Eur Arch Otorhinolaryngol
DOI 10.1007/s00405-015-3610-0

OTOLOGY

Surgical findings and auditory performance after cochlear implant revision surgery

R. Manrique-Huarte[1] · A. Huarte[1] · M. J. Manrique[1]

Received: 25 November 2014 / Accepted: 19 March 2015

Abstract The objective of this study was to review cochlear reimplantation outcomes in the tertiary hospital and analyze whether facts such as type of failure, surgical findings, or etiology of deafness have an influence. A retrospective study including 38 patients who underwent cochlear implant revision surgery in a tertiary center is performed. Auditory outcomes (pure tone audiometry, % disyllabic words) along with etiology of deafness, type of complication, issues with insertion, and cochlear findings are included. Complication rate is 2.7 %. Technical failure rate is 57.9 % (50 % hard failure and 50 % soft failure), and medical failure (device infection or extrusion, migration, wound, or flap complication) is seen in 42.1 % of the cases. Management of cochlear implant complications and revision surgery is increasing due to a growing number of implantees. Cases that require explantation and reimplantation of the cochlear implant are safe procedures, where the depth of insertion and speech perception results are equal or higher in most cases. Nevertheless, there must be an increasing effort on using minimally traumatic electrode arrays and surgical techniques to improve currently obtained results.

Keywords Cochlear implant · Reimplantation · Auditory performance · Failure · Revision surgery

✉ R. Manrique-Huarte
rmanrique@unav.es

M. J. Manrique
mmanrique@unav.es

[1] Otorhinolaringology Department, University of Navarra Clinic, Pio XII 36, 31008 Pamplona, Navarra, Spain

Introduction

From the beginning, the history of intra-cochlear multichannel cochlear implant (CI) development has been linked to the use of round-edged electrode arrays with contact points arranged linearly along the array. Results obtained have been clinically relevant. However, despite excellent data, currently implanted systems will foreseeably be substituted by new implants in the future, if devices are faulty or there are technological upgrades offering better features to patients. Substituting them will require explanting the old equipment and implanting the new one. First implantation and subsequent explantation–reimplantation procedures in the cochlea may injure this anatomical structure. Following classification criteria as Ramos et al. [1], we will classify potential changes in the cochlea after placing a cochlear implant as follows:

- Reaction to foreign body (electrode) [2, 3].
- Secondary to cochleostomy [4, 5].
- Traumatism due to the insertion [2, 3, 6–8].

Post-mortem histological studies and clinical experience published by the above-mentioned authors illustrate how the magnitude of these injuries may be significant enough in some cases so as to compromise the insertion of a new implant and the successful stimulation of the cochlear nerve, ultimately affecting clinical results.

Cochlear implant surgery began 30 years ago. During these decades, auditory performance has improved, resulting in broader implantation criteria. As the number of implanted patients grows and the lifespan of devices is outlived, an increasing number of device failures are expected. In consequence, the odds of ensuing complications are higher. Therefore, analyzing performance and

Published online: 27 March 2015

complications after cochlear implantation is of the utmost importance.

Indications for reimplantation follow the classification proposed by Zeitler [9]. They include hard failure, soft failure, device infection or extrusion, improper initial placement, wound or flap complications, and upgrade of cochlear implant technology. Hard device failure is defined as the complete interruption of the auditory input with disrupted communication between internal and external components. It is diagnosed by a failed integrity test. Soft failure is suspected in patients with gradual or intermittent dips in performance or non auditory complaints such as ear pain, facial nerve stimulation, vertigo, or tinnitus. Device infection may appear in the form of redness and fluctuation of the skin located over the receiver stimulator or an ulcerated wound. Once an infection or exposure of the device is suspected, antibiotics should be initiated immediately. If the infection persists, the explantation of the device is recommended. Reimplantation surgery can be planned 3–4 months later. Electrode extrusion accompanied by decreased auditory performance requires reimplantation surgery as well. Factors behind the extrusion of the array may be classified [10] as intracochlear factors (neo-ossification may push the electrode array out of the cochlea) or extracochlear factors (adhesions and fibrotic bands within the mastoid may pull the electrode array, especially in children, due to their skull growth, and other extrinsic factors such as trauma or infection may cause receiver package migration). Currently, revision surgery is not usually indicated to upgrade the cochlear implant technology, but the amount of reimplantations due to this reason is expected to increase sharply in the future.

Several published papers have studied the results obtained after reimplantation. Laszig et al. [11] reported on one of the largest series. They reported on 58 cochlear reimplantations. Electrode insertion depth was equal or deeper in 53 of 58 cases. Speech recognition scores after reimplantation had improved in 25 patients (71.4 %), showed little or no change in 7 (20 %), and decreased in 3 (8.5 %) out of 35 patients with available data for comparison. Nevertheless, Battmer et al. [12], having published the largest series of reimplantation cases, show less favorable results and report on 30 % of patients with worse speech discrimination levels than before the reimplantation.

