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Original Article

Hearing Restoration with Cochlear Implantation in Patients Deafened after Blunt Head Trauma

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OBJECTIVES: The objective of the study was to assess the outcomes of cochlear implantation in patients deafened following blunt head trauma.

MATERIAL and METHODS: Retrospective case series review of seven patients post-lingually deafened following blunt head trauma and aided with cochlear implants. The following data were analyzed: Cause of injury, computed tomography results, surgical information, intra- and post-implantation complications, audiometric and speech perception assessment, processor mapping, and data from follow-up appointments.

RESULTS: The median age of patients at the time of cochlear implantation was 29 years. The median time elapsed between head trauma and cochlear implantation was 5.77 months (minimum 0.8 and maximum 6.73 months). The median post-implantation follow-up time was 11.97 years. No facial nerve stimulation was observed in any case. All patients significantly improved their audiology and speech perception performances within a short time following cochlear implantation and CI performance did not decrease with long-term follow-up in any case.

CONCLUSION: The results of this study showed that cochlear implantation is an effective treatment method for patients deafened following blunt head trauma.

KEYWORDS: Audiometry, cochlear implant, craniocerebral trauma, hearing loss, speech perception, temporal bone

INTRODUCTION

In case of severe-to-profound sensorineural hearing loss (SNHL) following blunt head trauma, wherein even the most powerful hearing aids are unable to solve the auditory needs of these patients, cochlear implantation appears to be the optimal solution. However, SNHL following blunt head trauma may present several unique clinical challenges. Some factors, mostly specific to head trauma, may affect the outcomes of this high-technology device [1-9].

The aim of this study was to analyze the outcomes of cochlear implantation in patients deafened following blunt head trauma.

MATERIAL AND METHODS

Study group description and parameters analyzed

This retrospective study analyzes the data of seven consecutive patients with post-lingual bilateral profound hearing loss resulting from blunt head trauma. This study was approved by the local institutional review board (AKBE/183/17) and conforms to the code of ethics of the World Medical Association (Declaration of Helsinki). No free, informed consent was needed for this study since subject's identity was not divulged. All patients underwent cochlear implantation with a multichannel cochlear implant (CI) as the primary and only hearing intervention. The following data from medical records were analyzed: Cause of injury, computed tomography (CT) results, surgical information, intra- and post-implantation complications, audiometric and speech perception assessment, processor mapping, and data from the follow-up appointments. The follow-up appointments included audiometric evaluation and speech perception tests that assisted in speech processor fitting procedure (mapping). The study analyzes data collected prior to the CI surgery, on implant activation, 1 and 12 months after, and on the last follow-up visit for each patient.

This study was presented at the 4th Polish Lithuanian ENT Congress, 7-9 September 2017, Augustów, Poland.

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In pure tone audiometry, the thresholds at 500, 1000, 2000, and 4000 Hz and a mean threshold out of a frequency range of 500-4000 Hz (pure tone average) were evaluated.

Speech perception tests performed by an experienced speech therapist included syllable discrimination: one-syllable and multi-syllable words recognition and sentence recognition (open set) without lip-reading. The speech perception tests were performed with live-voice monitoring through the sound field at the level of 70 dB SPL.

The processor fitting (mapping) was always conducted carefully for obtaining the best possible performance. A brief evaluation of patients' everyday activities and implantation influence on their lives was also performed by asking questions during the follow-up appointments. The questions referred to the following issues: (1) Auditory-verbal communication along with the perception of spoken language through the auditory sensory modality, necessity of lip-reading; (2) ability to talk on the phone using a CI; (3) interactions with household members, relatives, and friends; (4) the openness to meet new people and to go into new interactions; (5) speech perception in noisy environments; and (6) independence in everyday activities such as going out or shopping. The responses to those questions were helpful in evaluating everyday benefits of cochlear implantation in those patients.

Statistical Analysis

Statistical analysis of collected data was performed using Statistica Software Version 12 (StatSoft Inc. 2014, Tulsa, Oklahoma, USA). The data were tested for normality and parametric and nonparametric criteria. As expected, the small size of the analyzed group did not guarantee the normality of distribution and the following nonparametric tests were used: Wilcoxon signed-rank test and Friedman repeated measures analysis of variance by ranks. $p<0.05$ was considered statistically significant.

