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Research Article

Hearing Performance Improves Over Time Using Long Flexible Electrode Arrays in Slovak Speaking Cochlear Implant Users

Bercikova B[1], Kabatova Z[1], Varga L[1], Simkova L[2], Groma M[2] and Profant M[1]*

[1]Faculty of Medicine, Comenius University Hospital in Bratislava, Bratislava, Slovakia

[2]University Hospital Bratislava, Slovakia

***Corresponding Author:** Profant M, Professor, Faculty of Medicine, Comenius University Hospital in Bratislava, Bratislava, Slovakia.

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Abstract

Background: Many cochlear implant (CI) users struggle to obtain speech understanding, particularly pre-lingually deafened CI users, and the relationship between audiological performance and insertion depth is not established.

Aims: To determine audiological performance in Slovak CI users using a long flexible electrode.

Materials and Methods: Tone and speech audiometry at 1- and 5-years after CI surgery; and monosyllable word testing.

Results: Post-lingual onset of deafness CI users performed better than pre-lingual in tone audiometry after 1-year (except 250Hz) and in speech audiometry. Tone audiometry at 1-year predicted speech audiometry at 5-years in pre-lingually deafened CI users; and the speech audiometry in post-lingual at 1- and 5 years. Tone audiometry at 5-years predicted speech audiometry at 5-years. Tone audiometry at 1- and 5-years predicted the monosyllable word score in post-lingual onset of deafness CI users. In general, post-lingual onset of deafness CI users had more monosyllables correct. The pre-lingual onset of deafness CI user's monosyllable word score was predicted by duration of deafness, but not CI use.

Conclusions and Significance:. This paper contributes to the few studies available in the Slovak language and shows that CI with a long flexible electrode improves audiological performance in pre- and post-lingually deafened CI users.

Keywords: Pre-Lingual; Post-lingual; Deafness; Monosyllabic Word Test; Tone Audiometry; Speech Audiometry; Long Electrode; Deep Insertion

Introduction

Many pre-lingual onset of deafness cochlear implant (CI) users struggle to obtain speech understanding. CI candidates with a pre-lingual or peri-lingual onset of deafness were originally considered poor CI candidates, because they performed poorly in speech understanding tests [1]. However, more recently participants with pre-lingual hearing loss, who had undergone rather late implantation, after the age of 8 years, demonstrated that they can and do achieve benefits in speech perception after cochlear implantation [2,3].

However, the relationship between audiological performance and insertion depth has not clearly been resolved. Moreover, it is not clear to which extent pre-lingual versus post-lingual CI users benefit under such conditions. Several studies have indicated that greater insertion depths are associated with better hearing outcomes [4,5]. It is thought that limiting the extent to which the electrode enters the, for instance an electrode that reaches only half the length of the organ of Corti, results in a poorly stimulated tonotopic region beyond the first and last contacts on the electrode array. With deep insertion and a long electrode extent, current spread is not needed to stimulate the tonotopic regions out of range of the first and last contacts on the electrode array [4]. Thus, deep insertion with a long electrode, is in theory, considered desirable. Furthermore, the relationship between deep insertion on long-term speech perception outcomes after several years of CI has not been determined, although it has been established that speech perception scores improve over time with CI use [6,7]. In all the aforementioned studies the subjects were either tested acutely or only up to one year post-surgery [4-6]; or subjects implanted with long electrodes were not looked at specifically [6,7].

Moreover, the studies conducted are specific to the English language. There is, to our knowledge, little if any published literature on these topics in Slovakian speaking CI users. The availability of audiology and speech and language therapy in eastern European countries is relatively poor [8].

Therefore, this retrospective study set out to ascertain, in a cohort of Slovak speaking CI users, the audiological performance of CI users implanted with a long (31.5 mm) flexible electrode. Cases were analyzed separately depending on whether they were pre- or post-lingual onset of deafness and only CI users with up to 5 years of CI use were included in this study. The comparison and improvement of services within Slovakia depends upon greater research and publication of literature on otolaryngologic health outcomes.

Methods

Subjects

All subjects implanted between 1995 and 2011, with a STANDARD electrode (MED-EL Medical Electronics) and Tempo+ or Opus audio processor (MED-EL Medical Electronics), at the University Hospital Department of Otorhinolaryngology in Bratislava, Slovakia were examined retrospectively.

Patient demographics for pre-lingual onset of deafness CI users is shown in table 1 and for post-lingual onset of deafness CI users in table 2.

Pre-lingual group					
Subject ID	**Onset of Deafness**	**Gender**	**Age**	**Implant**	**Processor**
1	Prelingual	Female	2.3	Pulsar	Opus
2	Prelingual	Male	5.4	Medel C40+	Tempo+
3	Congenital	Female	2.7	Pulsar	Opus
4	Congenital	Male	4.1	Medel C40+	Tempo+
5	Prelingual	Female	6.3	Medel C40	Tempo+
6	Prelingual	Male	2.5	Concerto	Opus
7	Prelingual	Female	26.4	Pulsar	Opus
8	Perilingual	Female	3.0	Medel C40+	Tempo+
9	Prelingual	Female	3.4	Pulsar	Opus
10	Prelingual	Male	2.5	Pulsar	Opus
11	Prelingual	Female	4.2	Medel C40+	Opus
12	Prelingual	Male	4.9	Pulsar	Opus
13	Prelingual	Male	6.3	Pulsar	Opus
14	Prelingual	Female	27.1	Pulsar	Opus
15	Prelingual	Female	3.2	Medel C40+	Opus
16	Prelingual	Male	3.9	Pulsar	Opus
17	Prelingual	Male	–	Pulsar	Opus

