ISSN: 2083-389X
eISSN: 2084-3127

J Hear Sci, 2024; 14(4): 42–46
DOI: 10.17430/jhs/202647

Received:
March 4, 2025
Revision accepted:
March 5, 2025
Published online:
March 28, 2025

DOES IMPEDED BIOMECHANICS INFLUENCE COCHLEAR IMPLANT HEARING PRESERVATION?

Adam Walkowiak[1A-CE], Marek Polak[2AC-F], Artur Lorens[1AC-F], Piotr H. Skarzynski[3,4AD], Henryk Skarzynski[5ACD]

[1] Implants and Auditory Perception Department, World Hearing Center, Institute of Physiology and Pathology of Hearing, Warsaw/Kajetany, Poland
[2] R&D, Med-El Medical Electronics GmbH, Innsbruck, Austria
[3] Teleaudiology and Screening Department, World Hearing Center, Institute of Physiology and Pathology of Hearing, Warsaw/Kajetany, Poland
[4] Institute of Sensory Organs, Kajetany, Poland
[5] Oto-Rhino-Laryngology Surgery Clinic, World Hearing Center, Institute of Physiology and Pathology of Hearing, Warsaw/Kajetany, Poland

Corresponding author: Adam Walkowiak, Implants and Auditory Perception Department, World Hearing Center, Institute of Physiology and Pathology of Hearing, Mokra 17, Kajetany, 05-830 Nadarzyn, Poland; email: a.walkowiak@ifps.org.pl

Contributions:
A Study design/planning
B Data collection/entry
C Data analysis/statistics
D Data interpretation
E Preparation of manuscript
F Literature analysis/search
G Funds collection

Abstract

Introduction: The insertion of a cochlear implant electrode may impede propagation of a travelling wave in the implanted cochlea. The primary objective of this study was to evaluate whether the impeded cochlea biomechanics affected the patient's hearing preservation.

Material and methods: There were 17 adults who were implanted with Flex 20 ($n = 1$); Flex 24 ($n = 8$); Flex 28 ($n = 1$); FlexSoft ($n = 5$); Medium ($n = 1$), and Standard ($n = 1$) electrode arrays with Pulsar, Concerto, or Sonata cochlear implants (Med-El). Implantation was via the round window. Acoustically evoked intracochlear potentials were recorded from cochlear implant electrodes. Tone pips at 500 Hz generated by a Nicolet EDX system (Natus Medical Inc.) were presented via inserts. Postoperative CT scans of the implanted cochlea were made and analysed. The unaided pre-implantation and post-implantation hearing thresholds were compared in all subjects.

Results: In 9 subjects the highest amplitude response to the tone pip matched the 500 Hz excitation area in the postoperative CT scan. The low-frequency difference was found between the pre-implantation and the post-implantation unaided thresholds in this group was 12.4 dB. Impeded basilar membrane biomechanics was observed in 8 other patients. In these 8 patients, the highest amplitude at 500 Hz was shifted either apically (1 case) or basally (7 cases) with respect to the 500 Hz excitation area suggested by the postoperative CT scan. The threshold difference in this group was 8.4 dB. However, the threshold differences in both groups were not statistically significant.

Conclusions: These preliminary data suggest that impeded biomechanics of the basilar membrane does not appear to affect hearing preservation.

Keywords: hearing preservation • cochlear implant • basilar membrane fixation

CZY ZABURZONA BIOMECHANIKA WPŁYWA NA ZACHOWANIE SŁUCHU PO WSZCZEPIENIU IMPLANTU ŚLIMAKOWEGO?

Streszczenie

Wprowadzenie: Głównym celem badania była ocena, czy zaburzona biomechanika ślimaka wpływa na zachowanie słuchu po wszczepieniu implantu ślimakowego.

