Audiology & Neurotology

Published online: February 20, 2015

Audiol Neurotol 2014;19(suppl 1):15–20
DOI: 10.1159/000371599

Predictive Factors of Cochlear Implant Outcomes in the Elderly

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Key Words
Profound hearing loss · Older adults · Cognition · Quality of life · Depression · Complications · Tinnitus · Vestibular symptoms

Abstract
Objective: To analyze predictive factors of cochlear implant outcomes and postoperative complications in the elderly. ***Study Design:*** Prospective, longitudinal study performed in 10 tertiary referral centers. ***Methods:*** Ninety-four patients aged 65–85 years with a profound, postlingual hearing loss were evaluated before implantation, at time of activation, and 6 and 12 months after cochlear implantation. Speech perception and lipreading were measured using disyllabic word recognition in quiet and noise, and lipreading using disyllabic words and sentences. The influence of preoperative factors on speech perception in quiet and noise at 12 months was tested in a multivariate analysis. Complications, presence of tinnitus and of vestibular symptoms were collected at each evaluation. ***Results:*** The effect of age was observed only in difficult noisy conditions at SNR 0 dB. Lipreading ability for words and sentences was negatively correlated with speech perception in quiet and noise. Better speech perception scores were observed in patients with shorter duration of hearing deprivation, persistence of residual hearing for the low frequencies, the use of a hearing aid before implantation, the absence of cardiovascular risk factors, and in those with implantation in the right ear. General and surgical complications were very rare, and the percentage of vestibular symptoms remained stable over time. ***Conclusion:*** This study demonstrates that cochlear implantation in the elderly is a well-tolerated procedure and an effective method to improve communication ability. Advanced age has a low effect on cochlear implant outcome. Analyses of predictive factors in this population provide a convincing argument to recommend treatment with cochlear implantation as early as possible in elderly patients with confirmed diagnosis of a severe-to-profound hearing loss and with only limited benefit from hearing aid use in one ear.

Introduction

The literature provides evidence that cochlear implantation in the elderly improves speech perception ability in quiet and noise and in the quality of life, even in patients aged 80 years and older, with a durable benefit over time [Budenz et al., 2011; Carlson et al., 2010; Clark et al., 2012; Cloutier et al., 2014; Dillon et al., 2013; Friedland et al., 2010; Lenarz et al., 2012; Leung et al., 2005; Lin et al., 2012; Mahmoud and Ruckenstein, 2014; Mosnier et al., in press; Olze et al., 2012; Roberts et al., 2013; Williamson et al., 2009]. Most of these retrospective studies compare speech perception scores between the elderly and a cohort of younger patients, and show that advanced age is correlated negatively with cochlear implant outcome, especially for tests in noise. Little is known about the other causes that may account for the variability in auditory performance observed after cochlear implantation in older adults.

The objectives of this prospective study were to analyze predictive factors of cochlear implant outcome at 12 months after implant in elderly patients aged 65 years and over and to evaluate the relative safety of the surgery.

Methods

Subjects. Between September 2006 and June 2009, 94 patients aged 65 years and older who were candidates for a cochlear implantation were prospectively included in this study in 10 tertiary referral centers. Patients were postlingually deafened with bilateral, severe-to-profound hearing loss and demonstrated a speech recognition score of ≤50% for French disyllabic words at 60 dB SPL presented in quiet in the best-aided listening condition. The mean age at implantation was 72 years (range: 65–85, median: 71). Demographic data for the patients are summarized in table 1. The brand of the device was decided primarily by each referral center with a view to ensuring adequate representation of each of the four devices available (table 1). The ethics committee (Comité Consultatif de Protection des Personnes dans la Recherche Biomédicale, GH Pitié-Salpêtrière, Paris, 2007) approved this study. Written in-

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Table 1. Patient demographics (n = 94)

