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**Title:** Analysis of electrical thresholds and maximum comfortable levels in cochlear implant patients.

## Abstract

Objective: It is well known that a proper fitting of the cochlear implant processor is relevant to provide good quality in speech perception. The aim of this study is to extract statistical information to be applied for fitting the processor.

Methods: This study is based on the programming maps of 121 patients, aged from 18 months to 68 years at the moment of implantation. All subjects were implanted with the COMBI 40+ cochlear implant at San Cecilio University Hospital, Granada (Spain). The patients were classified into groups based on their age at implantation: younger than 5 yrs, between 5 and 16 yrs, and older than 16 yrs. The patients in each age-based group were divided into two subgroups, considering whether they had recent hearing experience or not. A special group including patients affected by severe damages in the cochlea was also defined.

Results: Relationships between the programming parameters and factors like the age at implantation, the hearing experience and the presence of severe cochlear damage were found. The THR levels for patients younger than 5 yrs were significantly lower than those for patients implanted between 5 and 16 yrs, and this group presented significantly lower THR levels than adults. The MCL levels were not significantly influenced by the age at implantation. A significant increment was observed for both, MCL and THR levels, when patients were affected by severe cochlear damage. A significant increment in the THR levels were observed for patients with no recent hearing experience, while no significant differences were found for MCL levels. This study also analyzes the distribution along the cochlea of the stimulation levels. In the case of patients not affected by severe cochlear damage, the most basal electrodes presented a significant increment in the stimulation levels with respect to the rest of electrodes.

Conclusion: This work provides information of great value for programming the speech processors, particularly when the subjective responses of the patients are not sufficient. The application in our ENT Service has reduced substantially the average time needed to obtain an acceptable fitting of the processor, especially in children. Our study also shows that electrical thresholds are a good indicator of the functionality of the auditory nerve. The analysis of this parameter highlights the importance of an early intervention as well as a deep insertion of the electrode carrier in order to obtain the maximum functionality from the cochlear implant.

**Keywords:** Cochlear Implant, speech processor, electrical threshold (THR), maximum comfortable level (MCL).

## 1. Introduction

Electrical stimulation of the auditory nerve using cochlear implants constitutes an important step forward in the treatment of profound deafness. In multichannel cochlear implant systems, the input audio signal is split into frequency bands and the stimulation of each region of the cochlea (the cochlear partition associated to each channel) depends on the power of the signal in the corresponding spectral band. The power in each band is mapped into electrical impulses emitted by each electrode according to the coding strategy and the programming parameters obtained during the fitting sessions [1,2]. Therefore, obtaining all the potential benefits from the cochlear implant system requires accurate programming of the speech processor.

In order to program the multichannel cochlear implant system, each channel must be checked in order to (a) verify the functionality of the electrode; (b) estimate the perceptual threshold (THR) of the electrical impulses, i.e. the minimum stimulation level the patient can perceive in this channel; and (c) estimate the maximum comfortable level (MCL), i.e. the maximum stimulation level the patient can accept without uncomfortable sensation. Based on these estimations, the dynamic range in each audio band is mapped into the electrical dynamic range in the corresponding channel, defined by the THR and MCL levels for this electrode. An improper programming of the processor degrades the quality of the hearing perception and it usually causes an uncomfortable perception of the sound [3,4].

Usually, the information necessary for programming the speech processor is obtained from subjective responses to series of electrical impulses presented to the patient on different electrodes. This procedure is relatively easy for postlingually deafened adults but becomes more difficult in the case of very young children, prelingually deafened subjects, and in general, in case of poor auditory experience or extreme limitations in the communication skills. In these cases, the information obtained from objective measures can be useful to evaluate the functionality of the electrodes and to estimate the THR and MCL levels [5,6,7,8,9] even though the objective methods present some limitations [6,7,10,11]. When the subjective response is not clear enough for the programming requirements, the audiologist can also obtain information from behavioral audiometry, behavioral observation techniques and other indirect observation-based methods [12,13,14]. In these situations, the estimation of an accurate map takes longer (in some cases several months since the first switch-on) which delays obtaining benefits from the cochlear implant.

