Long-Term Outcome of Cochlear Implantation in Post-meningitic Deafness

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BACKGROUND: This study was planned (1) to evaluate long-term outcome after cochlear implantation in patients with post-meningitic deafness and (2) to compare the outcome measures with patients implanted for deafness due to other causes.

METHODS: Records of 54 patients deafened as a sequel of bacterial meningitis and implanted at the largest university-based cochlear implant program in Turkey were retrospectively reviewed. Fifty-four age- and sex-matched patients with a similar interval of implant use were selected for controls. Surgical and long-term audiological outcome (in terms of categories of auditory performance-II scores) was assessed and compared.

RESULTS: Twenty-seven (52%) patients had some degree of labyrinthitis ossificans and 19 of them had full electrode insertion via basal turn cochleostomy. Patients with and without labyrinthitis ossificans in the post-meningitic group had no difference in final categories of auditory performance-II score ($P= .559$). Median categories of auditory performance-II scores were 6 for post-meningitic group and 7 for controls, with a significant statistical difference ($P< .001$). Partial or full insertions did not differ in outcome ($P= .938$). Mean time to implantation was not correlated with the final categories of auditory performance-II score for the post-meningitic group ($P= .695$).

CONCLUSION: Cochlear implant recipients deafened due to meningitis have a worse long-term hearing and speech performance as measured by categories of auditory performance-II than patients implanted for congenital deafness. The presence of labyrinthitis ossificans or the limited extent of electrode insertion produced overall results that were comparable with other cases.

KEYWORDS: Cochlear implant, hearing loss, meningitis, labyrinthitis ossificans

INTRODUCTION

The leading cause of acquired profound sensorineural hearing loss (SNHL) in infants and young children is bacterial meningitis.1 There are unique challenges to cochlear implantation (CI) in this patient group. It is established that labyrinthitis ossificans (LO) resulting from meningitis may obliterate cochlear spaces and render CI unfeasible. Scala tympani, the usual target for electrode insertion, is primarily affected in its basal segment by LO due to its intimate connection with the subarachnoid space via the cochlear aqueduct, and LO in this location may produce an obstruction to basal turn cochleostomy. The auditory neural pathway may also be adversely affected by meningitis, and post-implant rehabilitation may be hampered by additional central nervous system (CNS) sequelae.1 In spite of these obstacles, CI without delay remains the sole recourse short of an auditory brainstem implant for rapidly developing LO and profound hearing loss after meningitis. The aim of this article is to review a series of patients implanted for post-meningitic deafness, evaluate surgical success and auditory performance outcome in this cohort, and compare these results with a control group that had CI due to profound hearing loss due to congenital deafness.
MATERIALS AND METHODS

Patient Characteristics
The medical records of patients who underwent cochlear implant surgery due to bilateral severe to profound SNHL in our tertiary referral center from January 1999 to December 2015 were retrospectively reviewed. Cases with meningitis recorded as the etiology of deafness were selected for the post-meningitic implant group (PMG). A control group (CG) matched with the PMG with respect to age and interval of cochlear implant use was assembled of cases implanted due to congenital hearing loss of hereditary or unknown etiology that had onset at birth. Post-meningitic implant group records were analyzed for the presence of labyrinthine ossification in preoperative high-resolution temporal computerized tomography (CT) and magnetic resonance imaging (MRI). Ossification in imaging was classified into 3 groups: gross, partial, and no ossification as described by Axon et al (Table 1). Indicators of operative success (possibility of a basal turn cochleostomy, extent of electrode insertion, alternative techniques such as circummodiolar drillout (CMD) or double electrode (DE) insertion if performed) were evaluated for each patient. Patients with poor adherence to follow-up, unrevised device (hard) failure, and insufficient chart records were excluded from the study. Patients with neurological comorbidities were not included in the CG group. The research was evaluated and approved by the institutional ethical committee.

Audiological Evaluation
Both groups were evaluated for hearing outcome as measured by categories of auditory performance-II (CAP-II) and sentence recognition test scores at the final follow-up. Categories of auditory performance-II is a standardized score of 10 categories of increasing sound/speech awareness and capability of spoken communication (Table 2). Patients are assigned to a category ranging from 0 (“No awareness of environmental sounds or voice”) to 9 (“Use of telephone with an unknown speaker in unpredictable context”). The highest CAP-II categories attainable depend on the age of the patient (as telephone use or group conversation are skills achieved later in life).