Age at implantation, years	72±0.5 [65–85] (71)
Male	72±0.7 [65–84] (72)
Female	72±0.8 [65–85] (71)
Male/female	45/49
Lateralization	
Right/left/ambidextrous	86/6/2
Duration of hearing loss, years	
Implanted ear	30±2.0 [1–77] (27)
Nonimplanted ear	29±2.1 [1–82] (27)
Male	27±2.9 [1–77] (23)
Female	32±2.8 [1–73] (28)
Duration of profound hearing loss, years	
Implanted ear	11±1.6 [1–61] (5)
Nonimplanted ear	11±1.9 [1–82] (4, 5)
Male	13±2.8 [1–61] (6)
Female	10±1.7 [1–45] (5)
Etiology[a]	
Unknown	44
Otosclerosis	15
Menière's disease	12
Congenital/familial	12
Traumatism	10
Chronic otitis	3
Meningitis	2
Ototoxicity	2
Use of hearing aids, implanted/nonimplanted ear	
Never	27/25
Abandoned before implantation	24/9
Medical history	
None or minor pathologies	50
Hypertension	34
Cardiovascular events	17
Diabetes mellitus	8
Respiratory disease	5
Cancer	4
Cochlear implantation	
Unilateral/simultaneous bilateral	94/1
Right/left	50/43
Neurelec[b]	29
Med-El[c]	26
Cochlear[d]	23
Advanced Bionics[e]	17
Percent activated electrodes at 12 months	97±0.7 [75–100]

Data are presented as mean ± SEM [range] (median) or number. [a] Any patient may have several etiologies. [b] Neurelec, Vallauris, France. [c] Med-el, Innsbruck, Austria. [d] Cochlear, Lane Cove, Australia. [e] Advanced Bionics, Valencia, Calif., USA.

formed consent was obtained from each subject before enrolment into the study.

Study Design. Speech perception and lipreading were scored before implantation and at 6 and 12 months after activation. Patients were tested for the auditory-only condition, both in quiet and noise, in the best-aided condition (i.e. CI in conjunction with a contralateral hearing aid, if used). Measurements were performed in a sound-treated room using recorded French materials (Fournier lists of 10 open-set, disyllabic words) presented at 60 dB SPL from a loudspeaker placed at 0° azimuth. Tests in noise were administrated at a signal-to-noise ratio (SNR) ranging from +15 to 0 dB, with the speech stimuli and a competing white noise coming from the front speaker. Two lists of words were presented at each level, and responses were scored as the percentage of words correctly identified.

To evaluate lipreading ability, the percentage of correctly identified words and sentences was scored for two lists of 10 disyllabic words (Fournier list), and for 15 sentences (Marginal Benefit from Acoustic Amplification sentences in French). These materials were presented by speech therapists in a visual-only condition. The ability of patients to communicate on the telephone with familiar speakers or with strangers was also assessed by the use of a questionnaire specifically developed for this study.

General and surgical complications were recorded at each session of evaluation, as well as assessments concerning balance problems and the presence and change of perception of tinnitus compared to the preimplantation period. Caloric testing was performed before implantation and at 6 and 12 months after activation.

Statistical Analysis. Values were expressed as mean ± SEM (standard error of the mean) or median (first through third quartiles) for continuous variables, and as percentages for categorical variables. Specific statistical tests were used depending of the data, as indicated in the results. All analyses were performed using commercially available statistical software (SAS, version 9.2; SAS Institute, Cary, N.C., USA).