Based on our clinical experience with cochlear implanted patients, we have found in a previous work that a statistical analysis of the programming maps can provide useful information to be applied to program the processors [15]. The present paper is devoted to the analysis of the stimulation levels in cochlear implanted patients and its application for programming the speech processors. The study is based on the programming maps estimated for the patients implanted in our ENT department. We analyze relationships between stimulation levels (THR and MCL parameters) and factors like age at implantation, damage to the cochlear structures, and the aetiology and duration of the deafness. We also analyze the variations along the cochlea of the stimulation levels. In this paper we present a statistical analysis of the programming maps and we discuss the application of the presented results for the first fittings of the cochlear implant processors, particularly for those patients providing poor information for the estimation of the THR and MCL parameters.

## 2. Materials and methods

### Subjects

Our analysis is based on measurements taken from 121 patients implanted in our ENT department, with ages at implantation between 18 months and 68 years. The patients were implanted with the 12 channels COMBI 40+ implant device at San Cecilio University Hospital, Granada (Spain). The patients are distributed into groups based on their age at implantation: younger than 5 (36.4% of the subjects), between 5 and 16 (26.4%), and older than 16 years (22.3%). A special group including patients affected by meningitis, otosclerosis and other severe damages in the cochlea is also defined. This group is labeled as SCD (severe cochlear damage) and includes 14.9% of the patients. The age-based groups have been split into two subgroups taking into account the duration of the deafness (ranged from 4 months to 22 years) and the hearing experience. The criterion for the inclusion in the RHE (recent hearing experience) category is that the aided pure tone hearing threshold (averaged between 250 and 4000 Hz) is below 60 dB at least during the first half of the lifetime in the case of children implanted before 5 years, and at least until 3 years before the implantation for the rest of the patients. Otherwise the patients have been categorized in the No-RHE group. Table 1 shows the distribution of patients considered in this study taking into account the age-based groups, the presence of cochlear damage and the hearing experience. The study was approved by the Ethic Committee of San Cecilio University Hospital, Granada (Spain).

Table 1 about here

### Procedures

The present study is based on the analysis of the programming parameters in these cochlear implanted patients. The data presented in this paper is a statistical analysis of subjective measurements of the THR and MCL parameters obtained during the fitting sessions. The procedure to obtain the stimulation levels is described below.

The speech processor is fitted and switched-on at first time 4 weeks after the surgery. In this session the audiologist determines the functionality of the different electrodes taking into account X-ray images, telemetry information and the response of the patient to electrical stimuli. The audiologist also obtains a first estimation of the THR and MCL levels from the subjective responses to electrical stimuli presented at each electrode at different levels.

During the next weeks (typically between 2 and 8, depending on the case), the patient is treated and studied by a group of specialists (including speech therapist, psychologist and audiologist). They help the patient in the development of basic skills in perception, discrimination, identification of speech sounds or speech understanding, depending on his/her previous abilities and hearing experience. This team also evaluates the evolution in the perception capability of the patient by means of behavioral or pure tone audiometries, perception tests, discrimination tests and other indirect methods adapted to the age and abilities of each patient. During this period, this information is used by the audiologist as a feed-back for a more accurate estimation of the THR and MCL levels in order to improve the performance of the cochlear implant.

Obtaining an accurate enough programming map typically requires between 2 weeks and 4 months, depending on the collaboration of the patient, his/her expressiveness, the attention capability, etc. After 6 months from the first fitting, almost all the patients have an accurate map programmed in their processors. The validity of the programming parameters is confirmed by several tests and most of the patients provide responses in pure tone audiometries for levels between 25 and 40 dB (HTL)[1]. In the present study, we have considered the data in the programming maps obtained at least 6 months after the first switch-on of the processor, according to the above described process. We have considered this minimum experience in order to guarantee the stability of the programming parameters and the reliability in the estimation of the THR and MCL levels [16].