18	Prelingual	Female	3.8	Concerto	Opus
19	Prelingual	Female	2.4	Medel C40+	Opus
20	Perlingual	Male	6.1	Medel C40+	Tempo+
21	Prelingual	Female	2.7	Concerto	Opus
22	Prelingual	Male	3.9	Medel C40+	Opus
23	Congenital	Male	3.0	Pulsar	Opus
24	Perilingual	Female	19.8	Medel C40	Tempo+
25	Prelingual	Male	1.8	Medel C40+	Tempo+
26	Prelingual	Female	4.9	Medel C40+	Opus
27	Prelingual	Female	2.3	Sonata	Opus
28	Prelingual	Female	3.8	Pulsar	Opus
29	Prelingual	Female	8.8	Medel C40+	Tempo+
30	Prelingual	Female	2.4	Medel C40+	Tempo+
31	Prelingual	Female	3.5	Pulsar	Opus
32	Prelingual	Female	1.7	Pulsar	Opus
33	Congenital	Male	3.0	Medel C40+	Opus
34	Prelingual	Male	7.5	Medel C40	Tempo+
35	Prelingual	Male	4.1	Pulsar	Opus
36	Prelingual	Female	2.9	Concerto	Opus
37	Prelingual	Female	1.6	Pulsar	Opus
38	Prelingual	Female	2.5	Concerto	Opus
39	Prelingual	Female	2.1	Medel C40+	Opus
40	Prelingual	Male	8.1	Medel C40+	Opus
41	Prelingual	Male	5.4	Pulsar	Opus
42	Prelingual	Female	7.6	Medel C40+	Tempo+
43	Prelingual	Female	6.8	Medel C40+	Opus
44	Prelingual	Male	2.0	Sonata	Opus
45	Prelingual	Female	7.8	Medel C40+	Tempo+
46	Prelingual	Male	4.0	Medel C40+	Opus
47	Prelingual	Male	3.2	Medel C40+	Tempo+
48	Perilingual	Female	21.7	Pulsar	Opus
49	Prelingual	Female	5.2	Pulsar	Opus
50	Prelingual	Male	9.3	Pulsar	Opus
51	Prelingual	Female	24.7	Pulsar	Opus
52	Prelingual	Male	3.2	Sonata	Opus
53	Prelingual	Female	3.9	Medel C40+	Tempo+
54	Prelingual	Male	6.3	Pulsar	Opus
55	Prelingual	Female	26.4	Medel C40+	Opus
56	Prelingual	Female	2.9	Pulsar	Opus

57	Prelingual	Male	3.6	Pulsar	Opus
58	Congenital	Male	3.4	Pulsar	Opus
59	Prelingual	Male	2.9	Pulsar	Opus
60	Prelingual	Female	5.6	Medel C40+	Tempo+
61	Prelingual	Male	1.9	Sonata	Opus
62	Perlingual	Male	8.1	Medel C40+	Tempo+
63	Prelingual	Female	5.4	Pulsar	Opus
64	Prelingual	Male	2.4	Pulsar	Opus
65	Prelingual	Male	4.1	Medel C40+	Tempo+
66	Congenital	Male	6.0	Medel C40+	Tempo+
67	Prelingual	Male	2.7	Medel C40+	Opus
68	Prelingual	Male	2.4	Pulsar	Opus
69	Prelingual	Female	2.5	Medel C40+	Tempo+
70	Prelingual	Male	5.9	Medel C40+	Tempo+
71	Prelingual	Male	3.4	Pulsar	Opus
72	Prelingual	Male	22.6	Medel C40+	Opus
73	Prelingual	Female	2.1	Pulsar	Opus
74	Prelingual	Female	4.0	Medel C40+	Opus
75	Prelingual	Female	6.6	Medel C40	Tempo+
76	Prelingual	Male	6.8	Medel C40+	Tempo+
77	Prelingual	Male	2.9	Medel C40+	Opus
78	Prelingual	Male	4.1	Medel C40+	Tempo+
79	Prelingual	Male	1.7	Sonata	Opus
80	Prelingual	Female	2.8	Sonata	Opus
81	Prelingual	Male	4.8	Medel C40+	Tempo+
82	Prelingual	Male	46.0	Medel C40+	Tempo+
83	Prelingual	Female	3.8	Pulsar	Opus
84	Prelingual	Female	5.6	Medel C40+	Tempo+
85	Prelingual	Male	2.1	Medel C40+	Tempo+
86	Prelingual	Male	1.8	Pulsar	Opus
87	Prelingual	Female	5.8	Medel C40+	Tempo+
88	Prelingual	Female	58.7	Medel C40+	Opus
89	Perilingual	Female	4.8	Medel C40+	Tempo+
90	Perilingual	Female	6.8	Pulsar	Opus
91	Prelingual	Female	5.1	Pulsar	Opus

Post-lingual group					
Subject ID	**Onset of Deafness**	**Gender**	**Age**	**Implant**	**Processor**
92	Postlingual	Female	20.5	Medel C40+	Opus
93	Postlingual	Female	55.6	Pulsar	Opus
94	Postlingual	Female	–	Medel C40+	Opus
95	Postlingual	Female	42.7	Pulsar	Opus

