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Individual Differences in Speech Recognition Changes After Cochlear Implantation

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Supplemental content

IMPORTANCE Cochlear implantation is highly effective at improving hearing outcomes, but results have been limited to groupwise analysis. That is, limited data are available for individual patients that report comparisons of preoperative aided speech recognition and postimplantation speech recognition.

OBJECTIVE To assess changes in preoperative aided vs postoperative speech recognition scores for individual patients receiving cochlear implants when considering the measurement error for each speech recognition test.

DESIGN, SETTING, AND PARTICIPANTS This cross-sectional study used a prospectively maintained database of patients who received cochlear implants between January 1, 2012, and December 31, 2017, at a tertiary, university-based referral center. Adults with bilateral sensorineural hearing loss undergoing cochlear implantation with 6- or 12-month postoperative measures using 1 or more speech recognition tests were studied.

EXPOSURES Cochlear implantation.

MAIN OUTCOMES AND MEASURES Postoperative word recognition (consonant-nucleus-consonant word test), sentence recognition (AzBio sentences in quiet), and sentence recognition in noise (AzBio sentences in +10-dB signal-to-noise ratio) scores, and association of each speech recognition score change with aided preoperative score to each test's measurement error.

RESULTS Analysis of data from a total of 470 implants from 323 patients included 253 male (53.8%) patients; the mean (SD) age was 61.2 (18.3) years. Most patients had statistically significant improvement in all speech recognition tests postoperatively beyond measurement error, including 262 (84.8%) for word recognition, 226 (87.6%) for sentence recognition, and 33 (78.6%) for sentence recognition in noise. A small number of patients had equivalent preoperative and postoperative scores, including 45 (14.5%) for word recognition, 28 (10.9%) for sentence recognition, and 9 (21.4%) for sentence recognition in noise. Four patients (1.6%) had significantly poorer scores in sentence recognition after implantation. The associations between age at implantation and change in speech recognition scores were −0.12 (95% CI, −0.23 to −0.01) for word recognition, −0.22 (95% CI, −0.34 to −0.10) for sentence recognition, and −0.10 (95% CI, −0.39 to 0.21) for sentence recognition in noise. Patients with no significant improvement were similarly distributed between all preoperative aided speech scores for word recognition (range, 0%-58%) and sentence recognition (range, 0%-56%) testing.

CONCLUSIONS AND RELEVANCE In this cross-sectional study, with respect to preoperative aided speech recognition, postoperative cochlear implant outcomes for individual patients were largely encouraging. However, improvements in scores for individual patients remained highly variable, which may not be adequately represented in groupwise analyses and reporting of mean scores. Presenting individual patient data from a large sample of individuals with cochlear implants provides a better understanding of individual differences in speech recognition outcomes and contributes to more complete interpretations of successful outcomes after cochlear implantation.

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Cochlear implantation has become the standard of care for patients with moderate to profound sensorineural hearing loss.[1,2] When this technology was first approved by the US Food and Drug Administration in 1985, cochlear implants were reserved for those patients with 0% speech recognition ability and no residual hearing at any test threshold.[3,4] Since then, patients with varying degrees of residual hearing have had improvement in speech recognition ability and quality of life after implantation.[5-12] As a result, candidacy criteria for conventional cochlear implantation, not including electric acoustic stimulation or hybrid devices, have continued to expand, and the current criteria require 60% or less open-set sentence recognition with properly fitted hearing aids.[13] This requirement has resulted in an increased number of patients who are now eligible for implantation.

For patients with severe to profound sensorineural hearing loss and very poor aided speech recognition ability, the decision to pursue implantation is straightforward. However, for patients with more residual hearing and aided speech recognition ability at or near the upper limit of candidacy, this decision is more complex. Patients and physicians must consider the potential outcomes from cochlear implantation against current and future hearing aid benefit. Studies[6-8] have found that patients have higher mean postoperative word recognition and sentence recognition scores compared with preoperative aided scores. Although important, differences between preoperative aided and postoperative scores for individual patients are less well known because they are rarely reported. Gifford et al,[6] Hughes et al,[7] and Zhang and Coelho[8] reported that individual patients with aided preoperative speech recognition scores at or near the expanded criteria limit nevertheless had improvements in speech recognition with their cochlear implants. However, each study had a small sample size (22-60 patients) and none considered the inherent statistical limitations (95% CIs) of percent-correct speech recognition scores when reporting outcomes.

