence of a well-functioning cochlear implant and assures the integrity of the auditory nerve.

An independent evaluation of the electrodes to verify the functionality of each one should be carried out in order to set up an implantable multi-channel system. An auditory detection level is estimated for each channel by electrical stimulation and also the maximum level of comfort (MLC most comfortable level) or maximum level of stimulation that the patient bears without a discomfort (8).

A less accurate estimation of these parameters is reflected in the quality of the auditory signal, limiting the ability of perception and reducing the ability of speech recognition. The set-up of the sound processor is based on subjective responses obtained from the patient by electrical stimulation of the electrodes. This subjectivity is important if patients do not cooperate, or are young children or adults with communication difficulties. In these cases, information obtained by objective measurements is very useful for estimating the maximum comfort and detection level.

## OBJECTIVES

The aim of this study was to investigate the impedance values changes of the intracohlear electrodes implanted in patients over a period of three months, the measurements at three different times being taken as reference: during surgery, during the cochlear implant activation (1 month postoperatively) and two months after that. There were taken into consideration the following effects on electrical impedance values: the electrode type, the topography of the electrodes, the surgery, how fast the tissue heals after surgery, changes in the intracohleare electrolyte, the lack of electrical stimulation for a period of one month after surgery.

## MATERIAL AND METHODS

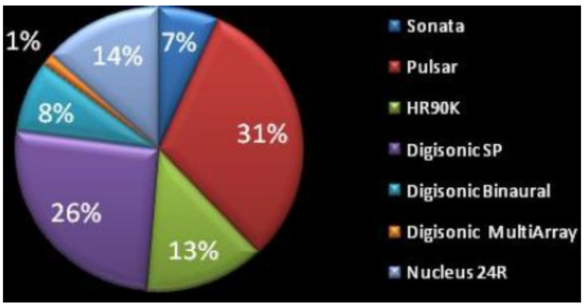
There were 72 hearing subjects who got the cochlear implant that have been recorded on each ear implanted electrode impedance resulting in a total of 80 "study units" (a total of 8 patients were implanted bilaterally). Records were made between November 2004 and November 2010 within the Rehabilitation Hospital in Iasi, the cochlear implant department. The criteria of choice were:

- The complete insertion of the portelectrode in the cochlea
- The existence of intraoperative impedance measurements, when the device is activated and three months after the surgery.
- The implant was carried out with one of the following devices: Medel Pulsar CI100 and Sonata TI100 type, type Cochlear Nucleus CI22, CI24 and Nucleus Nucleus Freedom, Neurelec Digisonic type SP, SP Digisonic multiarray and SP Digisonic binaural and Advanced Bionics HiRes Focus Helix type.

After analysing the study group we noticed a relatively balanced gender distribution as follows: 49% (35) female subjects and 51% (37) male subjects. Most subjects were children (81% children and 19% adults).

The 72 subjects (80 study units), depending on the type of implanted device and taking into account the particular situation among some of them were divided into the following seven groups:

- Group 1: 9 subjects with Nucleus 24R cochlear implant
- Group 2: 23 subjects with Pulsar CI 100 cochlear implant
- Group 3: 5 subjects with Sonata IT 100 cochlear implant
- Group 4: 19 subjects with Digisonic SP cochlear implant
- Group 5: 6 subjects with Digisonic Binaural cochlear implant
- Group 6: 9 subjects with Advanced Bionics HR90K cochlear implant
- Group 7: 3 subjects who had special problems, were implanted with different devices such Nucleus24R, DigisonicSP MultiArray, Advanced Bionics HR90K (Fig. 1.).