Reports of large reimplantation series are needed to guide surgeons on the expected failure rate and audiological performance after reimplantation surgery. Additionally, it is highly recommendable to have updated studies that shed light on these issues and analyze whether results vary over time, with new electrode arrays and more polished surgical techniques of implantation.

The main objective of this study was to compare patients' outcomes after re-implantation and analyze what factors could have an impact on outcome.

For all past and future recipients of a CI, the work proposed will provide essential information on the following:

- To identify as soon as possible the potential difficulties of repeatedly implanting CI electrode arrays. In order to anticipate to future problems, we will need to tackle when the currently implanted systems need to be replaced by new implants, in case the device turns out to be faulty or there are technological upgrades offering better features to patients. The latter option has far-reaching implications for children, given the foreseeably long lives ahead of them.
- In case there are negative consequences to the insertion, it will be helpful to identify the associated risk factors beforehand. This information is the key to be able to make the suitable modifications to prevent them in the future. Some modifications could be of a surgical nature, others could bring about the manufacture of less traumatic, better tolerated and more biologically reliable CI electrode arrays.

Materials and methods

Subjects

A retrospective review of our cochlear implant program database was undertaken to establish the number of cochlear implant explantations and reimplantations performed between 1989 and 2012. Out of 962 patients implanted in the period of time studied, 38 have been included in the study. Part of the reimplanted population was referred from other centers; 26 (68.42 %) had their first implantation in our hospital, whereas 12 (31.58 %) came to our center due to a complication.

Mean age at reimplantation was 20.18 years (ranging from 1 to 87 years old). There were 28 (73.68 %) children (<18 years old at the time of the first implantation) and 10 (26.32 %) adults. The waiting time for reimplantation was 4.76 months (ranging from 0 to 16 months). Mean follow-up period is 5 years (the minimum is 4 months and the maximum is 17 years). Patients implanted in the contralateral ear or explanted but not reimplanted have been excluded.

The following data were collected from each patient: demographics, etiology of hearing loss, type of failure, age at first implantation, time from first implantation to failure, surgical findings during reimplantation surgery and preoperative radiological findings, type of implant, depth of

insertion of the electrode array during reimplantation. Data on age at reimplantation, implanted ear, and etiology of deafness for each case are provided in Table 1. The etiology of deafness was unknown in 50 % of the 28 children with congenital hearing loss. Genetic mutations were diagnosed in 10.72 % of cases. CHARGE syndrome diagnosis was behind 3.57 % of cases. Cochlear malformation was diagnosed in 7.14 % of cases, neurofibromatosis in 3.57 %, and enlarged vestibular aqueduct in 3.57 % of cases, respectively. Bacterial meningitis was diagnosed in 7.14 % of cases. The etiology was unknown in 50 % of 10 adult patients, followed by history of chronic otitis media in 30 %. Bacterial meningitis caused hearing loss to 10 % of patients. For 10 %, the cause of deafness was traumatic.

Table 1 Summarizes demographics and surgical data from subjects included in the study

Patient #	Age at reimplantation (years)	Ear	Pre-op radiological findings	Surgical reimplantation findings of the cochlea	Etiology	Length of insertion 1st CI	Length of insertion revision surgery
1	1	Left	Normal	Normal	Genetic	Complete	Complete
2	1	Right	Normal	Normal	Unknown	complete	Complete
3	2	Left	Normal	Normal	Unknown	Partial	Complete
4	3	Left	Normal	Normal	Unknown	Complete	Complete
5	3	Left	Hipoplasia	Normal	CN hypoplasia	Complete	Complete
6	3	Right	Normal	Normal	Unknown	Partial	Complete
7	3	Left	Normal	Normal	Unknown	Partial	Complete
8	3	Left	Normal	Normal	Unknown	Complete	Complete
9	3	Right	No data	Normal	Unknown	Complete	Complete
10	3	Left	Normal	Normal	Unknown	Complete	Complete
11	3	Right	Normal	Normal	Unknown	Complete	Complete
12	4	Right	Malformation	Common cavity	Malformation	Complete	Complete
13	5	Left	Normal	Normal	Unknown	Complete	Complete
14	5	Left	Normal	Normal	Unknown	Complete	Complete
15	6	Right	Normal	Normal	Unknown	Partial	Complete
16	7	Left	Normal	Fibrosis	NF	Complete	Complete
17	7	Left	Ossification	Normal	Genetic	Complete	Complete
18	8	Left	No data	Normal	Unknown	Partial	Complete
19	8	Left	Malformation	Normal	CHARGE	Complete	Complete
20	9	Left	Normal	Ossification	Unknown	Complete	Complete
21	9	Left	Normal	Normal	Unknown	Complete	Complete
22	10	Right	Normal	Normal	Unknown	Partial	Complete
23	11	Right	Normal	Normal	EVA	Complete	Complete
24	15	Right	Normal	Normal	Unknown	Complete	Complete
25	16	Right	Normal	Normal	Unknown	Complete	Complete
26	18	Right	Ossification	Ossification	Meningitis	Partial	Complete
27	20	Right	Normal	Normal	Meningitis	Complete	Complete
28	20	Left	Normal	Ossification	Genetic	Partial	Complete
29	24	Right	Ossification	Ossification	EVA	Partial	Partial
30	39	Right	Normal	Normal	Meningitis	complete	Partial
31	40	Left	Normal	Fibrosis	Unknown	Partial	Complete
32	49	Left	Normal	Normal	COM	Complete	Complete
33	50	Left	Normal	Fibrosis	Unknown	Complete	Complete
34	50	Left	Normal	Otoesclerosis	Unknown	Complete	Complete
35	60	Right	Ossification	Ossification	COM	Partial	Partial
36	66	Right	Ossification	Ossification	COM	Partial	Complete
37	76	Left	Normal	Fibrosis	Trauma	Complete	Complete
38	86	Right	Normal	Normal	Unknown	Complete	Complete