Given that a patient's response to each item in a speech recognition task is a binomial outcome (correct or incorrect), results are typically presented as a percentage correct score. Because of this, measurement error should be considered in the same way as any outcome that follows the binomial model.[14] Interpretations of score changes (eg, preoperative aided vs postoperative) need to account for this inherent measurement error, which determines whether the change in score was caused by chance or can be interpreted as a meaningful improvement after implantation. The purpose of the current study was to assess differences in preoperative aided vs postoperative speech recognition scores for a large sample of patients while considering each assessment's measurement error. We investigated the number of patients whose preoperative aided speech recognition scores showed statistically significant improvement, had no significant change, or significantly decreased after cochlear implantation, with respect to the inherent statistical limitations of each measure and the degree of change for each patient.

Key Points

Question What are the differences between preoperative aided and postoperative speech recognition scores for individual patients undergoing cochlear implantation with respect to each measure's established 95% CIs?

Findings In this cross-sectional study, most patients had statistically significant postoperative improvements in word recognition, sentence recognition, and sentence recognition in noise testing. Preoperative and postoperative scores were equivalent for a small percentage of patients, and there was substantial variability in postoperative speech recognition outcomes for individual patients and a lack of association with preoperative aided scores.

Meaning Individual cochlear implantation outcomes with respect to preoperative aided speech recognition appear to be largely beneficial but subject to a large degree of variability.

Methods

Patients

This cross-sectional study retrospectively reviewed data from a prospectively maintained database for adult patients undergoing cochlear implantation for bilateral sensorineural hearing loss between January 1, 2012, and December 31, 2017. Evaluation for candidacy and surgery was performed at a tertiary, university-based otology practice. Inclusion criteria were documented history of postlingual onset of hearing loss, age of 18 years or older at the time of implantation, and preoperative aided and 6-month or greater postoperative scores in at least 1 of 3 speech recognition measures described in the Data Acquisition section. Exclusion criteria were revision and implantation for single-sided deafness. For 147 patients undergoing bilateral cochlear implantation, each ear was treated as an independent outcome. **Table 1** includes the demographics of the 323 patients (470 implants) who met the inclusion and exclusion criteria. Preoperative hearing aid use was defined as the patient's self-reported active hearing aid use at the time of the cochlear implantation evaluation (yes/no). Duration of hearing loss before cochlear implantation was defined by self-reported number of years with hearing loss before implantation. This study was approved by the Medical University of South Carolina Institutional Review Board, and informed consent was not required. The study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guideline.

Data Acquisition

The following data were obtained from our adult cochlear implantation patient database: age at implantation, sex, active hearing aid use before implantation, duration of hearing loss before implantation, and duration of follow-up after activation (6 or 12 months). Also obtained from the database were speech recognition scores measured separately for each ear in the best aided condition before implantation and with their cochlear implant 6 months (26.8%) or 12 months

(73.2%) after cochlear implant activation. Speech recognition scores included consonant-nucleus-consonant word test (CNC), AzBio sentences in quiet (AzBio Quiet), and AzBio sentences in noise at a +10-dB signal-to-noise ratio (AzBio +10). Noise was a multitalker babble.[15-17] AzBio +10 was only administered to patients whose AzBio Quiet scores were 50% or greater. These scores are referred to as word recognition, sentence recognition, and sentence recognition in noise, respectively. Preoperative speech recognition was measured in the sound field with hearing aids (personal or clinic stock aids) fitted to revised National Acoustic Laboratories targets.[18] All speech recognition testing was performed in a sound-treated room with speech presented at 60-dB sound pressure level (0° azimuth for speech and noise, when present). Complete aided and cochlear implant word recognition scores were available in 309 patients, sentence recognition scores in 258 patients, and sentence recognition in noise scores in 42 patients. All preoperative to postoperative speech recognition score comparisons were made within the same ear. The CNC and AzBio measures were chosen because they have little to no ceiling effect for most patients with cochlear implants in contrast to traditional hearing-in-noise test (HINT) sentences.[19]