Statistical Testing
For statistical comparison across groups, Mann–Whitney U-test was used for non-parametric data or non-normal distributions, and student’s t test was used for parametric data. Correlation between non-parametric variables was tested with Kendall’s τ-b. SPSS version 23 for Mac OS X (IBM, Armonk, NY, USA) was utilized for statistical testing.

RESULTS
The PMG comprised of 54 patients (24 females, 30 males) implanted for deafness not related to meningitis. All patients had bilateral severe to profound SNHL preoperatively. The mean age at implantation was 12.5 years for the PMG and 12.9 years for the CG with no statistically significant difference between groups (P = .891, t test). Mean interval of implant use was 10.3 ± 3.8 years for the PMG and 8.3 ± 3.1 years for controls.

Out of 54 patients in the PMG, there were 27 (50%) with some degree of LO in temporal CT or cochlear fibrosis in temporal MRI. Three cases (5%) had evidence of gross obliteration of cochlear spaces in preoperative imaging, while the remaining 24 (44%) had partial ossification. Partial ossification almost always included the cochlear basal turn in this patient group. Twenty-seven patients (50%) had no evidence of LO in preoperative CT or MRI. All 27 patients with no evident LO in imaging were fully inserted via a basal turn cochleostomy. Of the 3 patients with gross total LO in temporal imaging, 1 required a CMD procedure as described by Gantz et al and 2 were implanted with DE arrays with an additional second turn cochleostomy. Nineteen of 24 patients with findings of partial ossification in imaging were found to have an available cochlear lumen after clearing basal turn fibrous/osteoid tissue and fully inserted via a basal turn cochleostomy. Five were partially inserted, 2 of which required an ascending turn cochleostomy drilled inferior to the cochleariform process, anterior to the oval window to identify a cochlear lumen. A total of 6 revision procedures were required in PMG patients. Notably, 1 patient with a DE array had early revision due to electrode malposition. One case was revised due to skin complications, and 4 eventually had their implants replaced due to device failure. Patient characteristics for the PMG cases are presented in detail in Table 3. Patients in the CG had no labyrinthine ossification in preoperative imaging and were all fully inserted via a basal turn cochleostomy without any complications.

In the PMG, 13 of the 54 patients (24%) had co-morbid conditions that may have altered outcome, such as visual impairment in 3 cases, hydrocephalus in 3 cases, learning disability and/or attention-deficit hyperactivity disorder in 4 cases, autism spectrum disorder in 1 case, seizures in 1 case, and global developmental delay in 1 case.

Median CAP-II score for the PMG was 6 (Table 4). There was no statistically significant difference between the distribution of CAP-II scores

| Table 1. Axon Classification for Labyrinthine Ossification |
| Degree of Ossification | Finding |
| None | No ossification |
| Partial | Ossification localized to the basal turn of the scala tympani |
| Gross | Gross ossification of the scala tympani and variable amounts of the scala vestibuli |

| Table 2. Categories of Auditory Performance II (CAP-II) Scale |
| CAP-II Score | Corresponding Skill |
| 0 | No awareness of environmental sounds or voice |
| 1 | Awareness of environmental sounds |
| 2 | Response to speech sounds |
| 3 | Identification of environmental sounds |
| 4 | Discrimination of speech sounds without lip reading |
| 5 | Understanding of common phrases without lip reading |
| 6 | Understanding of conversation without lip reading |
| 7 | Use of telephone with known speaker |
| 8 | Follows group conversation in a reverberant room or where there is some interfering noise, such as a classroom or restaurant |
| 9 | Use of telephone with an unknown speaker in unpredictable context |
Table 3. Patient Characteristics for Cases Implanted Due to Post-meningitic Deafness