Materiał i metoda: Siedemnastu dorosłym osobom wszczepiono implanty z elektrodą Flex 20 ($n = 1$); Flex 24 ($n = 8$); Flex 28 ($n = 1$); Flex Soft ($n = 5$); Medium ($n = 1$) i Standard ($n = 1$) z implantami ślimakowymi Pulsar, Concerto lub Sonata, Med-El Corp. Każdemu z badanych wszczepiono elektrodę implantu przez okienko okrągłe. Wewnątrzślimakowe akustyczne potencjały wywołane zostały zarejestrowane z elektrod implantu ślimakowego. Ton o częstotliwości 500 Hz był generowany przez system Nicolet EDX, Natus Corp i podawany przez słuchawki wewnątrzuszne. Po operacji wykonano tomografię komputerową. Audiogram przed implantacją porównano z audiogramem wykonanym podczas badania.

Wyniki: Dziewięciu pacjentów miało najwyższą amplitudę odpowiedzi na ton 500 Hz na elektrodzie odpowiadającej obszarowi wzbudzenia dla tonu 500 Hz określonemu na podstawie pooperacyjnej tomografii komputerowej. Zaburzoną biomechanikę błony podstawnej zaobserwowano u 8 pacjentów. U tych pacjentów najwyższa amplituda w odpowiedzi na ton o częstotliwości 500 Hz była przesunięta w kierunku szczytowym (1 przypadek) lub podstawnym (7 przypadków) w stosunku do obszaru pobudzenia o częstotliwości 500 Hz ocenianego w pooperacyjnej tomografii komputerowej. Średni spadek czułości słuchu mierzony w audiometrii tonalnej w grupie osób z tonotopią wynosił 12,4 dB, podczas gdy w grupie z zaburzoną biomechaniką wynosił 8,4 dB. Różnica ta nie była istotna statystycznie.

Wnioski: Wstępne dane sugerują, że zaburzona biomechanika błony podstawnej nie ma wpływu na zachowanie słuchu.

Słowa kluczowe: zachowanie słuchu • implant ślimakowy • biomechanika błony podstawnej

Introduction

Hearing preservation after cochlear implantation is considered the most important factor in rating the success of the procedure [1]. The risk of causing trauma to the cochlea when implanting an electrode array is real, and could ultimately lead to complete hearing loss. Although relatively good hearing-preservation rates are achieved using lateral-wall flex electrodes [2], there is still a need to improve hearing-preservation rates.

One of the ways to assess hearing preservation is to look for evidence of a travelling wave inside the cochlea. Ever since 1935 when Fromm and colleagues first measured the cochlear potential in three subjects, electrocochleography (ECochG) has become a reliable measure of cochlear function. More recently, intracochlear ECochG has been introduced, and its feasibility was presented at the XXXII World Congress of Audiology in 2014 [3].

When pure-tone stimuli are acoustically applied to the ear, they generate a mechanical wave in the basilar membrane that progresses from the cochlear base and peaks at a place that corresponds to the frequency of the tone. After passing this region of the cochlea, the amplitude of the wave drops. This phenomenon was discovered and first measured in human-ear specimens by von Békésy in 1928 [4]. In the case of basilar-membrane fixation caused by electrode implantation, the wave energy is focused in regions adjacent to the point of fixation [5]. The impeded biomechanics of the basilar membrane not only affects the amplitude of the traveling wave, but also its phase.

The goal of this study is to evaluate whether impeded basilar-membrane biomechanics affects the hearing preservation in patients implanted with flex electrode arrays.

Material and methods

The Ethics Committee of the Institute of Physiology and Pathology of Hearing (decision KB.IFPS 16/2021) approved the study protocol. Prospective subjects were given an informed consent form that explained the purpose and procedures involved. The test procedures were in accordance with the ethical standards of the Helsinki Declaration.

Seventeen adults (9 females and 8 males) were selected for the study who had varying degrees of hearing abilities, both before and after receiving their cochlear implants (CIs). The subjects were implanted with the following electrode arrays: Flex 20 ($n = 1$), Flex 24 ($n = 8$), Flex 28 ($n = 1$), Flex Soft ($n = 5$), Medium ($n = 1$), and Standard ($n = 1$) (all Med-El) of Pulsar, Concerto, or Sonata cochlear implants (Med-El). Implantation was done using the round window insertion technique [6]. The mean age was 47 years and 2 months at the time of surgery (20–68 years). The mean time of measurements was 13 months (2–91 months after CI surgery). To minimise the damaging effect of the electrode insertion and to make hearing preservation possible, we selected electrodes suitable for deep insertion, i.e., reaching the region of 500 Hz and below (i.e., 250 Hz).

