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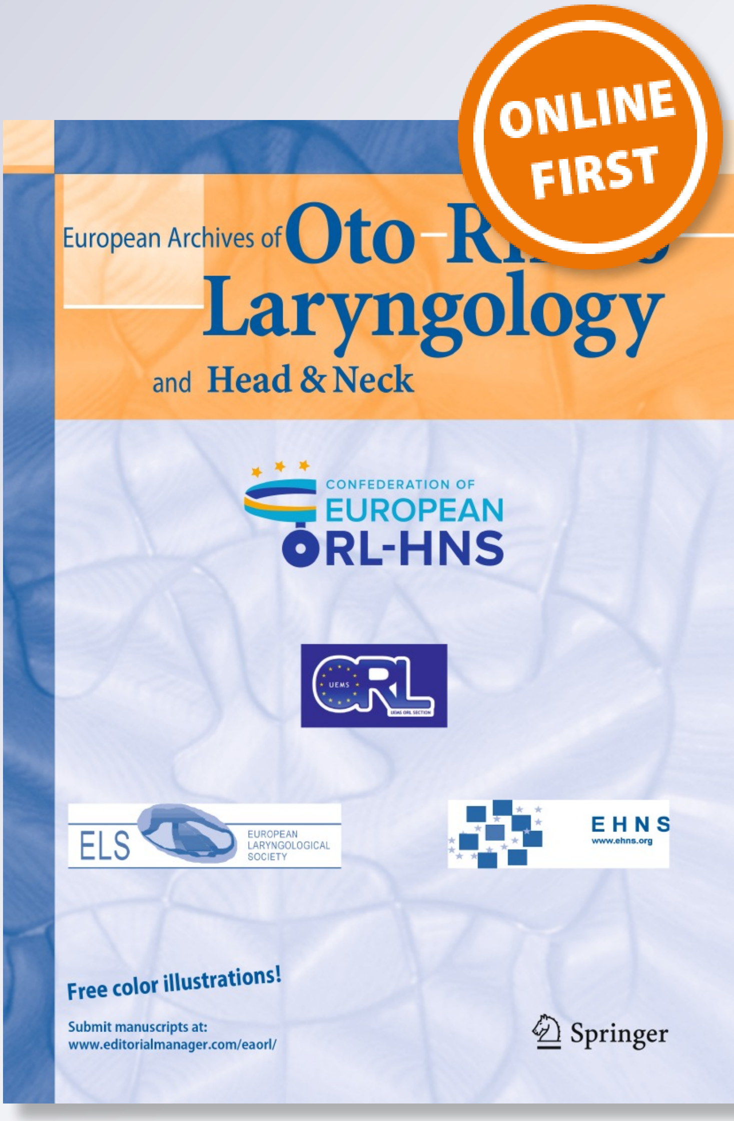

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OTOLOGY

Incomplete and false tract insertions in cochlear implantation: retrospective review of surgical and auditory outcomes

Ashish Vashishth[1] · Andrea Fulcheri[1] · Maurizio Guida[1] · Antonio Caruso[1] · Mario Sanna[1]

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Abstract

Objectives To evaluate incidence, demographics, surgical, and radiological correlates of incomplete and false tract electrode array insertions during cochlear implantation (CI). To evaluate outcomes in patients with incomplete electrode insertion (IEI).
Study design Retrospective analysis.
Setting Otology and skull base center.
Patients and methods Charts of 18 patients (19 ears) with incomplete or false tract insertions of the electrode array were evaluated who underwent CI, with at least 1 year follow-up (from 470 cases). Demographic findings, etiologies, pre-operative radiologic findings, operative records, post-operative plain radiographic assessment for extent of electrode insertion, and switch-on mapping were evaluated. Audiological outcomes were evaluated using maximum and last recorded vowel, word, sentence, and comprehension scores for patients with IEI.
Results Incidence of insertional abnormalities was 4.25% with 17 instances of incomplete and 2 cases of insertion into superior semicircular canal. Mean age and duration of deafness were 55.18 ± 4.62 and 22.12 ± 5.71 years. Etiologies in the IEI group were idiopathic, otosclerosis, meningitis, chronic otitis media (COM), temporal bone fractures, and Neurofibromatosis-2. 29.4% cases had cochlear luminal obstruction. Mean radiological and active electrophysiological length of insertion was 20.49 ± 0.66 and 19.49 ± 0.88 mm, respectively. No significant correlation was observed between audiological outcomes and insertional length except in time to achieve maximum word scores ($p = 0.04$). Age at implantation had significant correlations with last recorded word and comprehension scores at mean follow-up of 42.9 months, and with time to achieve maximum auditory scores.
Conclusions IEI during cochlear implantation using straight electrodes can occur with or without cochlear luminal obstruction. Age plays an important role in the auditory rehabilitation in this patient subset.