## Analysis of the THR and MCL levels

In the COMBI 40+ device, the different stimulation levels are obtained by combining the electrical intensity (i) and the duration (t) of the biphasic pulses generated by the implant. Since the loudness sensation mainly depends on the product (t x i), i.e., the total charge inserted in each phase of the electrical pulse (q), we have expressed the THR and MCL parameters in electrical charge units (nano-Coulombs, nC)[2]. This way, stimulation levels obtained with different durations of the pulses and different electrical intensities can be compared[3]. The THR and MCL parameters have been statistically processed in order to study the differences among the different groups of patients and to evaluate the factors influencing the different observed tendencies.

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[1] These thresholds are averaged over the frequencies 250, 500, 1000, 2000 and 4000 Hz.

[2] The amplitude and duration of the electrical pulses are expressed in µA (or current units, cu) and µs, respectively. For the conversion to charge units, it must be considered that 1 nC=1000 µA x µs.

[3] In the COMBI 40+ implant, the default duration of each phase of the electrical pulses is 26.7 µs. In order to convert the charge units (nC) into current units (cu, which corresponds to µA), the charge must be divided by the duration of the pulse. For example, a stimulation level of 2.0 nC corresponds to a pulse of 74.9 cu with a duration of 26.7 µs. Pulses with 50 cu x 40 µs or 20 cu x 100 µs would produce a similar loudness sensation.

## 3. Results

### Influence of the age at implantation and SCD

In order to study how the stimulation levels are influenced by the age at implantation and the presence of a cochlear damage, we have analyzed the distribution of the THR and MCL levels for each group. Table 2 shows the parameters describing the statistics of the THR and MCL levels for the different groups. The table includes the mean (μ), the 95% confidence interval for the mean (95%ci) and the standard deviation (σ) for the distributions of THR and MCL levels.

Table 2 about here

As the age at implantation is greater, an increment in the THR levels is observed. The THR levels of the 5-16 years group is about 30% greater than those for the 0-5 years group, and the adults present THR levels a 22% greater than the patients implanted at ages between 5 and 16. However, the MCL levels do not show significant variations for the different aged-based groups (the differences are small compared to the standard deviations). As could be expected, the cochlear damages cause an important increment in both, THR and MCL levels, which reach about 2 times the values estimated for the rest of the patients. The increment in the stimulation levels associated to the SCD patients is mainly due to the degeneration of the neural fibers in the cochlear nerve and the difficulties during the surgery to place the electrode carrier close to the modiolus.

The differences between the considered groups of patients have been statistically evaluated by means of the Welch test [17]. The THR levels for the patients younger than 5 are significantly lower than those for the patients implanted between 5 and 16 (with a confidence level better than 99%), and this group present lower THR levels than the group of adults (also with a confidence better than 99%). The MCL levels are not significantly influenced by the age at implantation (significance levels worse than 60%). Finally, a significant increment is observed for both, MCL and THR levels, when patients are affected by severe cochlear damage (confidence levels better than 99%). Therefore, the analyzed results show the age at implantation as an important factor affecting the THR values (but not the MCL levels, which present an important variability among the different patients). Cochlear damage is also shown to be a factor dramatically increasing the stimulation levels (both, THR and MCL) in the implanted patients.

### Influence of the hearing experience

For those patients in the same age-based group we have found very different tendencies in the programming parameters. Some patients show better sensitivity to the electrical stimulation than others. We have analyzed the clinic history of the patients, looking for factors involved in the observed differences [18]. We have found that those patients with hearing experience previous to the cochlear implantation (and especially those with more recent hearing experience) have lower electrical thresholds (i.e. better sensitivity for the electrical stimulation) and they also develop the perception skills faster than the patients affected by a long-term profound deafness or by congenital deafness.

The influence of the hearing experience over the programming parameters has been analyzed by classifying the patients in each age-based group into two subgroups, taking into account whether they had recent hearing experience (RHE) at the moment of implantation or not. Table 3 shows the results of the statistical analysis taking into account the hearing experience. In the table we show the mean, the 95% confidence interval for the mean and the standard deviation for the distributions of THR and MCL levels corresponding to each age-based and RHE-based group.

Table 3 about here.