RESULTS

The most common cause of blunt head injury was a fall from height (5 out of 7 cases). Five out of seven patients experienced temporal bone fractures, two of which were unilateral and three bilateral (Figures 1 and 2); however, none of them compromised the internal auditory canal. CT scans also revealed a cerebral contusion in all cases and hematoma in two. Five patients suffered from vertigo after head trauma before implantation and facial nerve palsy was observed in four cases. None of the patients had any problems with hearing before the head trauma. Prior to cochlear implantation, five patients had presented residual hearing at low frequencies at the level of a severe loss. Residual hearing was observed bilaterally in two of those patients, while in three patients it was unilateral with the patients being deaf in the second ear. The remaining two patients were bilaterally deaf. In the auditory brainstem responses no wave V was detected in any of the patients on either side. Caloric test findings showed no response in five patients, in two on both sides, in two on the left, and in one on the right side. None of the patients underwent the promontory stimulation test.

The median age at the time of cochlear implantation was 29 years old (minimum 19.04 and maximum 44.17 years). All seven patients were males. The median time elapsing between head trauma and

Figure 1. Enlarged axial computed tomography scan of the right temporal bone (the level of the lateral semicircular canal and bone window) with visible fractures involving the vestibule and the fracture line on the squamous part.

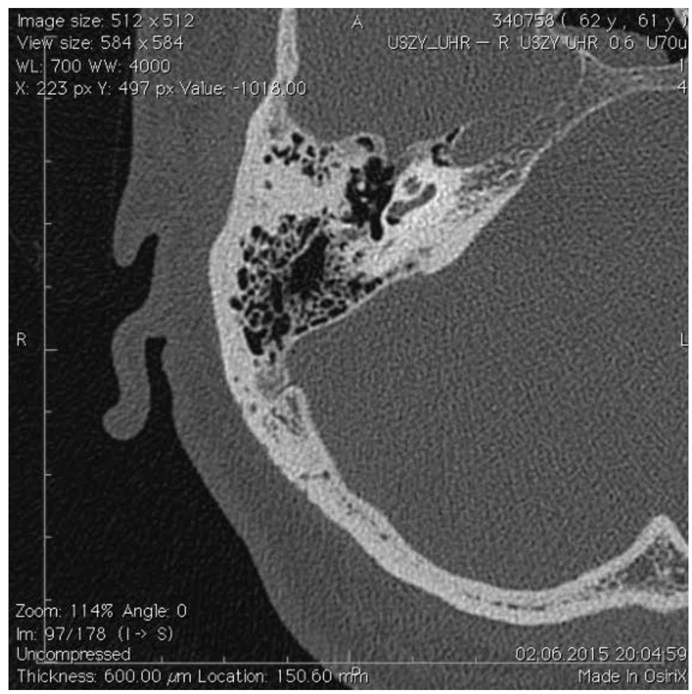

Figure 2. Enlarged axial computed tomography scan of the right temporal bone (the level of the otic capsule and bone window). Air can be seen in the basal turn of the cochlea indicating a pneumolabyrinth (black arrowhead).

the implantation was 5.77 months (minimum 0.8 and maximum 6.73 months). In all cases, the right ear was implanted with a multichannel CI. The patients received the following devices: Five patients received Cochlear Nucleus (Cochlear, Macquarie Park, Australia) and two Neurelec Digisonic SP (Neurelec, Vallauris, France, presently Oticon Medical, Askim, Sweden). After the implantation of the first ear, one patient (#1) expressed a wish to have both ears implanted and underwent sequential bilateral implantation with the time interval of nine months between the surgeries (first the right then the left ear, both Cochlear Nucleus devices). There were no difficulties while inserting the implant's electrode array in any case. There was no CI failure that required any reimplantation or removal of the device during follow up. The results presented in the following paragraphs describe

Table 1. Detailed patients' data concerning the time, etiology of trauma, Computer tomography results, facial nerve palsy, and vertigo symptoms due to trauma

Patient #	Age at CI surgery (years)	Etiology	Temporal bone fractures (CT scans)	Cochlear ossification (CT scans)	Facial nerve palsy due to trauma	Vertigo due to trauma
#1	29.00	Fall from the stairs	Bilateral transverse temporal bone fracture, cerebral contusion	No	Left	No
#2	37.83	Fall from a height	Bilateral transverse temporal bone fracture, cerebral contusion	No	Left	Yes
#3	44.17	Fall from a ladder	No visible fractures, cerebral contusion, hematoma	No	No	No
#4	24.86	Fall from the stairs	Bilateral transverse temporal bone fracture, cerebral contusion	No	Left	Yes
#5	40.10	Fall from a height	No visible fractures, cerebral contusion, hematoma	No	No	Yes
#6	24.71	Physical Assault	Left side transverse temporal Bone fracture, cerebral contusion	No	Left	Yes
#7	19.04	Car accident	Right temporal bone fractures, cerebral contusion	No	No	Yes

