LONG TERM ELECTRODE IMPEDANCE SURVEILLANCE AFTER COCHLEAR IMPLANTATION IN PRELINGUALLY DEAF CHILDREN

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Abstract: *Cochlear implant is a revolutionary neural prosthesis that restores hearing in deaf people. Electrical impedance measurement of the cochlear implant electrode using the telemetry feature of the circuit provides information about the integrity of the electrode. The aim of this study was to observe changes in electrodes' impedance after 10 to 12 years of device usage. The study enrolled children who underwent cochlear implantation with Nucleus devices, between February 2006 and September 2008. In all cases, impedances increased from the intraoperative to the initial fitting session, then decreased after the first fitting session and had different behaviours over long time of devices' use. In only 8 out of 20 cases (40%) electrical impedance values did not change over 10 years of implant use. Periodic impedance telemetry measurements after implant activation are important for monitoring the integrity of the electrodes and for modifying stimulation parameters that may help preserve auditory performance.*

INTRODUCTION

Electrical impedance measurement is a valuable tool in cochlear implant testing that allows identification of malfunctioning or electrical problems in each electrode of the cochlear implant array during surgery or following implant activation. Chronic neural stimulation requires electrodes that are biocompatible and have low impedance and high charge delivery capability.(1) The conducting coating has good adhesion to the electrode (E) surface. For chronic stimulation purposes, it is critical that these features are stable for a long period of time to achieve long term quality performance.(2) Even so, the cochlear implant is detected as a foreign body (3,4,5) and the implantation process is believed, but not totally proven yet, to generate fibrous encapsulation of the electrode which is responsible for the increase in electrode impedances after surgery.(6,7,8)

As noticed in literature data (9), in many cases after cochlear implantation, the electrode impedance does not remain stable over time and should be monitored as it may affect the optimal electric charge delivery at the neural tissue with consequences on the patient's auditory performance. Periodic measurements of the electrode impedance are important, as in some cases, mapping changes may preserve good auditory performance outcomes.

MATERIALS AND METHODS

The author performed a retrospective study that describes the behaviour of electrode impedance in 20 children implanted with Nucleus 24 cochlear implant system by using common ground and three monopolar modes of stimulation with a follow up period of 10 to 12 years. The patients underwent cochlear implantation between February 2006 and September 2008. All children suffered from prelingual hearing loss. The age of implantation varied between 16 months and 4 years and 8 months (median age at implantation time: 3 years). The cochlear implants used in this study were Nucleus CI 24k straight, Nucleus Freedom CI24 RE straight, Nucleus Freedom CI24 RE Contour Advance (CA). The impedance measurements were made during surgery, one month after surgery, every three months in the first year of implant stimulation, and then once a year in the following years. For Cochlear Ltd. devices, the software tests were performed in four coupling modes: common ground (CG), monopolar relative to MP1 (ball reference electrode under temporalis muscle), monopolar relative to MP2 (plate reference electrode on the lateral aspect of the receiver-stimulator) and monopolar relative to MP1 and MP2, shorted together (MP1+2). The software Custom Sound™ provides impedance data in both graphical and numeric forms. The short and open circuits are automatically flagged. Valid impedances for the contour array range from 0.565 kohms to 30 kohms. For the straight array, normal impedances range from 0.7 kohms to 20 kohms.(10)

RESULTS

Round window approach surgery was performed in 4 out of 20 cases. Intraoperative radiological control of the electrode position inside the cochlea was not possible in any case of the study due to technical constraints. All patients received steroid administration via cochleostomy or round window opening. Intraoperative measurements showed impedances within the normal range in 18 patients. In 2 of these 20 cases, open-circuit electrodes with impedances higher than 30 kohms were detected by telemetry measurements, one electrode in apical position and the other one in medial position. The open-circuit status of these two electrodes did not change by the time of implant activation. Two more electrodes became defective during the devices' switch on, beside the electrodes that failed intraoperatively. In other case, during the first year after activation, 6 electrodes with different locations in the electrode array of a Nucleus Freedom CI24RE (CA) implant failed as a result of open circuits, but the auditory performance of the child was not compromised and the patient did not require