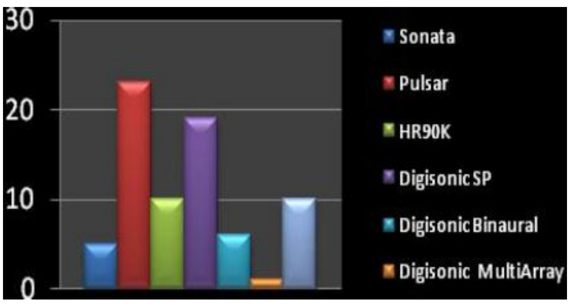




**Fig.1. Distribution of number of subjects by category of implants**

- The impedance measurement of the electrodes

In order to perform these measurements we used a digital cochlear implant connected either directly or through the sound processor. It consists of two parts: data stimulation / collection and data processing / back playing.

The measurement process was controlled by a computer and the available interfaces were used as hardware interfaces available from each producer company to be connected to the cochlear implant as well as the software interfaces (specific control programs with graphical interaction with the implant).

- Creating the database

We created a database containing the

results obtained by measuring the electrode impedance for each patient at successive moments as required in the official protocol. The results were gathered during the scheduled sessions as follows: the day of surgery, the implant activation day (one month after the implantation) and two months after the activation.

## RESULTS AND DISCUSSIONS

The electrodes impedance recording went very well with all the patients as a routine method, and there were no problems with children cooperation, so all in all the method is a reliable and reproducible as confirmed by several studies (9, 10, 11, 12).

Group 1 included 9 subjects implanted with the device type Cochlear Nucleus 24. Analysing the chart can notice a symmetric increase in the figures at 1 month after surgery, while keeping the same difference between the values measured during the first measurements on all electrodes. After two months of electrical stimulation there was a return to the previous values close to the intraoperative ones on the electrodes 3 - 22, the electrodes 1, 2 values having a slight upward trend compared to the previous determination (Fig. 2).

The second group was represented by 23 subjects implanted with the Medel Pulsar CI 100 device. Figure 3 shows an increase in impedance values postoperator, the growth being greater in the basal electrodes (9, 10, 11, and 12). There is also a constant trend of values at approximately same level as measured 2 months postactivation compare to the activation.

Figure 4 illustrates the results acquired on 5 subjects that are part of the 3rd lot, subjects implanted with the Medel Sonata device. Analysing the graph, there is a significant increase in the average impedances values in all the apical and basal electrodes (1-4, 9-12) at one month after the surgery and a slight increase of these values in the medial group of electrodes (5-8). This increase is followed 2 months later by a slight decrease in the impedance electrode with approximately the same number of units.

The results for the fourth group, which included 19 patients implanted with Digisonic device type DigisonicSP are illustrated in Figure 5. There is a slight upward trend of values in this group of subjects for the apical to basal electrode impedance during all 3 phases established by the study protocol. The trend of increasing values can be noticed when comparing the data measured intraoperatively with those at one month after surgery and compared with the data measured at the activation of the implant and after two months since the electrical stimulation.