CI: Cochlear implant, CT: Computer tomography

Table 2. Detailed patients' data concerning pre-implantation hearing status after head trauma and cochlear implant information

Patient #	Time after trauma Vertigo due to CI surgery (months)	Pre-implantation hearing status after head trauma	Implanted device	Implanted ear	Peri- and post-implantation complications	Electrodes switched off	Follow-up time (years)
#1	0.80	Bilateral deafness	Nucleus Cochlear	Right	None	None	5.20
#2	5.07	Deaf left ear, residual hearing in the right ear at low frequencies	Nucleus Cochlear	Right	None	None	0.82
#3	5.87	Deaf right ear, residual hearing in left ear	Nucleus Cochlear	Right	None	None	13.83
#4	6.73	Residual hearing in both ears	Nucleus Cochlear	Right	None	None	1.27
#5	6.10	Bilateral deafness	Nucleus Cochlear	Right	None	5 switched off (due to high impedance and no reactions to stimulation)	16.64
#6	1.43	Deaf left ear, residual hearing in the right ear at low frequencies	Digisonic SP Neurelec	Right	None	None	11.97
#7	5.77	Residual hearing in both ears	Digisonic SP Neurelec	Right	None	None	12.77

CI: Cochlear implant

the unilateral CI aided conditions. The bilateral CI single patient results are described at the end of this section.

Detailed patient data concerning time, etiology, CT results, pre-implantation hearing status after head trauma, and implant information are presented in Tables 1-4.

The speech processors were activated (switched-on) 4 weeks after the CI surgery in all cases, followed by mapping of the device. All the patients returned to our department for regular follow-up and fitting sessions. The median post-implantation follow-up time was 11.97 years (minimum 0.82 and maximum 16.64). All patients continued to use their CI on daily basis, and none of the patients became a non-user.

All patients significantly improved their audiology and speech perception performances within a short period of time (Table 5).

Pure tone audiometry results before and after cochlear implantation (Figure 3) were compared and the findings showed a significant improvement over time ($p<0.05$).

Speech perception tests performed by speech therapists before and after cochlear implantation also presented a significant improvement

Table 3. Free field pure tone audiometry results after trauma (pre-implantation free field hearing status)

	Free field pure tone audiometry results after trauma (before cochlear implantation)								
Patient	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 HZ**	**3000 HZ**	**4000 Hz**	**6000 Hz**	**8000 Hz**
#1	NR	NR	NR	NR	NR	NR	NR	NR	NR
#2	105	110	115	115	NR	NR	NR	NR	NR
#3	85	85	100	100	100	100	100	100	110
#4	70	80	80	80	85	85	90	80	80
#5	NR	NR	NR	NR	NR	NR	NR	NR	NR
#6	75	80	90	100	115	115	NR	NR	NR
#7	95	100	110	100	115	120	125	NR	NR

NR: No response

Table 4. Statistics concerning age at CI surgery, time which elapsed between head trauma and implantation, and follow-up time

	mean	SD	median	min	max
Age at CI surgery (years)	31.39	8.67	29.00	19.04	44.17
Time after trauma to CI surgery (months)	4.54	2.22	5.77	0.80	6.73
Follow-up time (years)	8.93	5.92	11.97	0.82	16.64

CI: Cochlear implant, SD: Standard deviation

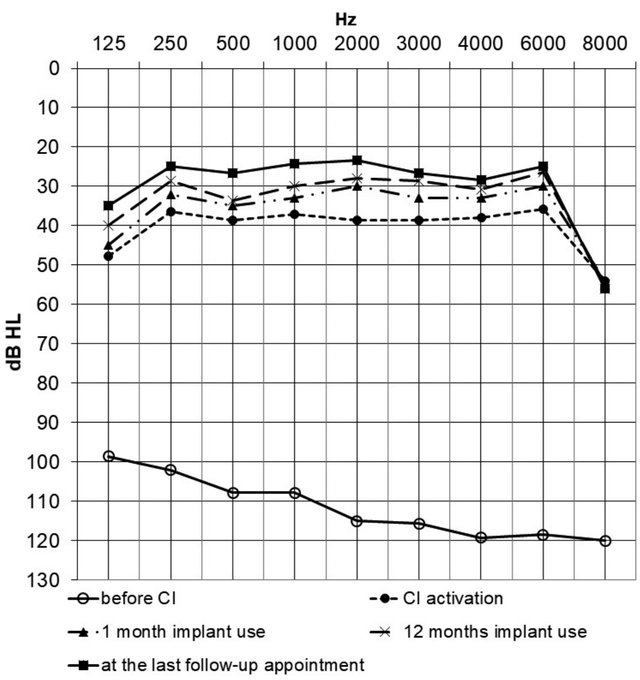

Figure 3. Pure tone audiogram before and after cochlear implantation showing a rapid improvement of results after implantation.