CI cochlear implant, *COM* chronic otitis media, *CN* cochlear nerve, *EVA* enlarged vestibular aqueduct, *NF* neurofibromatosis

Types of explanted implant belong to three manufacturers. From Cochlear Ltd (Sydney, Australia), 61.29 % (19/31) was perimodiolar electrode array, 19.35 % (6/31) was straight array, and 3.22 % (1/31) was slim straight. From Advanced bionics AG (Stäfa, Switzerland), all of the arrays explanted were HiRes 90 K [6.45 % (2/31)]. From MED-EL (Innsbruck, Austria), arrays explanted were the standard array [9.67 % (3/31)]. Unfortunately, electrode array features were missing for 7 subjects. For reimplantation surgery, usually the same manufacturer was maintained. From Cochlear Ltd, 73.68 % (28/38) was perimodiolar electrode array, 2.63 % (1/38) was straight array, 2.63 % (1/38) was double array, and 5.26 % (2/38) was 422 slim straight array. From Advanced bionics, 5.26 % (2/38) was HiRes 90 K. From MED-EL, 2.63 % (1/38) was standard array, 5.26 % (2/38) was compressed array, and 2.63 % (1/38) was split array.

Surgical technique

If the anatomy was preserved, implantation surgery was performed following conventional surgical steps [13]. Briefly, an incision is made behind the ear and then mastoidectomy, posterior tympanostomy, drilling of a bone bed for receptor–stimulator, cochleostomy at the level of the promontory or round window depending on the electrode array, telemetry test, X-ray, and suture. In cases where previous surgical procedures lead to a radical cavity, implantation was performed following surgical technique as described by Manrique et al. [14] where CI cables were covered with cartilage and fascia graft and a periosteal flap.

During reimplantation surgery, the same approach was performed as in the first surgery, considering receptor–stimulator protrusion. After opening the fibrotic capsule wrapping up the implant, the beginning of the cable was identified. It was dissected through the cortical bone and the mastoidectomy until posterior tympanostomy. Fibrotic tissue was removed so as to identify the cochleostomy site. The electrode array was removed, and at that moment, the presence of intra-cochlear fibrosis or ossification was evaluated. If obliteration was encountered, a 1-mm diamond burr was used to drill.

In cases of electrode array migration in radical cavities, it was related to an exposure of the CI cables in the mastoid due to graft deterioration. The middle ear was surgically revised, removing the squamous epithelium that covered the radical cavity. Then, the external auditory canal and the Eustachian tube were closed down.

Depth of insertion of the electrode array during implantation and reimplantation surgery was measured counting the number of electrodes in the cochlea, and the depth of insertion of the markers on each array was inserted with microscopic control. Considering the type of electrode array and its length of insertion, the depth of insertion is deducted. No radiological measurements were undertaken for this purpose.

Auditory tests

Patients included have been followed up, and aided free-field auditory tests were undertaken wearing the CI, before the complication and after reimplantation. Pure tone audiometry (PTA) and speech audiometry, using disyllabic words, were administered in quiet in a calibrated sound-field room with the loudspeaker at 1 m and 0° azimuth to the seating subjects [15]. Mean PTA thresholds (0.5, 1, 2, and 4 kHz) with CI and % of disyllabic words were measured so as to show the auditory outcome with CI.

Neuroimaging studies

Before the first implantation, all patients underwent some imaging study in order to detect CI contraindications and for surgical planning purposes. Our center has historically chosen different radiological tests to select candidates. High-definition computerized tomography (CT) was used exclusively at first, then magnetic resonance imaging (MRI), along with CT in cases of labyrinth malformation, and now MRI and CT for all candidates. Fibrosis or ossification diagnoses before first surgery were based on radiological findings. However, such findings were analyzed under microscopic visualization by the surgeon during explantation–reimplantation surgery. CT was not considered a useful tool to determine obliteration before reimplantation surgery due to the artifact, provoked by the electrode array.

