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Cochlear implant outcomes in the elderly: a uni- and multivariate analyses of prognostic factors

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Abstract

Purpose To assess preoperative features that could predict the audiological outcome after cochlear implantation in the elderly, in terms of pure tone audiometry, speech audiometry, and speech perception performance.

Methods All available records of patients with cochlear implants aged 65 or more at the time of their implantation at our Institution were reviewed (50 patients, mean age 70.76 ± 4.03 years), recording preoperative clinical features. Pure tone audiometry, speech audiometry, and speech perception performance 1 year after cochlear implant activation and fitting were used as outcome measures.

Results No statistically significant association emerged between clinical features and pure tone audiometry. On univariate analysis, progressive sensorineural hearing loss of unknown origin was associated with a better outcome in terms of speech audiometry and speech perception performance ($p = 0.035$ and $p = 0.033$, respectively). On multivariate analysis, progressive sensorineural hearing loss retained its independent prognostic significance in terms of speech perception performance ($p = 0.042$). The discriminatory power of a two-variable panel (age and etiology of hearing loss) featured an AUC (ROC) of 0.738 (an acceptable discriminatory power according to the Hosmer–Lemeshow scale).

Conclusions A progressive sensorineural hearing loss of unknown origin was associated with a better outcome in terms of speech perception in the elderly in our case study. Further features that can predict audiological outcome achievable with cochlear implants in the elderly are desirable to perform adequate counselling and rehabilitation programs.

Keywords Cochlear implants · Elderly · Outcome · Multivariate

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Introduction

Cochlear implantation in the elderly has become commonplace in selected cases to restore an adequate social hearing function, and the overall audiological outcome is reportedly comparable with the results obtainable in younger adults [1, 2]. Aural rehabilitation in the elderly is very important because hearing impairment is associated with depression, a worse quality of life [3], and a higher risk of falls and trauma [4]. Hearing impairment is also believed to have a role in the onset of cognitive impairment and dementia [5, 6]. While cochlear implantation surgery is a safe procedure even in the elderly, a high variability in the functional outcomes has been reported [2]. There is very little information in the literature about whether and to what degree patients' preoperative features might influence the functional audiological efficacy of a cochlear implant. Even when the patients are treated and followed by experienced teams, outcomes for individual patients with homogeneous clinical features are still hard to predict.

The primary aim of the present study was to evaluate, with univariate and multivariate statistical analyses, the potential presence of preoperative features that could predict a favourable audiological outcome in elderly patients eligible for a cochlear implant, in terms of pure tone audiometry, speech audiometry and continuous speech comprehension testing.

Materials and methods

Patients

All available clinical records concerning patients who underwent cochlear implant surgery between 2001 and 2017 were reviewed. Patients aged 65 or more at the time of their surgical procedure were considered eligible for this study, according to the definition of "elderly" adopted by the National Institute of Aging [7]. All patients underwent surgery at our Department and were implanted with devices that were state-of-the-art at the time. Patients' available demographic and clinical information were gathered: age at time of device implantation, sex, family history of hearing loss ('yes' if at least one first-degree relative was affected), systemic comorbidities (yes/no), radiological anomalies on preoperative CT and/or MRI, preoperative pure tone average (PTA) in both ears, characteristics of the implant and etiology of hearing loss. Considering this aspect, etiology was dichotomized as known etiology hearing loss versus unknown progressive hearing loss. We considered eligible for this study only patients who underwent at least a 1-year follow-up examination after speech processor activation and fitting (which took place 1 month after surgery) and who used the cochlear implant during ordinary day life.

In all, 58 patients were identified, but only 50 were recruited (26 males and 24 females, mean age at surgery 70.76 ± 4.03 years), due to the lack of adequate follow-up data for 8 patients. The study was conducted in accordance with the principles of the Helsinki Declaration. Data were examined in compliance with Italian privacy and sensible data laws (D. Lgs 196/03) and the internal rules of Padova University's Otolaryngology Section.

Follow-up

Our follow-up protocol is based on several assessments after activating a cochlear implant. We considered 1 year a sufficient interval for judging hearing and speech perception performance, bearing in mind that patients need to become accustomed to the device and complete their aural rehabilitation. All patients attended aural rehabilitation with a speech therapist, who was chosen bearing patients' place of residence in mind, to maximize their compliance.

