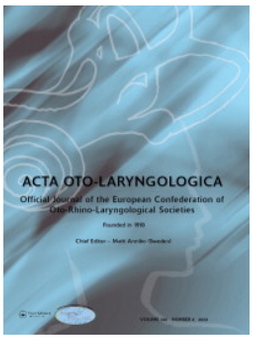

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RESEARCH ARTICLE

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Do different types of cochlear implant electrode influence hearing preservation and speech perception?

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ABSTRACT

Background: Hearing can be preserved in patients with considerable low-frequency hearing implanted with cochlear implants. However, the most favorable electrode type for hearing preservation and speech perception has been debated.

Objective: The aim was to evaluate hearing preservation and speech discrimination one year post-implantation for all types of cochlear implant electrode used for adult patients implanted between 2014 and 2022.

Methods: The HEARING group formula was used to calculate the degree of hearing preservation, which was defined as minimal (0-25%), partial (25-75%) or complete (≥ 75%). Speech perception was measured by monosyllabic words.

Results: Analysis of hearing preservation for the various electrode types revealed that FLEX 24 preserved hearing statistically significantly better ($p < 0.05$) than FLEX 28, FLEX soft, and contour advance. Also, FLEX 20 preserved hearing statistically significantly better ($p < 0.05$) than contour advance. No statistically significant difference was found for the monosyllabic word score for the different electrode types.

Discussion: There was a statistically significant difference between the electrode types in terms of hearing preservation but not for speech perception. The result of this study contributes important information about hearing preservation and speech perception that can be used for pre-surgery patient counselling.

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Cochlear implant; hearing preservation; speech perception; low-frequency hearing

Introduction

Today, cochlear implantation (CI) is used as a successful routine treatment for severe sensorineural hearing loss. Historically, patients with little or no hearing were chosen for implantation, but as technical and surgical techniques developed, patients with considerable low-frequency hearing were implanted with preserved hearing [1–4]. Even though residual hearing has been found to decrease over time [5,6] it is considered important to preserve the delicate structures in the cochlea [7,8]. The goal is to preserve the neural elements in the cochlea that are the target of electrical stimulation. Initially, hearing preservation was believed necessary only for electroacoustic stimulation (EAS) candidates, but the benefits of hearing preservation are now recognized for all CI users, even those with poor residual hearing. Residual hearing may also allow severely hearing impaired CI users to benefit from future hearing restoring treatments [9]. Rajan et al. strongly recommend that structure/hearing preservation surgery should be used when implanting children, irrespective of the degree of preoperative hearing [10].

There have been debates about the best characteristics of a CI electrode for preserving hearing and the most favorable electrode length for the patient in the long term, in cases where the residual low frequency hearing is declining [11–13]. Tarabichi and colleagues conclude that thin, flexible, lateral wall arrays are preferable for hearing preservation. However, the choice of optimal implant is an issue of ongoing investigation, as hearing preservation outcomes remain highly variable regardless of implant design or length [14]. Dhansingh and Jolly conclude that it is difficult to achieve an optimal electrode design due to the many factors that need to be considered and because all major CI manufacturers have their own electrode design, which they believe is the best for ensuring better hearing outcomes for patients [15]. Earlier studies have shown that preserved low frequency hearing with shorter CIs provides speech perception comparable with longer CIs [16,17]. Furthermore, no difference could be found in speech or music perception when comparing medium-length and longer CIs [18].

The degree of hearing preservation is an important part of the counselling process before CI. However, hearing preservation varies between patients and post-operative outcomes are difficult to predict [19]. The aims of this study were to evaluate hearing preservation and speech

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discrimination results in the implanted ear one year post-implantation for all CI electrode types used for adult patients implanted in our clinic between 2014 and 2022. The study was approved by the Swedish Ethical Review Authority (2023-07049-02).