Statistical analysis

Audiological data along with neuroimaging and surgical findings were analyzed statistically. Single-subject design was used, where each subject acts as his/her own control. SPSS for Windows 15.0 software (Chicago, Ill., USA) was used for all analyses. Single mean imputation was used to replace missing values. Correlations between pre and post-reimplantation pure tone audiometry (PTA) thresholds, speech comprehension results, and depth of electrode insertion were analyzed using Pearson product–moment correlations.

Results

Reason for reimplantation

The reason for explantation–reimplantation was related to complications in all cases, be it failure of the implanted system or medical complication (Table 2).

The complication rate was 2.7 % (26/962) in the group of patients who had their first cochlear implant surgery in the reference center. The most frequent complication was technical failure in 65.39 % of the cases (17/26). Hard failure was seen in 52.9 % (9/17) and soft failure in 47.1 % (8/17). Medical complications occurred in 34.61 % of the cases (9/26). Skin dehiscence along with implant contamination caused 22.22 % (2/9) of reimplantations. Device infection without skin ulcer was diagnosed in 44.4 % (4/9). Partial migration of the electrodes complicated 33.33 % of the cases (3/9). Note that in all the migration cases, cochlear implantation was performed in radical cavities. Cables were fixed with bone cement and protected with cartilage and fascia grafts. Along the years, cables became exposed in the cavity in all these cases.

Regarding the group of patients referred to the reference hospital with complications, the most frequent reason was medical complication (58.33 %). Improper initial placement occurred in 71.43 % (5/7). Skin dehiscence or erosion of the external canal walls and implant contamination was seen in 28.57 % (2/7). Device failure occurred in 41.66 % (5/12). Soft failure was documented in 60 % (3/5) and hard failure in 40 % (2/5).

Surgical and neuroimaging findings

Table 1 shows the preoperative radiological findings and the observed cochlear findings by the surgeon during reimplantation surgery and etiology of the deafness and depth of electrode array insertion in the first cochlear implantation and reimplantation procedures case by case.

Thus, ossification was initially diagnosed based on radiological findings in 5 cases (13.16 %). In 2 out of the 5 cases, the ossification was connected to a history of Chronic Otitis Media (COM), in one case to meningitis and in the last 2 cases, there was nothing of a physiopatological nature in the medical record that suggested ossification. No type of ossification whatsoever was observed during reimplantation surgery in one of the latter, but it was evidenced in the other 4 cases. Thus, ossification was suspected in 5 cases; however, it was confirmed surgically in only 4 of 5 radiologically diagnosed cases. 32 patients (84.21 %) had not shown any type of cochlear occlusion in the preoperative radiological exploration. However, signs of cochlear ossification in 6 cases and fibrosis in 4 cases were found during the reimplantation surgery. This means that 13.15 % of patients (5/38) had no prior alterations of their cochlear permeability and saw signs of occupation appear, potentially related to the insertion of the electrode array. Such findings were described intraoperatively by the surgeon, after removal of the electrode array. Microscopic evaluation of the cochleostomy site and intracochlear permeability allowed the final diagnosis. In these cases, the first millimeters of the basal turn had to be permeated with a 1-mm diamond burr, to insert the new electrode array, which was fully inserted in all cases. Figure 1 correlates depth of insertion before and after reimplantation with the findings in the cochleostomy area observed during the reimplantation surgery. This figure shows the depth of insertion measured from the electrode array in millimeters. It was between 4 and 15 mm shorter than in the initial implantation surgery in 7 cases. If we take a more functional concept, such as the full or partial insertion of active electrodes—and we define partial insertion as one or more active electrodes placed outside the cochlea—partial insertion in the first implantation was achieved in 10/38 patients, whereas it has been described in 3/38 patients during reimplantation surgery. In 2 out of these 3 cases, partial insertion was achieved, while in the third case, complete insertion with a nucleus straight electrode array was carried out during first surgery. This case was an urgent surgery, since the cochlea was ossifying due to meningitis. A partial insertion was achieved during reimplantation with a nucleus contour advance perimodiolar electrode array. Depth of insertion was improved in 8 cases during reimplantation. These cases corresponded with the group of medical complications (Fig. 2), particularly the 4 cases where the electrode arrays had not been properly placed in the first surgery.

A cochlear implant from the same manufacturer than in the initial surgery was used in all patients except one

Table 2 Classifies every case considering type of failure

Center	Technical failures	Medical complications	Total
Reference center	17 (65, 4 %)	9 (34, 6 %)	26 (68, 42 %)
	Hard failure 9	Skin dehiscence 2	
	Soft failure 8	CI contamination 4	
		Electrode migration 3 (radical cavities)	
Other	5 (41, 66 %)	7 (58, 33 %)	12 (31, 57 %)
	Hard failure 2	Skin dehiscence 2	
	Soft failure 3	CI contamination 1	
		Electrode malposition 4	
Total	22 (57, 89 %)	16 (42, 10 %)	38 (100 %)