Recordings of intracochlear ECochG

Intracochlear acoustically evoked potentials were recorded from the CI electrodes. Patients were positioned in a comfortable semi-lying position. Inserts were placed inside their implanted ear. The inserts were connected to the Nicolet EDX system (Natus Medical Inc.), which was used for acoustic stimulation. The Meastro AP research software (Med-El), was run from a PC communicating with a MAX Interface (Med-El). The MAX interface communicated via an external coil connected to the CI, which is possible when the coil is placed on the CI. When recording was initiated, the MAX interface triggered the Nicolet EDX, which acoustically stimulated the patient. TIP 300 inserts were used during the acoustic stimulation.

Short 8 ms (4 cycle) 500 Hz tone pips were used as acoustic stimuli. The stimuli had condensation polarity. Before measuring the intracochlear ECochG, the subject's maximum comfortable level (MCL) was obtained. All recordings were then performed at the MCL. The mean stimulation level was 103.8 dB HL (85–122 dB HL). For each subject, an unaided preoperative audiogram was measured less than 4 weeks prior to surgery, and an unaided postoperative audiogram was measured on the day of the study. For situations where no acoustic threshold was obtained at 115 dB HL, 120 dB HL was used. At the time of the study, a postoperative CT scan was obtained for each subject and the electrode placement was evaluated. Further details on the technical procedure, as well as other tests performed to evaluate possible artefacts, see [7].

The location of the intracochlear electrode contacts was derived from the postoperative computed tomographic imaging. The Greenwood function was used to infer the characteristic frequency corresponding to the electrode location [8,9]. Estimation of the cochlear angle of rotation and characteristic frequency region was done according to Polak et al. [10], which has the characteristic location for 500 Hz at 457°. In all patients, the electrode placement that was closest to the insertion angle of 457° was estimated to correspond to the 500 Hz excitation area.

After the intracochlear ECochG was recorded at all electrode contacts, the 500 Hz frequency place was estimated from the response, and the electrode with the maximum amplitude was selected. If the maximum amplitude was registered within one contact of the selected tonotopic electrode identified in the postoperative CT scan,