Results

Predictive Factors of Cochlear Implant Outcome. Mean speech performance in quiet and noise has previously been reported by Mosnier et al. [in press]. In brief, the report shows that speech perception scores dramatically improved in quiet at 6 months after cochlear implantation compared to the preimplantation scores (58 ± 3.2 vs. 14 ± 2.1%, $p < 0.0001$, paired t tests) and further improved between 6 and 12 months (64 ± 3.2%, $p = 0.005$, paired t tests). Furthermore, it was reported that in noise, speech perception scores increased at 6 months after cochlear implantation compared to preimplantation scores, at each SNR ($p < 0.0001$, paired t tests), and remained stable between 6 and 12 months (at 12 months: SNR +15 dB: 50 ± 3.8 vs. 5 ± 1.6% before implantation; SNR +10 dB: 41 ± 3.5 vs. 3 ± 0.9%; SNR +5 dB: 30 ± 3.5 vs. 0%; SNR 0 dB: 20 ± 3.2 vs. 0%). Mean speech perception scores at 12 months in quiet and noise were similar between males and females. Speech performance at 12 months at SNR +5 and 0 dB was positively correlated with the residual hearing threshold before implantation at frequencies of 250 and 500 Hz (SNR +5 dB: $r = -0.23$, $p < 0.05$; SNR 0 dB: $r = -0.25$, $p < 0.05$). Speech perception scores at 12 months varied as a function of the brand of the device, without interaction with the test condition ($p < 0.01$, two-way ANOVA, fig. 1). The greatest effect was observed in difficult noisy conditions at SNR 0 dB (brand C > brand A, $p < 0.0001$, one-way ANOVA, fig. 1). The mean age of the patients was similar in the four groups of patients. Multivariate analysis found that longer duration of hearing deprivation of the implanted ear was associated with poorer speech perception scores only in quiet with the cochlear implant alone condition ($p < 0.005$). The positive effect of preimplant hearing aid use on the performance in the implanted

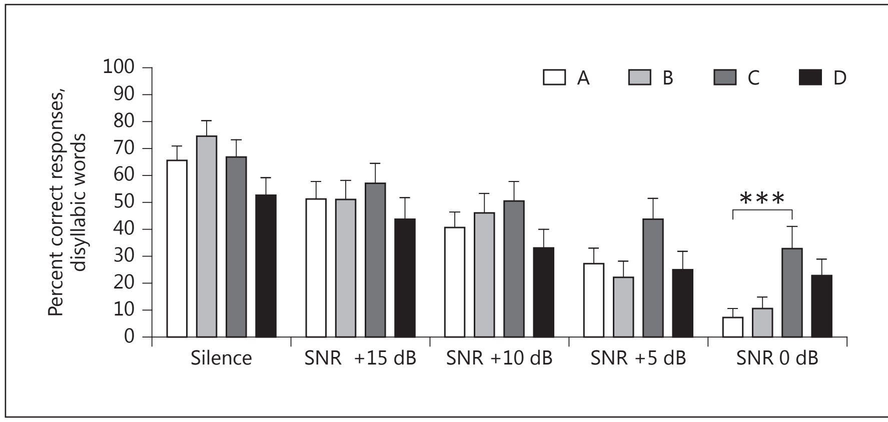

Fig. 1. Mean speech performance in quiet and noise at different SNR as a function of the brand of the device at 12 months after activation. Patients were tested in 'best-aided' conditions, with contralateral hearing aid, if used. Test material was disyllabic words presented at 60 dB. Each brand has been arbitrarily defined by the letters A, B, C, D. Values are means ± SEM. Speech perception scores at 12 months were different as a function of the brand of the device, without interaction with the test condition ($p < 0.01$, two-way ANOVA). The greatest effect was observed in difficult, noisy conditions at SNR 0 dB: *** $p < 0.0001$, one-way ANOVA.

ear was observed in noise at SNR +15 dB [patients using hearing aid (51/94): 48 ± 4.6%; patients without hearing aid: 32 ± 5.1%, $p < 0.05$]. Patients with cardiovascular risk factors (40/94) obtained poorer speech scores in noise compared to patients without cardiovascular disease (SNR +10 dB: 34 ± 4.8 vs. 44 ± 4.5%, $p < 0.05$; SNR +5 dB: 19 ± 3.6 vs. 34 ± 4.6%, $p < 0.05$). Patients implanted in the right ear (50/93) performed better in difficult noisy conditions compared to patients implanted in the left ear (SNR +5 dB: 34 ± 3.2 vs. 23 ± 3.7%, $p < 0.05$; SNR 0 dB: 25 ± 4.7 vs. 12 ± 2.8%, $p < 0.005$). Finally, an effect of age at implantation was observed only in the most difficult noise condition tested at SNR 0 dB with better speech performance observed in younger patients ($p < 0.05$). We found no influence of gender, duration of profound hearing loss or speech perception scores before implantation on cochlear implant outcomes.