($p<0.05$) over time (Table 5). Before implantation, no patient was able to recognize any of the syllables or sentences in the open set tests. After the CI surgery, the results improved quickly over time.

On implant activation, one-syllable word recognition was 0%, multi-syllable word recognition 0%, and sentences recognition 0%. After 1 month, the scores in speech perception tests increased reaching the median of 70%, 80%, and 100%, respectively. After 12 months, the scores improved, even more, reaching the median of 80%, 100%, and 100%, respectively. Table 5 presents the average, median, and minimum and maximum speech perception test results on implant activation, 1 and 12 months after CI.

The CI provided all patients with great help in communication. The patients demonstrated a very good perception of spoken language without any help of lip reading (through the auditory-sensory modality only) with only one who occasionally required support via lip reading. All patients were able to have a conversation with a little help of lip reading in noisy environments, which indicated background noise difficulties in everyday life conversations. Five of the seven patients were able to have conversations on the phone. All the patients became everyday users of their implants. CI performance did not decrease with time in any case.

No intra- or post-surgical complications were observed, and all the patients had an uneventful recovery. None of the patients experienced facial nerve stimulation. Five patients suffered from vertigo due to head trauma before CI surgery. They were scheduled for postural rehabilitation. In four cases, vertigo diminished with time; however, it did not subside, and in one patient dizziness remained at the same level.

In one patient (#5), 5 electrodes had to be switched off due to high impedance and no response to electrical stimulation even to high current. These were the electrodes located in the basal turn of the cochlea, which most probably influenced the patient's hearing performance. He was the only patient who did not reach the 100% score in multi-syllable word and sentence recognition tests after 12 months of CI use and later with time and was unable to have a conversation on the phone. He scored 90% and 90%, respectively, and according to his statements he was satisfied with those results and decided not to undergo reimplantation.

One patient expressed a wish for bilateral implantation and underwent a sequential procedure. Even after a long-time follow-up, lasting 5.2 years in his case, speech perception in noisy environments with two CIs on still presented a problem. Therefore, he required little support from lip reading as with one implant before. However, sound localization improved.

DISCUSSION

Profound SNHL may be one of the results following head trauma. It may be associated with cochlear concussion and/or temporal bone

Table 5. Post-operative average, median, minimum and maximum speech perception tests results on implant activation, 1 and 12 months after CI

	On implant activation (7 patients)				1 month after CI (7 patients)				12 months after (6 patients)			
Speech perception test	**Average**	**Median**	**Minimum**	**Maximum**	**Average**	**Median**	**Minimum**	**Maximum**	**Average**	**Median**	**Minimum**	**Maximum**
One-syllable word recognition (% score)	0	0	0	0	61.43	70	30	70	83.33	80	60	100
Multi-syllable word recognition (% score)	0	0	0	0	75.71	80	60	80	98.33	100	90	100
Sentence recognition (% score)	0	0	0	0	94.29	100	60	100	98.33	100	90	100

CI: Cochlear implant

fracture [1-4] that may result in the destruction followed by the degeneration of hair and supporting cells in the organ of Corti and the degeneration of ganglion cells [5, 6]. In time, blunt head trauma may also result in the ossification of the cochlea, primarily affecting the basal turn of the scala tympani, especially when there are temporal bone fractures that involve the otic capsule [1, 7-9]. It may lead to difficulties with the insertion of the CI electrode array [3, 7]. From this perspective, early cochlear implantation would provide less time for ganglion degeneration and increase a chance for successful hearing rehabilitation with the device. In addition, in case of possible cochlear osteoneogenesis later in life, early CI surgery creates a greater probability of successful full electrode insertion [2, 4, 10, 11]. In the literature, the authors suggest that the ossification of the cochlea in case of transverse temporal bone fracture is possible; however, even with no signs of the cochlear ossification in CT scans there may be some obstruction within the basal turn of the cochlea [10] which was described in their case report by Shin et al. [3] The authors did not achieve the full implant electrode insertion with two contact points being left out due to the resistance. Similar difficulties with the insertion were reported by Camilleri et al. [7] due to which their two cases underwent partial insertion. All patients in this study underwent the implantation of a short period of time after the head trauma with the shortest being 4 weeks and the longest 6.73 months. Five of them presented temporal bone fractures (three bilateral and two unilateral), and in four cases, the CI was inserted on the side with fractures present. In all four patients, otolaryngology surgeons encountered no difficulty regarding the full insertion of the CI electrode array, and there was no need to switch off any of the electrodes. Blunt head trauma may also result in hearing loss without any evidence of temporal bone fracture, [4] which was the case in two out of seven presented patients. There was no problem with full electrode array insertion in those cases as well.