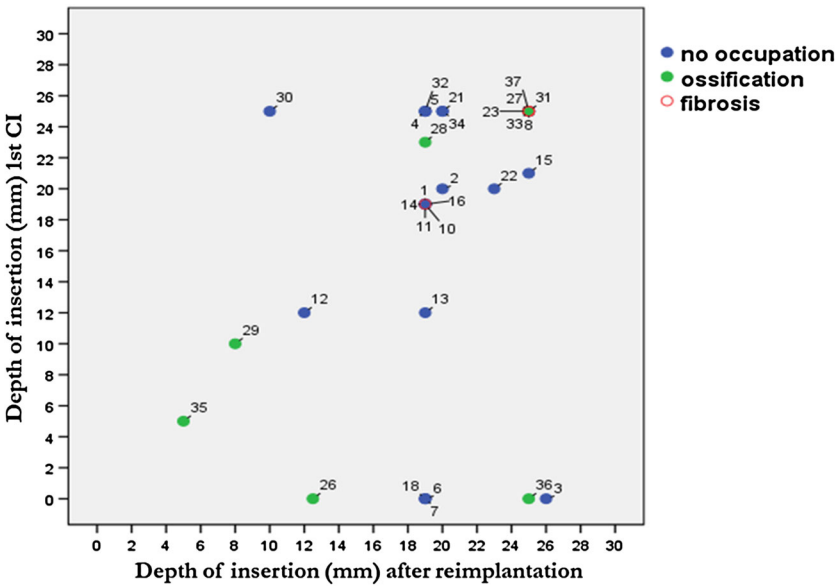

Fig. 1 Correlation between depth of insertion before and after reimplantation with the findings in the cochleostomy area observed during the reimplantation surgery

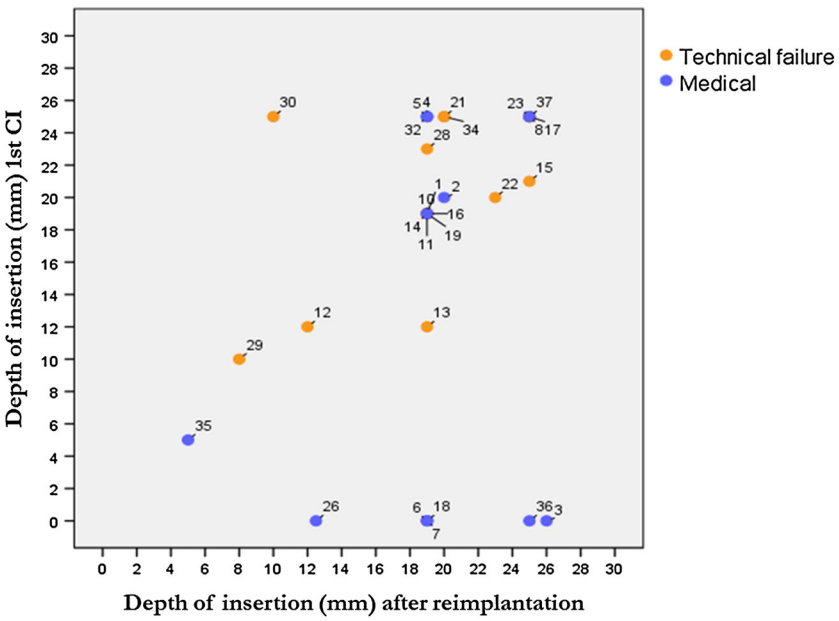

Fig. 2 Correlation between depth of insertion before and after reimplantation with the type of complication leading to the explantation–reimplantation surgery

(case#13). In this case, the depth of insertion during the reimplantation was longer, not because of the initial partial insertion, but because the new electrode array was longer (12 versus 19 mm).

Auditory performance

Figure 3 and 4 show auditory outcomes before and after reimplantation.

From a statistical standpoint, a highly significant correlation was observed ($p < 0.001$) between aided thresholds before and in the last follow-up (CC Pearson 0.666). Nevertheless, PTA thresholds improved in 44.44 % of patients. No change is observed in 11.11 %. PTA thresholds worsen between 12 and 19 dB in 44.44 % of reimplanted patients. These results remained unaltered regardless of the type of complication, be it failure of the device or medical complications (Fig. 3).

Generally speaking, speech perception results changed after reimplantation compared with results recorded before the surgery. There was no statistically significant correlation (Rho Spearman 0.368, $p = 0.266$). Regarding auditory outcomes in disyllabic test, 63.64 % of patients improved, and 9.09 % of patients did not change and 27.27 %