Keywords Cochlear implantation · Incomplete electrode insertion · Extra-cochlear electrode insertion

Introduction

Though cochlear implantation (CI) techniques have evolved over years to accommodate varying anatomical and surgical situations, a complete and atraumatic insertion of the electrode array in the scala tympani (ST) remains the goal of surgery [1, 2]. Optimum electrode placement is one of the critical factors influencing post-implantation auditory and speech outcomes [3, 4]. Estimated to be occurring in 0.17–9.2% of cochlear implants [5], electrode array-related problems can range from extra-cochlear misplacement [6] to minor ones such as incomplete electrode insertions (IEIs) [7, 8], kinking [7, 8], tip-rollovers [8, 9], scalar transitions [8], and immediate electrode migrations [10].

Though well known in cases of cochlear ossification or luminal obliteration in pathologies such as meningitis [11, 12], IEI is not uncommon in cases with no clinical or radiological evidence of luminal obstruction or obliteration as well [13–15]. IEI is caused not only by scalar luminal obstruction by new bone formation or soft tissue, but also due to inadvertent electrode contact or trauma to one or more intra-cochlear structures such as basilar membrane, osseous spiral lamina and spiral ligament [15]. Such contact or trauma, apart from permitting less intra-cochlear electrode

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contacts, also carries the potential to amplify the biologic response to the implant [16].

The current study was conducted to review the cases of IEI that occurred in CI patients, and to evaluate the pre-operative assessment, intra-operative events, post-operative electrophysiology, radiology, and post-implantation auditory outcomes in the same.

Materials and methods

Cochlear implant database was evaluated from 2006 to 2016 and records of 470 patients who underwent implantation (predominantly adult implant center) with at least 1 year follow-up period were analyzed to evaluate "imperfect electrode insertions". Defining complete ST insertion of the array as the norm, any deviations from the same were noted. This yielded 23 patients (24 ears) in the above said criteria. Four patients had intended complete scala vestibuli (SV) insertion (confirmed intra-operatively based on cochlear landmarks and on post-operative computed tomography) for total basal turn ST ossification and were excluded from the analysis. One patient with IEI (post bilateral temporal bone fractures) was lost to follow-up with no available records, and was excluded from analysis. This yielded a study cohort of 18 patients (19 ears) including one bilateral simultaneous implantation. Two patients had major extra-cochlear electrode array misplacement in the superior semicircular canal (SSC) confirmed radiologically. Both the patients underwent re-insertion of the array within 24 h of the primary procedure and had complete intra-cochlear insertion confirmed by radiology and electrophysiology.

Sixteen patients (17 ears) had incomplete insertion of the array that was confirmed radiologically through plain radiographs in the modified Stenver's view (obtained on first post-operative day). The number of extra-cochlear electrodes was estimated using air–bone interface of middle ear and cochlea to act as reference of cochlear entrance, based on recommended guidelines [17, 18]. Additional electrode abnormalities such as kinking of the array were sought on post-operative radiographs. Switch-on mapping records were evaluated to ascertain number of active/inactive electrodes as an indicator of electrode function. Pre-operative clinical and imaging records were analyzed to evaluate any features contributing to incomplete insertion. Operative records were evaluated for posterior tympanotomy (PT) or subtotal petrosectomy (STP) approach, surgeon notes on extent of insertion or mention of any "difficulty" for the same. All patients underwent a round window (RW) insertion, except cases of cochlear ossification, where the basal turn was drilled from the region of RW to obtain patent cochlear lumen. Straight/lateral wall electrodes were used in all cases. Medel devices with standard and medium electrode arrays and Oticon/MXM devices with standard arrays were used in all patients. Radiological and electrophysiological insertional lengths were calculated by noting the number of intracochlear electrodes (based on imaging and mapping, respectively) followed by calculation of length of array (mm) per electrode, based on manufacturer specifications of active electrode length (26.4 mm for Medel Standard, 20.9 mm for Medel Medium, and 25 mm for Oticon/MXM). Post-operative audiological outcomes were evaluated using pre-operative, maximum and last recorded vowel, word, sentence and speech comprehension scores for patients with incomplete insertions. Audiological outcomes were evaluated for IEIs only, with extra-cochlear insertions described separately.

Results

The mean age of patients in the IEI group was 55.18 ± 4.62 years ranging from 14 to 82 years. Eight males and eight females (1 male with bilateral implantation) were operated including 10 right and 7 left ears. Table 1 describes the demographic details, etiologies, pre- and post-operative imaging analysis, operative records, and number of active electrodes on switch-on mapping. Sixteen out of 17 were primary cases with one revision implantation. The only bilateral implantation was simultaneous and was indicated for bilateral temporal bone fractures involving otic capsule. Etiologies ranged from idiopathic, temporal bone fractures, chronic otitis media (COM), otosclerosis, and meningitis to Neurofibromatosis-2 (NF-2). Eight out of 17 cases (47.05%) were operated using STP for indications for improved access to ossified cochlea/COM/otic capsule fractures. Rest of the cases were operated using the standard PT approach. The overall incidence of electrode insertion abnormalities (major/minor) was 4.25%, with incomplete insertion being 3.82% (including cases lost to follow-up). Five out of 17 cases with IEI had pre-or intraoperative evidence of cochlear luminal obstruction (29.4%) and 3 cases (17.64%) had fractures traversing through otic capsule without any evidence of ossification. Rest of the cases (52.9%) had no pre-or intraoperative evidence of luminal obstruction. Nine out of 17 cases (52.9%) had kinking of the array visible in post-operative radiographs. The patient with revision incomplete insertion using the standard electrode array had primary implantation at another center using a short Hybrid array.