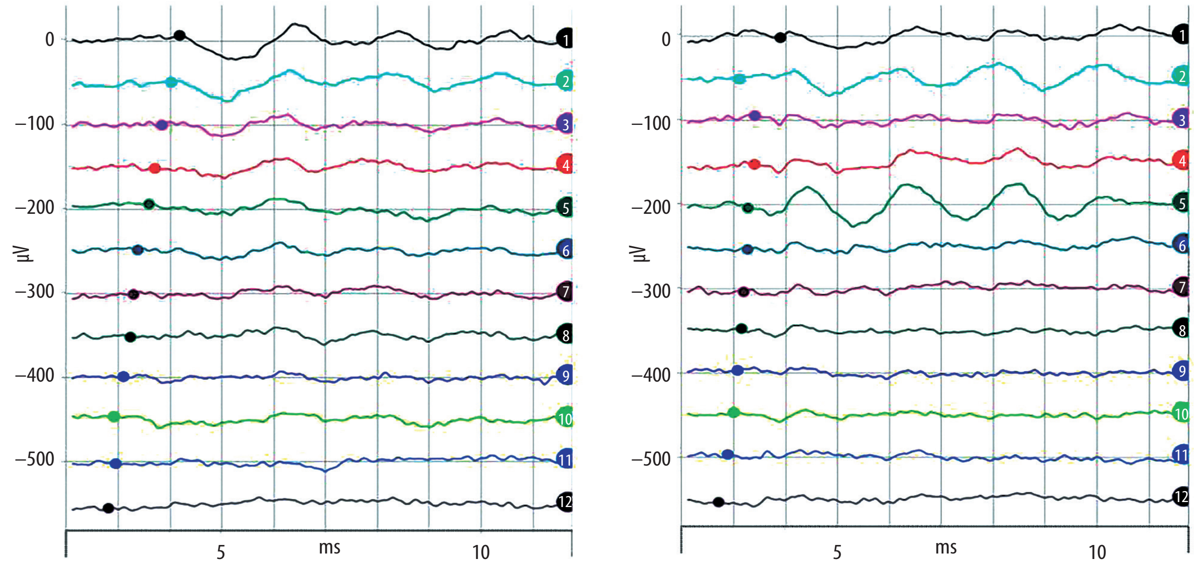

Figure 1. Examples of intracochlear ECochG recordings of 500 Hz tone pips at 95 dB HL from all 12 electrodes of the Med-El Flex 24 array, as captured by the Maestro AS software. *Left*: Examples from a patient in the tonotopy group. The electrode insertion depth was 450°. From the postoperative CT scan, the expected maximum amplitude was at electrode 1 (8.2 µV), as confirmed by the intracochlear ECochG electrode 1. *Right*: Example of an ECochG recording of a patient from the non-tonotopy group. The electrode insertion depth was 520°. From the postoperative CT scan, the expected maximum amplitude should be at electrode 2. However, the intracochlear ECochG showed the largest response at electrode 5 (17.5 µV). An additional local minimum was found at electrode 2 (8.9 µV). Electrode 1 is the most apical and electrode 12 the most basal. The coloured dots mark the latencies of the responses

the patient was classified as belonging to the tonotopy group. Otherwise, the patient was classified as belonging to the non-tonotopy group.

Data analysis

To compare the postoperative audiometric thresholds and the differences between preoperative and postoperative thresholds for all characteristic frequencies between the tonotopy and non-tonotopy groups, a two-tailed *t*-test was used. To evaluate if the data was normally distributed, a Lilliefors test of conformity was performed, using a significance criterion of $\alpha = 0.05$. The sample size was selected to achieve statistical power greater than 0.9.

Results

The mean electrode insertion at the tip of the array was 515° (381–729°). In 16 out of 17 cases the excitation area of 500 Hz was reached. The tonotopy group comprised 9 patients and the non-tonotopy group comprised 8 patients.

Figure 1 shows an example of intracochlear ECochG recordings of 500 Hz tone pips in patients from both the tonotopy and the non-tonotopy groups. In the tonotopy group recording, the maximum amplitude matched the electrode number estimated from the postoperative CT scan. In contrast, in the non-tonotopy-group, the difference between the maximum amplitude electrode and the estimated electrode number from the postoperative CT scan were two contacts or more. **Figure 1** (right) shows that the travelling-wave energy is focused between electrodes 5 and 2, suggesting that the point of fixation lies between them. In 7 other cases, the maximum amplitude was more basal and in one case it was more apical. For the tonotopy group, the 500 Hz peak was at 442° (360–540°), which was consistent with the Polak et al. model estimate of 457°. However, for the non-tonotopy group, the mean peak angle was 170° (45–360°).

Figure 2 depicts the mean and standard deviation of the unaided postoperative audiograms of the tonotopy and non-tonotopy groups. The difference between the postoperative and preoperative mean threshold are plotted as well. For the tonotopy group, the low-frequency (125–1000 Hz) pure-tone average difference was 12.4 dB, while for the non-tonotopy group it was 8.4 dB.

The hearing thresholds of both test groups were normally distributed at all frequencies, according to the Lilliefors test of normality (using a significance level of 0.05 and *p*-value lower than the critical value $Dn = 0.285$ for all frequencies). No statistical differences between preoperative and postoperative thresholds were found in any of the groups (two-tailed *t*-test: $\alpha = 0.05$, $p > 0.05$). **Table 1** provides the numerical threshold data of **Figure 2**.