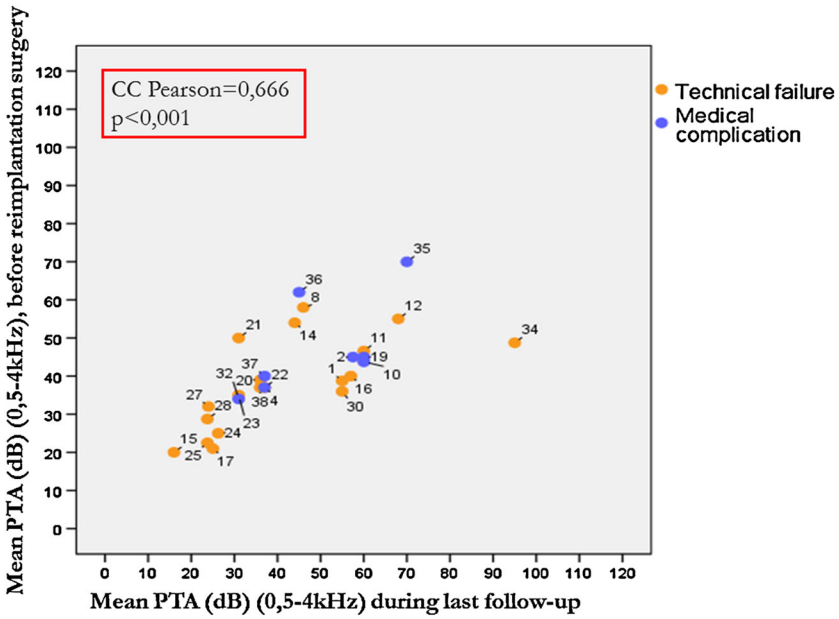

Fig. 3 Correlation between mean PTA thresholds (0.5–4 kHz) before and after reimplantation with the type of complication leading to the explantation–reimplantation surgery ($n = 27$)

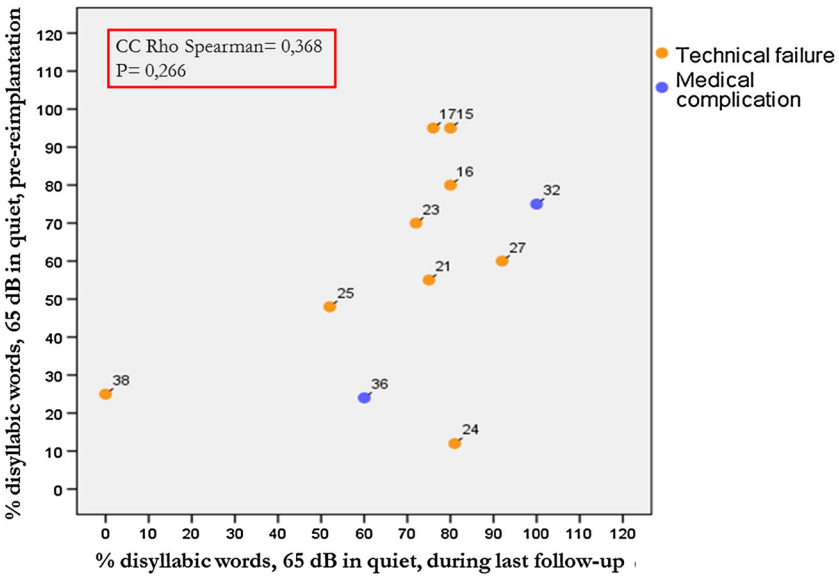

Fig. 4 Correlation between mean % dysyllabic words at 65 dB before and after reimplantation with the type of complication leading to the explantation–reimplantation surgery ($n = 11$)

worsened. The decrease in speech discrimination ranged from 15 to 25 % and the increase from 20 to 35 %. Better results were generally linked to reimplantations due to medical complications, suggesting that medical complications tended not to interfere in the inner ear as much as technical failure. This fact may be due to cases where electrode array was malpositioned or partially inserted in the cochlea during first surgery (3 cases with electrode migration in radical cavities and 4 subjects with electrode malposition). Reimplantations due to device failure did not record significant changes in speech perception before and after reimplantation (Fig. 4).

Discussion

The explantation–reimplantation of a cochlear implant is usually linked to technical failures in the implanted system or some medical complications. It is less frequently indicated for technological upgrades. Since the beginning of cochlear implantation, the failure rate has decreased [16]. But technical and medical complications are still inherent to the implantation procedure. The rate of revision surgery has ranged from 3.8 to 7.2 % [16]. Many reports have shown that the complication rate is higher among children [17], mainly because children are more prone to head

trauma than adults [18]. Compared with the failure rates published in the literature, our series shows a similar total failure rate (2.7 %). While soft failure rate in other series ranges form 15 to 41.7 % [19, 20], our center is at 47.1 %. Hard failure rate has been reported in 42–83 %, while the rate in our center is 52.9 %. In our study, subjects that underwent revision surgery were classified based on first implantation surgery. Note that the main reason for revision surgery for patients in our hospital was technical failure (65.4 %). However, for subjects whose first surgery was performed by other centers with smaller numbers of implantations per year, the reason for revision surgery was medical complication (58.33 %). These data suggest that acquiring surgical experience may reduce explantation–reimplantation surgery rate.