Figure 1 demonstrates distribution of age at implantation with age of onset of deafness. Mean duration of deafness in the study group was 22.12 ± 5.71 years ranging from 1 to 67 years. Figure 2 shows distribution of radiological insertional length of electrode array (in millimeters) versus usable length based on electrophysiology. The mean radiological insertional length was 20.49 ± 0.66 mm and ranged from 15 to 25 mm. The mean electrophysiological

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Table 1 Demographics, etiologies, implant used, pre-operative radiological assessment for cochlear luminal patency, operative details, and extent of electrode array insertion based on surgeon records, post-implantation plain radiographic assessment, and switch-on mapping data

S. no.	Age/sex	Side	Aetiology	Implant	Pre-operative imaging	Approach/intra-operative assessment of insertion	No. of extra cochlear electrodes on imaging	Electrode abnormalities on imaging	Usable electrodes on switch-on/mapping
1	62/M	R	Idiopathic	Medel pulsar ci 100 + standard	N/A	PT/2 electrodes out	3 (12)	N/A	3 Disabled due to no response (10,11,12)
2	58/M	R	B/L temporal bone fracture, post ABI	Neurelec digisonic SP	B/L fractures lines through otic capsule, no ossification	STP/full insertion with CSF gusher	3 (20)	Kinking of the array	3 Electrodes (1–3) inactive. Electrodes 11–20 switched off due to no neural/auditory response at maximal intensity
3	65/F	R	B/L sudden SNHL (revision)	Neurelec digisonic SP	N/A	STP/5 electrodes out	8 (20)	Mutiple bends/kinking of the array	8 Electrodes inactive (1–8)
4	56/F	R	Otosclerosis	Oticon neuro Zti + CLA	RW ossification	PT/full insertion	2 (20)	Minor kinking of the array	2 Electrodes inactive (1,2)
5	21/F	L	NF2	Oticon	Minimal basal turn obliteration in MRI	PT/4 electrodes out	7 (20)	Kinking of the array	7 Electrodes inactive (1–7)
6	75/F	R	Idiopathic	Medel pulsar ci 100 + standard	N/A	PT/3 electrodes out	3 (12)	N/A	3 Electrodes disabled due to no response (10,11,12)
7	14/M	R	Meningitis	Oticon neuro Zti + CLA	Normal cochlear patency on CT/MRI	PT/basal turn obliterated partially, 3 electrodes out	2 (20)	Kinking of the array	1 Electrode inactive (1)
8	66/F	L	B/L COM with tympanosclerosis	Oticon neuro Zti + CLA	BT obliteration	STP/full insertion	6 (20)	N/A	6 Electrodes inactive
9	69/F	L	Idiopathic	Oticon standard	N/A	PT/2 electrodes out	2 (20)	Kinking of the array	2 Electrodes inactive
10	41/M	R	B/L sudden SNHL	Medel pulsar ci 100 + medium	N/A	PT/1 electrode out	1 (12)	Minimal kinking of the array	1 Electrode disabled due to no response (12)
11	82/F	R	COM	Medel sonata + medium	Normal cochlear patency on CT/MRI	STP/2 electrodes out	2 (12)	N/A	1 Electrode disabled due to no response (12)
12	54/M	L	B/L temporal bone fractures	Oticon standard	Normal cochlear patency but B/L promontory fractures	STP/2 electrodes out	2 (20)	N/A	3 Electrodes inactive (1–3)
13	54/M	R	B/L temporal bone fractures	Oticon standard	Normal cochlear patency but B/L promontory fractures	STP/difficult but full insertion	0 (20)	Kinking of array	3 Electrodes inactive (1–3)

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Table 1 (continued)

S. no.	Age/sex	Side	Aetiology	Implant	Pre-operative imaging	Approach/intra-operative assessment of insertion	No. of extra cochlear electrodes on imaging	Electrode abnormalities on imaging	Usable electrodes on switch-on/mapping
14	27/F	L	Otosclerosis	Oticon standard	N/A	PT/2 electrodes out	2 (20)	N/A	2 Electrodes inactive (1,2)
15	66/M	L	COM	Oticon standard	Partial basal turn ossification	STP/2 electrodes out with difficult insertion	2 (20)	Kinking of the array	4 Electrodes inactive (1–4)
16	73/M	R	COM	Neurelec digisonic SP	N/A	STP/1 electrode out	2 (20)	N/A	2 Electrodes inactive
17	66/M	L	Idiopathic	Medel pulsar + standard	N/A	PT/3 electrodes out	3 (12)	N/A	3 Electrodes inactive (10, 11, 12)