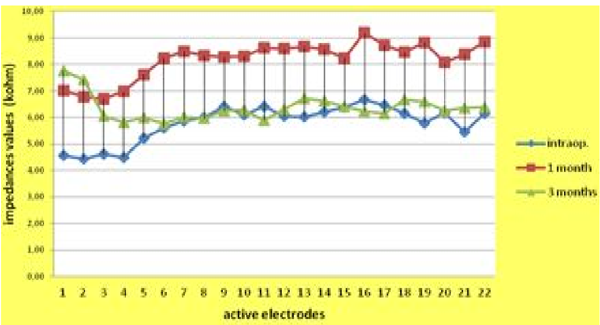



**Fig. 2. Average values of each active electrode impedance measured in subjects in the three times studied**

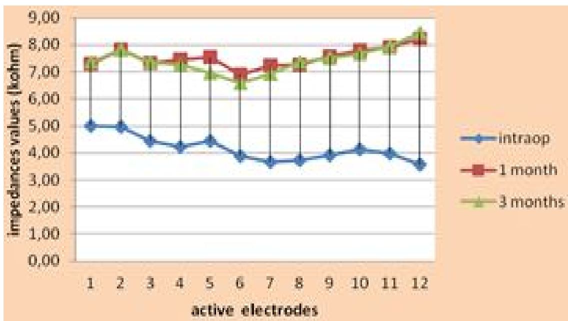



**Fig. 3. Average values of each active electrode impedance measured in subjects in the three times studied**

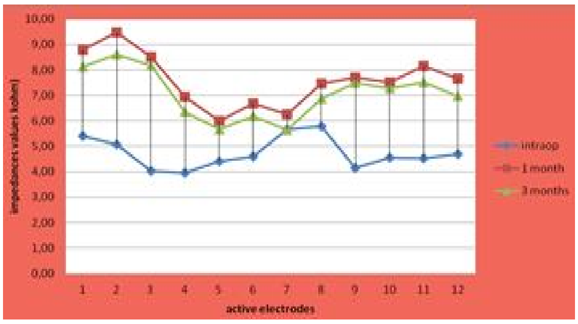



**Fig 4. Average values of each active electrode impedance measured in subjects in the three times studied**

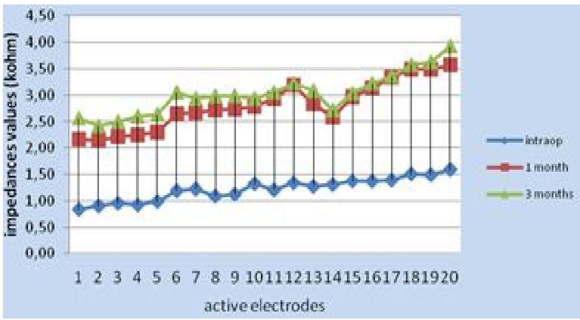



**Fig. 5. Average values of each active electrode impedance measured in subjects in the three times studied**

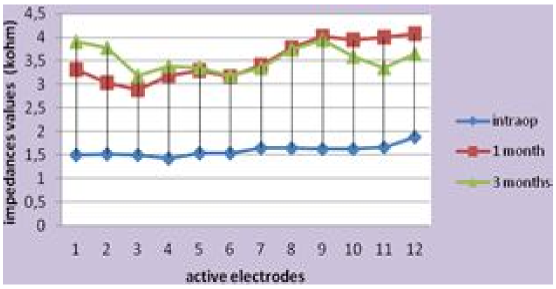



**Fig. 6. Average values of each active electrode impedance measured in subjects in the three times studied**

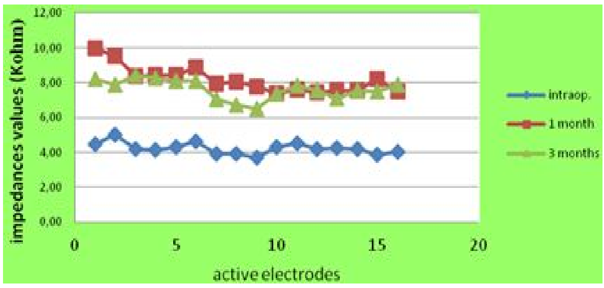



**Fig. 7. Average values of each active electrode impedance measured in subjects in the three times studied**

The results presented in Figure 6 are from the 5th group, which included 5 subjects with bilateral cochlear implant carrying the Digisonic Binaural device type.

The average of impedance values for each electrode measured in all the patients in those 3 times set by the study protocol, shows a growth in values one month after the cochlear implant. There is a different variation of impedance electrodes 2 months after activation, depending on their intracochlear location: increasing values in the basal electrodes, lowering them to the apical electrodes and maintain approximately the same value at medial electrodes.

Subjects included in the 6th group, consisting of 9 subjects wearing the Advanced Bionics cochlear implant type HR90K, acquired an increase in the average electrode impedance values at activation, followed by a slight decrease 3 months after surgery (Fig. 7). Two months after activation there are variations of the apical impedance electrodes and uniformity of the values for the medial and basal ones.