At each follow-up, patients underwent pure tone audiometry, speech audiometry and a continuous speech comprehension test. Pure tone audiometry was performed in open-field mode, using the cochlear implant, with no hearing aids in the other ear. The results were recorded as PTA, calculated considering thresholds at 500, 1000, 2000 and 4000 Hz. To dichotomize the outcome as positive or negative for statistical purpose, we used the median of the PTA distribution (38.125 dB HL) as a cut-off value for the PTA. Speech audiometry was conducted using simple two-syllable Italian words and the results were recorded as positive or negative depending on whether the patients were able to reach the speech recognition threshold (SRT), i.e. at least a 50% word recognition. Speech comprehension tests were conducted by specialized speech therapists and were scored in terms of aural performance in three steps, each of which tested higher hearing capacities, as reported in a previous work by our group [8]. The first step concerned detection, or speech sound awareness, using Ling 6 sounds, and a successful result corresponded to a Ling 6 sound score > 80%. The second step concerned identification, assessed with two-syllable Italian words that had to be recognized in a closed set list of four similar words, and the test was considered passed when a respondent correctly identified > 50% of the words. The third and final step consisted in asking patients to recognize in open set a list of ten meaningful two-syllable words without lip-reading, and the outcome was positive when they succeeded in recognizing > 50% of the words.

All patients had positive outcomes in the first two steps, but not all of them succeeded in the third. We therefore used this third criterion as an indicator of a "positive outcome" to identify patients with a better general speech comprehension in everyday life.

Statistics

Fisher's exact test was used to investigate the association between each patient's preoperative variables and their hearing outcome after 1 year of implant use. A p value < 0.05 was considered significant, while values in the range of $0.10 > p \geq 0.05$ were assumed to indicate a statistical trend.

A multivariate logistic model was developed where possible, adding the parameters for which Fisher's exact test disclosed a p value < 0.20. The results were expressed as odds ratios (ORs) and p values and 95% confidence intervals (CIs) were calculated. During the analysis, the model was checked for multicollinearity with a variance inflation factor test.

The quality of the model was assessed by calibration, as proposed by Steyerberg et al. [9]. Applying the Hosmer and Lemeshow test, a non-significant result ($p > 0.05$) meant that the model fitted the data well. The effectiveness of the discrimination was assessed on the scale proposed by Hosmer and Lemeshow [10], where: an area under the receiver operating characteristic (ROC) curve (AUC [ROC]) 0.5 means no discrimination; an AUC (ROC) between 0.7 and 0.8 means an acceptable discrimination; an AUC (ROC) between 0.8 and 0.9 means an excellent discrimination; an AUC (ROC) beyond 0.90 means an outstanding discrimination. Additional statistics derived from the model (sensitivity, specificity, positive predictive value, negative predictive value, and accuracy) were also calculated.

The STATA™ statistical package 8.1 (Stata Corp, College Station, TX, USA) was used for all analyses.

Results

Patients' clinical data

Table 1 shows patients' demographic and clinical information. Among the 20 patients with a known etiology of their hearing loss, this involved otosclerosis in 8, Ménière's disease in 3, sequelae of meningitis in 3, sequelae of head trauma in 2, acoustic neuroma in 2, streptomycin ototoxicity in 1, and severe sequelae of acoustic trauma in 1.

Table 1 Patients' clinical features

Clinical variable	Value
Age	70.76 ± 4.03 years
Sex	26 males vs 24 females
Presence of comorbidities	16 yes
	19 no
	15 not stated
Familiarity of hearing loss	10 yes
	40 no
	0 not stated
Etiology of hearing loss	20 known
	27 unknown
	3 not stated
Radiologic anomalies	13 yes
	29 no
	8 not stated
Cochlear implant brand	21 Brand A
	12 Brand B
	17 Brand C
PTA in the ear which received the implant	100.94 ± 20.39 dB HL
PTA in the other ear	89.95 ± 24.40 dB HL

Clinical variables and 1-year outcome: univariate analysis

All patients' clinical records included their pure tone audiometry and speech audiometry results with the cochlear implant after 1 year, and information was available on the speech comprehension tests for 47 out of 50 patients.

When the aided PTA outcome at 1 year was considered, the statistical analysis failed to disclose any significant association with the clinical variables. A higher PTA at the intermediate follow-up tests 1 month and 6 months after activating the cochlear implant was associated with a better PTA outcome after 1 year (Mann–Whitney U test, $p = 0.004$ and $p = 0.0001$ at 1 and 6 months, respectively). As for speech recognition, patients whose hearing loss had no known etiology had a better outcome (Fisher's exact test, $p = 0.035$), while those with a family history of hearing loss showed a statistical trend toward a better outcome (Fisher's exact test, $p = 0.092$). Here again, a better speech recognition performance during at the intermediate follow-up tests was associated with a better outcome at 1 year, or showed a statistical trend in this direction (Fisher's exact test, $p = 0.046$ and $p = 0.050$ for 1-month and 6-month follow-up, respectively).