B/L bilateral, *COM* chronic otitis media, *ABI* auditory brainstem implant, *STP* subtotal petrosectomy, *PT* posterior tympanotomy, *SNHL* sensory neural hearing loss, *NF* neurofibromatosis

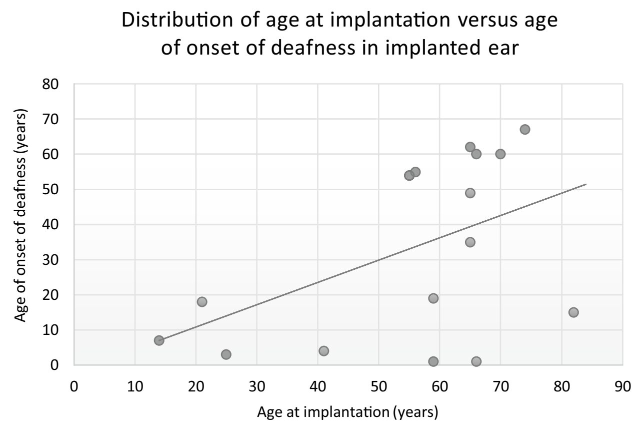

Fig. 1 Distribution of age at implantation and age of onset of deafness (years)

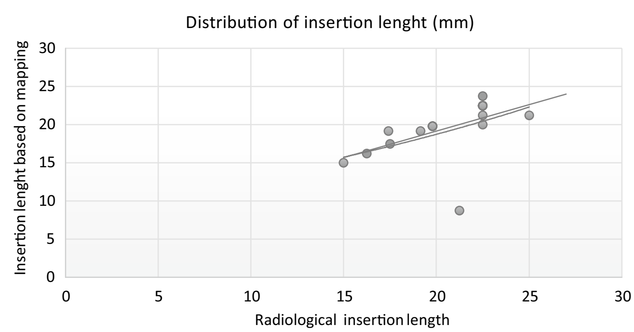

Fig. 2 Distribution of radiological insertion length of electrode array and insertional length based on switch-on mapping

usable insertional length was 19.49 ± 0.88 mm and ranged from 8.75 to 23.75 mm.

One patient (Table 1, Case 14) underwent revision implantation 2 years after primary surgery due to electrode migration, device-related issues, and non-auditory sensations and had full electrode insertion at time of revision utilizing the same device and electrode subtype.

Two cases merit individual description as follows:

Case 1: (Table 1, patient 2) 58-year-old male patient presented with bilateral profound hearing loss following head trauma 40 years back. Patient underwent right sided auditory brainstem implantation (ABI), an year before presentation at another center, with no auditory benefit and non-auditory stimulation. Consequently, his ABI was deactivated and he underwent right-sided CI. Post-operative radiograph demonstrated 3 extra-cochlear electrodes out of 20. Switch-on mapping confirmed the same and additionally electrodes 11–20 could not elicit any neural response (with normal impedances) and had to be switched off, rendering just 7 active electrodes. Patient could only obtain voice detection and no open-set speech post auditory rehabilitation.

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Case 2: (Table 1, patient 5) 21-year-old female with NF-2 and bilateral vestibular schwannomas and profound hearing loss underwent translabyrintine (TLA) tumor removal and ABI on right side. Patient did not receive any significant auditory benefit from the same. 4 years later, she underwent left sided TLA tumor excision and concurrent CI, though with incomplete insertion with 7 extra-cochlear electrodes. Despite delay in auditory improvement, she achieved open-set speech and had comparable outcomes to other patients.

Audiological outcomes

Three out of 16 patients (17 ears) in the study cohort (Table 1, patients 2, 3, and 14) obtained limited auditory benefit and were excluded from audiological analysis. Out of the three, one patient with revision implantation despite having 12/20 electrodes inserted remained non-user and used the opposite sided cochlear implant which was placed earlier than the side in question. One patient with otosclerosis had peri-lingual hearing loss and despite revision implantation for electrode migration could only obtain closed-set vowel recognition post-extensive auditory–visual rehabilitation. Case 1 ("Results" section) described earlier could also only achieve closed-set voice recognition. One patient implanted post-meningitis received post-operative auditory rehabilitation in his native country and was referred for surgical intervention at the present center. This left a data set of 12 patients (13 ears) for audiological evaluation and analysis. Figure 3 displays the distribution of maximum obtained audiological scores post-operatively and the time in months required to obtain the same. Figure 4 demonstrates the distribution of maximum and last recorded auditory scores plotted against the corrected electrophysiological insertion lengths for the same cohort of patients with the addition of case 1 ("Results" section) and the non-user from revision implantation. Last recorded scores varied based on individual follow-up periods and ranged from 12 to 60 months (mean 42.9 months). Mean pre-and post-operative maximum obtained and last recorded auditory scores along with mean interval required to obtain the same are displayed in Table 2.

Auditory outcomes were correlated with length of electrode array insertion, age at implantation and duration of deafness (Table 3).