The last group consists of 3 subjects who were special cases. They were implanted with 3 different types of devices: Nucleus 24R, Digisonic MultiArray and Advanced Bionics HiRes90K.

The first subject is a child with inner ear malformation (single cochlear cavity) and he was implanted with an Advanced Bionics device type - HiRes90K. High impedance is observed intraoperatively on 15 electrodes. These values were decreased in activation of the implant and continued their downward trend within three months after. As a special feature there can be noticed a huge difference between the intraoperative and the successive values from 25 Kohm to values around 5 Kohm (Fig. 8).

The second subject of this group misses the 1-13 electrodes records during three months, because after the implant activation, during the adjustments after 1 month there came the need to be disconnected from electrodes 1-13 because they were creating an unpleasant and aggressive auditory sensations. Electrodes 2, 4 and 5 could not be identified intraoperative, without impedance values recording, which can mean either a machine failure or deterioration of electrode because of insertion manoeuvres.

Unlike other patients with Nucleus enrolled in this study, at this patient, although impedance values tend to decrees from 1 month to 3 months, they remain stubbornly high to the intraoperative values (Fig. 9).

During the imaging examinations performed at preimplantation, one of the subjects presented the appearance of ossified cochlea, and a double electrode device was used for implantation. In this case we can notice the absence of the impedance recording for 2 electrodes of a portelectrod, and for one electrode of the second one. Probably some damage was done during the electrode insertion manoeuvres, very likely taking into account the difficulty of the case, which dealt with a bone insertion into two channels, in a completely ossified area.

Impedance values are kept largely between 1-5 Kohm, as well as for the patients with normal cochlea, although in this case the air leakage or fluid environment around the electrode is entirely absent. This case is special because the impedance increases significantly after 3 months on most electrodes.