Statistical Analysis

Analyses were performed with SPSS software, version 25.0 (IBM Inc). Nominal variables (sex and hearing aid use) were summarized by number (percentage). Continuous variables (age at implantation, duration of hearing loss, follow-up time, and audiologic data) were summarized by mean (SD). Scatterplots were created by comparing aided preoperative speech recognition scores (CNC, AzBio, and AzBio +10) with postoperative scores within the same ear. Each data point was compared to published 95% CIs for the CNC and AzBio tests.[14,17] Comparisons of mean change in speech recognition scores based on preoperative aided scores were performed using a 2-tailed, unpaired *t* test (**Table 2**). Strength of association among continuous variables was assessed by using the Pearson correlation coefficient (r) or Spearman ρ, depending on the normality of the variables. A correlation coefficient of 0 to 0.3 is considered poor, 0.31 to 0.5 is fair, 0.51 to 0.7 is moderate, and greater than 0.7 is very strong.[20] Effect sizes (Cohen d) were used as the measure of strength of association or effect for all statistical tests. Cohen d for the difference among continuous variables was calculated by dividing the mean difference by the pooled SD. An effect size of 0.2 to 0.49 is considered small, 0.5 to 0.79 medium, 0.8 to 1.29 large, and greater than 1.3 very large.[21] For each speech recognition measure, patients were placed into 1 of 3 groups based on change from preoperative aided to postoperative speech recognition score with respect to 95% CIs (**Table 3**). Patients who had improvements in their speech recognition scores above the upper 95% CI limit of that measure were considered to have statistically significant improvement. Those who had changes in their score within the two 95% CI limits were considered to have no significant change, and those who had changes in their score below the lower 95% CI limit were considered to have significant decline.

Table 1. Patient Demographics

Demographic	Finding[a] (N = 470 implants)
Age at implantation, mean (SD), y	61.2 (18.3)
Patient sex	
Male	253 (53.8)
Female	217 (46.2)
Active hearing aid use at the time of cochlear implant evaluation	
Yes	282 (60.0)
No	174 (37.0)
Unknown	14 (3.0)
Duration of hearing loss before cochlear implantation, mean (SD), y	24.3 (17.3)
Cochlear implant device	
Med-El	138 (29.4)
Cochlear Americas	239 (50.9)
Advanced Bionics	93 (19.8)
Follow-up after activation	
6 mo	126 (26.8)
12 mo	344 (73.2)

[a] Data are presented as number (percentage) of implants unless otherwise indicated.

Results

Data from a total of 470 implants from 323 patients included 253 male (53.8%) patients; mean (SD) age was 61.2 (18.3) years. Patient demographics are provided in Table 1. Bilateral implantation was performed in 147 patients. Most patients (282 [60.0%]) reported using hearing aids at time of cochlear implantation evaluation. Mean (SD) duration of hearing loss before implantation was 24.3 (17.3) years. Mean speech recognition scores are given in Table 2. The mean percentage improvement in scores (postoperative score minus preoperative score) 6 or 12 months after implantation was 33.7% (d = 2.01; 95% CI, 1.84-2.17) for CNC, 45.6% for AzBio Quiet (d = 2.09; 95% CI, 1.92-2.26), and 33.6% for AzBio +10 (d = 1.79; 95% CI, 1.63-1.95). In all tests, most patients have some improvement in score, but there is variability in the magnitude of improvement between tests and within each test. No one test has a true normal distribution. Although word recognition and sentence recognition had statistically significant associations, the strength of these associations was poor, with associations between age at implantation and change in speech recognition scores of −0.12 (95% CI, −0.23 to −0.01) for word recognition, −0.22 (95% CI, −0.34 to −0.10) for sentence recognition, and −0.10 (95% CI, −0.39 to 0.21) for sentence recognition in noise.

Comparison of Preoperative Aided and Postoperative Speech Recognition Scores With 95% CIs

To provide a method to determine significant change for individual patients, postoperative aided speech recognition scores are plotted against preoperative scores in **Figure 1**. Speech recognition for most patients significantly improved

Table 2. Mean Preoperative and Postoperative Speech Recognition Scores and Mean Change