Discussion

This study evaluated hearing preservation in patients implanted with various Med-El Flex electrodes. One of the measures of hearing preservation is evidence of a travelling wave in the cochlea. The study found that after electrode implantation not all patients exhibited propagation of a travelling wave induced by 500 Hz tone pips. In the non-tonotopy group of patients, the measured

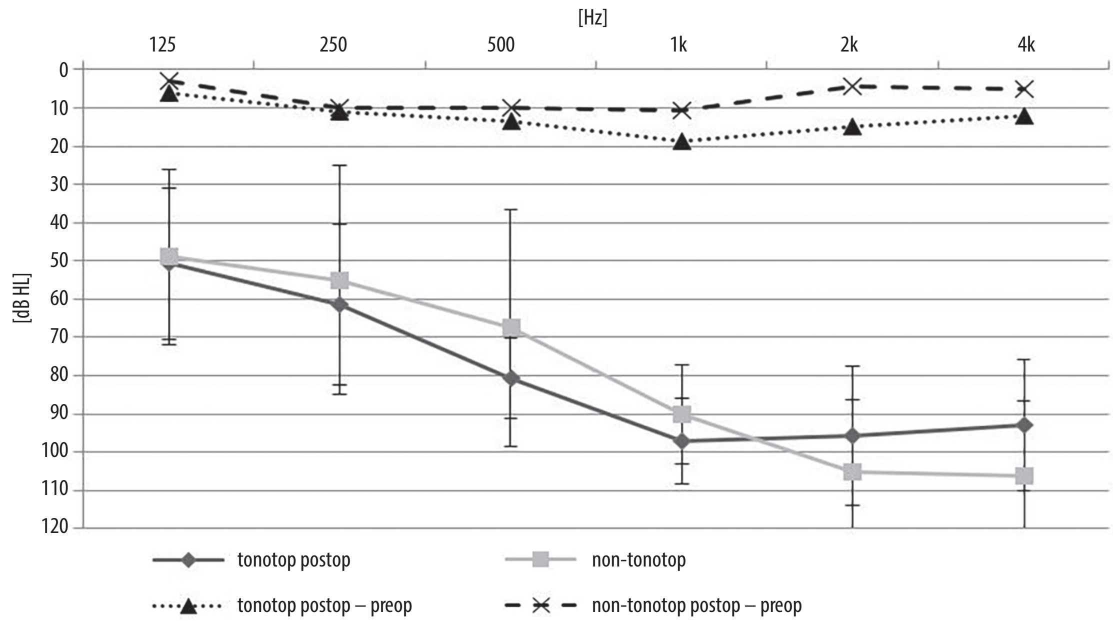

Figure 2. Mean unaided postoperative audiograms of the tonotopy and non-tonotopy groups (continuous lines) and the mean difference between their preoperative and the postoperative audiograms (dotted lines)

Table 1. The numerical data of the plots in Figure 2

Frequency	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz
Tonotopy group postop mean ± *SD* [dB HL]	48.9 ± 22.9	55 ± 29.9	67.5 ± 31.1	90 ± 12.9	105 ± 18.7	106.3 ± 19.5
Non-tonotopy group postop mean ± *SD* [dB HL]	50.7 ± 19.9	61.4 ± 21	80.7 ± 10.6	97.1 ± 11.1	95.7 ± 18.1	92.9 ± 17
Tonotopy group postop – preop mean ± *SD* [dB HL]	6.1 ± 17.6	11.1 ± 17.5	13.3 ± 12.2	18.9 ± 20.1	15 ± 7.9	12.2 ± 10.3
Non-tonotopy group postop – preop mean ± *SD* [dB HL]	2.9 ± 14.1	10 ± 13.5	10 ± 12.6	10.7 ± 9.3	4.3 ± 3.5	5 ± 8.2

maximum amplitude in the electrode recordings did not match the expected excitation area of 500 Hz according to the Greenwood and Polak models. The sound energy in the cochleas of these patients was concentrated in regions adjacent to the point of basilar membrane fixation [5].

