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Original Article

Surgical Methods and Auditory Outcomes of Cochlear Implantation in Cochlear Ossification

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BACKGROUND: The aim of this study was to evaluate the surgical and auditory outcomes of cochlear implantation in patients with cochlear ossification.

METHODS: This study comprised 54 patients with cochlear ossification who underwent cochlear implantation in the cochlear implant center of a tertiary care hospital between January 1998 and May 2019. Clinical data were evaluated including surgical findings and audiological performances. The auditory outcomes of the implanted patients were assessed through the Categories of Auditory Performance-II test and Speech Intelligibility Rating test, respectively. The outcomes of patients with cochlear ossification were compared with those of 54 patients selected for the control group who underwent implantation with no cochlear ossification.

RESULTS: Auditory outcomes were comparable between the study group and the control group. The control group obtained significantly higher scores than those of the study group when compared using the Categories of Auditory Performance-II test and Speech Intelligibility Rating test batteries. Patients with meningitis produced poorer outcomes within the group comparisons of the study group. None of the patients experienced surgical complications. The extent of ossification was analyzed in terms of its effectiveness on audiological performance. Patients with complete ossification had significantly lower Categories of Auditory Performance-II and Speech Intelligibility Rating test scores.

CONCLUSION: Cochlear implantation is a safe and beneficial procedure, even in patients with cochlear ossification. The ossified cochlea may require varied drill techniques beyond traditional implantation surgery for the insertion of the electrode array. It is, however, still difficult to predict audiological outcomes in patients with cochlear ossification.

KEYWORDS: Cochlear implantation, cochlear ossification, electrode array insertion, hearing loss

INTRODUCTION

Cochlear ossification is a pathological condition characterized by new bone formation after an inflammatory or devastating process within the perilymphatic spaces of the cochlea.[1] Most often, cochlear ossification is a result of infection, which can spread through tympanic, hematogenous, or meningeal sources.[2] When the infection reaches the cochlea from these sources, the cochlear fluids are invaded by pathogenic agents. This causes an acute inflammatory response, marking the beginning of the acute stage of inflammation.[3] Inflammation and the subsequent fibrosis result in ossification, which is characterized by new bone formation within the cochlear structures.[4] The hair cells and the organ of Corti may be damaged and eventually sensorineural hearing loss occurs.[5]

Neo-ossification is mostly confined to the round window (RW) and proximal scala tympani. It may progress within the cochlear lumen and cause partial or total obliteration of the lumen.[6] The extent of ossification varies depending on the causal factors, which have been reported as otosclerosis, inflammation, trauma, ototoxic medications, leukemia, temporal bone tumors, and autoimmune and idiopathic processes.[7] Cochlear ossification can manifest itself within the initial weeks of infection in aggressive cases of meningitis; however, the spreading of otosclerotic foci, resulting in cochlear otosclerosis, may take a long time.[8]

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It is a pressing concern that new bone formation may lead to a non-patent cochlear lumen, which could make it difficult to insert an electrode array during cochlear implantation (CI).[9] Therefore, modified surgical techniques such as cochlear drilling to a different extent or insertion of the electrode array into the scala vestibule need to be adopted to provide sufficient electronic stimulation to the spiral ganglion cells.[10,11] The postoperative performance results of CI in patients with ossified cochlea have been evaluated by many different authors; however, the outcomes obtained are still controversial.[12-15]

The aim of this study was to evaluate the surgical and auditory outcomes of CI in cochlear ossification and to share our experiences related to this type of surgery.

METHODS

This study included cochlear implant recipients who underwent CI with cochlear ossification in our tertiary referral center. The study protocol was approved by the ethics committee of Bozyaka Training and Research Hospital and informed consent was obtained from all participants (January 30, 2019, Decision number: 4).

All patients had a postlingual hearing loss because the study excluded children with postmeningitic prelingual deafness, for which information can be obtained from our related publication.[16] All patients were diagnosed using pure tone audiometry and auditory brainstem response. High-resolution computed tomography and magnetic resonance imaging of the temporal bone of the patients were performed to clarify the inner ear anatomy, cochlear nerve integrity, patency of the cochlear lumen, and ossification degree.

Surgical records were reviewed to determine the extent of drilling necessary for obtaining a patent cochlear lumen, the degree of ossification present in the scala vestibuli, the surgical technique used for electrode insertion, the extent of electrode insertion (complete/partial), intraoperative complications, and if any, information on facial nerve injury. All patients included in the study were followed up for at least 3 years, beginning from implant activation.