A significant increment in the THR levels is observed for the No-RHE patients with respect to the RHE ones (with a confidence better than 99% for all the three age-based groups). The average increment in the THR levels for the No-RHE with respect to the RHE groups is 1.08 nC, which corresponds to an increment of 41%. This increment in the thresholds (this reduction of the sensitivity to the electrical stimulation) could be associated to the retrograde degeneration of the neural fibers due to the absence of stimulation for a long period of time. In the case of adults affected by a long and severe deafness, the coincidence of the increments in the THR levels associated to the age and the No-RHE factors could make the THR levels too high, especially for the most basal electrodes, and sometimes some of them must be disconnected in order to avoid collateral stimulations. This fact introduces a bias which reduces the increment in the THR levels associated to the No-RHE factor for the group of adults (only 18%) with respect to the other aged-based groups (58% and 44% for 5-16 and 0-5 years old, respectively).

No significant differences are observed for the MCL levels due to the hearing experience factor. For those patients affected by long duration or congenital deafness we have observed two different tendencies. Some patients need very high MCL levels in order to have a proper loudness sensation, while others only accept relatively low stimulation levels and they find the stimulation uncomfortable if the MCL parameters are increased. This fact causes the relatively great standard deviations of the MCL parameters for the patients in the No-RHE groups.

## Distribution along the cochlea of the electrical levels

The stimulation levels usually present variations for the different electrodes mainly because: (a) the distance between the electrode carrier and the modiolus is different for each electrode (usually, this distance is smaller for the apical electrodes than for the basal ones) and this influences the efficiency of the electrical stimulation, and (b) in sensorineural deafness, the basal area of the cochlea is usually affected before than the apical one, and the hearing experience is commonly better for the lower frequencies; therefore, the retrograde degeneration of the neural fibers is more important for the basal part. For these reasons, differences in the stimulation levels between the basal and the apical electrodes should be expected. In this section we analyze the variability of the stimulation levels along the cochlea. For this analysis we have normalized the programming map of each patient by dividing the programming parameters (THR and MCL) by the average THR and MCL levels (respectively) associated to this patient. This procedure removes the inter-patient variability, which was studied in the previous sections, and focuses this analysis on the distribution along the cochlea of the programming parameters.

Taking into account X-ray images and the direct observation of the surgeon, we have estimated the insertion depth of all the electrodes for each patient. The insertion depth of each electrode is measured from the cochleostomy. The plots in Figure 1 represent the normalized stimulation levels (THR or MCL levels relative to the average THR or MCL of each patient, respectively) versus the insertion depth (expressed in mm from the cochleostomy). As the insertion depth increases, the electrodes are placed in a more apical area of the cochlea. In these plots we have also included the mean and the 95% confidence interval of the normalized THR and MCL levels for the typical insertion depth of each electrode. Different plots have been considered for the patients affected by severe cochlear damage (SCD) and for the rest of the patients (No-SCD). In these plots, a high correlation is observed in the stimulation levels associated to adjacent electrodes.

Figure 1 about here

Table 4 shows the average normalized THR and MCL levels for the typical insertion depth of each electrode. The table also indicates the electrodes associated to each depth for the case of a complete insertion of the electrode carrier. In the case of patients not affected by SCD, the most basal electrodes present a significant increment in the normalized stimulation levels with respect to the rest of electrodes. Increments of 41% and 22% are observed, respectively, for the normalized THR and MCL levels of the most basal electrode with respect to the most apical one. The increments in the stimulation levels for the electrodes in the basal area could be associated to the retrograde degeneration (usually more important in the basal area) and the increment in the distance between the electrodes and the modiolus. This tendency is also observed for the SCD group. However, in this case the confidence intervals are wider and a significantly lower correlation between adjacent electrodes is observed.

Table 4 about here

## 4. Discussion

### Applications and limitations of the statistical analysis

The results presented in the previous sections provide information about the programming parameters for different groups of patients, taking into account factors like the age at implantation, the hearing experience previous to the implantation or the presence of damage in the cochlear structures. This information can be applied for the first fittings of the speech processor, especially when the patient does not provide coherent subjective responses.