Methods

In this study all adult patients (≥18 years old) implanted at Uppsala university hospital between 2014 and 2022 were evaluated. Implants used were Concerto, Synchrony, or Synchrony 2 from MedEl (Innsbruck, Austria) and CI422, CI522, CI512, CI612, or CI632 from Cochlear (Lane Cove, NSW, Australia). Electrodes were classified as slim straight (CI422, CI522), contour advance (CI512, CI612), slim modiolar (CI632), FLEX soft, FLEX 28, FLEX 24, or FLEX 20 in accordance with the electrode lead characteristics. At our clinic most patients with considerable low frequency hearing before surgery were implanted with FLEX 20 or FLEX 24 if we considered acoustic amplification of the lower frequencies at activation. However, not all patients with considerable low frequency hearing pre-surgery were interested in using a combined electro acoustic stimulation post-surgery and were therefore implanted with other electrodes. The longest electrodes from MedEl (Innsbruck, Austria) were mainly chosen when there was a rapid hearing decline in the low frequencies or when the patient had no pre-surgery hearing thresholds. Also, the size of the patient's cochlea was considered when the electrode length was decided. We did not choose electrodes from Cochlear (Lane Cove, NSW, Australia) for hearing preservation. The contour advanced electrode was mostly chosen in cases of otosclerosis because of its stiffness that facilitates electrode-insertion in these cases. The patients were largely involved in the decision on what electrode from the different manufacturers to implant, even though their decisions were mainly based on the characteristics of the external parts of the cochlear implant system, i.e. the sound processor.

To calculate the degree of hearing preservation (HP) the formula from the HEARING group was used [9]:

$$HP = \left(1 - \frac{PTApost - PTApre}{PTAmax - PTApre}\right) \times 100[\%]$$

Pure tone average (PTA), PTApre, and PTApost were calculated as the average hearing level (HL) threshold for nine frequencies 125-8000Hz. PTApre was measured pre-surgery and PTApost 1 year post-implantation. Hearing levels were measured using TDH039 headphones in a soundproof booth in accordance with the international standard for audiological testing (ISO 8253-1:1989). PTAmax in this formula is the maximal PTA available for the audiometer used, namely 115 dB HL. Non-detected thresholds were replaced with the levels presented in Table 1. In the analysis HP patients with a pre-surgery hearing threshold of ≥85dB HL at 250 Hz were excluded, as it was not considered meaningful to analyze HP for patients with very poor pre-surgery hearing. HP was defined as minimal (0-25%), partial (25-75%), or complete (≥ 75%) in accordance with the HEARING group definition [9].

Speech perception was measured pre-surgery and at 1 year post-implantation by monosyllabic (MS) words in Swedish. The MS-words were measured in a soundproof booth in free field at 65 dB SPL with the loudspeaker at 0° with a hearing aid at pre-surgery and with the CI at post-surgery. If the patient had hearing in the contralateral ear, it was masked by noise or by use of hearing protectors.

Data on patients' age, surgical technique (insertion *via* round window or cochleostomy), and etiology was extracted from the medical records. SPSS was used for statistical evaluation. The Kruskal Wallis test ($\alpha = 0.05$) was employed for analyzing hearing preservation and speech discrimination with the different electrode types, as the data was not normally distributed. The significance levels were adjusted by the Bonferroni correction for multiple tests.

Results

A total of 290 patients were extracted from our database, 153 women and 137 men. Their mean age at time of surgery was 64.4 years (range 19 to 89 years) with 148 implanted in the right ear and 142 in the left ear. Patient etiologies are presented in Figure 1.

Of the 290 patients, 206 had a pre-surgery HL threshold better than or equal to 85 dB at 250 Hz. Twenty-six of these 206 did not attend the one-year hearing-threshold-measurement for various reasons. 180 patients were included in the HP analysis. Figure 2.

Hearing preservation

In Table 2 the 180 patients included in the HP analyes are presented. Thirty-six percent (9 out of 25) of the patients implanted with a slim straight electrode had minimal hearing preservation one year post-surgery. For the contour advance electrode this figure was 82% (9 out of 11) and for the slim modiolar electrode the figure was 29% (2 out of 7). With the FLEX soft electrode, 48% (15 out of 31) had minimal HP one year post-surgery, with the FLEX 28 this figure was 41% (33 out of 80), with the FLEX 24 it was 5% (1 out of 19) and with the FLEX 20 it was 0% (0 out of 7).