The control group comprised 54 patients who underwent CI in our institute due to bilateral severe-to-profound hearing loss. Patients in the control group were comparable in age at implantation (±1 year) with the study group patients. They had postlingual hearing loss and normal inner ear anatomy. They had electrodes fully inserted into the scala tympani without further drilling procedures.

Surgical Procedure

All procedures were conducted under general anesthesia at the same institution. The retroauricular approach was adopted using a conventional incision for CI. Subsequently, the cochlea was observed after a mastoidectomy via posterior tympanotomy in the facial recess. Patients with chronic otitis media (COM) primarily underwent radical mastoidectomy, which provided a clean field. In the second operation, the covering of the mastoid cavity was elevated, and a fat graft was inserted. The external ear canal was closed permanently to protect the entry point of the electrode array from bacterial invasion. As described previously,[17,18] for stage I, if the RW niche was composed of 1.5-2.0 mm of just the anterior and inferior edges of the footplate of the stapes, the patency of the scala was exposed by drilling, and the electrode was inserted normally. For stage II, if basal turn ossification (BTO) contained the entire inferior part of the basal turn until 180° , a patent lumen was obtained by limited drilling (2-7 mm) along the obliterated basal turn. The electrode was inserted partially or completely. For stage III, if the ossification spread beyond 180° of the cochlear basal turn and BTO involved more than 2 turns (Figure 1), a circumodiolar drill-out procedure was needed for complete obliteration of the cochlea. The electrode was only inserted partially.

Audiological Assessment

All audiological tests were performed in a silent room with a live voice pronounced at nearly 70 dB sound level. Speech intelligibility was measured using speech intelligibility rating (SIR) scores. It is a time-effective global outcome measure of speech intelligibility in real-life situations.[19] Speech perception was evaluated through central auditory processing (CAP)-II scores. The CAP-II test is a non-linear and hierarchical scale on which the patients' developing auditory abilities are rated according to increasing difficulties.[20,21] All audiological tests were performed by the same audiology team in our center. The tests were performed once every 3 months in the first year and once every 6 months until 3 years after implantation.

Statistical Analysis

The data were analyzed using the Statistical Package for the Social Sciences 21.0.0 software package (IBM SPSS Corp.; Armonk, NY, USA). The results are shown as the mean ± standard deviation, median (minimum–maximum), n, and percentage. The data were analyzed to test the conformity to normal distribution by using the Kolmogorov–Smirnov and Shapiro–Wilk test. The independent *t*-test was performed for the analysis of normally distributed continuous variables. The Mann–Whitney *U* test and Kruskal–Wallis test were performed for the analysis of non-normally distributed continuous variables. Kruskal–Wallis test and post hoc Bonferroni's correction were used for pairwise comparison. Pearson's chi-square analysis was used for categorical comparisons. Values of $P < .05$ were considered statistically significant.

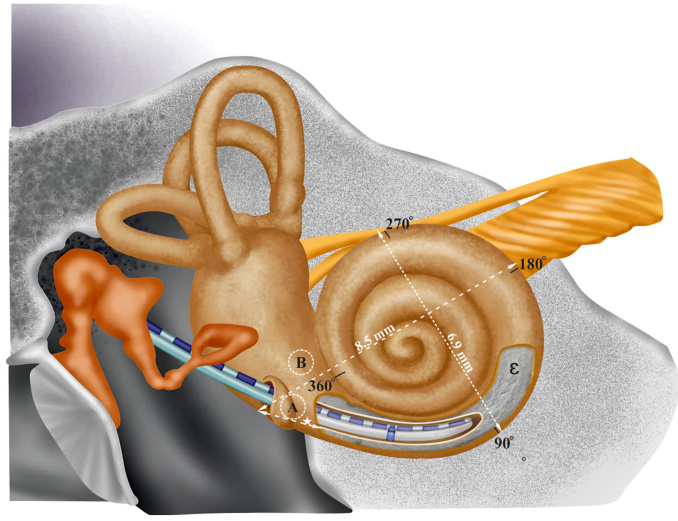

Figure 1. Image of surgical methods in ossified cochlea. Stage II ossification contains the part of the basal turn until 180°. The tunnel is drilled from the cochleostomy (A). The ossification (ε) within the lumen is followed anteriorly with a diamond drill.

Table 1. Characteristics of Subjects with Ossified Cochleas and Postoperative Test Results

Extent of Ossification	Etiology/Pathology			*P*
	Meningitis	COM	Otosclerosis	
BTO	13	8	3	.037
	54%	33%	13%	
Complete BTO	7	3	0	
	70%	30%	0%	
RWO	4	8	7	
	21%	42%	37%	
Electrote insertion				
Partial	8	8	3	.764
	42%	42%	16%	
Full	16	11	7	
	47%	32%	21%	
Surgery procedure				
None	7	1	4	.065
	58.3%	8.3%	33.3%	
Partial drilling	11	15	6	
	34.4%	46.9%	18.8%	
Total drill-out	7	3	0	
	70%	30%	0.00%	

Pearson's chi-square test was used and $P < .05$ was considered significant.
COM, chronic otitis media; BTO, basal turn ossification; RWO, round window ossification.