Non parametric Spearman correlation coefficient was used for correlation between quantitative variables not following normal distribution curves. Non-parametric Wilcoxon Signed rank sum test was used for pairwise comparison of non-quantitative variables not following normal

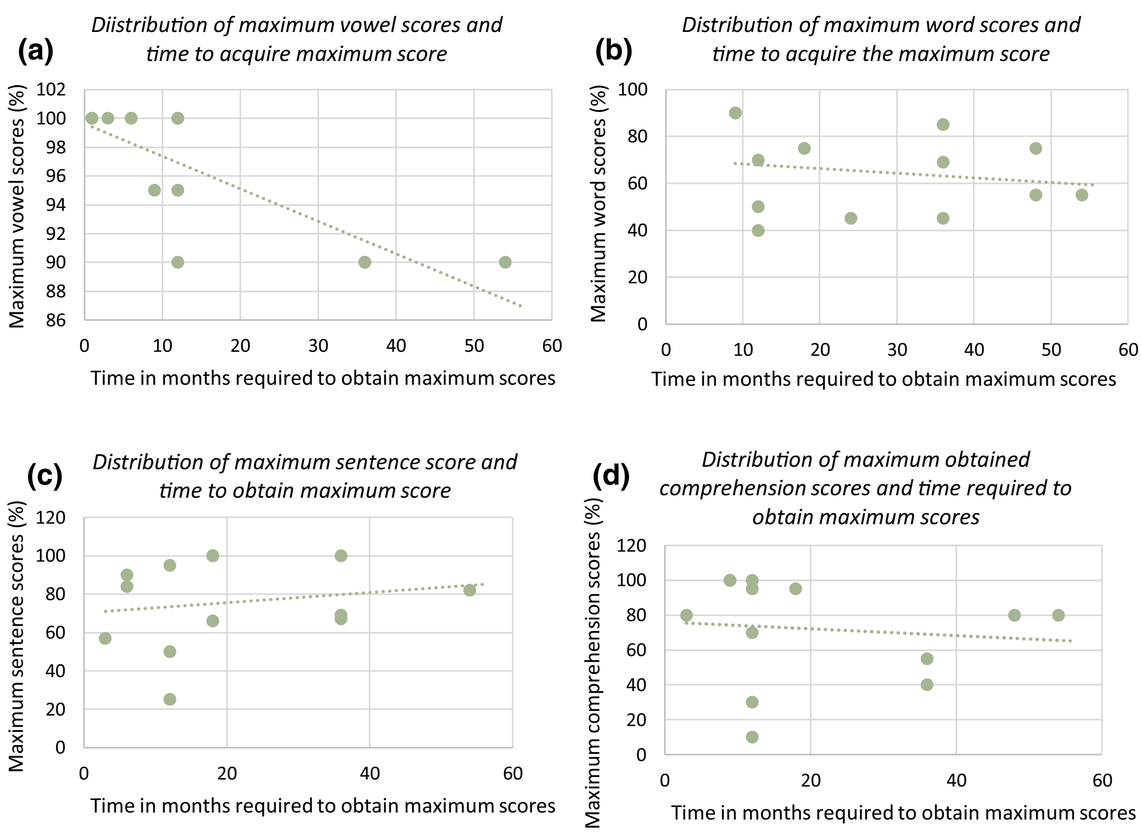

Fig. 3 **a–d** Distribution of maximum auditory scores (%) and time required (months) to time to obtain the same

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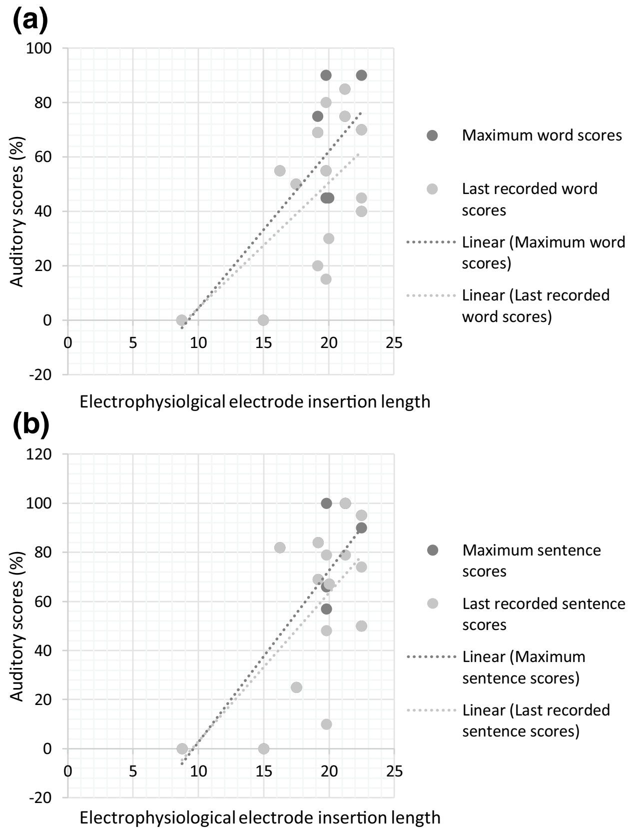

Fig. 4 Scatter plots demonstrating word and sentence scores (%) against corrected electrophysiological electrode insertion lengths (mm) ($n=15$)

distribution curves. The level of statistical significance was kept at $p<0.05$ and the data was analysed using SPSS Statistical software version 22.0.