Analyzing the percentage of HP provided by the different electrode types revealed statistically significant differences between contour advance and FLEX 20 ($p = 0.044$) and FLEX 24 ($p = 0.001$) as well as between FLEX soft and FLEX 24 ($p = 0.010$), and between FLEX 28 and FLEX 24 ($p = 0.013$). Flex 24 preserved hearing statistically significant ($p < 0.05$)

Table 1. Max-values used for calculations.

f (Hz)	125	250	500	1k	2k	3k	4k	6k	8k
Max-value (dbHL)	90	110	115	120	120	120	120	120	115

F: frequency in Hz; dB HL: max-values in decibel hearing level.

better than flex 28, flex soft and contour advance. Flex 20 preserved hearing statistically significant ($p < 0.05$) better than contour advance (Figure 3).

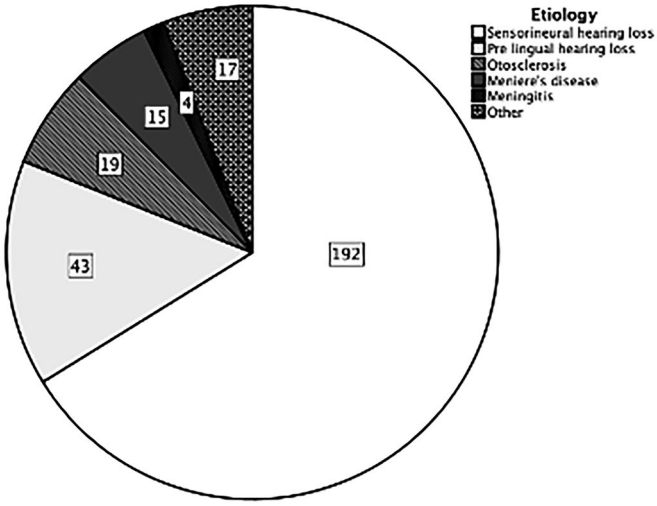

Figure 1. Etiology of the patients in this study. The number of subjects is presented in the chart.

Speech perception

In Table 3 the MS-word scores for each electrode are presented, pre-surgery measured with a hearing aid (HA) and one year post-surgery with the CI. No statistically significant difference can be found between the MS-word score post-surgery for the different electrode types. Comparing the two groups (those with pre-surgery HL at 250 Hz ≤85dB and those with pre-surgery HL at 250 Hz >85dB) yielded no statistically significant difference in the post-surgery MS-word score. The mean post-surgery MS-word score for all patients included in this study was 39.5% (range 0% to 84%). Pre-surgery the MS-word score was statistically significantly higher with the FLEX 24 than the slim straight ($p < 0.001$), contour advance ($p = 0.10$), slim modiolar ($p = 0.045$), and FLEX soft ($p = 0.004$).

Figure 4 shows the post-surgery MS-word scores for the three hearing preservation groups (minimal, partial, and complete). No statistically significant difference in the post-surgery MS-word score could be found between the groups.

Of the 290 patients, 31 were implanted using cochleostomy and the remaining 259 *via* the round window. The 31 patients who underwent cochleostomy were implanted with contour