96	Postlingual	Male	41.4	Medel C40	Tempo+
97	Postlingual	Female	41.5	Medel C40	Tempo+
98	Postlingual	Male	48.3	Pulsar	Opus
99	Postlingual	Female	32.0	Medel C40+	Opus
100	Postlingual	Female	36.2	Pulsar	Opus
101	Postlingual	Male	14.4	Medel C40	Tempo+
102	Postlingual	Male	48.3	Medel C40+	Tempo+
103	Postlingual	Male	8.3	Pulsar	Opus
104	Postlingual	Female	8.9	Pulsar	Opus
105	Postlingual	Female	48.7	Medel C40	Tempo+
106	Postlingual	Male	36.6	Concerto	Opus
107	Postlingual	Female	39.2	Pulsar	Opus
108	Postlingual	Male	39.3	Medel C40+	Tempo+
109	Postlingual	Male	34.6	Medel C40+	Tempo+
110	Postlingual	Female	7.0	Pulsar	Opus
111	Postlingual	Female	5.2	Pulsar	Opus
112	Postlingual	Female	34.3	Medel C40	Tempo+
113	Postlingual	Male	48.8	Medel C40+	Tempo+
114	Postlingual	Male	56.7	Pulsar	Opus
115	Postlingual	Male	14.3	Medel C40+	Opus
116	Postlingual	Male	24.4	Pulsar	Opus
117	Postlingual	Male	38.9	Medel C40+	Tempo+
118	Postlingual	Female	70.1	Medel C40+	Opus
119	Postlingual	Male	30.7	Medel C40	Tempo+
120	Postlingual	Male	23.0	Medel C40+	Tempo+
121	Postlingual	Male	9.7	Medel C40	Tempo+
122	Postlingual	Male	50.9	Medel C40+	Tempo+
123	Postlingual	Male	68.2	Pulsar	Opus
124	Postlingual	Male	9.4	Pulsar	Opus
125	Postlingual	Male	46.1	Medel C40+	Opus
126	Postlingual	Male	39.9	Medel C40	Tempo+
127	Postlingual	Female	39.1	Medel C40	Tempo+
128	Postlingual	Female	26.5	Medel C40	Tempo+
129	Postlingual	Female	52.2	Sonata	Opus
130	Postlingual	Female	27.1	Pulsar	Opus
131	Postlingual	Female	31.6	Medel C40+	Opus
132	Postlingual	Male	52.9	Medel C40+	Tempo+
133	Postlingual	Male	62.8	Medel C40+	Tempo+
134	Postlingual	Male	66.6	Pulsar	Opus
135	Postlingual	Male	15.2	Pulsar	Opus
136	Postlingual	Male	23.0	Pulsar	Opus
137	Postlingual	Male	14.1	Sonata	Opus
138	Postlingual	Female	17.8	Medel C40+	Opus
139	Postlingual	Male	46.7	Medel C40+	Tempo+
140	Postlingual	Female	11.7	Medel C40+	Opus

All tests were conducted at the University Hospital Department of Otorhinolaryngology in Bratislava, Slovakia, according to ISO standards.

Tone audiometry

Tone audiometry in the free field was performed using a clinical audiometer (Interacoustics AC40), which is regularly controlled and calibrated in the free field condition. Sound was presented from a single loudspeaker directly in front of the patient. The tone audiometry room was sound-proofed. Tone audiometry was evaluated at 250, 500, 1000, 2000, 4000 and 6000 Hz. The average tone audiometry was calculated as the mean at 500, 1000, 2000, and 4000 Hz.

Speech audiometry

The test set up for speech audiometry was the same as for the tone audiometry. The test administered in Slovak consisted of 10 groups of words. Each group contained 10 words (46 phonemes). The test was performed with a signal to noise ratio of 60/50dB at 1 and 5 years after CI surgery. This test is considered of moderate difficulty in the Slovakian language. Slovak speech audiometry (SSA) contains mono, bi and trisyllabic words phonetically balanced. The speech audiometry test is calibrated against a normal curve, i.e. 'normal' hearing adults.

Monosyllabic word testing

The T1SS test, administered in Slovak, consists of 10 groups of 20 words. Each group contains 19 nouns, 1 adverb, and 1 cardinal number. In each group there are 60 phonemes altogether; 12 words containing 3 phonemes and 8 words containing 4 phonemes. Each phoneme is presented at the same rate as normal in the Slovak language. The test was performed with a signal to noise ratio of 60/50dB. The monosyllabic test (T1SS) is calibrated against a normal curve, i.e. 'normal' hearing adults. This test is considered the most difficult in the Slovakian language. The T1SS test has only been in use since 2000 and was administered to some patients retrospectively at routine clinical follow up or new patients at the time of CI testing.

Analyses

Descriptive statistics were used to describe the demographic data. Quantitative data are shown graphically as mean and standard deviation or range (min. and max.).

Paired sample t-tests were performed to analyze the differences between pre- and post-lingually implanted subjects, and to analyze the differences between the test intervals. (1- vs. 5-years) after CI surgery on the tone audiometry and speech audiometry tests. A p-value of less than or equal to 0.05 was considered statistically significant. The mean tone audiometry was calculated as the average of all the frequencies (500-4000 Hz). Is Regression analyses was performed to determine if: 1) tone audiometry at 1- and 5 years was a significant predictor of monosyllable word scores or speech audiometry; 2) the duration of deafness was a significant predictor of monosyllable word scores; and, 3) the duration of CI use was a significant predictor of monosyllable word scores.