The corrected electrophysiological length of insertion of electrode array exhibited negative correlations with interval required to achieve maximum auditory scores, with significance only observed in time required to obtain maximum word scores ($p=0.04$). For all other auditory outcomes, no statistical significance could be observed with respect to length of insertion. The analysis was repeated with inclusion of two patients ($n=15$), previously exlcuded, with least number of active intra-cochlear electrodes (revision implantation with 12 and post-ABI with 7 intra-cochlear active electrodes) (Table 1, cases 2 and 3). Maximum and last recorded auditory scores were kept at zero for analysis for both these patients. Re-analysis revealed statistically significant correlation between maximum obtained sentence ($p=0.033$) and comprehension scores ($p=0.016$) with a trend towards significance with respect to maximum word scores ($p=0.08$). No significant association was observed with respect to last recorded auditory scores though ($p>0.05$).

Age at implantation had negative correlation with both maximum and last recorded auditory scores with statistically significant correlations with last recorded word ($p=0.004$), comprehension scores ($p=0.02$) and time required to obtain maximum sentence ($p=0.000$) and comprehension scores ($p=0.016$). No significant associations were observed though with maximum auditory scores.

Duration of deafness had negative correlations with maximum and last recorded auditory scores, but no statistically significant association could be observed with respect to any of the audiological parameters.

False tract insertions

Two cases had false tract insertions in SSC, one being primary otosclerosis with RW ossification and other being revision implantation due to soft device failure (Fig. 5). Both cases occurred with right handed surgeons in right ear and involved drilling of the RW region to obtain patent cochlear lumen. Telemetric responses were absent in all but first electrode in one instance with higher than normal impedances. Revision performed within 24 h of primary surgery was uneventful in both cases with correct intra-cochlear electrode array placement confirmed radiologically and on electrophysiology.

Table 2 Mean audiological scores (%) and mean of time to acquire maximum scores (months)

	Pre-op scores	Max post-op scores	Last recorded post-op scores	Significance pre- to max post-op scores	Significance pre- to last recorded post-op scores	Time in months to acquire max scores
Vowel	23.85	96.15	90.77	0.001	0.002	15.38
Word	8.46	64.92	53.00	0.001	0.004	27.23
Sentence	9.77	75.77	66.31	0.002	0.006	20.54
Comprehension	8.46	71.92	59.62	0.002	0.008	21.00

Last recorded audiological scores were observed at variable periods ranging from 1 to 5 years post-operatively

Significance levels ($p<0.05$, 2-tailed with non-parametric analysis)

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Table 3 Non-parametric correlations (significance levels $p < 0.05$, two-tailed) of audiological outcomes

	Max word	Last word	Time for max word	Max sentence	Last sentence	Time for max sentence
Radiological insertion length						
P.co	0.16	0.28	− 0.45	0.36	0.11	− 0.05
p	0.59	0.34	0.11	0.22	0.7	0.86
Electrophysiological corrected insertion length						
P.co	0.16	0.13	− 0.56	0.3	0.17	− 0.26
p	0.58	0.66	0.04	0.3	0.56	0.38
Age at implantation						
P.co	− 0.21	− 0.73	− 0.26	− 0.41	− 0.42	− 0.83
p	0.47	0.004	0.38	0.15	0.15	0.000
Duration of deafness						
P.co	− 0.05	− 0.51	0.07	− 0.26	− 0.29	− 0.26
p	0.85	0.07	0.79	0.38	0.33	0.37

Electrode insertion length was measured in mm. Age and duration of deafness measured in years

Max word maximum word scores, *max sentence* maximum sentence scores, *time for max* time in months required for obtaining maximum scores, *last word* last recorded word score, *last sentence* last recorded sentence scores, *P.co* Pearson's correlation coefficient, *p* significance value