Eshraghi et al. [11] proposed a grading system for cochlear trauma ranging from 0 to 4, where a higher grade indicates greater cochlear trauma. Grade 0 is defined as no trauma, while Grade 1 corresponds to a mechanical elevation of the basilar membrane. In our study, we identified 8 patients with impeded biomechanics of the basilar membrane. However, we found that this group did not experience poorer hearing preservation 1 year after cochlear implantation compared to the group without any impeded biomechanics. This finding suggests that touching or elevating the basilar membrane to only a certain degree does not significantly affect the hearing loss induced by cochlear implantation and may, therefore, still be considered as Grade 0.

Bester et al. [12] evaluated 39 patients implanted with Cochlear Nucleus CI422 and CI522 CIs with a 20 mm-long straight electrode array with 22 contacts. The electrode insertions varied between 20 to 25 mm. Tone pips of 500 Hz were applied and recorded at all 22 contacts along the electrode array. In perioperative ECochG recordings, 22 subjects (56%) had the peak response at around the tip of the electrode array (apical-peak, AP; EL20 or EL22), whereas 17 subjects (44%) had maximum amplitude in more basal regions (mid-peak, MP; EL18 or lower). The responses were not compared with postoperative CT scans. In 6 subjects with perioperative apical peaks, the location of the largest ECochG response had shifted basally (apical-to-mid-peak, AP–MP). The mean postoperative hearing loss in the AP group was 13 dB ($n = 16$, $SD = 9$). A significantly larger hearing loss was detectable in the MP and AP–MP groups with 28 ($n = 17$, $SD = 10$) and 35 dB ($n = 6$, $SD = 13$). The authors concluded that after cochlear implantation, MP and AP–MP ECochG response patterns were correlated with poorer postoperative hearing and higher four-point impedances in comparison with AP response patterns, all of which may suggest increased intracochlear fibrosis.

In our study, we did not find any difference in the hearing preservation between the tonotopic and the non-tonotopic groups. The differences may be in the type of array used and in the electrode insertion depth. In our study, the mean insertion depth was 515° (381–729°) and the 500 Hz excitation area was reached in all but one case, whereas the mean electrode insertion achieved with the CI422/CI522 slim straight electrode was 373° (233–470° [13]), which suggests that the insertion depth was always equal to or more basal than the 500 Hz excitation area. Therefore, the most apical electrode contact in all cases is the one closest to the excitation area of 500 Hz.

Walia et al. [14] evaluated 50 adults implanted with the Cochlear CI632 perimodiolar array, with a mean electrode insertion depth of 404° ± 35°. Tone burst stimuli were independently administered at frequencies of 250, 500, 1000, 2000, 3000, and 4000 Hz for all 22 electrodes, and intracochlear ECochG recordings were obtained. For each frequency presented, the electrode with the highest peak was selected as the excitation frequency area. Based on this information, the authors created individual tonotopic maps for frequencies between 500 and 4000 Hz. The authors found a near-octave apical shift from the Greenwood model at all frequencies. In our case, for a 500 Hz tone burst, the mean peak place was 295° (45–630°), while the mean 500 Hz peak reported by Walia et al. was 330° (220–380°). The similarity in results between both studies may be explained by impeded cochlear biomechanics. In our study, for the tonotopy group the mean peak place was 442° (360–540°), which was consistent with the Greenwood and Polak et al. models (estimated to be 457° at 500 Hz). However, the mean insertion angle at the peak was 170° (45–360°) in the non-tonotopy group.

Conclusions

Our preliminary data suggest that impeded biomechanics of the basilar membrane does not necessarily impair hearing preservation. It would be of interest to investigate this phenomenon in more detail and specifically find out whether basilar-membrane impedance of the degree that was found here has any negative effect on patients.