Regarding other surgical complications of cochlear implantation in the present study, we did not observe any intra- nor post-operative problems. However, it should be kept in mind that complications may happen in such patients with prior head trauma, especially with temporal bone fractures [4, 12]; that is, cerebrospinal fluid leakage or meningitis.

The role of the promontory stimulation test as the candidacy criterion for CI is still discussed, according to reported results. Some of the authors in the literature state that a positive test result correlates with very good CI outcomes; however, the others state that a negative response (absence of the response) does not necessarily indicate a discontinuity or absence of cranial nerve VIII and its function [13, 14]. In the present study, no patient underwent the promontory stimulation test.

The results of this study demonstrate that cochlear implantation in patients deafened due to head trauma improved hearing and speech perception ability. All the analyzed patients presented very good results. According to their statements, they could not imagine a life without the device. Adaptation to the new mode of hearing with CI took them a short time. Most of the patients started to notice a difference on activation of the implant that provided the restoration of sound detection. After 1 month of implant use, all patients were able to start verbal communication using the implant with quick progress over the next few months. Their hearing outcomes and speech perception improved dramatically and did not decrease with long time passing from the implantation. The results of this study support those presented in the literature on this topic, both in case series articles that usually present a small number of patients; that is, Camilleri et al. [7] seven; Serin et al. [9] five; Greenberg et al. [8] eleven; Hagr [15] five; Vermeire et al. [16] four; or Medina et al. [4] eleven patients, as well as the present paper (in this study we analyzed the data of seven patients), and in case reports concerning one patient outcome [2, 3, 11, 17].

Another complication that may occur in CI patients after head trauma is facial nerve stimulation which may be solved by mapping adjustments of the responsible channels but in some cases, the CI has to be removed [7]. However, it is a rare complication in those patients and most authors, including our study, report no evidence of nerve VII stimulation by CI [4, 8, 9, 15, 16].

As demonstrated in this study, CIs in deafened patients after head trauma are of great help in communication with other people and returning to everyday life activities. The CI provided the possibility of verbal communication with other people, and being able to have phone conversations proved it without a doubt. Without an implant, those patients would be dependent on their family members, friends or others in their verbal communication.

Patients with unilateral CI frequently report difficulties with speech understanding in noisy environments, which was the issue reported by all patients in this study as well. As shown in the literature, bilateral CIs provide advantages over unilateral in those environments [18, 19]. In the present study, one patient expressed a wish for bilateral implantation and underwent a sequential procedure. However, even after a long time (5 years of follow-up) with both implants, he was still unable to overcome those problems. This is a disappointing result, but notably the patient's sound localization improved. Vermeire et al. [16] described a similar problem with one of their patients who underwent sequential bilateral cochlear implantation after head trauma.

CONCLUSION

The results of this study showed that cochlear implantation in deafened patients after head trauma provided great and quick improvement in auditory performance, speech perception skills, and communication ability. It is one more piece of evidence that CI is indeed a successful hearing restoration method in deafened patients including those deafened due to head trauma. This group of patients is not homogeneous when it comes to the extent of damage caused by head trauma meaning the presence of temporal bone fractures, cerebral contusion, or intracranial hemorrhage as shown in our study; however, they all suffered from deafness, and the intragroup post-implantation results did not vary. The results of this study support cochlear implantation as very effective treatment modality for patients with deafness resulting from head trauma.

Ethics Committee Approval: Ethics committee approval was received for this study from the ethics committee of Medical University of Warsaw (AKBE/183/17) and conforms to the code of ethics of the World Medical Association (Declaration of Helsinki).

Informed Consent: Informed consent was not needed for this study since subject's identity was not divulged.

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