Results

Subjects

One hundred and forty subjects/ears were included in this retrospective analysis. Two subjects were implanted on both ears, therefore 138 CI users (71 males, 67 female) were included in this study; 91 CI users with pre-lingual deafness (81 pre-lingual, 6 congenital, and 4 peri-lingual), and 47 with post-lingual deafness. The mean age of the pre-lingual group (n = 91 ears) at implantation was 6.8 years (min. 1.6, max. 58.7) and the mean age of the post-lingual group (n = 49 ears) at implantation was 34.6 years (min. 5.2, max. 70.1). The cumulative mean age of all the CI users at implantation was 16.5 years (min.1.6, max 70.1).

Tone audiometry

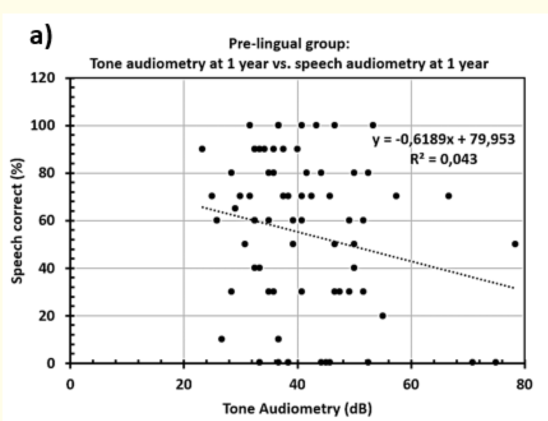
The pre-lingual group had a significant improvement on their hearing thresholds across all the frequencies tested between 1 and 5 years after CI surgery ($p < .001$ at 250-, 500-, and 1000 Hz; $p = .002$ at 2000 Hz; $p = .009$ at 4000 Hz; and, $p = .005$ at 6000 Hz) (Figure 1). The post-lingual group had a significant improvement on their hearing thresholds at 250 Hz between 1 and 5 years after CI surgery ($p = .003$) and at 500Hz between 1 and 5 years after CI surgery ($p = .031$) (Figure 1).

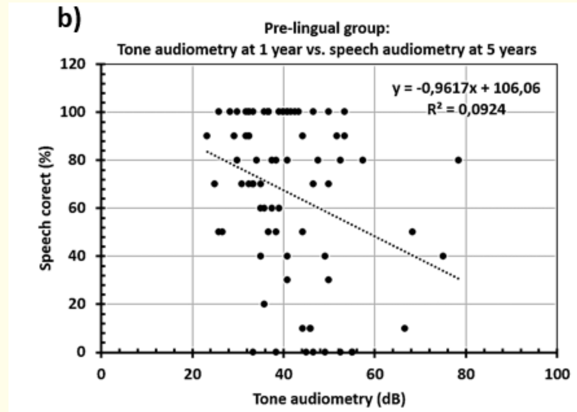
The post-lingual group had significantly better hearing thresholds 1 year after CI surgery than the pre-lingual group 1 year after CI surgery on all frequencies; except at 250 Hz ($p < .001$ at, 500-, 1000 Hz, and 2000Hz; $p = .009$ at 4000 Hz; and, $p = .007$ at 6000 Hz). The post-lingual groups' hearing thresholds 5 years after CI surgery were not significantly different to the pre-lingual

Figure 1: Tone audiometry at 1- and 5-years after cochlear implant surgery, in CI users with either pre- or post-lingual onset of deafness. A lower score indicates better comprehension.

groups' hearing thresholds 5 years after CI surgery (all frequencies) (Figure 1). However, there was a trend towards an improvement in the post-lingual groups hearing thresholds compared to the pre-lingual groups' 5 years after CI surgery (Figure 1).

The average tone audiometry of the pre-lingual group at 1-year was not a significant predictor of the speech audiometry of the CI users at 1-year (Figure 2a). The average tone audiometry of the pre-lingual group at 1- year was a significant predictor of the speech audiometry of the CI users at 5-years ($p = .020$) (Figure 2b). The average tone audiometry of the pre-lingual group at 5-years was a significant predictor of the speech audiometry of the CI users at 5-years ($p < .001$) (Figure 2c).





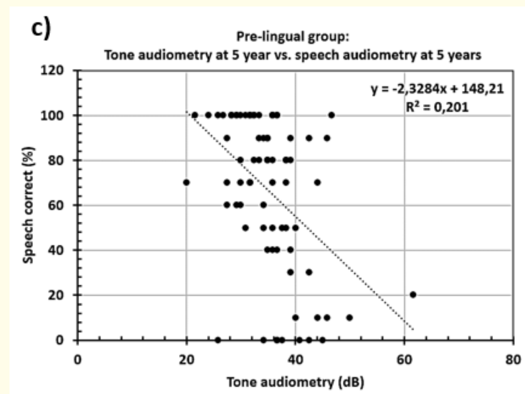


Figure 2: a) Tone audiometry 1- year after CI surgery in CI users with a pre-lingual onset of deafness versus speech audiometry 1-year after surgery in CI users with a pre-lingual onset of deafness; b) Tone audiometry 1-year after CI surgery in CI users with a pre-lingual onset of deafness versus speech audiometry 5-years after surgery in CI users with a pre-lingual onset of deafness; and, c) Tone audiometry 5-years after CI surgery in CI users with a pre-lingual onset of deafness versus speech audiometry at 5-years after surgery in CI users with a pre-lingual onset of deafness.