| Pt. No. | Age at Meningitis (mo/yr) | Age at Implantation (mo/yr) | Duration of Implant Use (yr) | Pre-Implantation LO? | MRI Insertion Method | Extent of Insertion | Laterality | Active Electrode % | Revision | CI Brand | Additional Disabilities | Post-op CAP-II | Post-op SRT |
|---------|---------------------------|-----------------------------|-----------------------------|----------------------|---------------------|---------------------|------------|---------------------|----------|----------|------------------------|---------------|-----------|
| 1       | 7 mo                      | 7 yr                        | 16                          | Prelingual           | None                | Normal              | Full       | Unilateral/right ear | 100      | No       | Nucleus                |               | 5         |
| 2       | 4 mo                      | 5 mo                        | 7                           | Prelingual           | Partial             | Cochlear fibrosis   | Full       | Bilateral (simultaneously) | 100      | No       | Nucleus                |               | 5         |
| 3       | 1 mo                      | 5 yr                        | 7                           | Prelingual           | Partial             | Cochlear fibrosis   | Full       | Unilateral/left ear   | 83       | No       | Medel                  |               | 4         |
| 4       | 3 yr                      | 4 yr                        | 14                          | Perilingual          | Gross               | Cochlear fibrosis   | CMD Drillout | Unilateral/right ear | 91       | No       | Nucleus ADHD          |               | 100       |
| 5       | 3 yr                      | 44 yr                       | 10                          | Perilingual          | None                | Normal              | Full       | Unilateral/right ear   | 100      | No       | Clarion                |               | 6         |
| 6       | 6 mo                      | 12 yr                       | 13                          | Prelingual           | None                | Normal              | Full       | Unilateral/right ear   | 100      | No       | Nucleus                |               | 4         |
| 7       | 21 yr                     | 21 yr                       | 11                          | Postlingual          | None                | Cochlear fibrosis   | Full       | Unilateral/left ear    | 91       | No       | Nucleus                |               | 5         |
| 8       | 3 yr                      | 12 yr                       | 5                           | Perilingual          | None                | Normal              | Full       | Unilateral/left ear    | 83       | No       | Medel                  |               | 6         |
| 9       | N/A                       | 3 yr                        | 9                           | Prelingual           | Partial             | Lateral SCC fibrosis | Full       | Unilateral/left ear    | 100      | No       | Nucleus Cleft palate |               | 6         |
| 10      | 11 mo                     | 12 yr                       | 10                          | Prelingual           | Partial             | Cochlear fibrosis   | Full       | Unilateral/right ear   | 100      | No       | Nucleus Global developmental delay |               | 5         |
| 11      | 3 mo                      | 11 yr                       | 17                          | Prelingual           | None                | Normal              | Full       | Unilateral/right ear   | 100      | No       | Nucleus                |               | 0         |
| 12      | 6 yr                      | 10 yr                       | 11                          | Postlingual          | Gross               | Cochlear fibrosis   | Partial    | Unilateral/right ear   | 60       | No       | Nucleus double array   |               | 5         |
| 13      | 7 yr                      | 26 yr                       | 12                          | Postlingual          | None                | Normal              | Full       | Unilateral/left ear    | 92       | No       | Medel                  |               | 7         |
| 14      | N/A                       | 57 yr                       | 7                           | Postlingual          | None                | Normal              | Full       | Unilateral/left ear    | 100      | No       | Nucleus                |               | 7         |
| 15      | 6 mo                      | 3 yr                        | 10                          | Prelingual           | Partial             | Cochlear fibrosis   | Partial    | Unilateral/right ear   | 50       | No       | Nucleus double array Learning disorders |               | 1         |
| 16      | N/A                       | 3 yr                        | 11                          | Prelingual           | None                | Normal              | Full       | Unilateral/right ear   | 91       | No       | Nucleus Learning disorders |               | 3         |
| 17      | 9 mo                      | 2.5 yr                      | 11                          | Prelingual           | Partial             | Cochlear fibrosis   | Full       | Unilateral/right ear   | 91       | No       | Nucleus                |               | 6         |
| 18      | N/A                       | 7 yr                        | 8                           | Prelingual           | Partial             | Cochlear fibrosis   | Full       | Unilateral/left ear    | 100      | No       | Nucleus                |               | 5         |
### Table 3. Patient Characteristics for Cases Implanted Due to Post-meningitic Deafness (continued)