RESULTS

Between January 1, 2000, and May 1, 2019, a total of 2154 patients underwent CI in our institute. Among these 2154 patients, 62 had ossified cochlea, and 54 (34 males and 20 females) were included in the study. Among them, 24 had histories of meningitis, 19 had COM, 10 had otosclerosis, and 1 had Cogan's syndrome. Table 1 shows the characteristics of the patients with the ossified cochlea.

The age at implantation in the study group ranged from 10 to 62 years (mean: 35.1 ± 17.6 years). The mean age of patients in the control group was from 11 to 62 (mean 37.9 ± 1.8 years). It was determined that there was no statistically significant difference between both groups.

Table 2 shows the audiological outcomes in the study group and the control group. The duration of hearing loss did not differ significantly between both groups. As it is emphasized in the previous studies, the control group had significantly higher CAP and SIR scores than the study group ($P < .001$ and $P = .020$, respectively) (Table 2).

The patients of the study group used the following cochlear implant devices: 14 Cochlear (Sydney, Australia) (Slim Straight 422 array), 28 Medel (Innsbruck, Austria) (Standard and Split array), 10 Advanced Bionics HiRes (Southern California, USA) (Standard array), 2 MXM/Oticon (Chemin Saint Bernard, France) (Standard/CLA array). The patient with Cogan's syndrome presented with bilateral BTO and CI was performed with partial electrode insertion. In this patient, poor audiological outcomes were obtained (CAP II: 6 and SIR: 4).

Surgical Findings

Cochlear ossification to different extents was observed during the surgery in patients in the study group. Electrodes in 35 of the 54 patients were fully inserted into the cochlear lumen, and in the remaining 19 patients, electrodes were inserted partially, which means the part of the electrode array was visible outside the cochlea (Table 1).

In the 19 patients, the ossification involved only the RW. Of the 19 patients, the ossification was removed by drilling to expose the patent scala tympani in 16 patients. Although the ossification was limited to the RW, further drilling was needed in 3 patients. In all these patients, the electrode was then inserted normally (RW ossification (RWO); CAP II 8.3 ± 0.8 and SIR 4.6 ± 0.8).

Obstruction of the scala tympani was observed in 3 patients during surgery, and it was decided to insert the electrode array into the scala vestibuli. A cochleostomy was drilled anterior-superior to the RW, to achieve a patent lumen of the scala vestibuli (Figure 1B). The entire electrode array was inserted into the scala vestibuli without any difficulty. A modified Stenvers view demonstrated suitable positioning of the electrode array postoperatively.

In 25 patients, the ossification had spread to the basal and/or apical region of the basal turn and required further drilling to achieve a patent lumen (BTO; CAP II 6.7 ± 1.3 and SIR 4.1 ± 0.8). The total drill-out procedure was performed in 10 patients whose cochlea was totally obliterated, and the electrode arrays were partially placed in the drilled tunnel (complete BTO) (Table 3). There were statistically significant differences between the extent of ossification and CAP scores ($P < .001$). Consistent with previous studies, patients with complete BTO achieved poorer CAP scores than other patients (6.5 ± 1.8) (Table 3). Essentially, partial insertions may be correlated with satisfactory results (in 3 patients in the present study). Additionally,

Table 2. Comparison of Audiological Outcomes Between the Ossified Group and Control Group

Groups	Study Group (n = 54)			Control (n = 54)			*P**
	Mean ± SD	Median	Range	Mean ± SD	Median	Range	
CAP	7.2 ± 1.5	7	4.0-9.0	8.3 ± 0.7	8	7.0-9.0	<.001*
SIR	4.3 ± 0.9	4	2.0-7.0	4.6 ± 0.5	5	4.0-5.0	.025*
Onset of deafness (years)	35.9 ± 15.7	37.4	10.1-62.0	37.1 ± 13.5	35.3	10.4-55.0	.196**
Duration of deafness (years)	5.2 ± 3.7	4.4	0.3-16.0	4.4 ± 3.5	3.6	0.8-24.0	.291**

*Independent *t*-test and **Mann–Whitney *U* test were used. $P < .05$ was considered significant.
SD, standard deviation; CAP, central auditory processing; SIR, speech intelligibility rating score.