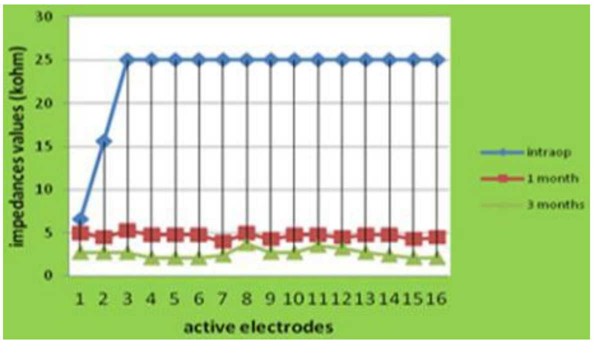



**Fig. 8. Graphical representation of electrode impedance values in a patient with a single cochlear cavity**

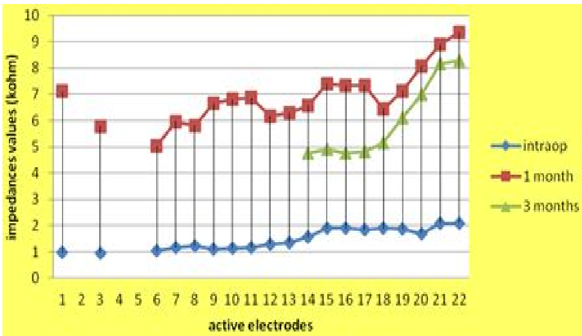



**Fig. 9. Graphical representation of electrode impedance values at the second subject**

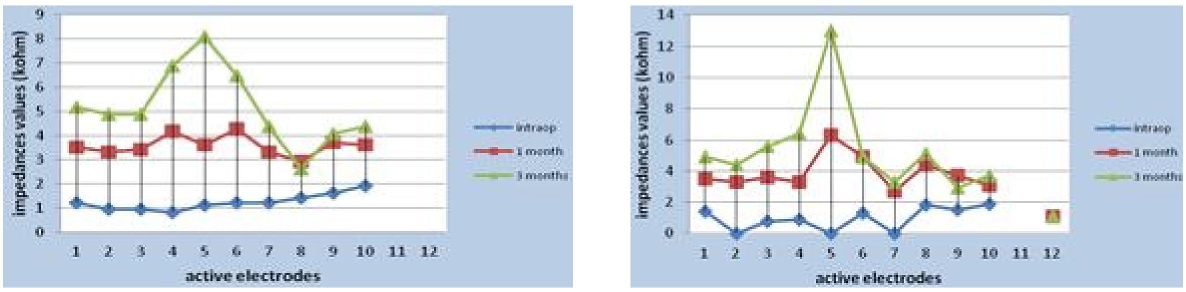



**Fig.10. Graphical representation of electrode impedance values in a subject with ossified cochlea**

## CONCLUSIONS

Because of the absence of the electrical stimulation, during the time between surgery and the device activation, there is an increase of impedance on all electrodes in all models of cochlear implant. This can be explained by local postoperative tissue repair phenomena.

After studying the four brands we found out that for Nucleus implants after surgery the impedance tend to increase after 1 month then they come back around the values measured intraoperatively at a 3 months interval. For all other brands this trend of increased postoperative impedance is maintained, but even though from one month to three months there are generally decreasing values on most electrodes, they remain significantly higher than intraoperative measurements.

In terms of cochlear malformations, impedance values profile is different from the one we encounter in patients implanted with normal cochlea, this profile varies depending on the available electrode in the malformed cochlea.

The intraoperative impedance values and their postoperative fluctuations are part of the common trends specific to each brand separately. Besides the parameters related to the device, the individual organic features of the inner ear may play an important role, as confirmed by the patients from the latest group of study.

**REFERENCES**

1. Dillier N, Lai WK, Almqvist B, Frohne C, Muller-Deile J, et al., Measurement of the electrically evoked compound action potential via a neural response telemetry system. Ann Otol Rhinol Laryngol 2002; 111: 407-414.
2. Neihart NM, Harrison RR, Micropower circuits for bidirectional wireless telemetry in neural recording applications. Biomedical Engineering, IEEE Transactions on. 2005; 52:1950–1959.
3. Swanson B, et al., Impedance measurement of the Nucleus 22 - Electrode Array in patients. Ann Otol Rhinol Laryngol 1995; (Suppl.) 166: 141-144.
4. Tykocinski M, et al., Measurement and analysis of access resistance and polarization impedance in cochlear implant recipients. Otol Neurotol 2005; 26: 948-956.
5. Schulman JH, Using impedance telemetry to diagnose cochlear electrode history, location and functionality. Ann Otol Rhinol Laryngol 1995, 166 (Suppl.), 85-87.
6. Finley CC, Holden TA, Holden LK, Whiting BR, Chole RA, Neely GJ, Hullar TE, Skinner MW, Role of Electrode Placement as a Contributor to Variability in Cochlear Implant Outcomes. Otol Neurotol 2008; 29(7): 920-8.
7. Dorman MF, et al., Long-term measures of electrode impedance and auditory thresholds for the Ineraid Cochlear Implant. J Sp Hear Res 1992; 35: 1126-1130.
8. Snyder RL, Middlebrooks JC, Bonham BH, Cochlear implant electrode configuration effects on activation threshold and tonotopic selectivity. Hear Res 2008; 235: 23–38.
9. Henkin Y, et al., A longitudinal study of electrical stimulation levels and electrode impedance in children using the Clarion cochlear implant. Acta Tot Laryngologica 2006; 126: 581-586.
10. Hughes M, et al., A longitudinal study of electrode impedance, the electrical evoked compound action potential, and behavioral measures in Nucleus 24 Cochlear implant users. Ear Hear 2001; 22: 471-486.
11. Paasche G, et al., Changes of postoperative impedances in cochlear implant patients: The short-term effects of modified electrode surfaces and intracochlear corticosteroids. ONO 2006; 27: 5.
12. Neuburger J, et al., Spontaneous increases in impedance following cochlear implantation: Suspected causes and management. International Journal of Audiology 2009; 48: 233-239.