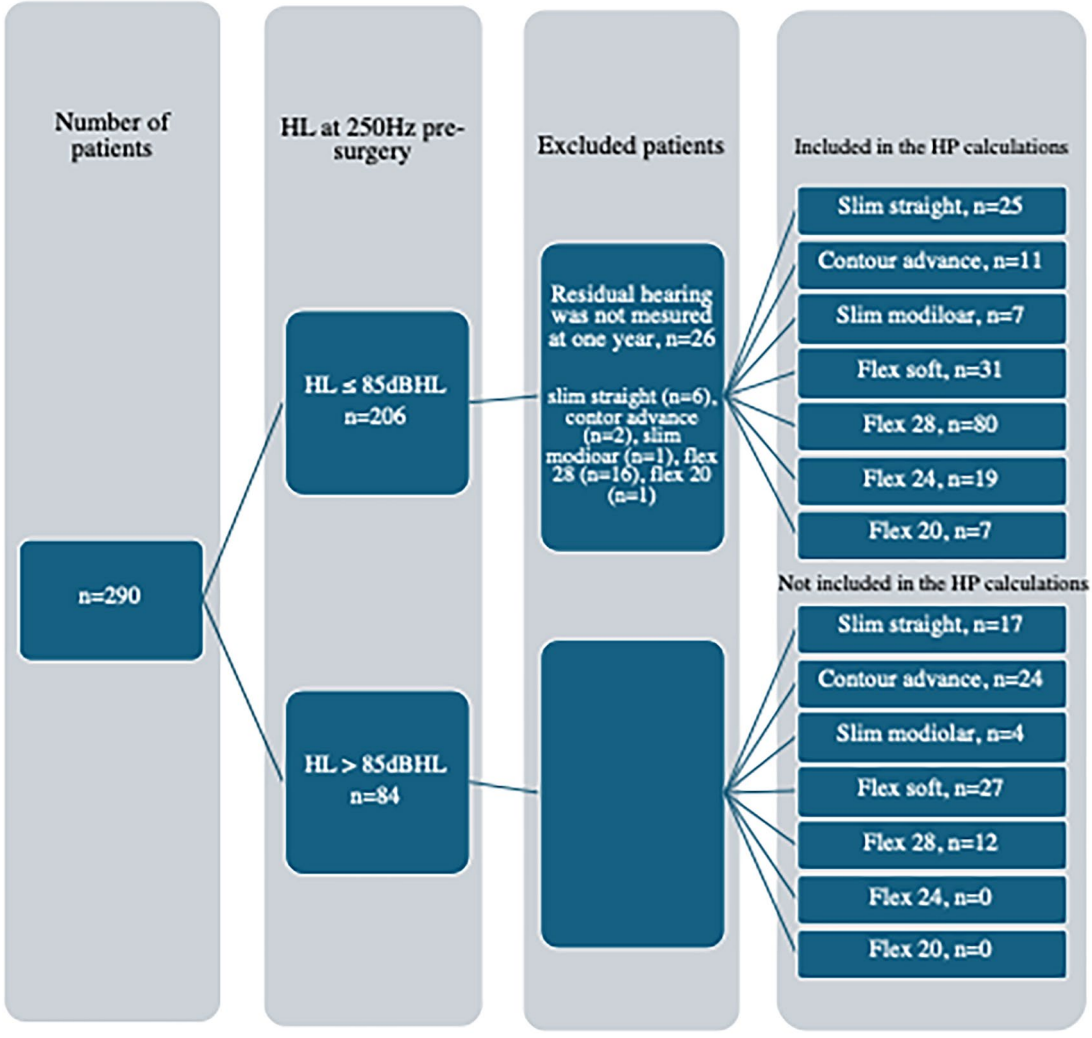

Figure 2. Patients included in the study and details of the 180 patients included in the hearing preservation (HP) analyses as well as the 110 patients not included in the HP analyses.

Table 2. The 180 patients included in analyses of hearing preservation (HP).

Electrode:	Slim straight	Contour advance	Slim modiolar	Flexsoft	Flex28	Flex24	Flex20
N:	25	11	7	31	80	19	7
PTA pre mean (dB HL):	90,84	85,96	95,40	94,21	85,28	77,81	84,21
PTA post mean (dB HL):	102,84	110,10	107,20	107,87	101,95	89,09	93,33
HP mean (%):	52,4	16,6	44,9	34,6	41,1	70,1	65,4
HP max (%):	163,6	70,8	96,6	105,6	103,8	111,3	94,4
HP min (%):	3,2	3,3	5,9	3,9	2,3	3,2	31,3
N COMPLETe:	7	0	2	6	12	8	3
N partial:	9	2	3	10	35	10	4
N minimal:	9	9	2	15	33	1	0

The table displays mean pure tone average (PTA) pre-surgery, mean PTA 1 year post-surgery, hearing preservation (HP) (mean, max and min) and degree of HP for each electrode. N indicates number of patients.