The average tone audiometry of the post-lingual group at 1- year was a significant predictor of the speech audiometry of the CI users at 1-year ($p < .001$) (Figure 3a). The average tone audiometry of the post-lingual group at 1- year was a significant predictor of the speech audiometry of the CI users at 5-years ($p < .001$) (Figure 3b). The average tone audiometry of the post-lingual group at 5-years was a significant predictor of the speech audiometry of the CI users at 5-years ($p < .001$) (Figure 3c).

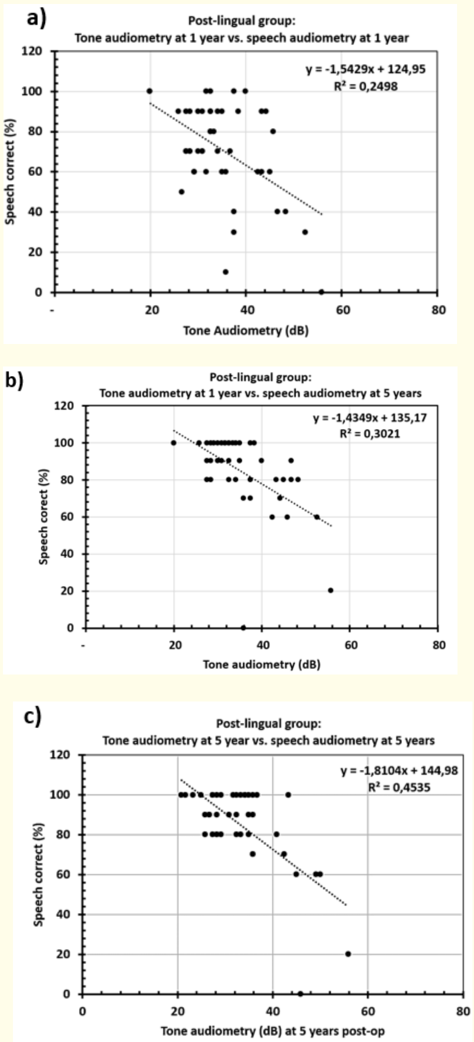


Figure 3: a) Tone audiometry 1- year after CI surgery in CI users with a post-lingual onset of deafness versus speech audiometry 1-year after surgery in CI users with a post-lingual onset of deafness; b) Tone audiometry 1-year after CI surgery in CI users with a post-lingual onset of deafness versus speech audiometry 5-years after surgery in CI users with a post-lingual onset of deafness; and, c) Tone audiometry 5-years after CI surgery in CI users with a post-lingual onset of deafness versus speech audiometry at 5-years after surgery in CI users with a post-lingual onset of deafness.

The average tone audiometry of the pre-lingual group at 1-year was not a significant predictor of the percentage of words scored correct in the monosyllabic word test by CI users (Figure 4a).

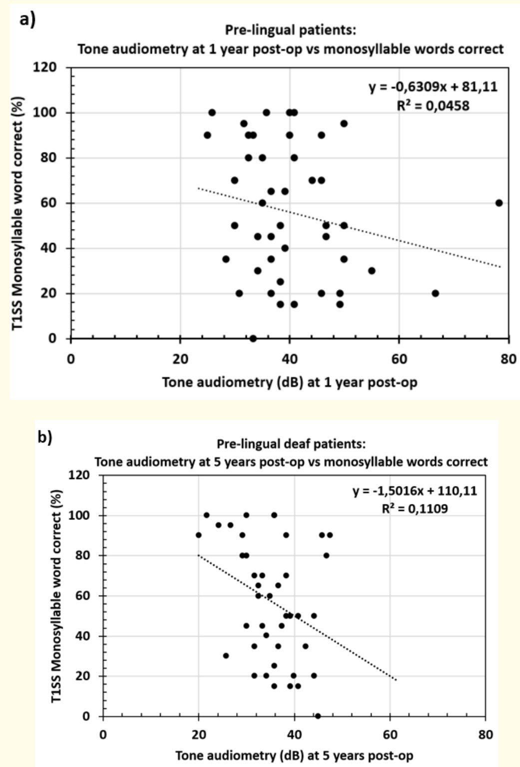


Figure 4: a) Tone audiometry 1- year after CI surgery in CI users with a pre-lingual onset of deafness versus monosyllable word test percentage correct in CI users with a pre-lingual onset of deafness; and, b) Tone audiometry 5- years after CI surgery in CI users with a pre-lingual onset of deafness versus monosyllable word test percentage correct in CI users with a pre-lingual onset of deafness.

The average tone audiometry of the pre-lingual group at 5-years was not a significant predictor of the percentage of words scored correct in the monosyllabic word test by CI users (Figure 4b).

The average tone audiometry of the post-lingual group at 1-year was a significant predictor of the percentage of words scored correct in the monosyllabic word test by CI users ($p = .003$) (Figure 5a).

The average tone audiometry of the post-lingual group at 5-years was a significant predictor of the percentage of words scored correct in the monosyllabic word test by CI users ($p < .001$) (Figure 5b).