| Pt. No. | Age at Meningitis (mo/yr) | Age at Implantation (mo/yr) | Duration of Implant Use (yr) | Pre-Postlingual | LO? | MRI | Insertion Method | Extent of Insertion | Laterality | Active Electrode % | Revision | CI Brand | Additional Disabilities | Post-op CAP-II | Post-op SRT |
|---------|--------------------------|-----------------------------|-----------------------------|-----------------|-----|-----|------------------|---------------------|------------|----------------------|----------|----------|-----------------------|---------------|-------------|
| 19      | 18 mo                    | 2 yr                        | 10                          | Prelingual      | None | Normal | Full              | Unilateral/right ear | 100        | No                    | Clarion  | Autism spectrum disorder | 3          | 0         |
| 20      | N/A                      | 62 yr                       | 6                           | Postlingual     | None | Normal | Full              | Unilateral/right ear | 91         | No                    | Nucleus   | -                     | 6          | 71        |
| 21      | N/A                      | 25 yr                       | 3                           | Postlingual     | None | Normal | Full              | Unilateral/right ear | 100        | No                    | Nucleus   | -                     | 6          | 65        |
| 22      | N/A                      | 5 yr                        | 7                           | Prelingual      | Partial | Cochlear fibrosis | Partial | Unilateral/right ear | 58        | Yes/skin flap complications | Medel    | Hydrocephalus | 5          | 45        |
| 23      | N/A                      | 19 mo                       | 5                           | Prelingual      | Partial | Cochlear fibrosis | Full    | Unilateral/left ear | 100       | No                    | Nucleus   | -                     | 5          | 52        |
| 24      | 3 yr                     | 11 yr                       | 13                          | Perilingual     | None | Cochlear fibrosis | Full    | Unilateral/left ear | 91        | No                    | Nucleus   | -                     | 6          | 85        |
| 25      | N/A                      | 39 yr                       | 5                           | Postlingual     | Partial | Cochlear fibrosis | Full    | Unilateral/right ear | 100       | Yes/device failure | Nucleus   | -                     | 8          | 100       |
| 26      | 2 mo                     | 4 yr                        | 13                          | Prelingual      | Partial | Cochlear fibrosis | Full    | Unilateral/left ear | 83        | No                    | Medel    | ADHD                  | 6          | 60        |
| 27      | 3 mo                     | 5 yr                        | 12                          | Prelingual      | Partial | Cochlear fibrosis | Full    | Unilateral/right ear | 91        | No                    | Nucleus   | Vision impairment | 6          | 100       |
| 28      | 40 yr                    | 41 yr                       | 5                           | Postlingual     | Partial | Cochlear fibrosis | Full    | Unilateral/left ear | 91        | Yes/Device failure | Nucleus   | -                     | 5          | 55        |
| 29      | 1 mo                     | 16 mo                       | 7                           | Prelingual      | Partial | Cochlear fibrosis | Partial | Unilateral/left ear | 100       | No                    | Nucleus   | -                     | 6          | 62        |
| 30      | 6 yr                     | 22 yr                       | 6                           | Postlingual     | None | Normal | Full              | Unilateral/right ear | 95         | No                    | Nucleus   | -                     | 8          | 87        |
| 31      | 3 mo                     | 3 yr                        | 7                           | Prelingual      | Partial | Cochlear fibrosis | Full    | Bilateral (simultaneously) | 95        | No                    | Nucleus   | Hydrocephalus     | 6          | 62        |
| 32      | 6 mo                     | 3 yr                        | 8                           | Prelingual      | None | Normal | Full              | Unilateral/left ear | 80         | No                    | Medel    | -                     | 5          | 65        |
| 33      | N/A                      | 10 mo                       | 3                           | Prelingual      | None | Normal | Full              | Unilateral/left ear | 100        | No                    | Nucleus   | -                     | 5          | 30        |
| 34      | N/A                      | 3 yr                        | 10                          | Prelingual      | None | Normal | Full              | Unilateral/right ear | 100        | No                    | Nucleus   | -                     | 5          | 45        |
| 35      | 2 yr                     | 5 yr                        | 11                          | Prelingual      | None | Normal | Full              | Unilateral/right ear | 100        | No                    | Clarion  | Vision impairment | 4          | 0         |
| 36      | 8 yr                     | 28 yr                       | 13                          | Postlingual     | None | Normal | Full              | Unilateral/right ear | 92         | No                    | Medel    | -                     | 8          | 100       |