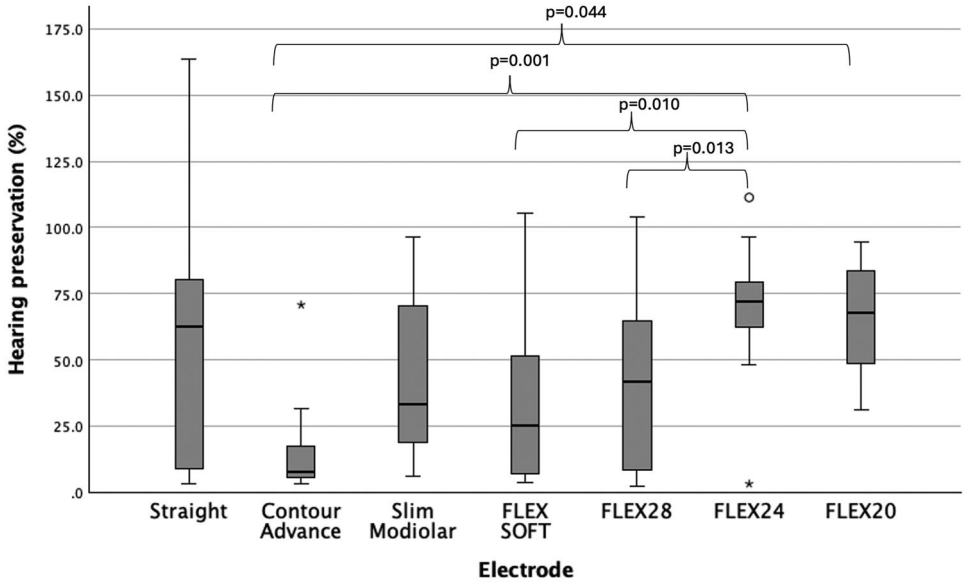

Figure 3. Hearing preservation for each electrode calculated by means of the hearing preservation formula. Statistically significant differences are highlighted. Hearing preservation above 100% indicates better postoperative hearing thresholds than preoperative hearing thresholds.

Table 3. Monosyllabic (MS) word scores pre- and post-surgery.

	Electrode:	Slim straight	Contour advance	Slim modiolar	Flexsoft	Flex28	Flex24	Flex20
Pre ≤ 85dB HL	N :	31	13	8	31	96	19	8
	MS-words Pre Mean (%)	1.5 [25]	2.1 [11]	0.8 [5]	1.1 [15]	6.8 [92]	15.6 [17]	8.4 [5]
	MS-words Post Mean (%)	34.7 [25]	29.6 [12]	51.0 [6]	39.8 [25]	39.4 [80]	40.1 [16]	44 .0 [5]
	N:	17	24	4	27	12	0	0
Pre >85dB HL	MS-words Pre Mean (%)	0 [9]	1.2 [18]	4.0 [1]	5.6 [11]	1.5 [11]	–	–
ALL	MS-words Post Mean (%)	32.0 [9]	26.8 [19]	63.0 [2]	41.2 [17]	34.3 [8]	–	–
	All patient: MS-words Pre mean (%)	1.1 [34]	1.6 [29]	1.33 [6]	3.0 [26]	6.3 [103]	15.6 [17]	8.4 [5]
	All patient: MS-words Post mean (%)	34.0 [34]	32.7 [31]	54.0 [8]	40.6 [42]	38.9 [88]	40.1 [16]	44.0 [5]