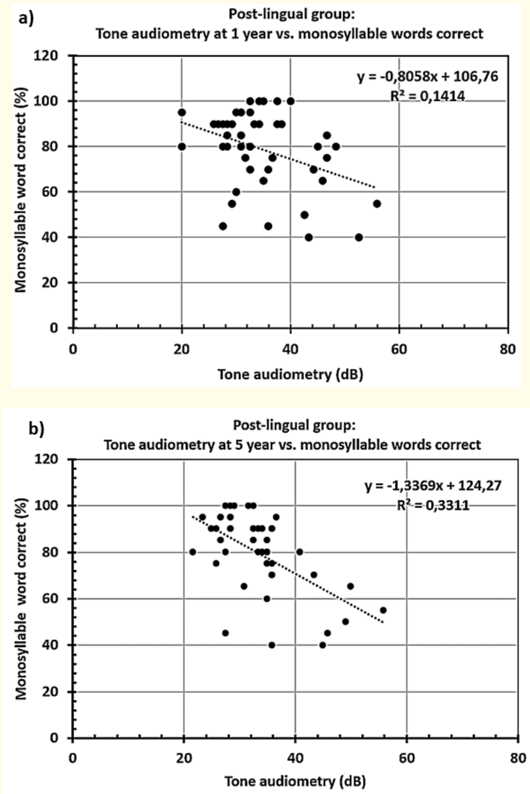


Figure 5: a) Tone audiometry 1- year after CI surgery in CI users with a post-lingual onset of deafness versus monosyllable word test percentage correct in CI users with a post-lingual onset of deafness; and, b) Tone audiometry 5- years after CI surgery in CI users with a post-lingual onset of deafness versus monosyllable word test percentage correct in CI users with a post-lingual onset of deafness.

Speech audiometry

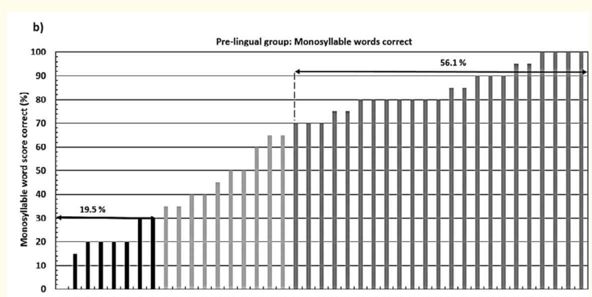
The pre-lingual group had a significant improvement in their speech audiometry between 1 and 5 years after CI surgery ($p < .001$) (Figure 6). The post-lingual group had a significant improvement speech audiometry test between 1 and 5 years after CI surgery ($p = .007$) (Figure 6).

The post-lingual group performed significantly better in their speech audiometry 1 year after CI surgery than the pre-lingual group 1 year after CI surgery ($p < .001$) (Figure 6). The post-lingual group did not perform significantly better in their speech audiometry 5 years after CI surgery than the pre-lingual group 5 years after CI surgery (Figure 6). However, there was a trend towards an improvement in the post-lingual group's percentage correct on the speech audiometry test compared to the pre-lingual groups' 5 years after CI surgery (Figure 6).

Figure 6: Speech audiometry at 1- and 5-years after cochlear implant surgery, in CI users with either pre- or post-lingual onset of deafness.

Monosyllabic word score

In the monosyllabic word test, out of all the CI users, 58.4% achieved ≥ 70% of the words correct, 12.3% achieved ≤ 30% of the words correct, and 29.3% achieved between >30 < 70% of the words correct (Figure 7a).



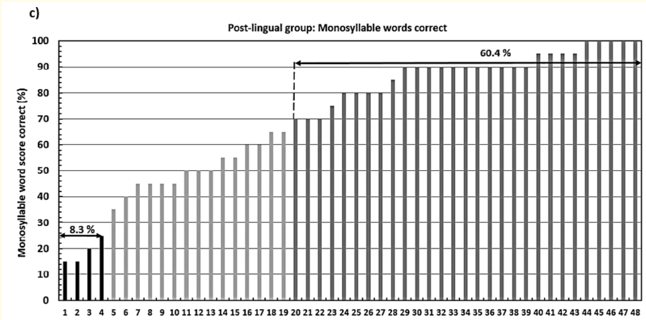


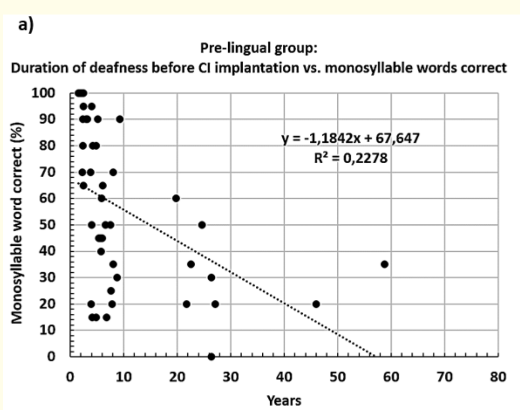
Figure 7: a) Monosyllable word test percentage correct in CI users with pre- and post-lingual onset of deafness; b) Monosyllable word test percentage correct in CI users with pre-lingual onset of deafness; and, c) Monosyllable word test percentage correct in CI users with post-lingual onset of deafness.