In these cases, in order to obtain an acceptable programming map, the first step is to determine the electrodes to be switched-on, based on telemetry integrity testing and the allocation of each electrode[4]. The average THR level can be selected taking into account the patient group. For example, if the patient is younger than 5 and has no recent hearing experience, the average THR level should be coherent with a distribution with mean 2.20 nC and standard deviation 0.49 nC. A conservative estimate of the average THR level could be the mean minus the standard deviation (in the example 1.71 nC, which corresponds to 64.0 cu, for the default pulse duration of 26.7 µs). The THR level of each electrode can be programmed taking into account its allocation in the cochlea and the normalized stimulation levels reported in Table 4. If the 12 electrodes are inserted and switched-on in the example, and increment of 41% is expected in the THR of the most basal electrode with respect to the most apical one. So, the THR level would be progressively increased from 59.1 cu in the electrode 1 (inserted about 27 mm) up to 85.8 cu in the electrode 12 (situated close to the cochleostomy), according to Table 4.

Similarly, the MCL levels for the different electrodes can be balanced making use of the corresponding column in the table. The statistical results in Table 3 provide some information about the average MCL level (in the example, mean and standard deviation 26.65 nC and 7.88 nC, respectively, which corresponds to 998.1 cu and 295.1 cu for the default pulse duration). However, this interval is too wide for a reliable estimate of the average MCL level. In addition, the audiologist should consider that during the first period using the cochlear implant, the average MCL levels are significantly lower than after 6 month using it [16]. Therefore, the average MCL level should be estimated by observing the reactions of the patient to sounds at different levels. Since the global volume can be controlled by the patient (or by the parents), a very accurate estimate of the average MCL level is not necessary during the first fitting sessions. Special attention must be paid during the first fittings in order to avoid an over-estimation of the

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[4] The allocation can be estimated from X-ray images and the direct observation of the surgeon during the implantation.

average MCL level, because it would cause an uncomfortable perception of the sound. The uncertainty in the estimations must be solved by underestimating the stimulation levels, and a fine balancing of the electrodes and an accurate adjustment of the programming parameters can be obtained later, as the patient provides more information.

In the case of severe cochlear damage, the estimation of the programming parameters is more complicated. Important differences in the stimulation levels for adjacent electrodes are frequently observed. This behavior is due to the differences in the state of the neural ends and the specific surgical technique for the device implantation. Even though the stimulation levels are usually significantly greater than those for the other groups of patients, sometimes there are electrodes providing relatively high loudness sensation or even an uncomfortable sensation without a high stimulation level. In these patients, collateral stimulation of the facial or vestibular nerves are also frequently found. For this reason, when the clinic history reports severe cochlear damage, the electrodes to be switched on must be carefully selected, and the stimulation levels must be carefully estimated. In these cases, when the patient does not provide sufficient information, the adequate fitting of the processor usually needs more fitting sessions.

The statistics presented in this paper can be useful for the first fitting sessions when the patients do not collaborate (since the statistics provides indicative levels for the THR and MCL parameters) and also in the case of collaborative patients (by providing some complementary information). However, when the audiologist fits the processor, the programming parameters must not be based only in these statistical results. All the available information, coming from objective measures or subjective responses to the stimulation must be considered in addition to the statistical results [19,20]. Moreover, the subjective and objective measures must prevail over the statistical conclusions (specially for long term fitting) since the former provide specific information about each electrode of the implant system to be fitted while the statistical results just provides general behavior of the patients in each group. In addition, there are patients who are difficult to be classified into a group since the hearing experience previous to the implantation or the cochlear damage are sometimes difficult to be evaluated. All these facts must be taken into account in order to properly apply the information provided by this study for fitting cochlear implant systems.

### Clinic experience applying the statistical information

The origin of the presented study is based on our clinic experience with implanted patients: after several years involved in the cochlear implant program we detected typical patterns for the THR and MCL parameters associated to patients with similar characteristics. The analysis of factors affecting the THR and MCL parameters was shown to be useful for processor fitting, especially for patients providing poor subjective information. The need of a statistical study motivated the work presented in this paper.