For the 206 patients with HL ≤ 85 dB HL at 250 Hz pre-surgery and the 84 patients with HL > 85 dB HL at 250 Hz pre-surgery. N indicates number of patients. N in squared brackets indicates number the valid measures included in the calculations, i.e. some patients did not attend word score measures for various reasons.

advance ($n=24$), FLEX soft ($n=4$), and FLEX 28 ($n=3$) electrodes. The etiology of these 31 patients were otosclerosis ($n=11$), meningitis ($n=2$), trauma ($n=1$), sudden deafness ($n=2$), and other ($n=15$). The mean MS-word score for the 31 patients implanted *via* cochleostomy was 40.0% (0 to 84%), which figure did not differ from the mean MS-word score of all patients in the present study. Nine out of the 31 had pre-surgery HL ≤ 85 dB and were thus included in the calculations of HP. They exhibited HP between 3.8% and 70.8%. None had complete HP, six had minimal HP, and 3 had partial HP. The 3 patients with partial HP were implanted with contour advance (2 patients) and FLEX soft (1 patient).

Discussion

The present study demonstrated that statistically, HP differed significantly for the various electrodes. However, no statistically significant difference in speech perception was found for the various electrode types or degrees of HP. One can speculate that in the present study the HP results may have been masked by the fact that two electrode types (FLEX 20 and FLEX 24) were mainly chosen for patients who had pre-surgery hearing that we aimed to preserve for post-surgery amplification. There was a statistically significant difference in favor of the shorter Med-El electrodes compared to FLEX

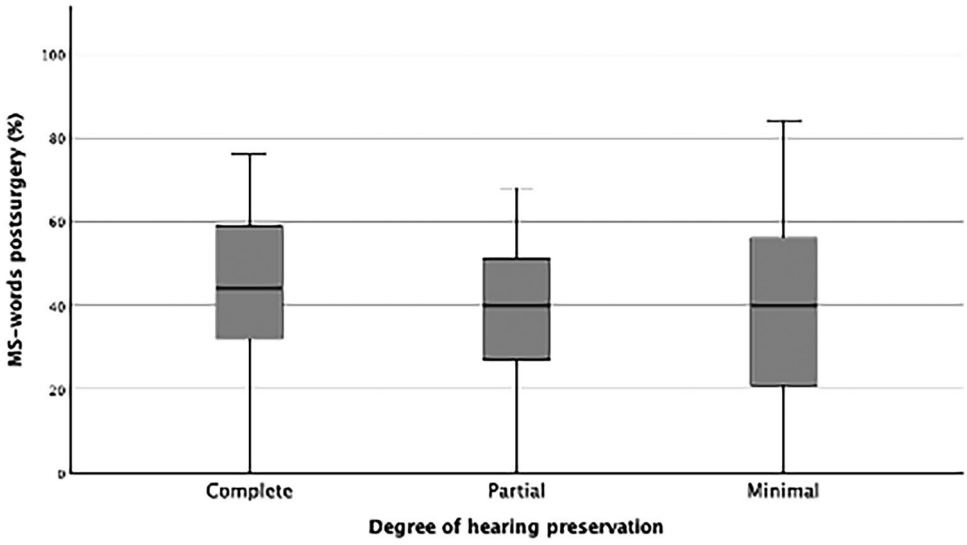

Figure 4. Hearing preservation (complete, partial or minimal) and Monosyllabic (MS) word score post-surgery.

28 or FLEX soft. However, there was no statistically significant difference in HP between the most used HP electrodes at our clinic (FLEX 20 and FLEX 24) and slim straight or slim modiolar in this study (bearing in mind that the number of slim modiolar electrodes was very low, making the result uncertain). One patient implanted with a slim straight electrode was found to have considerably better hearing post-surgery, HP 163.6%. Why that patient's hearing threshold increased to such an extent after implantation is unknown. Although it is assumed that patients always perform at their best during pre-surgery hearing assessments, we cannot rule out the possibility that some might have underperformed for various reasons, e.g. fear of not receiving a CI or having to wait for a longer time if their hearing is not poor enough, or other psychological explanations. However, even excluding the vastly improved patient from the analyses did not change the statistical results.