Lipreading scores for words and sentences remained stable after cochlear implantation over time in the total population (words before implantation: 30 ± 2.8%; 6 months: 28 ± 2.7%; 12 months: 28 ± 2.4%, n.s., one-way ANOVA; sentences before implantation: 29 ± 3.0%; 6 months: 32 ± 3.0%; 12 months: 32 ± 3.2%, n.s., one-way ANOVA), and within male and female groups. Females obtained better scores than males for words and sentences ($p < 0.05$ and $p < 0.0001$, respectively, two-way ANOVA, fig. 2) with no interaction of the test interval. Lipreading scores for words and sentences were correlated with duration of hearing loss (words: $r = 0.35$, $p < 0.005$; sentences: $r = 0.37$, $p = 0.00$, data not shown) but no correlation was found for the duration of profound hearing loss and age at implant. Multivariate analysis showed that good lipreading ability before implantation had a negative influence on speech performance at 12 months in quiet and in noise. Patients with poorer lipreading scores for words obtained better speech perception scores in quiet ($p < 0.05$) and in noise at SNR +15 dB and +5 dB ($p < 0.05$). Patients with poorer lipreading scores for sentences obtained also better speech perception scores in noise at SNR +10 dB ($p < 0.05$) and SNR 0 dB ($p < 0.005$).

Telephone Use. Before cochlear implantation, 22% (21/94) of the patients used the telephone, and if only with familiar speakers. Six months after cochlear implantation, 51% (48/94) of patients were able to use the phone. At 12 months, 65% (61/94) of the patients indicated that they were able to use the phone ($p < 0.0001$, Fisher's test), and half of these could do so with unfamiliar speakers. Sixty-one percent (37/61) of the telephone users were female ($p < 0.05$, Fisher's test). The mean age was similar between users and nonusers (unpaired t test). The distribution of patients who

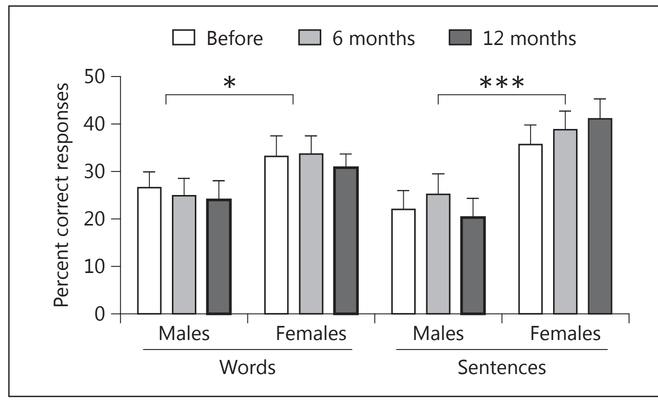

Fig. 2. Mean lipreading scores for disyllabic words and sentences before implantation, and at 6 and 12 months after activation, for males and females. Values are means ± SEM. Females obtained better scores than males for words and sentences: * $p < 0.05$; *** $p < 0.0001$ (two-way ANOVA). Scores remained stable after implantation in the two groups.

did not use the phone or who could talk with familiar speakers or with unfamiliar speakers was similar between CI users aged between 65 and 74 years and those over 75 years (32, 31, 37% and 44, 40, 16%, respectively, n.s., χ^2).

Complications, Tinnitus and Balance Problems. All patients underwent successful placement of the electrode array; no intraoperative complications were reported. Immediate postoperative neurologic complications occurred in 2 men aged 76 and 72 years: in the first case, episodes of confusion occurred; the second case, demonstrated a temporary speech disorder. The mean length of hospital stay was 3.4 ± 0.13 days (1–7). A flap necrosis occurred at 3 months postoperatively in one woman aged 68 years without a history of medical problems, leading to explantation and reimplantation 8 months after the initial surgery. No other major complications were observed.