During the last years, we have applied the statistical results of this study to the patients implanted in our ENT service. The application of the statistics has reduced substantially the average time needed to obtain an acceptable fitting of the processor, especially in the case of the youngest children. Before applying this information, obtaining an acceptable map took more than 2 months for 20% of the patients. Currently, 90% of the patients are programmed with acceptable maps during the first week after the first switch-on of the processor, and for the rest of the patients, it takes less than one month. This has improved our cochlear implant program in several facts. The time spent for the patients take-off (i.e. for obtaining significant benefits from the use of the cochlear implant system) has been reduced. There has also been a reduction of the duration of the basic hearing rehabilitation (i.e. the stage for developing basic perception skills). Consequently, the patients can return faster to their usual environment, which reduces the stress caused by the implantation process. Additionally, the availability of the staff involved in the basic rehabilitation has been increased, allowing our program to assume a higher number of patients to be implanted.

## Importance of age at implantation, hearing experience and cochlear damage

The factors which are shown to affect the stimulation levels must be taken into account in order to evaluate the importance of early intervention in cochlear implantation. The presented results show that the increment of THR levels is associated to a degradation of the functionality of the auditory nerve which produces, as consequence: (a) a reduction of the sensitivity to electrical stimulation, (b) a reduction in the electrical dynamic range, which reduces the resolution in the perception of intensity and (c) a reduction of the efficiency of the electrical stimulation. These effects produce an important reduction in the hearing quality of the cochlear implanted patients and leads to limitations in the long term development of perception and speech understanding abilities.

This suggests the importance of early intervention in order to avoid the degradation of the auditory nerve caused by the absence of stimulation. In the case of profound congenital deafness, the patients should be implanted at ages between 6 and 12 months in order to preserve most of the functionality of the auditory nerve. In the case of progressive deafness, the implantation should not be delayed too much when there is no benefit from the hearing aids, in order to avoid the absence of stimulation. Also, the deep insertion of the electrode carrier should be considered as an important factor improving the quality of the cochlear implantation, since the apical areas of the cochlea are usually better preserved against the pathogenic agents (and usually the hearing experience is more recent for the apical area) and the functionality of the electrodes is better as they are more inserted into the cochlea.

## 5. Conclusion

In this work we have analyzed the programming maps of 121 patients implanted at our ENT service. The electrical thresholds (THR) and maximum comfortable levels (MCL) have been compared in different groups of patients. Factors like the age at implantation, the hearing experience previous to the implantation and the presence of severe cochlear damage have been studied in order to analyze their influence over the stimulation levels. We have also studied the distribution along the cochlea of the stimulation levels.

The age is a factor which significantly influences the THR levels. The older the patient is implanted, the greater THR is observed. The hearing experience is also shown to influence the programming parameters: as the patient has a better and more recent hearing experience, lower THR parameters are observed. No significant effect of the age at implantation or the hearing experience over the MCL parameters is observed. Severe cochlear damage significantly increases both, THR and MCL stimulation levels. With respect to the distribution along the cochlea of the programming parameters, a systematic increment of both, MCL and THR parameters, is observed for the electrodes in the basal area with respect to the apical ones.

The THR parameters are shown as a good indicator of the functionality of the auditory nerve for the different cochlear partitions associated to each electrode of the implant. This explains the behavior of the THR levels associated to the analyzed factors. The statistical results obtained in this work show the importance of an early intervention for sensorineural deafness in order to avoid damages in the auditory nerve derived from the absence of stimulation as well as the importance of a deep insertion of the electrode carrier in order to stimulate the cochlear partitions better preserved against pathogenic factors and with better and more recent hearing experience. Early intervention and deep insertion are factors increasing the efficiency of the electrical stimulation and providing better hearing quality with the cochlear implants.

The presented results provide useful information for programming the cochlear implant processor. We think the specialist involved in cochlear implant fitting would improve the programming map if the statistical information is combined to the information obtained from subjective responses and objective measures. In our clinic, we have successfully applied the statistical results for fitting the processors. A significant reduction in the time necessary to obtain benefits from the use of the cochlear implant has been observed.

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## Conflict of interest

None

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## FIGURE LEGENDS

- Figure 1. Distribution of the stimulation levels (THR and MCL relative to average) as a function of the insertion depth. The vertical bars represent the 95% confidence interval for the normalized stimulation levels associated to each electrode.