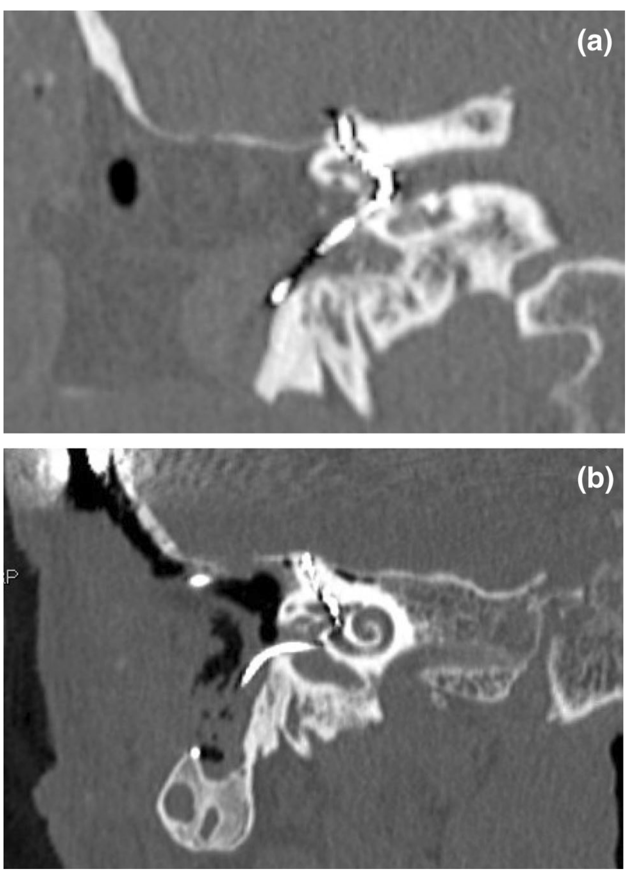

Fig. 5 **a** Coronal CT image of patient with otosclerosis who underwent subtotal petrosectomy for access to round window ossification with electrode array seen in SSC. **b** Reconstructed CT image of patient with revision implantation with array visible in SSC through vestibule

Discussion

Remarkable variations in cochlear size and shape can potentially influence the insertional dynamics of the cochlear implant electrode array [19, 20], including the depth of insertion. The length of lateral wall of cochlea can vary from 38 to 45 mm with basal turn contributing to as much as 53% of the total length [20]. Apart from length, the angulations between the two segments of basal turn and first and second cochlear turns [19–21], unusual constrictions in basal turn of cochlea in as much as 7.5% cases [21] and the ST morphology [22] can all affect the depth of insertion. This carries significance as apart from obvious causes of cochlear luminal obstruction, putative contact with normal intrascalar structures can potentially increase resistance to insertion [15]. Such contact, on its own, or exaggerated by above mentioned "unfavorable cochlear dimensions" can alter the trajectory of electrode array to the threshold of incomplete insertion.

In the present study, the incidence of IEIs was 3.8% (4.2% including extra-cochlear misplacement), which is lesser than the previous reported rates of 9.2% [7, 17]. Disorders such as otosclerosis, meningitis, petrous fractures, and vestibular schwannomas invading cochlea are known etiologies predisposing to IEI. In the present cohort, however, in the sole case of schwannoma, no intracochlear invasion was noted. Most cases (> 50%) had no adverse factors predisposing to IEI. Lee et al. in a histopathological analysis of 27 temporal bones analyzed for IEI remarked no soft tissue or bony intrascalar obstruction in most of the cases [15]. They concluded that spiral ligament dissection to the lateral cochlear wall was the most significant histopathological

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feature associated with IEI and noted a trend towards the same with respect to number of times the electrode crossed from one scala to another. Though interscalar transitions could not be accounted for in the current study due to predominant utilization of plain post-operative radiographs, the prevalence of electrode array kinking in more than 50% of patients with incomplete insertion did point to increased resistance to the electrode tip with an eventual altered position of contacts inside ST. Apart from the above-mentioned risk factors, revision implantation with different electrodes has also been associated with incomplete insertion [23]. In the current study, one out of 17 cases was of revision surgery post-primary implantation with incomplete insertion at another center. Though primary implantation was done using a short hybrid electrode, the revision implantation using the standard array resulted in eight extra-cochlear electrodes (Table 1, case 3). Contrary to the same, in another instance, an otosclerotic patient (Table 1, case 14) who had partial insertion during the primary surgery underwent revision due to electrode migration and non-auditory sensations. Revision surgery for the same patient resulted in full electrode insertion, using same implant and electrode subtype. Lee et al. [24] in a histopathological analysis remarked that the trajectory of the revision electrode does not always follow the primary track, a feature that carries potential bearing on the depth of electrode insertion during revision CI.

The insertion length in the previous publications on incomplete electrode insertions has varied from 6.5 to 19.4 mm [15] and 9 to 23.5 mm [14]. The mean insertion length in the current study was 20.49 mm, which approximates with the bend between basal and middle cochlear turns, assuming lateral wall placement of the straight electrodes [20, 21]. Furthermore, the basement membrane is thick and narrow at the base and becomes broad and narrow towards the apex, thus increasing possibility of perforation by the advancing electrode array with increasing depth of insertion [20].

Despite correlations, discrepancies in extent of electrode insertion have been observed between surgeon observations, post-implantation imaging, and switch-on mapping [7, 17, 25].

In the current study, 52.9% cases had similar estimation of number of extra-cochlear electrodes based on operative records and post-implantation mapping, whereas it was 70% between imaging and switch-on mapping assessments. The reasons for discrepancy could range from inaccuracy in estimation of exact number of extra-cochlear electrodes due to line of sight to immediate recoil/migration of part of array due to lateral cochlear wall forces. The radiographs in the current cohort of patients were obtained the day after surgery and hence reflected the state of array post the same interval. The number of usable electrodes differed in 5 cases out of 17 in the current subset of patients between imaging and switch-on mapping. Two patients had more non-usable electrodes than evident from imaging, though in continuation of the extra-cochlear ones (apart from case described in results section with 7/20 active electrodes). Kinking was observed in the array in both instances on radiographic imaging. Two cases displayed higher number of usable electrodes with auditory percept as compared to imaging (single electrode more than what was evident on imaging). Similar uncommon findings have been observed in other studies as well [7] highlighting usable auditory perception from the electrode immediately near the round window, despite being extra-cochlear.