Reimplantation raises the issue of whether the depth of insertion of the new electrode array will be equal to the depth attained in the first implantation surgery. Based on the concept of partial or full insertion of active electrodes, as previously described, there are 8 cases described in this series where the depth of insertion was significantly deeper after reimplantation. There were medical complications in all these cases. In four of these cases, the electrodes were not placed correctly. Upon solving this problem, the positive result ensued is obvious, since the cochlear anatomy was untouched and uninjured. In the other four cases, the electrodes had migrated, and the cables had become exposed. In 3 cases, this happened in the mastoid (they had a history of radical cavities) and in one case in the external auditory canal, at the level of the lumen, due to an eroded posterior wall. However, the electrode array reinsertion depth was partial in 1 case (2.94 %) despite having been fully inserted in the initial surgery. In this case, meningitis was the cause of the hearing loss. The first surgery revealed partial cochlear ossification. We estimate that the partial insertion was due to a progression in the ossification and an electrode array model different—stiffer but bigger in diameter—from the one initially used. These findings agree with Laszigś [11]. Some considerations must be taken into account for reimplantation purposes. Electrode array reinsertion should, if possible, be carried out through the original cochleostomy. Fibrosis should be removed previously. The electrode array must be reinserted immediately after explantation. New electrode array should have an equal or smaller diameter than the old one. In case, fibrosis or ossification is suspected due to the etiology of the hearing loss or previous traumatic insertion, the electrode array should be stiffer. In any case, it is noteworthy that depth of insertion in most patients was at least equal or deeper, and partial insertion was finally associated to cases of previous cochlear ossification. If implantation surgery takes place in a radical cavity, a subtotal petrosectomy with external auditory canal and Eustachian tube close up is recommended as a standard procedure [21].

Speech perception in the reimplanted population is maintained or enhanced in the majority of cases (66.7 %). In our study, etiology of hearing loss plays a role in terms of depth of insertion and therefore auditory performance. In some cases, auditory performance worsened (27.27 %), ranging from 15 to 25 %. The largest review of device failure was undertaken by Battmer [12]. Auditory outcomes in 3400 implantees improved in 30 % of the cases and worsen in 30 %.

Regarding the presence of ossification or fibrosis in the cochleostomy site, assertions can be made with no histopathological evidence to back it up. Ossification and/or fibrous tissue may be related to surgical trauma during first surgery. It is assumed that the entrance of bone dust in the cochlea during drilling maneuvers, electrode array insertion at the level of the scala vestibuli, fracture of the spiral lamina, foreign body reaction, or a contamination secondary to an acute otitis media may play a role. In order to shed light on the mechanisms involved in a potential cochlear deterioration subsequent to reimplantation surgery, special attention has been paid not only to auditory performance with cochlear implant but also to histological findings. Removing an electrode array and inserting a new one in the cochlea could potentially injure this anatomical structure. Lee et al. [22] reported histopathological changes in the temporal bones of 4 human subjects who underwent cochlear implantation revision. New bone and fibrous tissue are observed. It seems to be related to the insertion trauma of the lateral cochlear wall. In spite of this, depth of insertion of the reimplanted electrodes was deeper than the initial depth of insertion. Other post-mortem histological studies and clinical experience from several authors [2, 3, 22–24] illustrate how these injuries may be significant enough in some cases so as to compromise the insertion of a new implant and the successful stimulation of the cochlear nerve, ultimately affect clinical outcomes. As a result and for a few years now, minimally traumatic cochlear surgery is systematically supported when fitting the cochlear implant [25–31]. Among other reasons, we believe that preserving the cochlear anatomy and function must be a priority. Therefore, it is necessary to know exactly and anticipate to the effects of multiple intra-cochlear insertions, carried out under the premise of atraumaticity.

Conclusions

Management of cochlear implant complications and revision surgery is increasing due to a growing number of implantees. Cases that require explantation and reimplantation of the cochlear implant are safe procedures, where

the depth of insertion and speech perception results are equal or higher in most cases. The etiology of hearing loss and surgical technique used may suggest potential difficulties during revision surgery in terms of electrode array insertion.

Acknowledgments The project performed at the University of Navarra has been supported by funds from Cochlear AG.