## TABLE LEGENDS

- Table 1: Number of patients in each group considering the age at implantation, the presence of severe cochlear damage (SCD) and the recent hearing experience (RHE).
- Table 2: Statistics of the THR and MCL levels considering age-based groups and the presence of cochlear damage.
- Table 3: Statistics of the THR and MCL levels considering the hearing experience.
- Table 4: Distribution along the cochlea of the average normalized THR and MCL levels. The first column represents the typical insertion depth of each electrode and the corresponding electrode in the case of a complete insertion of the electrode carrier.

**Table**

| Age | | RHE | |
|---|---|---|---|
| 0-5: | 44 | No-RHE: | 36 |
| | | RHE: | 8 |
| 5-16: | 32 | No-RHE: | 21 |
| | | RHE: | 11 |
| >16: | 27 | No-RHE: | 6 |
| | | RHE: | 21 |
| SCD: | 18 | | |

Table 1: Number of patients in each group considering the age at implantation, the presence of severe cochlear damage (SCD) and the recent hearing experience (RHE).

| | THR (nC) | | MCL (nC) | |
|---|---|---|---|---|
| Age | µ±95%ci | σ | µ±95%ci | σ |
| 0-5 | 2.09±0.15 | 0.49 | 26.68±2.21 | 7.31 |
| 5-16 | 2.83±0.31 | 0.85 | 27.17±4.91 | 13.8 |
| >16 | 3.59±0.39 | 0.98 | 29.19±4.80 | 12.1 |
| SCD | 5.96±1.43 | 2.88 | 55.60±12.5 | 25.1 |

Table 2: Statistics of the THR and MCL levels considering age-based groups and the presence of cochlear damage.

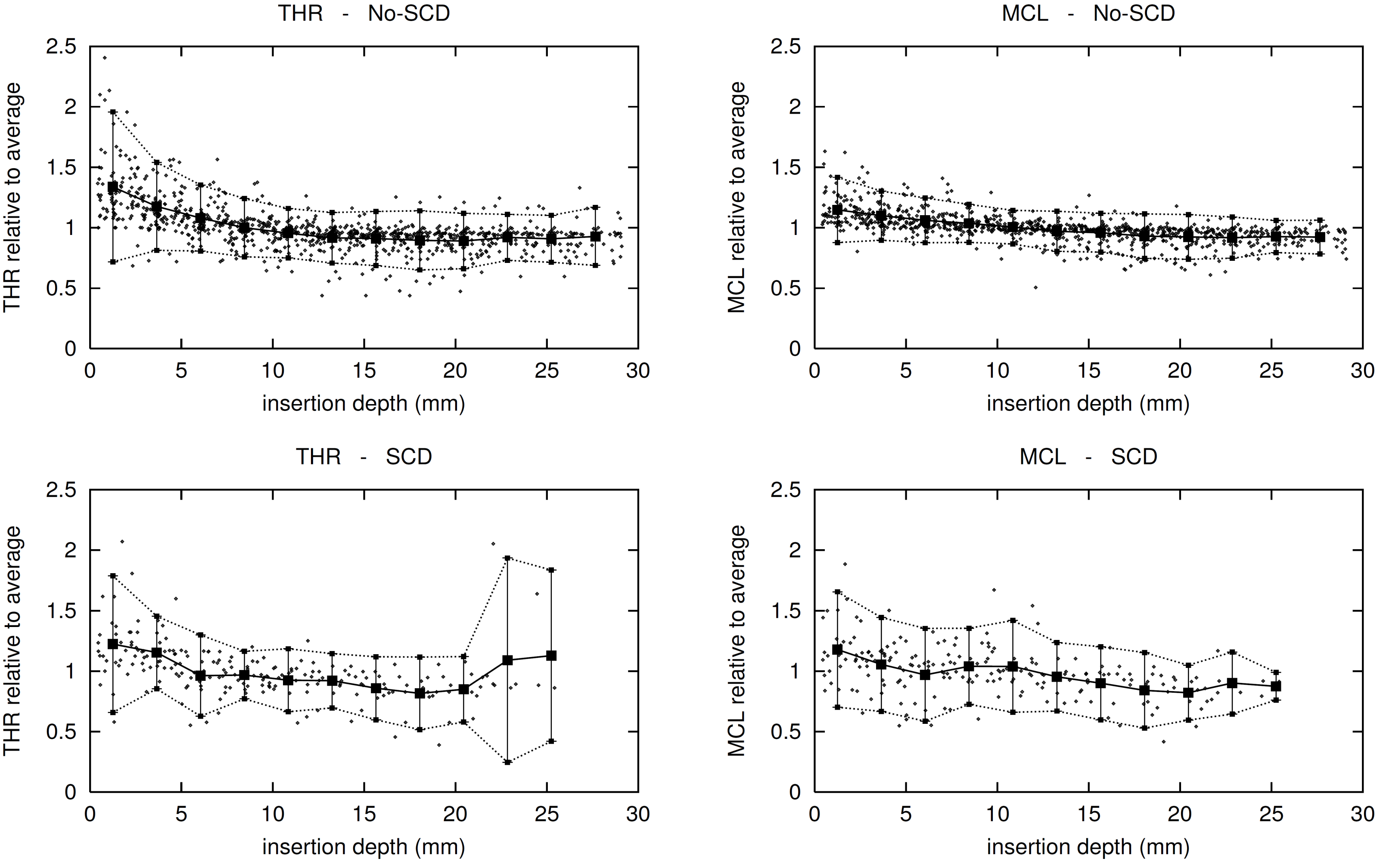
| | | THR (nC) | | MCL (nC) | |
|---|---|---|---|---|---|
| Age | RHE | µ±95%ci | σ | µ±95%ci | σ |
| 0-5 | No-RHE | 2.20±0.17 | 0.49 | 26.65±2.66 | 7.88 |
| | RHE | 1.62±0.25 | 0.30 | 26.82±3.16 | 3.79 |
| 5-16 | No-RHE | 3.23±0.39 | 0.86 | 27.40±7.18 | 15.7 |
| | RHE | 2.06±0.26 | 0.38 | 26.72±5.92 | 8.80 |
| >16 | No-RHE | 4.05±0.42 | 0.40 | 33.42±18.6 | 17.7 |
| | RHE | 3.46±0.49 | 1.07 | 27.98±4.44 | 9.73 |