| 37      | 12 yr                    | 26 yr                       | 11                          | Postlingual     | Partial | Cochlear fibrosis | Partial | Unilateral/left ear | 100       | No                    | Nucleus   | -                     | 6          | 72        |
| Pt. No. | Age at Meningitis (mo/yr) | Age at Implantation (mo/yr) | Duration of Implant Use (yr) | Pre-postlingual | LO? | MRI | Insertion Method | Extent of Insertion | Laterality | Active Electrode % | Revision | CI Brand | Additional Disabilities | Post-op CAP-II | Post-op SRT |
|--------|---------------------------|-----------------------------|-----------------------------|----------------|-----|-----|-----------------|-------------------|------------|-----------------|----------|-----------|----------------------|---------------|------------|
| 38     | 3 mo                      | 7 yr                        | 11                          | Perilingual    | Partial | SCC fibrosis | Lateral           | Full              | Unilateral/right ear | 90        | No        | Nucleus Epilepsy      | 3              | 0          |
| 39     | 4 mo                      | 16 yr                       | 17                          | Prelingual     | None     | Normal | Full            | Unilateral/left ear | 91         | No              | Nucleus -           | 5              | 55         |
| 40     | N/A                       | 11 yr                       | 3                           | Prelingual     | Partial | Cochlear fibrosis | Full            | Unilateral/right ear | 95        | No              | Nucleus -           | 5              | 45         |
| 41     | N/A                       | 20 mo                       | 11                          | Prelingual     | None     | Normal | Full            | Unilateral/right ear | 100        | No              | Medel -             | 7              | 90         |
| 42     | 5,5 yr                    | 12 yr                       | 13                          | Postlingual    | None     | Normal | Full            | Unilateral/right ear | 91         | No              | Nucleus -           | 6              | 77         |
| 43     | N/A                       | 15 yr                       | 14                          | Prelingual     | None     | Normal | Full            | Unilateral/right ear | 80         | No              | Nucleus -           | 5              | 43         |
| 44     | N/A                       | 3 yr                        | 4                           | Prelingual     | Partial | Cochlear fibrosis | Full            | Unilateral/left ear | 100        | No              | Nucleus -           | 5              | 40         |
| 45     | 2 yr                      | 8 yr                        | 10                          | Postlingual    | Partial | SCC fibrosis | Partial           | Lateral           | Unilateral/right ear | 100        | No              | Medel -             | 6              | 90         |
| 46     | 7 yr                      | 26 yr                       | 17                          | Postlingual    | None     | Normal | Full            | Unilateral/left ear | 100        | No              | Nucleus -           | 6              | 65         |
| 47     | N/A                       | 16 yr                       | 11                          | Prelingual     | Partial | Cochlear fibrosis | Partial           | Unilateral/left ear | 50         | Yes/ device failure | Medel -             | 6              | 88         |
| 48     | N/A                       | 22 yr                       | 3                           | Postlingual    | None     | Normal | Full            | Unilateral/left ear | 100        | No              | Nucleus -           | 5              | 45         |
| 49     | 7 yr                      | 41 yr                       | 10                          | Postlingual    | None     | Cochlear fibrosis | Full            | Unilateral/right ear | 91         | No              | Nucleus -           | 5              | 42         |
| 50     | 5 yr                      | 5 yr                        | 9                           | Postlingual    | Partial | Cochlear fibrosis | DE               | Full              | Unilateral/left ear | 42         | Yes/electrode malposition | Medel -             | 8              | 90         |
| 51     | N/A                       | 4 yr                        | 3                           | Prelingual     | None     | Normal | Full            | Unilateral/right ear | 91         | No              | Nucleus Hydrocephalus | 6              | 50         |
| 52     | N/A                       | 4 yr                        | 3                           | Prelingual     | None     | Normal | Full            | Unilateral/right ear | 95%        | No              | Nucleus -           | 4              | 0          |
| 53     | N/A                       | 26 yr                       | 2                           | Postlingual    | Partial | Cochlear fibrosis | Full            | Unilateral/left ear | 91         | Yes/device failure   | Nucleus -           | 8              | 80         |
| 54     | N/A                       | 7 yr                        | 10                          | Prelingual     | Partial | Cochlear fibrosis | Full            | Unilateral/right ear | 58         | No              | Nucleus Vision impairment | 4              | 32         |