Before cochlear implantation, 53% (49/92) of the patients reported tinnitus. At 6 and 12 months after cochlear implantation, the prevalence of tinnitus decreased on both the implanted and the contralateral side compared to before implantation (table 2). Among the 32% (30/94) of patients reporting tinnitus at 12 months,

Table 2. Tinnitus and vestibular function before and after cochlear implantation

	Before	Activation	6 months	12 months
Tinnitus	n = 92	n = 90	n = 91	n = 94
Implanted/nonimplanted ear	48 (52)/41 (45)	37 (41)/24 (27)	30 (33)/23 (25)	30 (32)/25 (27)
p value (Fisher's test)[a]		n.s. n.s.	0.01 <0.01	<0.01 <0.05
Vestibular symptoms	n = 94	n = 90	n = 91	n = 94
Rotatory vertigo	14 (15)	6 (7)	6 (7)	4 (4)
Unsteadiness	12 (13)	23 (26)	20 (22)	22 (24)
Positional vertigo	1 (1)	3 (3)	3 (3)	3 (3)
Absence	67 (71)	58 (64)	62 (68)	65 (69)
p value (χ^2)[a]		<0.05	n.s.	<0.05
Falls[b]	6	0	1	4
Caloric test	n = 77		n = 69	n = 63
Implanted/nonimplanted ear				
Areflexia	9 (12)/5 (7)		18 (26) 7 (10)	10 (16) 7 (11)
Hyporeflexia	11 (14)/14 (18)		15 (22) 11 (16)	15 (24) 6 (10)
Normal	57 (74)/58 (75)		36 (52) 51 (74)	38 (60) 50 (79)
p value (χ^2)[a]			<0.05/n.s.	n.s./n.s.
Worsening[c]			15 (25)/6 (9)	14 (25)/7 (12)
Stable[c]			45 (75)/59 (91)	41 (75)/50 (88)

Values are presented as number (%). [a] Compared to preimplantation data. [b] Number of patients with at least 3 falls in the latest 3 months. [c] Worsening: change from normal function to hyporeflexia, or from hyporeflexia to areflexia (compared to preimplantation data), after exclusion of patients with preoperative areflexia.

13 stated that the tinnitus loudness had decreased compared to preimplantation, 9 patients displayed stable loudness, 2 (2%) patients described an increase in loudness of their tinnitus, and 6 (6%) patients developed tinnitus after the cochlear implantation.

Vestibular symptoms and caloric test results are detailed in table 2. Seventy-one percent of the patients reported no balance problems before cochlear implantation. This percentage remained stable at the time of sound processor activation, and at 6 and 12 months after cochlear implantation (χ^2); the number of reports for patients reporting falls over time also remained stable. We observed, however, that the percentage of patients with rotatory vertigo decreased while the percentage of patients complaining of unsteadiness increased at 12 months ($p < 0.05$, χ^2). The percentage of patients with vestibular symptoms at 12 months was similar for those between 65 and 74 years old (29%) and those over 75 years old (36%, n.s., Fisher's test). At 6 and 12 months after activation, 25% of the patients demonstrated a worsening in the caloric function test of the implanted ear versus 9 and 12% for the nonimplanted ear. Before implantation, the percentage of patients complaining of vertigo and dizziness was 44% among patients with bilateral abnormal caloric responses, 25% among patient with unilateral abnormal caloric response and 35% among patients with normal caloric response (n.s., χ^2). In patients with worsening of the caloric response in the implanted ear at 12 months (15/60), 43% (3/15) of them complained of vestibular symptoms versus 27% (12/45) in patients without change (n.s., Fisher's test).