References

1. Ramos A, Manrique M (2005) Histopatología de la Cóclea en relación con la Implantación Coclear. Acta Otorrinolaringol Esp 1:82–87
2. Fayad J, Linthicum FH Jr, Otto S, Galey FR, House WF (1991) Cochlear implants: histopathological findings related to performance in 16 human temporal bones. Ann Otol Rhinol Laryngol 100:807–811
3. Linthicum FH Jr, Fayad J, Otto SR, Galey FR, House WF (1991) Cochlear implant histopathology. Am J Otol 12:245–311
4. Lenhardt E (1993) Intracochlear placement of cochlear implant electrodes in soft surgery technique. HNO 41(7):356–359
5. Franz BK, Clark GH (1987) Refined surgical technique for insertion of banded electrode array. Ann Otol Rhinol Laryngol 96(128):15–16
6. Sutton D, Miller JM, Pfingst BE (1980) Comparison of cochlear histopathology following two implant designs for use in the scala timpani. Ann Otol Rhinol Laryngol 399:19–31
7. Fraysse B, Dillier N, Klenzner T, Laszig R, Manrique M, Morera-Pérez C, Morgon AH, Muller-Deile J, Ramos A (1998) Cochlear implants for adults obtaining marginal benefit from acoustic amplification: a European study. Am J Otol 19:591–597
8. Fraysse B, Ramos A, Sterkers O, Burdo S, Ramsden R, Albegger K, Deguine O (2006) Residual hearing conservation and electroacoustic stimulation with the nucleus 24 contour advance. Otol Neurotol 27(5):624–633
9. Zeitler DM, Budenz CL, Roland JL Jr (2009) Revision cochlear implantation. Curr Opin Otolaryngol Head Neck Surg 17:334–338
10. Vaid N, Roland T, Vaid S (2011) Extracochlear electrode extrusion. Cochlear Implants Int 12(3):177–180
11. Laszig AA, Zwolan TA, Telian SA (2005) Cochlear implant failures and revision. Otol Neurotol 26:624–634
12. Battmer R, Lenarz T (2009) A review of device failure in 3400 implantees. Otol Neurotol 30:455–463
13. Manrique M, García-Ibañez L, García-Ibañez E (2002) Bases de la cirugía del implante coclear en adultos. In: Manrique M, Huarte A (eds) Implantes cocleares, 1st edn. Masson, Barcelona, pp 201–208
14. Manrique M, Cervera-Paz FJ, Espinosa JM, Perez N, García Tapia R (1996) Cochlear implantation in radical cavities of mastoidectomy. Laryngoscope 106(12):1562–1565
15. Huarte et al (1996) Protocolo para la valoración de la audición y el lenguaje en lengua española en un programa de implantes cocleares. Acta Otorrinolaringologica Española 47(1)
16. Wang JT, Wang AY, Psarros C, Da Cruz M (2014) Rates of revision and device failure in cochlear implant surgery: a 30 year-experience. Laryngoscope 124(10):2393–2399. doi:10.1002/lary.24649
17. Brown KD, Connell SS, Balkany TJ (2009) Incidence and indications for revision cochlear implant surgery in adults and children. Laryngoscope 119:152–157
18. Weise JB, Muller-Deile J, Brademann G, Meyer JE, Ambrosch P, Maune S (2005) Impact to the head increases cochlear implant reimplantation rate in children. Auris Nasus Larynx 32:339–343
19. Venail F, Sicard M, Piron JP (2008) Reliability and complications of 500 consecutive cochlear implantations. Arch Otolaryngol Head Neck Surg 134:1276–1281
20. Rivas A, Marlowe AL, Chinnici JE, Niparko JK, Francis HW (2008) Revision cochlear implantation surgery in adults: indications and results. Otol Neurotol 29:639–648
21. Free RH, Falconi M, Di Trapani G, Ciannuzzi AL, Russo A, Sanna M (2013) The role of subtotal petrosectomy in cochlear implant surgery—a report of 32 cases and review on indications. Otol Neurotol 34(6):1033–1040
22. Lee J, Eddington D, Nadol J (2011) The histopathology of revision cochlear implantation. Audiol Neurotol 16:336–346
23. Galey FR (1984) Initial observations of a human temporal bone with a multi-channel implant. Acta Otolaryngol Suppl (Stockh) 411:38–44
24. Linthicum FH Jr, Galey FR (1983) Histologic evaluation of temporal bones with cochlear implants. Ann Otol Rhinol Laryngol 92:610–613
25. Gantz BJ, Turner C, Gfeller KE, Lowder MW (2005) Preservation of hearing in cochlear implant surgery: advantages of combined electrical and acoustic speech processing. Laryngoscope 115(5):796–802
26. James C et al (2005) Preservation of residual hearing with cochlear implantation: how and why. Acta Otolaryngol 125(5):481–491
27. Brown R, Hullar T, Cadieux J, Chole R (2010) Residual hearing preservation after pediatric cochlear implantation. Otol Neurotol 31:1221–1226
28. Kiefer J, Gstoettner W, Baumgartner W, Pok S, Tillein J, Ye Q, Von Ilberg C (2004) Conservation of low frequency hearing in cochlear implantation. Acta Octolaryngol 124:272–280
29. Kuo S, Gibson W (2000) The influence of residual high frequency hearing on the outcome in congenitally deaf cochlear implant recipients. Am J Otol 21:657–662
30. Skarzynski H, Lorens A, D'Haese P, Walkowiak A, Piotrowska A, Sliwa L, Anderson I (2002) Preservation of residual hearing in children and post lingually deafened adults after cochlear implantation: an initial study. J ORL 64:247–253
31. Verhaegen V, Snik A, Beynon A, Rens Leeuw A, Mylanus E (2010) Preservation of low frequency residual hearing after cochlear implantation. Is soft surgery effective? Int Adv Otol 2:125–130