Performance in the speech comprehension test after 1 year of using the cochlear implant revealed a positive association with unknown causes of hearing loss and with certain cochlear implant brands (Fisher's exact test, $p = 0.033$ and $p = 0.014$, respectively). A family history of hearing loss and the presence of comorbidities also showed a statistical trend towards significance for a better speech comprehension (Fisher's exact test, $p = 0.092$ and $p = 0.090$, respectively). Unlike the other outcome variables, the speech comprehension outcome showed no significant association with PTA in the early months of follow-up.

Clinical variables and 1-year outcome: multivariate analysis

Considering PTA and speech recognition at the 1-year follow-up, after backward elimination there were too few variables with a $p < 0.20$ to enable a proper logistic model to be developed. Conversely, for the speech comprehension, age, presence/absence of comorbidities, family history of hearing loss, etiology of hearing loss, and cochlear implant brand were eligible for inclusion in the logistic regression model. Family history was automatically excluded, however, because none of the patients with a positive family history had a poor speech comprehension outcome; and the presence/absence of comorbidities was not available in the clinical records for more than one in three patients, so its inclusion in the final model would have drastically reduced the total number of patients in the logistic regression model. As for the other three variables, a preliminary statistical analysis for the logistic regression model showed a significant association between etiology and cochlear implant brand ($p = 0.038$), so the cochlear implant brand was excluded from the analysis. In the multivariate model, etiology of hearing loss retained its independent prognostic significance as regards speech comprehension outcome ($p = 0.042$). Age ($p = 0.303$) was not significantly prognostic of outcome in the present multivariate logistic model.

The discriminatory power of the variable hearing loss etiology featured an AUC [ROC] of 0.738 (95% CI 0.554–0.911) for predicting speech comprehension outcome after 1 year (Fig. 1). Model calibration according to the Hosmer–Lemeshow scale indicated an acceptable discriminatory power of this variable. Additional statistics derived from the model included: sensitivity (0.912), specificity (0.091), positive predictive power (0.756), and negative predictive power (0.250).

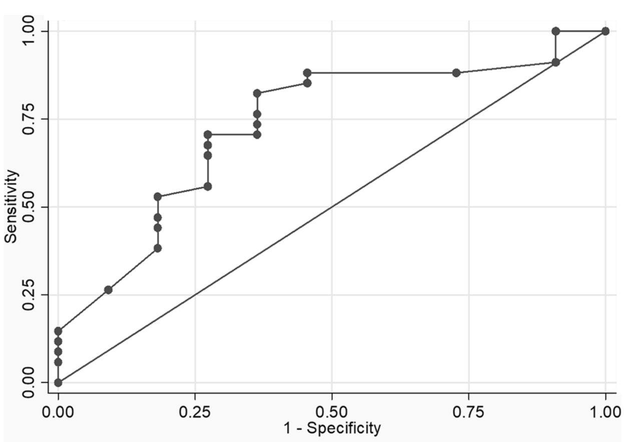

Fig. 1 Receiver operating characteristic (ROC) curve for the hearing loss etiology variable in predicting a better speech comprehension outcome 1 year after cochlear implant surgery

Discussion

Audiological outcome after hearing rehabilitation is not easy to assess because there are different hearing conditions to consider (pure tone hearing, speech hearing, hearing in noise, and more). In the available literature, the outcome of cochlear implant surgery in the elderly is judged mainly using speech perception tests, but some authors [11] also consider pure tone and speech audiometry thresholds as outcome measures. In addition to these diverse assessment methods, there have also been reports of a greater variability in the results among elderly patients [2].

In our series, age did not correlate significantly with audiological outcome in the elderly after cochlear implant surgery. Similar results have already been reported. In one recent paper, Jolink et al. [2] compared 20 patients aged 70 or more at the time of their cochlear implant surgery with 37 patients aged 40–60. They found no difference in speech discrimination between the two groups. Similarly, Wong et al. [12] divided a sample of elderly patients with cochlear implants into three age groups, i.e. patients who were 75–79, 80–84 and 85+ years at the time of their implant surgery. Statistical tests found no difference in audiological outcome between the three groups' speech recognition test results.