Table 3: Statistics of the THR and MCL levels considering the hearing experience.

| insert. depth (electrode) | | **No-SCD** | | **SCD** | |
|---|---|---|---|---|---|
| | | THR | MCL | THR | MCL |
| 27.6 mm | (1) | 0.93 | 0.92 | - | - |
| 25.2 mm | (2) | 0.91 | 0.93 | 1.12 | 0.88 |
| 22.8 mm | (3) | 0.92 | 0.92 | 1.09 | 0.90 |
| 20.4 mm | (4) | 0.90 | 0.92 | 0.85 | 0.82 |
| 18.0 mm | (5) | 0.90 | 0.93 | 0.81 | 0.84 |
| 15.6 mm | (6) | 0.91 | 0.96 | 0.86 | 0.90 |
| 13.2 mm | (7) | 0.92 | 0.97 | 0.92 | 0.95 |
| 10.8 mm | (8) | 0.95 | 1.01 | 0.93 | 1.04 |
| 8.4 mm | (9) | 1.00 | 1.04 | 0.97 | 1.04 |
| 6.0 mm | (10) | 1.08 | 1.06 | 0.96 | 0.97 |
| 3.6 mm | (11) | 1.17 | 1.10 | 1.15 | 1.05 |
| 1.2 mm | (12) | 1.34 | 1.14 | 1.22 | 1.17 |

Table 4: Distribution along the cochlea of the average normalized THR and MCL levels. The first column represents the typical insertion depth of each electrode and the corresponding electrode in the case of a complete insertion of the electrode carrier.

**Figure**


THR - No-SCD
MCL - No-SCD
THR - SCD
MCL - SCD
THR relative to average
MCL relative to average
insertion depth (mm)
0
0.5
1
1.5
2
2.5
0
5
10
15
20
25
30