Funding

This research and article did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Tessler I, Gecel NA, Glicksberg BS, Shivatzki S, Shapira Y, Zimlichman E, et al. A five-decade text mining analysis of cochlear implant research: where we started and where we are heading. Medicina (Kaunas), 2023; 59(11): 1891. https://doi.org/10.3390/medicina59111891
2. Van de Heyning PH, Dazert S, Gavilan J, Lassaletta L, Lorens A, Rajan GP, et al. Systematic literature review of hearing preservation rates in cochlear implantation associated with medium- and longer-length flexible lateral wall electrode arrays. Front Surg, 2022; 9: 893839. https://doi.org/10.3389/fsurg.2022.893839
3. Lorens A, Polak M, Walkowiak A, Skarzynski H. Recordings of acoustic evoked potentials directly from the different places of cochlea via in tracochlear electrodes in cochlear implantees. Book of abstracts. XXXII World Congress of Audiology, 3–7.05.2014, Brisbane, Australia, p. 102.
4. Wever, EG. Development of traveling-wave theories. J Acoust Soc Am, 1962, 34.9B: 1319–24. https://doi.org/10.1121/1.1918337
5. Kiefer J, Böhnke F, Adunka O, Arnold W. Representation of acoustic signals in the human cochlea in presence of a cochlear implant electrode. Hear Res, 2006; 221(1–2): 36–43. https://doi.org/10.1016/j.heares.2006.07.013.
6. Skarzynski H, Lorens A, Piotrowska A, Anderson I. Preservation of low frequency hearing in partial deafness cochlear implantation (PDCI) using the round window surgical approach. Acta Otolaryngol, 2007; 127(1): 41–8. https://doi.org/10.1080/00016480500488917
7. Lorens A, Walkowiak A, Polak M, Kowalczuk A, Furmanek M, Skarzynski H, et al. Cochlear microphonics in hearing preservation cochlear implantees. J Int Adv Otol, 2019; 15(3): 345–51. https://doi.org/10.5152/iao.2019.6334
8. Greenwood DD. A cochlear frequency-position function for several species: 29 years later. J Acoust Soc Am, 1990; 87(6): 2592–605. https://doi.org/10.1121/1.399052
9. Stakhovskaya O, Sridhar D, Bonham BH, Leake PA. Frequency map for the human cochlear spiral ganglion: implications for cochlear implants. J Assoc Res Otolaryngol, 2007; 8(2): 220–33. https://doi.org/10.1007/s10162-007-0076-9
10. Polak M, Lorens A, Furmanek M, Skarzynski H. Electrode estimation in the acoustic region of the human cochlea. Acta Otolaryngol, 2020; 140(6): 487–96. https://doi.org/10.1080/00016489.2020.1736337
11. Eshraghi AA, Yang NW, Balkany TJ. Comparative study of cochlear damage with three perimodiolar electrode designs. Laryngoscope, 2003; 113(3): 415–9. https://doi.org/10.1097/00005537-200303000-00005
12. Bester C, Dalbert A Collins A, Razmovski T, Gerard J-M, O'Leary S. Electrocochleographic patterns predicting increased impedances and hearing loss after cochlear implantation. Ear Hear, 2023; 44(4): 710–20. https://doi.org/10.1097/AUD.0000000000001319
13. Verberne J, Risi F, Campbell L, Chambers S, O'Leary S. The effect of scala tympani morphology on basilar membrane contact with a straight electrode array: a human temporal bone study. Otol Neurotol, 2017; 38(1): 47–53. https://doi.org/10.1097/MAO.0000000000001259
14. Walia A, Ortmann AJ, Lefler S, Holden TA, Puram SV, Herzog JA, et al. Electrocochleography-based tonotopic map: I. Place coding of the human cochlea with hearing loss. Ear Hear, 2025; 46(1): 253–64. https://doi.org/10.1097/AUD.0000000000001579

Adam Walkowiak, email: a.walkowiak@ifps.org.pl • 0000-0001-6663-9331
Marek Polak, email: marek.polak@medel.com • 0000-0003-3197-7300
Artur Lorens, email: a.lorens@ifps.org.pl • 0000-0001-8618-7651
Piotr H. Skarzynski, email: p.skarzynski@ifps.org.pl • 0000-0002-4978-1915
Henryk Skarzynski, email: h.skarzynski@ifps.org.pl • 0000-0001-7141-9851