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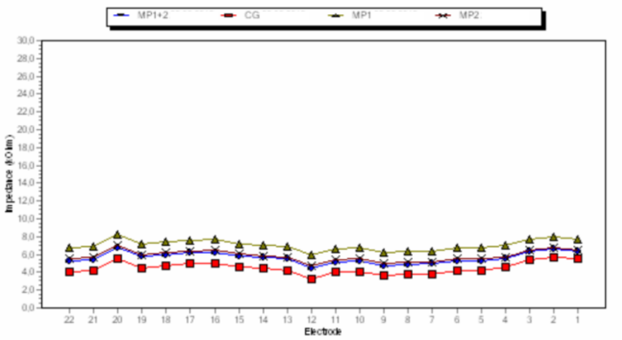
surgery for device replacement.

In 9 out of 20 cases, the graphic of automatic intraoperative impedance telemetry had a relatively smooth profile. In 9 out of 20 cases, intraoperative impedances for all electrodes were within normal limits but the recorded graphic profile was irregular.

Smooth profile of the impedance telemetry recordings at 10 years after implantation was noticed in 4 cases only (figure no. 1).

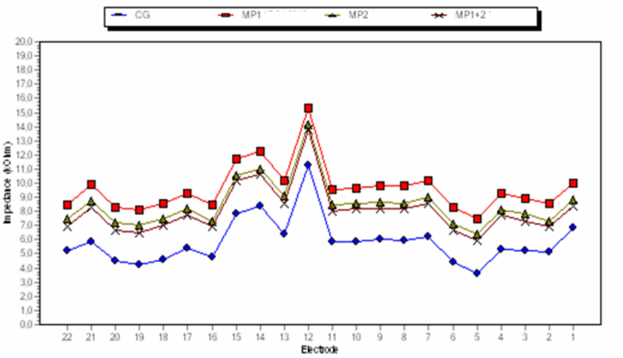
Figure no. 1. Graphic (Custom Sound™) of electrodes' impedance showing smooth profile, recorded in all stimulation modes, 10 years after implant activation



Monitoring electrodes' impedance every 12 months after the first year of implant stimulation showed that the impedance of intracochlear electrodes remained constant in a total of 8 cases, including the cases with smooth graphic profile of recorded impedance telemetry and those with irregular graph profile. Of these 8 cases with constant impedance over time, the electrode insertion was through the round window in one patient and through anterior inferior cochleostomy in 7 cases.

There was an increase in impedance of intracochlear electrodes in 8 cases, different segments of the array being involved as follows: only basal electrodes in 3 cases, only the apical electrodes in two cases, basal and medial electrodes in one case, apical, medial and basal electrodes in one case and all electrodes in one case. Abrupt increase of electrical impedance, especially in the medial segment of the multi-electrode array (between electrode 12 and electrode 15), was detected in a patient implanted with Nucleus CI24k straight electrode (figure 2) who experienced worsening of speech intelligibility, 10 years after the device had been switched -on.

Figure no. 2. Graphic (Custom Sound™) showing the increase of electrodes' impedance between E12 and E15, recorded in all stimulation modes, 10 years after implant activation

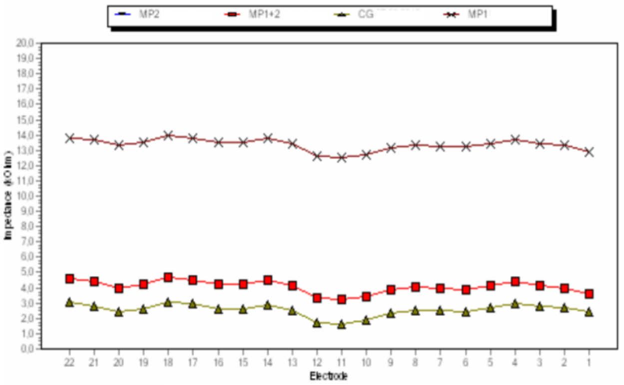


Upgrading the Esprit 3G (Cochlear's third generation of behind-the-ear speech processor) to CP 800 (Nucleus 5 behind-the-ear speech processor) allowed mapping changes with an increase in the current pulse duration from 25 µsec (microseconds) to 50 µsec and adjustments of C and T levels. These changes resulted in the improvement of the patient's speech understanding.