Table 3. Comparison Between the Extent of Ossification of Patients and Audiological Outcomes

	RWO (n = 19) (Stage I)		BTO (n = 25) (Stage II)		Complete BTO (n = 10) (Stage III)		*P**
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
CAP	8.3 ± 0.8	7.0-9.0	6.7 ± 1.3	5.0-9.0	6.5 ± 1.8	4.0-9.0	<.001
SIR	4.6 ± 0.8	4.0-7.0	4.1 ± 0.8	3.0-5.0	4.0 ± 1.2	2.0-5.0	.195

*Kruskal–Wallis test and post hoc Bonferrroni's correction test were used. $P < .05$ was considered significant.
CAP; Comparisons; Stage I-stage II and stage I-stage III were considered statistically signficant.
CAP, central auditory processing; SIR, speech intelligibility rating score; BTO, basal turn ossification.

patients with partial insertion who underwent total drill-out procedures exhibited poor outcomes.

Within-Group Comparison of the Ossified Group

The analyses revealed that the 3 subgroups in the study group differed significantly in terms of their age at onset of hearing loss and duration of hearing loss (Table 4). However, their effects on the present study were limited. Auditory outcomes were compared to determine the effect of causal factors of the ossification on the implantation progress among subgroups within the study group (cochlear ossification). Although patients with meningitis achieved lower CAP scores than patients with otosclerosis and COM, there was no statistically significant difference among the 3 groups in terms of CAP scores ($P = .096$). Additionally, SIR scores differed significantly between meningitis and COM subgroups ($P = 0.016$) (Table 4). The effects of the etiology of hearing loss on auditory outcomes were analyzed by comparing patients with full insertion in the study group and the control group. The comparison showed that patients with meningitis had significantly poorer CAP-II scores than other subgroups (7.00 ± 1.10, $P < .001$). Speech intelligibility rating scores in patients with meningitis also trended to poorer, but no statistically significant differences were found. Furthermore, patients with full insertion who had an etiology of otosclerosis and COM were compared with patients in the control group, and no significant differences were found among the groups.

DISCUSSION

Although cochlear ossification is no longer considered a contraindication in many implant centers, the unpredictable auditory outcomes and the challenges experienced during surgery remain to be resolved. The conventional CI technique is unable to address the challenges during surgery caused by cochlear ossification. Therefore, to ensure that the implanted electrode array establishes adequate contact with the neuronal population in the cochlea, various modifications to the traditional implantation technique are required.

Previous studies demonstrated that ossification generally occurs in the proximal part of the scala tympani and the RW. Kaya et al[22] analyzed the pathologic findings of the labyrinthitis ossificans in 23 human temporal bone specimens and found that ossification occurred most often in the scala tympani. It is reasonable to consider that these patients are expected to achieve similar satisfactory results as patients with normal cochlear anatomy.

According to Nichani et al[23] if the ossification was confined to the scala tympani in the region of the RW, it is usually possible to drill past it to obtain a clear lumen and insert an implant to its full extent. Similarly, full electrode insertion was performed in patients with RWO in our study. Additionally, they found that partial insertions may be associated with satisfactory CAP scores. Rotteveel et al[24] reported that patients with partial insertion could show a satisfactory but lower performance than patients with complete insertion. In agreement with this, patients with RWO achieved better CAP scores than patients with BTO and complete BTO (8.3 ± 0.8, $P < .001$). However, the ossification may be extended from the RW to the deeper parts of the labyrinth, and in such cases, the spiral ganglion is at risk.[25] Steenerson et al[26] reported that in cases of ossification beyond the RW, the scala tympani might be obstructed and, therefore, the electrode could be inserted into the scala vestibule. Accordingly, due to ossification of the scala tympani in 2 patients in the study group, the electrode array was inserted into the scala vestibuli. Electrode insertion into the scala vestibuli is also an effective alternative when electrode insertion is difficult.[27] In the present study, patients in whom the electrode was implanted in the scala vestibuli exhibited satisfactory performance.