Like Schaefer et al. and Adunka et al. we found no difference in speech perception in a quiet environment with the various electrode types [16,17]. The results from this study show that patients gain good speech perception after CI regardless of electrode type and degree of HP. Buchman et al. compared speech results and music appreciation among patients implanted with a standard-length and a medium-length electrode from MedEl [18]. They found a trend indicating better speech perception with the longer electrode and no difference between the two electrode groups in terms of subjective benefit or music perception. In a review by Schaefer et al. it was found that low frequency HP was associated with better speech perception in noise as well as better music perception in a majority of the studies reviewed. In contrast, in their study of 478 adult patients Vohra et al. found that statistically, those implanted with perimodiolar electrodes scored significantly better in speech tests in both a quiet and a noisy environment than patients implanted with lateral wall electrodes [20].

In this study patients implanted with FLEX 24 had better speech perception pre-surgery compared to those implanted with other electrode types, with the exception of FLEX 20 and FLEX 28. This means that the speech perception of patients implanted with FLEX 24 electrodes did not improve as much as that of the other patients after CI. The reason for the better pre-surgery speech perception with the shorter Med-El electrode types is that those electrodes were chosen for patients who had good quality hearing before implantation, which we aimed to preserve for post-surgery amplification. At the time of the study only those implants were given to patients with the above-mentioned hearing characteristics at our clinic.

As we found no difference in speech perception for the various electrode types or degrees of HP, the decision about which electrode to implant boils down to the individual patient's needs and preferences. Some patients do not want an electro acoustic stimulation (EAS)/Hybrid processor for low frequency sound amplification, because they do not wish to have an earmold in their ear, despite the fact that their hearing could be amplified post-surgery. Some patients cannot bear hearing the CI-sound without the EAS/Hybrid processor, even though they have almost no, or very little, low frequency hearing that can be amplified. How the patient uses and appreciates the unaided hearing in the ear to be implanted and how he/she experiences the quality of that hearing is of great importance in patient consultations before implantation. For some preserved hearing is of no importance whatsoever, while for others it is their lifeline, which they use to hear their children at night or the rhythm in music when dancing.

In this study neither the RW nor the cochleostomy implant method seemed to affect post-surgery speech perception. The 9 of the 31 patients implanted using cochleostomy included in the HP analysis had HP from minimal (6 patients) to partial (3 patients), thus it was possible to preserve hearing in a few patients even using the cochleostomy method. In a review of 16 studies on the surgical approach (RW or cochleostomy) and HP, Havenith et al. concluded that they could find no clear benefit of one surgical approach over the other in terms of HP [21]. However, they also stated that more randomized controlled studies are necessary in which possible confounding factors, such as electrode type, are taken into account. Adunka et al.

compared HP and speech perception in 20 adult patients implanted *via* the RW or cochleostomy approach and found no statistically significant differences [22]. In a study by Elafandi et al. analyzing 200 children, 100 implanted *via* the RW and 100 implanted using cochleostomy, the researchers found that the RW approach had superior outcomes regarding speech perception, language acquisition, and speech production [23]. They speculated that the RW insertion was superior to cochleostomy due to the minimal trauma to the cochlea and significantly smaller amount of fibrosis. Structure/hearing preservation surgery may also allow CI users to benefit from future hearing restoring treatments [9].

Conclusion

Speech perception improved for most patients one year after implantation and there was no statistically significant difference due to electrode type. HP, however, showed different results depending on electrode type. In this study FLEX 24 preserved hearing statistically significantly better ($p < 0.05$) than FLEX 28, FLEX soft, and contour advance, while FLEX 20 preserved hearing statistically significantly better ($p < 0.05$) than contour advance. The result of this study contributes important information regarding HP and speech perception that will be used for pre-surgery patient counselling at our clinic.

Ethical approval

The study was approved by the Swedish Ethical Review Authority (2023-07049-02) without the need for informed consent.

Disclosure statement

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this paper.

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