In the monosyllabic word test, 56.1% of the pre-lingual group achieved ≥ 70% of the words correct, 19.5% of the pre-lingual group achieved ≤ 30% of the words correct, and 24.4% achieved between >30 < 70% of the words correct (Figure 7b).

In the monosyllabic word test, 60.4% of post-lingually deafened CI users achieved ≥ 70% of the words correct, 8.3% of the post-lingual group achieved ≤ 30% of the words correct, and 31.3% achieved between >30 < 70% of the words correct (Figure 7c).

The post-lingual group tended to perform slightly better than the pre-lingual group (see Figure 7b *vs.* Figure 7c).

The duration of deafness of the pre-lingual group was a significant predictor of the percentage of words scored correct in the monosyllabic word test by CI users (p = .001) (Figure 8a).



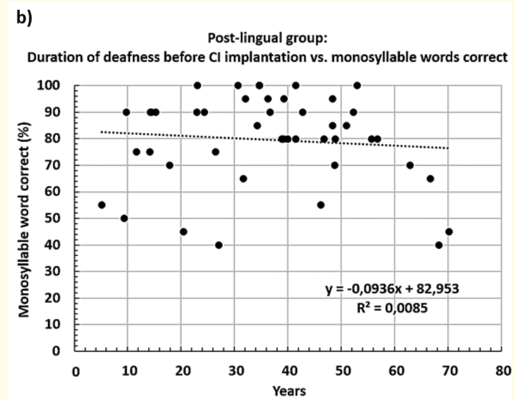


Figure 8: a) Duration of deafness in CI users with pre-lingual onset of deafness versus monosyllable word test percentage correct in CI users with pre-lingual onset of deafness; and, b) Duration of deafness in CI users with post-lingual onset of deafness versus monosyllable word test percentage correct in CI users with post-lingual onset of deafness.

The duration of deafness of the post-lingual group was not a significant predictor of the percentage of words scored correct in the monosyllabic word test by CI users (Figure 8b).

The length of time of CI usage of the pre-lingual group was not a significant predictor of the percentage of words scored correct in the monosyllabic word test by CI users (Figure 9a).

Figure 9: a) Duration of CI usage in CI users with pre-lingual onset of deafness versus monosyllable word test percentage correct in CI users with pre-lingual onset of deafness; and, b) Duration of CI usage in CI users with post-lingual onset of deafness versus monosyllable word test percentage correct in CI users with post-lingual onset of deafness.

The length of time of CI usage of the post-lingual group was not a significant predictor of the percentage of words scored correct in the monosyllabic word test by CI users (Figure 9b).

Discussion

The data presented herein showed that in Slovak speaking CI users, implanted with a 31.5 mm long flexible electrode, the overall hearing ability of post-lingual onset of deafness CI users was in general better than that of pre-lingual onset of deafness CI users. Tone audiometry to determine the hearing thresholds showed that post-lingual onset of deafness CI users scored better than CI users with a pre-lingual deafness one year after CI surgery. Pre-lingual onset of deafness CI users hearing thresholds improved significantly over time. All CI user's speech audiometry improved significantly over time, but post-lingual onset of deafness CI users tended to perform better. Similarly, post-lingual onset of deafness CI users tended to perform better on the monosyllable words test than pre-lingual onset of deafness CI users. However, it appears that pre-lingual onset of deafness CI users gain as much benefit as post-lingual onset of deafness CI users over time. Moreover, the analyses of the data showed that for the pre-lingual onset of deafness CI users their duration of deafness impacts their speech perception significantly.

Much like the prospective hearing performance of each CI user, the size of the cochlea, shape, and distribution of spiral ganglion cells of each differs [9]. This is thought to be of particular importance in CI surgery when choosing the electrode array; particularly as the anatomic conditions greatly affect the difficulty and outcomes of CI surgery [10]. However, much controversy exists regarding the significance of various electrode position factors in practice; in particular electrode insertion depth [11,12]. However, in theory, stimulating the entire length of the cochlea (frequency range) via the electrode has several benefits. When the electrode extends towards the apex of the cochlea it can provide additional low-pitched auditory percepts near the apex of the spiral ganglion, where the ganglion cells are closely grouped, which should increase the spectral information available to the CI user [12]. We believe from our own perspective that both pre- and post-lingually deafened CI users can benefit from the use of a long electrode array. Of the CI users included in the present study 92.2% had a full insertion. It is possible that the long electrode offers recipients close to natural hearing because it stimulates the entire frequency range of the cochlea. However, being a retrospective study, data collection was limited to the information that was recorded in the clinical file. Thus, we cannot exclude the effects of uncontrolled factors such as the actual insertion depth or the number of active electrodes. In general, we noticed from our analyses that the hearing ability, as determined via tone audiometry and speech perception, improved over time with the long electrode used. Tone audiometry to determine the hearing thresholds improved significantly across all the frequencies from 1 to 5 years after surgery in the pre-lingual group and showed a trend towards an improvement from 1 to 5 years after surgery in the post-lingual group of CI users implanted with the long electrode. Similarly, speech audiometry improved significantly from 1 to 5 years after surgery in both the pre- and post-lingual group of CI users with a long electrode. Likewise, Canfarotta., *et al*. has shown that in English speaking, post-lingual onset of hearing loss adult CI users, a 31.5 mm array offers superior speech recognition, when analyzed 4 years post CI activation [13].