Discussion

This prospective study demonstrates that cochlear implantation improves speech perception in quiet and in noise in an elderly population. As suggested in previously reported retrospective research, our multivariate analysis confirms that advanced age is associated with poorer speech perception scores, but only in very difficult noisy conditions, such as 0 dB SNR [Budenz et al., 2011; Carlson et al., 2010; Friedland et al., 2010; Gaylor et al., 2013; Lazard et al., 2012; Leung et al., 2005; Mahmoud and Ruckenstein, 2014; Roberts et al., 2013]. Shorter duration of hearing deprivation, residual hearing and preimplant hearing aid use in the future implanted ear positively influence cochlear implant outcomes in elderly patients and is supported by research in younger adult populations [Lazard et al., 2012; Holden et al., 2013]. Most of the elderly patients reported long-term, bilateral, progressive deafness. Our results present a compelling argument for providing cochlear implants as early as possible in the elderly population that obtains only limited benefit with their hearing aid in one ear in order to avoid the degeneration of auditory pathways and possible central reorganization. Association between cardiovascular risk factors and hearing loss is reported in the literature [Lin et al., 2012] but, to our knowledge, their negative effect on postimplant speech performance outcomes in noise has not been described to date. Vascular impairment affects both peripheral and central auditory systems, and we can hypothesize that central auditory disorders may contribute to the poorer scores for speech perception in noise observed in our group of patients. The asymmetry of the central auditory pathways, with a left temporal lobe assigned to speech specialization, and the fact that fibers of the auditory pathways cross the midline, may largely explain why patients implanted on the right side obtain better results in noise. Budenz et al. [2011] also describe a right-ear advantage in the elderly group; however, other researchers report no influence of the side of the implantation for the elderly or younger patient groups [Holden et al., 2013; Mahmoud and Ruckenstein, 2014; Roberts et al., 2013].

DOI: 10.1159/000371599

Lipreading scores in our elderly population are similar to those previously reported in younger adult patients using the same test materials; despite the improvement of aural communication after cochlear implantation, lipreading ability remained stable at 12 months, probably because visual cues continue to be used by cochlear implant users to improve speech comprehension in difficult, noisy conditions [Rouger et al., 2007]. At each test interval, females demonstrated better lipreading skills than males for disyllabic words and sentence recognition. This is consistent with a previous study showing a gender difference for lipreading words amongst deaf patients, as well as in normal-hearing subjects [Strelnikov et al., 2009]. They reported lipreading scores improved in males at 2 years after implant, resulting in an insignificant gender difference in the long term. Brain imaging studies have documented the gender difference in showing more diffuse brain activation in females during lipreading tasks and language processing, and it was suggested that females present better predictive and integrative cognitive processes than males [Strelnikov et al., 2013]. Nevertheless, in our study, as in the younger population, gender does not influence cochlear implant speech performance in quiet or in noise [Lazard et al., 2012; Holden et al., 2013]. Interestingly, this study demonstrates the negative influence of lipreading ability before implantation on cochlear implant outcome in quiet and in noise at 12 months after implant. A limited number of studies examined whether lipreading ability may contribute to cochlear implant outcome. In a multivariate analysis including 37 adult patients (mean age: 54 years; range: 24–80), Heyderbrand et al. [2007] reported that lipreading is strongly correlated with age, and that verbal learning and lipreading account for 72% of the variance in word recognition in quiet observed at 6 months. Behavioral and brain imaging studies demonstrate a cross-modal reorganization of the visual and auditory strategies induced by deafness. Indeed, in a group of 10 postlingually deaf adults (mean age 54 years; range: 35–81), lipreading tasks induced an activation of the right anterior regions of the superior temporal sulcus, normally involved in human voice recognition, and the level of activation was shown to correlate to the lipreading scores at the time of implantation [Rouger et al., 2012]. This abnormal activation decreases rapidly after implantation, whereas a progressive activation of the frontal area, involved in auditory phonological tasks and lipreading tasks in normal-hearing subjects appears, suggesting a 'reversed' pattern of neuroplasticity after cochlear implantation. In the same group of patients, the analysis of brain activation using a speech-processing task demonstrated strong positive correlations between activity at time of implantation in the occipital cortex involved in visual processing and in the posterior temporal cortex known for audio-visual integration, and the level of auditory recovery, but a negative correlation between superior temporal sulcus activation and cochlear implant outcomes. Authors suggest a synergy between visual and auditory modalities that may facilitate improvement of speech intelligibility after implantation [Strelnikov et al., 2013]. Further studies examining neural plasticity after cochlear implantation in elderly deaf patients are needed to better understand the role of the visual modality in this population.