In cases of meningitis and otosclerosis, the ossification may involve the entire cochlea. The cochlear implant performance in these patients could be anticipated to be poorer than in patients with normal cochlear anatomy. Therefore, for patients with ossified cochlea, advanced special electrode systems and different surgical methods are required. Gantz et al[28] suggested a drill-out technique for the BTO

Table 4. Comparison Between Subgroups Within Cochlear Ossification Group

Subgroups/Parameters	Menengitis (n = 24)		COM (n = 19)		Otosclerosis (n = 10)		*P**
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range	
CAP	6.8 ± 1.5	4.0-9.0	7.7 ± 1.5	5.0-9.0	7.6 ± 1.3	5.0-9.0	.096
SIR	4.0 ± 0.9	2.0-5.0	4.7 ± 0.8	3.0-7.0	4.2 ± 0.6	3.0-5.0	.016
Onset of deafness (years)	28.7 ± 14.9	10.1-58.0	37.1 ± 14.5	19.0-62.0	51.2 ± 5.3	45.4-59.2	<.001
Duration of deafness (years)	3.5 ± 3.8	0.3-16.0	6.1 ± 3.0	2.0-10.9	7.7 ± 2.8	3.2-11.6	.001

*Kruskal–Wallis test and post hoc Bonferrroni's correction test were used. $P < .05$ was considered significant.
Comparisons: SIR; menengitis – COM, onset of deafness; menengitis – otosclerosis, duration of deafness; menengitis – COM and menengitis – otosclerosis were considered statistically signficant.
CAP, central auditory processing; COM, chronic otitis media; SIR, speech intelligibility rating score.

of the cochlea. Balkany et al[29] proposed a revision of this method in which the approximately 4 mm initial part of the basal turn could be left intact, which could allow the attachment of the electrode array (Figure 1; distance marked with ★). Rauch et al[30] implanted the electrodes into a bony trough in a spiral form to obtain optimum coupling of the electrode array with the modiolus. In our study, total ossification that may be defined as complete BTO was performed in 10 patients. Drill-out procedures were needed in these patients to create a lumen for electrode insertion. The electrode arrays were partially placed in the drilled tunnel. The patients showed poorer audiological outcomes than patients with RWO and BTO ($P < .001$), similar to the findings of Rauch et al.[30]

In their study of the temporal bone, Hinojosa et al[31] reported a large variability in the ganglion cell populations of deaf patients without and with ossification. Nadol et al[32] reported a correlation between total spiral ganglion cell counts and the cause of deafness. In patients with ossification, the number of active electrodes reduces with time; this may lead to poorer auditory outcomes than in cochlear implant recipients with other causes of deafness. This possibility should be acknowledged when counseling patients with cochlear ossification; thus, the long-term hearing outcome may be improved with adequate rehabilitative therapy.

Green et al[33] carried out a histopathologic study on 24 temporal bones with labyrinthitis ossificans with different etiologies. They found that cochlear nerve fibers in the osseous spiral lamina and spiral ganglion cells were decreased to various degrees in all the temporal bones. In line with this finding, we observed that patients with ossified cochlea exhibited poorer performance than those in the control group (Table 2). In a recent study, Vashishth et al[34] evaluated the effect of the extent and etiology of ossification on auditory outcomes. They found that patients with otosclerosis had better vowel and word scores than patients without otosclerosis, but the difference was not statistically significant. Consistent with previous studies, our patients with otosclerosis had better CAP-II and SIR scores than patients with meningitis and COM (Table 1). However, patients with otosclerosis had poorer auditory outcomes than patients with normal cochlear anatomy who received CI (Table 4). In the within-group analysis of the study group, patients with meningitis had poorer auditory outcomes even if they had the electrode array fully inserted. The poorer outcomes may be associated with an inadequate number of spiral ganglion cells that could be stimulated, which might negatively influence CI performance.

Although computed tomography has a high specificity in diagnosing bone tissue pathologies, previous studies have reported a more frequent and extent of ossification in the intraoperative observation than the preoperative evaluation.[35] Therefore, if the doubt of ossified cochlea is present based on the history of the patient and radiological findings, the surgeon should predict the need to perform a cochlear drill-out. Accordingly, if the extent of ossification includes the inferior part of the basal turn or RW niche, usually a patent lumen may be obtained by limited drilling. In cases with complete scala tympani ossification, scala vestibuli insertion may be an effective option. When extensive ossification is present, the audiological outcomes depend on the surviving spiral ganglion cell population and the number of intracochlear electrodes coupling with this population. Consequently, the innovation of electrode array systems and the improvement of techniques of drilling have become quite important for these patients.

CONCLUSION

Reports on the performance of cochlear implants in the ossified cochlea are conflicting. Thus, auditory outcomes are still difficult to predict. However, encouraging results can be achieved with the newly developed electrode designs and the current surgical techniques. The results of our study indicate that cochlear implants may provide significant benefits to patients with the ossified cochlea, even in the presence of extensive cochlear ossification.

Ethics Committee Approval: The study protocol was approved by the ethics committee of Bozyaka Training and Research Hospital, İzmir, Turkey (January 30, 2019, Decision number: 4).

Informed Consent: Informed consent was obtained from all participants.

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