Pt, patient; mo, months; yr, years; LO, labyrinthitis ossificans; CAP-II, categories of auditory performance; SRT, sentence recognition test; CMD, circummodiolar drillout; DE, double electrode; AC, ascending turn cochleostomy; SCC, semicircular canal; ADHD, attention deficit-hyperactivity disorder; MRI, magnetic resonance imaging; CI, cochlear implant.
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A frequency distribution of CAP-II scores of patients with and without LO is presented in Figure 1. Median CAP-II score for the CG was 8, and the difference between the PMG and CG in CAP-II was statistically significant ($P < .001$, Mann–Whitney $U$-test). A visual comparison of CAP-II scores of patients in the PMG and CG is presented in Figure 2.

Among patients who required non-standard insertion techniques, the patient implanted via a CMD achieved a post-op CAP-II score of 6, while both patients who were implanted with DE arrays had a CAP-II outcome of 1 (sound awareness with no response to speech). In the PMG, 46 cases who were fully inserted had a median CAP-II score of 5, while 8 who had partial insertions had a median CAP-II score of 6. This difference in CAP-II score distributions between partial and full insertions was not statistically significant ($P = .938$, Mann–Whitney $U$-test).

Patients implanted due to post-meningitic deafness were evaluated for the impact of time from the onset of deafness to any intervention for auditory rehabilitation (either with a hearing aid or cochlear implant) on the outcome as measured by the CAP-II score. Mean time to implantation (TTI) was 67 months for this group, but no significant correlation was identified between TTI and CAP-II outcomes (Kendall's $\tau$-$b = -0.044$, $P = .695$). A scatterplot of CAP-II outcome with regard to age at implantation is presented in Figure 3.

DISCUSSION

Cochlear implantation in the setting of post-meningitic deafness has been a controversial subject since the advent of implant surgery. Earlier reports suggest that due to lack of former auditory stimulation, congenitally deaf children would be outperformed by their counterparts with acquired deafness. Particularly after the recognition of additional barriers posed on rehabilitation by neurologic sequelae of meningitis, this outlook reversed in favor of the congenitally deaf, with occasional reports revealing equivalent results. The apparent contraindication has remained unsolved in current opinion and may be associated with numerous outcome-influencing factors: the presence of LO or additional CNS sequelae, insertion technique, age at implantation, or time elapsed from the onset of deafness to CI surgery.

The incidence of any extent of LO has been reported to range from 48.7% to 62% in recent series. A comparison of CI outcome between subjects with and without LO has yielded worse results for LO-positive cases in earlier papers. El-Kashlan et al. found decreasing mean speech perception categories (SPC) for patients with worsening LO with the gross ossification group obtaining a mean SPC of 3 ("beginning word identification") within 24 months postoperatively. The authors attribute this finding to a significantly better preoperative residual hearing in patients with patent cochleae. Philippon et al. reported an inverse correlation between auditory performance and LO only if cases with stage III ossification according to Smullen and Balkany ($> 180^\circ$ ossification of the basal turn) are included in the comparison. Recent investigations reveal a modest advantage favoring LO-negative cases: Nichani et al. have found that 88% of LO-negative versus 74% of LO-positive CI recipients achieved open-set speech with a mean CAP score of 5.9 and 5.4, respectively. Liu et al. on the other hand, report no statistically significant difference between SPC outcomes of cases with and without LO. The present cohort has a 46% partial and 6% gross ossification rate that is consistent with previous literature, and our results confirm that if at least partially inserted, cases with LO have statistically equivalent outcome with that of LO-negative patients.