In our sample of elderly patients, a family history of hearing loss showed a trend towards a better speech perception performance. Roberts et al. [13] reported the same finding, and suggested this feature as a novel potential prognostic variable. The possible reasons for this association may lie in patients and their families having a greater degree of awareness and empathy concerning hearing problems, and possibly in these patients being more motivated to seek help for their hearing issues. Unfortunately, it was impossible to assess the role of a family history of hearing loss in the multivariate setting for our series, due to the relatively small number of patients involved.

Our data showed an intriguing independent relationship between a better speech comprehension and a hearing loss of unknown etiology. Among the elderly, most of such patients are cases of age-related progressive sensorineural hearing loss. The literature has little to say about the etiology of hearing loss in relation to the outcome of cochlear implant surgery, deriving mostly from studies that focus on specific etiologies. Vashishth et al. [14] reported that patients with advanced otosclerosis have much the same audiological outcome as other patients, providing they have no extensive cochlear ossification. The data are still inconsistent in the case of advanced Menière's disease: some Authors report a worse outcome than adult patients with other etiologies of hearing loss [15], while others found comparable outcomes [16]. For deafness following a head trauma, it has been reported a worse outcome compared to other etiologies [17], possibly also due to brain trauma sequelae, and, similarly, post-meningitic patients have a worse speech recognition outcome [18]. Concerning patients who underwent vestibular schwannoma surgery, Rooth et al. [19] reported an overall satisfying outcome, which is, however, worse than other patients undergone cochlear implantation. Our preliminary findings suggest that, among the elderly, patients with age-related progressive sensorineural hearing loss have a better outcome than those with other etiologies, and this might be worth taking into account during the preoperative assessment and selection of elderly patients for cochlear implant surgery.

In our archives there also were no detailed data concerning the use of hearing aids prior of after cochlear implantation in our case series. It has been reported that bimodal stimulation granted better speech recognition both in quiet and in noise [20], and most of our patients with available data were instructed to use bimodal stimulation after the implant, when there was a sufficient gain; some of them abandoned the hearing aid in time due to progressive loss of gain. Also precise information about the duration of the deafness of our patients is missing, but there is growing body of knowledge on the capacity of patients with long post-lingual deafness to achieve good functional outcomes using cochlear implants [21]. This can be partially explained by: (1) the evidence of the damage related to age-related hearing loss being located mainly in the synapses between the inner hearing cells and neural fibers [22]; (2) the durability of spiral ganglion neurons [23]; and (3) the plasticity of the auditory pathway, a feature that persists even in the elderly [24]. Although it is still not clear which inner ear structure is stimulated directly by the cochlear implant, the overall durability of the auditory pathway might justify the better outcome seen in patients with age-related hearing loss.

The main strengths of this study lie in the relatively large number of cases considered, and the homogeneity of the series of patients: (1) all patients underwent cochlear implant surgery performed by the same team; (2) a standardized follow-up protocol was implemented for all patients; and (3) only patients with an approved definition of "elderly" were considered. On the other hand, the main weakness of this study concern its retrospective setting, which could affect the strength of this data; another weakness is the fact that some data are missing for some patients.

In recent years, the approach taken to the aural rehabilitation of cochlear implant users has been tending towards a broad, neuro-psychological perspective. To give an example, some authors [25] have investigated the role of musical rehabilitation in improving cochlear implant users' overall speech intelligibility. It is becoming increasingly clear that hearing performance in cochlear implant patients can be further improved even once they reach a plateau after a "standard" rehabilitation [26]. This is particularly true of patients who perform less well, as newly reported by Moberly et al. [27].

Conclusion

In our series, among preoperative features of patients, only an unknown etiology of hearing loss was identified as an independent predictor of positive outcome. Because of the small number of patients and the retrospective setting, this finding needs further confirmation with larger cohorts possibly in prospective-designed studies.

The availability of preoperative predictors capable of identifying which cochlear implant recipients are most likely to find the device difficult to use could enable a more appropriate counselling prior to any surgery and a more intensive rehabilitation program afterwards. This would mean giving patients an accurate idea of their prospects before any procedure and a tailored training after the cochlear implant procedure to restore a socially useful hearing function.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This retrospective study was conducted in accordance with the principles of the Helsinki Declaration. Data were examined in agreement with the Italian privacy and sensitive data laws, and the internal regulations of Padova University's Otolaryngology Section.

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

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