Two cases implanted with Nucleus Freedom CI24RE Contour Advance devices had electrodes with high impedance at the basal and medial segments of the array which required an increase in pulse duration and adjustments of C and T levels to ensure stimulation remains within voltage compliance, but these changes were not followed by impedance decrease at the electrodes involved.

In 4 out of 12 cases that did not preserve stable impedances over time, the values only increased in the monopolar stimulation modes, strictly involving the extracochlear reference ball electrode (MP1) (figure no. 3) in 3 cases and the extracochlear reference plate electrode (MP2) in one case.

Figure no. 3. Graphic (Custom Sound™) showing increased impedance only in MP1 ball electrode, (plotted in red), 10 years after implant activation



Two of these four cases required changes in stimulation modes from MP1+P2 to MP1 or MP2.

DISCUSSIONS

This retroactive study aimed at observing the behaviour of electrodes' impedance in patients implanted with Cochlear™ devices, including Nucleus CI24k, Nucleus Freedom CI24RE straight and Nucleus Freedom CI24RE Contour Advance (CA), 10 to 12 years after surgery. Of the total of 20 patients with prelingual deafness who underwent cochlear implant surgery, the electrodes' impedance maintained stable values 10 years after implantation in only 8 cases (40%). Of the 12 cases that did not preserve stable long-term electrodes' impedance, 3 cases required changes of current pulse width and adjustments of C (comfort) and T (threshold) levels in order to restore the effectiveness of electrical stimulation and comfortable hearing to the patient. Two of four cases with high impedance of extracochlear electrodes (ball and plate electrodes) required changes in stimulation mode. So far, literature data does not provide a satisfactory explanation as for why the electrode impedance of the cochlear implant starts to increase at a certain time after implantation. Adhesion of biological particles around the electrode (11) is a possible reason that may explain the increased impedance at the electrode-tissue interface. Also, it is not completely understandable why, in some situations, the impedance temporarily decreases and then increases again, or why, despite atraumatic surgery, some electrodes fail during or after surgery.

At the moment, in the absence of in vivo tests, a certain explanation for the unpredictable electrodes' impedance behaviour, during and after surgery, cannot be given. It is not clear how many intraoperative abnormal electrical impedances resolve spontaneously by the time of the initial activation, and therefore no hasty decision regarding the use of the back-up implant during surgery should be made. If the impedance increases at the interface electrode-tissue, a higher voltage is required to maintain unchanged the current flow which is not financially feasible for the patient as it implies fast battery consumption. Restoring electrical stimulation within voltage compliance may sometimes be achieved by modifying the electrical pulse duration which implies adjustments of C (comfort) and T (threshold) stimulation levels to preserve the patient’s comfortable auditory perception.

Unfortunately, the surgeons still lack routine real time guidance into the cochlea or feedback from electrode status and position after its progression through the cochlear opening. Developing specific tools that record and monitor biomarkers as impedance or intracochlear electrocochleography, during electrode insertion (12), promises to improve the performance of electrode placement within the cochlea.

Regardless of the fact that most of the electrodes had increased impedance over time, some cases requiring changes in stimulating parameters, none of the participants in this study needed reimplantation as a consequence of decrease in speech performance or adverse symptoms. The moment such situations occur cannot be predicted, therefore long-term impedance monitoring is needed, and further studies on longer implant use periods will contribute to enriching literature data on various types of implantable technologies.

CONCLUSIONS

Increased values of electrodes’ impedance at the first mapping of the speech processor are always present but it is not predictable if the electrical stimulation determines a decrease in impedance in all electrodes and keeps them at that level or the impedance of electrodes starts increasing after a while. The results of this study showed that less than half of cochlear implants (40%) preserved stable electrical impedance values after a long period of device use. The duration of the electrode’s optimal functioning cannot be estimated during surgery or upon activation time, therefore all candidates for cochlear implantation should be considered from the beginning as potential candidates for revision surgery if functioning of the cochlear implant becomes suboptimal and leads to a decrease in the auditory performance.

Periodic impedance measurements after activation are important for monitoring the integrity of electrodes and for adjusting the stimulating parameters that may help maintain a good auditory performance.

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