The role of cognitive processing in speech intelligibility in noise has clearly been demonstrated and, consequently, it is speculated that cognitive factors may contribute to variability in cochlear implant outcomes. This study also assessed cognitive abilities using a battery of tests exploring episodic memory, visuospatial abilities, attention span, speed of processing, mental flexibility, rule of compliance and executive function. We observed a significant impact only in long-term memory, evaluated by the verbal fluency test for letters, on speech perception scores in noise at 12 months. In addition to the speech perception benefit, we found a reduction in depressive symptoms, a positive effect on quality of life and social activity and, above all, an improvement in global cognitive function for 81% of the patients at 1 year after implantation [Mosnier et al., in press].

The last objective of this study was to analyze prospectively the safety of the procedure; results indicate that the surgery is well tolerated with low rates of general and surgical complications. These findings are corroborated by previous retrospective studies [Chen et al., 2013; Clark et al., 2012; Cloutier et al., 2014; Olze et al., 2012; Roberts et al., 2013]. The prevalence of tinnitus before implantation is lower in our study (53%) compared to that in other reports (>70%) [Kompis et al., 2012; Olze et al., 2012]. The heterogeneity of the study population and variability in evaluation methodology across studies are likely explanations for this difference. The rate of improvement (27%) and complete resolution (51%), as well as the rate of deterioration (8%) of tinnitus after cochlear implantation reported in our study, are consistent with published investigations that report no influence of age upon the change of tinnitus perception; similarly, the positive impact upon bilateral tinnitus from unilateral electrical stimulation has also been reported [Kompis et al., 2012; Olze et al., 2012]. The assessment of the influence of cochlear implantation on vestibular symptoms is critical in older patients due to the higher incidence of balance problems and the risk of injury with falls. After cochlear implantation, a worsening of the caloric response in the implanted ear was observed in 25% of patients, possibly caused by a damage of the horizontal semicircular canal. A decrease in the vestibular function, however, was also observed in 12% of the nonimplanted ears, suggesting that changes in caloric response can also be related to the progression of the inner ear disease. These changes are not always associated with subjective balance problems since the overall percentage of patients with subjective vestibular symptoms remained stable over time, even in the first month after implantation. It is noteworthy that the number of falls was also unchanged after implantation, and that vestibular symptoms were similar between patients aged 75 years and older and those aged between 65 and 73 years. In the literature, patients older than 65 years did not experience more balance problems compared to younger patients [Carlson et al., 2010; Roberts et al., 2013]. In a retrospective review, however, Chen et al. [2013] report a slightly higher prevalence of vestibular symptoms in patients aged 75 years and older (9.5%) compared to patients aged between 60 and 74 years (4.5%, $p = 0.05$). A key limitation of our study is that we only assessed horizontal semicircular canal function and that the analysis of the Dizziness Handicap Inventory was not possible because of the missing data.

Conclusion

Our results, based on a large group of elderly patients prospectively evaluated, demonstrate that cochlear implantation restores aural communication, reduces the prevalence of tinnitus, improves the quality of life, reduces symptoms associated with depression and improves global cognitive function. The effect of age and cognitive abilities on cochlear implant outcomes are low as shown in our study group; however, further studies that more precisely examine the role of specific cognitive factors involved in speech perception in noise and the neural plasticity in elderly deaf patients are needed.

Acknowledgement

We gratefully acknowledge the help of Blandine Pasquet (INSERM CIE 801, GH HUPNVS, Bichat Claude-Bernard, Paris, France) for assistance in statistical analyses, Dr. Evelyne Ferrary (UMR-S 1159, Inserm Université Paris 6 Pierre et Marie Curie, Paris, France) for helpful comments during manuscript preparation, and Dr. Arach Madjlessi (Paris) for his continuing support.

Disclosure Statement

This work was equally funded by Advanced Bionics AG (Stäfa, Switzerland), Cochlear France (Saint-Aubin, France), Vibrant Medel Hearing technology (Sofia Antipolis, France) and Oticon medical/Neurelec (Vallauris, France). The companies had no role in the preparation or study design; in the collection, management, analysis and interpretation of the data; in the review or approval of the manuscript, and in the decision to submit the manuscript for publication.

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