In the present study, the post-lingual group of CI users generally performed better than their pre-lingual counterparts. After 1 year of CI use, the post-lingual group had significantly better tone audiometry compared to the pre-lingual group, except at 250 Hz. Likewise, after 1 year the post-lingual group's speech audiometry was significantly better than their pre-lingual counterparts. It is likely that the post-lingual onset of deafness CI users perform better because they have pre-implant hearing experience that enables them to accustomize to their CI sooner; or looked at alternatively, the pre-lingual group are negatively affected by their auditory deprivation in early life.

Several studies indicate that auditory deprivation, particularly in children, has negative effects on their speech perception after CI surgery [14]. Children that are implanted early reach an age-equivalent level of language understanding and have better vocabulary than those implanted later on [14]. Long term language deprivation, greater than 15 years, appears to have the most pronounced negative influence on hearing outcomes [14]. Adults aged 50 and over can even benefit from their CIs, independent of their age [15]. Older subjects show a greater improvement in post-operative sound perception in cases of shorter duration of hearing loss [15]. Nonetheless, it is unclear when CI users reach their maximum performance capacity after implantation. In our analyses post-lingual onset of deafness CI users did not perform significantly better in tone audiometry or speech audiometry compared to pre-lingual onset of deafness CI users after 5 years. Nor did post-lingual onset of deafness CI users perform significantly better over time; between 1- and 5 -years (except threshold at 250 Hz). This suggests that somewhere between 1- and 5-years they do not make a significant gain in hearing ability. Indeed, the data showed that the length of time of CI use was not a significant predictor of the percentage of monosyllable words correct in either the pre- or post-lingual group. However, the data also showed that between 1 and 5 years after implantation the pre-lingual group had a significant improvement in tone audiometry and speech audiometry. This shows that in this group of CI users given time they improve further to reach levels similar to post-lingually deafened CI users. Likewise, Sorrentino., *et al*. showed that despite auditory deprivation, where CI users had 1.6 to 58.8 years of pre-lingual deafness, the results obtained overall with a CI looked positive in many cases [16]. This may be dependent upon: the age specific audiological improvement in children [17], or the hours of CI use, i.e. wear time [18], neither of which were accounted for in this retrospective study. However, the duration of deafness of the pre-lingual group was a significant predictor of the monosyllable word score.

If we look at the percentage of monosyllables correct, we can see that a slightly greater number of CI users in the post-lingual group achieved greater than 70% of the words correct compared to their pre-lingual counterparts, and less than half the number of post-lingual onset of deafness CI users achieved less than 30% of words recognized correct compared to the pre-lingual group. Perhaps the post-lingually deafened CI users found the monosyllable test too easy at the time of testing, or the tests used was not sensitive enough to detect more modest contributions of the implant.

The CI users tone audiometry was a predictor of their performance in speech audiometry. However, the tone audiometry was a predictor of the percentage of monosyllable words identified correct for the post-lingual group; but not for the pre-lingual group 1- and 5-years after cochlear implantation. The fact that tone audiometry was not a significant predictor of the pre-lingual group's monosyllable words correct suggests that the initial delay they may encounter is not predictive of their performance. We may also have missed the predictive period in our retrospective analyses [7,19]. Hunter., *et al*. show the predictive period after CI in deaf children is between 6 to 18 months [7]; and Debruyne., *et al*. in late implanted but early deafened adults, 6 months [19]. Altogether, the data presented appears to corroborate with information provided in the literature, which indicates that CI users can 'catch up' [16,20], particularly if implanted at the 'right' age [20], but at one point all CI users are likely to plateau in their abilities. Long durations of auditory deprivation appear to be a negative prognostic factor [16], but CI outcome is frequently satisfying even if it takes more time and added rehabilitation [15,16]. Even middle aged and older adults can benefit with appropriate rehabilitation [15]. We must also consider that there is abundant evidence in the most recent literature indicating that the impact of cochlear implantation should not only be evaluated in terms of objective hearing outcomes, but also with respect to subjective changes in quality of life, which we should not underestimate.

One must also bear in mind that the tests used were specific to the Slovak language. This creates certain limitations in the comparability of studies, because the methods of evaluation are different to each other, and depend mainly on the features of the native language and quality of the provision audiology and speech and language therapy services in that geographic location [8]. While the provision of services in Slovakia is comparatively good in comparison to many Eastern Europe countries, there are 2.8 otolaryngologists per 100 000 population in Slovakia (considerably more than countries like the UK), the availability of audiology and speech and language therapy is poor [8]. Hopefully, the research and methodology presented herein will contribute considerably to further guide the improvement of the provision of otolaryngology health services in Slovakia.

Conclusion

In conclusion, the data herein shows that the audiological performance of Slovakian CI users implanted with a long flexible electrode tends to improve over time. In general, post-lingually deafened CI users perform better than pre-lingually deafened CI users. CI users tone audiometry is a predictor of their performance in speech audiometry and the percentage of monosyllable words identified correct; except not for pre-lingual onset of deafness CI users after cochlear implantation. Overall, the post-lingual onset of deafness CI users do better at identifying the percentage of monosyllables correct. The pre-lingual onset of deafness CI user's monosyllable word score is predicted by their duration of deafness, but not their duration of CI use. There are several limitations to retrospective studies. However, this paper contributes to the small number of studies available in the Slovak language and shows that using a long electrode improves hearing ability and speech perception in both pre- and post-lingually deafened CI users.

Declarations of Interest

None.

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