Table 4. FINAL CAP-II Scores, Age at Implant, Time to Implant, and Duration of Implant Use Among Subgroups

| Group                      | CAP-II (Median (Range)) | Age at Implant (Mean (Years)) | Time to Implant (Mean ± SD (Months)) | Duration of Implant Use (Mean ± SD (Years)) |
|----------------------------|--------------------------|-------------------------------|--------------------------------------|---------------------------------------------|
| Post-meningitic group (overall) | 6 (0-8)                  | 12.5                          | 67                                   | 10.3 ± 3.8                                  |
| LO positive                | 6 (1-8)                  | 7.8                           | 50                                   | 10.3 ± 2.9                                  |
| LO negative                | 5 (0-8)                  | 17.5                          | 84                                   | 10.3 ± 4.7                                  |
| Control group              | 8 (5-9)                  | 12.9                          |                                       | 8.3 ± 3.1                                   |

CAP-II, categories of auditory performance; LO, labyrinthitis ossificans; SD, standard deviation.
One case with gross ossification that achieved remarkable auditory performance with a CAP-II score of 6 was implanted via CMD. Split or DE arrays have given dismal performance, though, with both cases partially inserted with DEs achieving only sound awareness. This finding mirrors that of Nichani et al15 who reported 4 of the 7 split insertions in their series had a final CAP < 5.

For a comparative evaluation of post-meningitic and congenital deafness cases, a majority of previous research reveals no significant difference in postoperative hearing outcome with regard to etiology of deafness19-21. Nikolopoulos et al21 report that 77% of congenitally deaf patients versus 73% of post-meningitic deafness cases have achieved a CAP score of ≥ 5. Both etiologic groups in the series of Bille et al19 have a median CAP of 6 and speech intelligibility rating of 4. The findings of El-Kashlan et al17 are contradictory and demonstrate a markedly different mean SPC for post-meningitic cases and controls (3.7 vs. 5.1, respectively). Results of our cohort support the latter research, with PMG patients attaining significantly lower CAP-II scores compared to controls. This apparent difference may be due to alteration of central auditory processing capability after meningitis, of which there currently is no objective method of testing in CI recipients. Another factor of note may be the inclusion of 2 new categories to the CAP score that measure previously untested skills, such as the ability to follow group conversation.

Time to implantation from onset of deafness is another important consideration for CI outcome. Durisin et al22 achieved significantly better results in post-meningitic patients implanted within 6 months from the onset of hearing loss. Our analysis did not reveal any significant correlation between the time to implant and final CAP-II scores for PMG patients. In the current medical era with wider access to healthcare, it may be surmised that children with meningitis have an expedited course to CI due to the perceived urgency of the illness. This temporal advantage does not translate into improved outcome, however, as evidenced by a trend toward equivalent or worse results in post-meningitic implant recipients.

Our series has one of the longest mean durations of implant use (over 10 years for PMG) hitherto reported in the English literature, and we believe it is reasonable to state that our results represent the final performance attainable by these patients. Certain limitations of this research are the inclusion of cases with a wide range of ages and prelingual/postlingual patients in the same group. Despite these shortcomings, our data indicate that post-meningitic implant recipients...
have poorer outcome than congenitally deaf patients, irrespective of the presence of labyrinthine ossification. The root cause of this finding may lie in a central auditory processing difficulty, co-morbid developmental/neurologic impairment, or a global CNS dysfunction as a sequel of meningitis. Whether central auditory processing is affected by an infectious process such as meningitis remains hitherto undefined in the literature.

CONCLUSION

In this study, cochlear implant recipients who were deafened as a sequel of meningitis had a worse long-term outcome than that of patients with deafness due to congenital causes. The final overall outcome is unaffected by the presence of labyrinthine ossification and the extent of electrode insertion. Central nervous system sequelae may also contribute to hearing loss in this patient group. Further research is needed to objectively assess the central auditory pathway in post-meningitic deafness.

Ethics Committee Approval: The research was evaluated and approved by the Hacettepe University institutional review board.

Informed Consent: Informed consent was obtained from all participants.

Peer Review: Externally peer-reviewed.

Author Contributions: Authors OMA and BO handled data collection and manuscript preparation. DB, GS and LS designed the study, reviewed and advised the manuscript. LS is the senior surgeon who operated a significant majority of the cases.