Auditory outcomes

Svirsky and colleagues [26] evaluated two patients of bilateral CI with large asymmetries in electrode insertion lengths. They concluded that auditory plasticity allowed for a remarkable adaptation in terms of speech performance, though limitations existed for the ear with shallower insertion with alterations in frequency allocation tables accounting for significant improvements in speech performances in the worst performing ear. While the previous studies have shown no significant association between the electrode insertion depths (with respect to IEI) and auditory performance scores [14, 27], Skinner et al. [13] remarked on significant association between depth of insertion and post-implantation word scores. Coombs et al. [7] mentioned significant association between IEI and post-operative speech scores, though limited to 6 months. In the current study, follow-up ranged from 12 to 60 months, and although no significant association was observed between maximum or last recorded auditory scores, significant association was observed between electrophysiological estimation of insertion length and time to obtain maximum word scores ($p = 0.04$). This seems to indicate a trend towards sufficient neural and auditory adaptation post rehabilitation despite varying lengths of insertion (excluding two cases with least active insertion length), though patients with lesser depth of insertion achieved maximum word scores later when compared to those with more intra-cochlear usable electrodes. Furthermore, the neural adaptability could be limited by the number of intra-cochlear electrodes as significance was observed in the current series when maximum sentence and comprehension scores were correlated with length of insertion, post inclusion of two more cases (Table 1, cases 2 and 3). Though details of frequency allocation tables were not available for the case with revision implantation unlike Svirsky and colleagues [26], this could potentially have implications for bilateral implantation or single sided deafness when concerning significant incomplete insertion or bilateral asymmetry of insertion.

In the current cohort of patients, age at implantation had negative correlations with last recorded word ($p = 0.004$) and

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comprehension ($p = 0.02$) scores. Furthermore, patients with increasing age achieved their maximum sentence and comprehension scores significantly later as compared to those with lesser age groups, though no significant difference in maximum obtained scores could be observed. Auditory scores can decrease and plateau over time after reaching peak levels due to ongoing changes in central processing and cognition. Significant associations between age at implantation and auditory performance has been observed by Lee et al. [27], though not by others [13] when evaluating patients with incomplete or varying depths of electrode insertion.

Though duration of deafness has been correlated as an independent factor adversely affecting outcomes after cochlear implantation [14], others have not observed the same [13, 27] while evaluating IEIs. No association between duration of deafness was observed with any of the recorded auditory outcomes in the present cohort of patients.

False tract insertions

Ying et al. [6] in their review of electrode misplacements remarked SSC to be the commonest location of misplaced electrode array, amongst others such as internal auditory canal, internal carotid artery and Eustachian tube. Reasons attributed have ranged from incorrect angle of insertion and site of cochleostomy to improper inclination of patient's head on operating table[6]. Both cases of electrode misplacement in SSC in the current series occurred in right ear with right handed surgeons post drilling or RW region to obtain patent cochlear lumen. A superior trajectory of insertion was most likely the reason for entry of the array into the SSC through the vestibule. Like the review by Ying et al. [6], no significant telemetric responses were observed in the current series and the misplacement was observed on post-implantation imaging followed by correct replacement.

Limitations

One of the most obvious limitation of the current study is the limited sample size thus not permitting a multivariate analysis to evaluate variances in presence of multiple factors potentially affecting auditory outcomes. Factors that could not be accounted for but potentially influence auditory outcomes are the previous duration of hearing aid use, variations in intra-cochlear electrode position apart from length of insertion, differences in calculation of length of insertion based on calculations from number of intra-cochlear electrodes on plain radiography, CT based calculations and histopathological assessments and finally programming strategies.

Conclusions

Incomplete insertion during cochlear implantation using the standard lateral wall electrodes can occur in both cases with and without cochlear ossification/luminal obstruction. Intra-operative X-ray control is recommended in all cases, where surgical observation of incomplete or "difficult" insertion is made as discrepancies can exist in intra-operative surgical and post-operative plain radiographic assessments. Though patients may take longer to obtain maximum word recognition scores due to incomplete insertion or less usable electrodes, the same may have no significant bearing on eventual maximum auditory scores, in the absence of other adverse factors and a certain threshold of extent of insertion. In patients with IEI, age at implantation may negatively affect post-implantation auditory performance.

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Compliance with ethical standards

Conflict of interest The authors declare no potential conflict of interest.

Ethical approval All procedures performed in the current study were in accordance with the institutional ethical standards and with the 1964 Helsinki declarartion with its amendments. No research involving animals was done in the current study.

Informed consent Informed consent was obtained from all individual participants included in the study.

Plagiarism The authors declare that the manuscript is original.

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