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REFERENCES

1. Smith RJ, Bale JF, Jr, White KR. Sensorineural hearing loss in children. Lancet. 2005;365(9462):879-890.
2. Green JD, Jr, Marion MS, Hinojosa R. Labyrinthitis ossificans: histopathologic consideration for cochlear implantation. Otolaryngol Head Neck Surg. 1991;104(3):320-326.
3. Taylor HG, Michaels RH, Mazur PM, Bauer RE, Liden CB. Intellectual, neuropsychological, and achievement outcomes in children six to eight years after recovery from Haemophilus influenzae meningitis. Pediatrics. 1984;74(2):198-205.
4. Axon PR, Temple RH, Saeed SR, Ramsden RT. Cochlear ossification after meningitis. Am J Otol. 1998;19(6):724-729.
5. Archbold S, Rutman ME, Marshall DH. Categories of auditory performance. Ann Otol Rhinol Laryngol Suppl. 1995;166:312-314.
6. Gilmour L. The Inter-Rater Reliability of Categories of Auditory Performance- II (CAP-II). Southampton: University of Southampton; 2010.
7. Gantz BJ, McCabe BF, Tyler RS. Use of multichannel cochlear implants in obstructed and obliterated cochleas. Otolaryngol Head Neck Surg. 1988;98(1):72-81.
8. Boothroyd A, Geers AE, Moog JS. Practical implications of cochlear implants in children. Ear Hear. 1991;12(suppl 4):815-95.
9. Staller SJ, Dowell RC, Beiter AL, Brimacombe JA. Perceptual abilities of children with the nucleus 22-channel cochlear implant. Ear Hear. 1991;12(suppl 4):345-475.
10. Gantz BJ, Tyler RS, Woodward GG, Tye-Murray N, Fryauf-Bertschy H. Results of multichannel cochlear implants in congenital and acquired prelingual deafness in children: five-year follow-up. Am J Otol. 1994;15(suppl 2):1-7.
11. Nikolopoulos TP, O'Donoghue GM, Robinson KL, Gibbin KP, Archbold SM, Mason SM. Multichannel cochlear implantation in postmeningitic and congenitally deaf children. Am J Otol. 1997;18(suppl 6):S147-S148.
12. Waltzman SB, Cohen NL, Gomolin RH, Shapiro WH, Ozdamar SR, Hoffman RA. Long-term results of early cochlear implantation in congenitally and prelingually deafened children. Am J Otol. 1994;15(suppl 2):9-13.
13. Mitchell TE, Ptasaro C, Pegg P, Rennie M, Gibson WP. Performance after cochlear implantation: a comparison of children deafened by meningitis and congenitally deaf children. J Laryngol Otol. 2000;114(1):33-37.
14. Liu CC, Sweeney M, Booth TN, et al. The impact of postmeningitic labyrinthitis ossificans on speech performance after pediatric cochlear implantation. Otol Neurotol. 2015;36(10):1633-1637.
15. Nichani J, Green K, Hans P, Bruce L, Henderson L, Ramsden R. Cochlear implantation after bacterial meningitis in children: outcomes in ossified and nonossified cochleas. Otol Neurotol. 2011;32(5):784-789.
16. Philippou D, Bergeron F, Ferron P, Bussières R. Cochlear implantation in postmeningitic deafness. Otol Neurotol. 2010;31(1):83-87.
17. El-Kashlan HK, Ashbaugh C, Zwolan T, Telian SA. Cochlear implantation in prelingually deaf children with ossified cochleae. Otol Neurotol. 2003;24(4):596-600.
18. Smullen JL, Balkany TJ. Implantation of the ossified cochlea. Oper Tech Otolaryngol Head Neck Surg. 2005;16(2):117-120.
19. Bille J, Ovesen T. Cochlear implant after bacterial meningitis. Pediatr Int. 2014;56(3):400-405.
20. Francis HW, Pulsifer MB, Chinnici J, et al. Effects of central nervous system residua on cochlear implant results in children deafened by meningitis. Arch Otolaryngol Head Neck Surg. 2004;130(5):604-611.
21. Nikolopoulos TP, Archbold SM, O’Donoghue GM. Does cause of deafness influence outcome after cochlear implantation in children? Pediatrics. 2006;118(4):1350-1356.
22. Durisin M, Arnoldner C, Stöver T, Lenzar T, Lesinski-Schiedat A. Audiological performance in cochlear implanted patients deafened by meningitis depending on duration of deafness. Eur Arch Otorhinolaryngol. 2008;265(4):381-388.