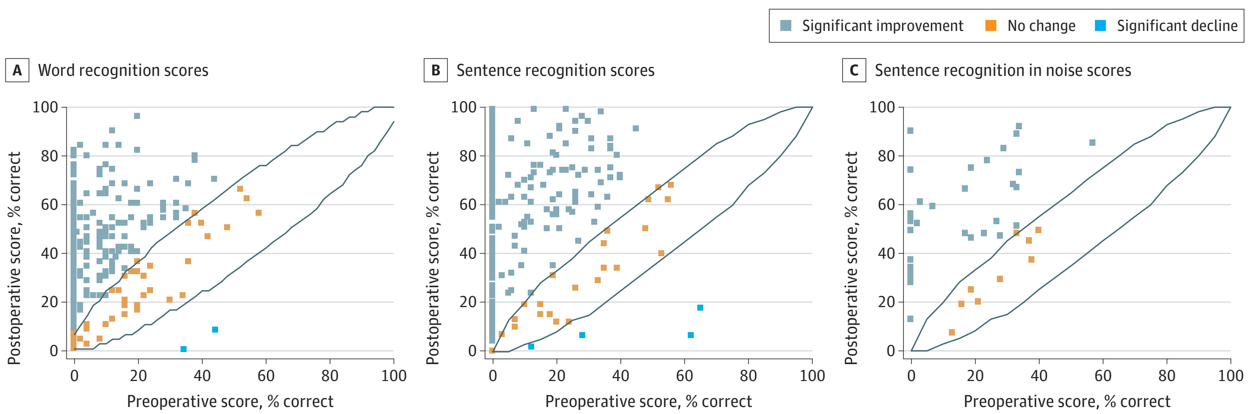
Speech recognition test	Mean (SD) % Correct			Effect size (Cohen *d*) (95% CI)
	Aided preoperative	Postoperative	Change	
CNC	7.4 (11.5)	41.1 (20.8)	33.7 (1.8)	2.01 (1.84-2.17)
AzBio Quiet	10.3 (14.5)	55.8 (27.1)	45.6 (3.8)	2.09 (1.92-2.26)
AzBio +10	17.5 (15.4)	51.1 (21.6)	33.6 (17.1)	1.79 (1.63-1.95)

Abbreviations: AzBio Quiet, AzBio sentences in quiet; AzBio +10, AzBio sentences in +10-dB signal-to-noise ratio; CNC, consonant-nucleus-consonant word test.

Table 3. Number (Percentage) of Patients in 3 Groups Based on Change From Preoperative Aided Speech Recognition Scores to Postoperative Scores With Regard to Each 95% CI

Outcome	Significant improvement (postoperative score greater than the upper limit of 95% CI of preoperative aided score)	No significant change (postoperative score within 95% CI of preoperative aided score)	Significant decline (postoperative score less than the lower limit of 95% CI of preoperative aided score)
Word recognition	262 (84.8)	45 (14.5)	2 (0.6)
Sentence recognition	226 (87.6)	28 (10.9)	4 (1.6)
Sentence recognition in noise	33 (78.6)	9 (21.4)	0

Figure 1. Individual Postoperative Speech Recognition Scores Plotted Against Preoperative Aided Speech Recognition Scores



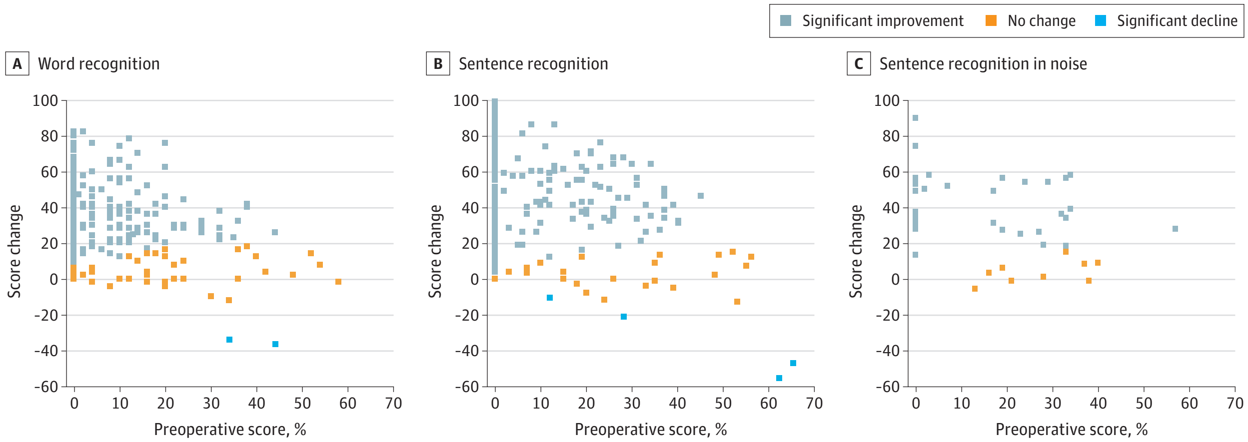
The solid lines indicate the upper and lower limits of the 95% CI for the corresponding speech recognition measure.

from aided preoperative to postoperatively (Table 3 and Figure 1), with 262 patients (84.8%) having significant improvement in word recognition, 226 (87.6%) in speech recognition, and 33 (78.6%) in speech recognition in noise. No statistically significant differences were found between the proportion of patients with significant improvements for word recognition vs sentence recognition (d = 0.18; 95% CI, -0.10 to 0.46) or sentence recognition vs sentence recognition in noise (d = 0.44; 95% CI, -0.02 to 0.90). A within-group t test was performed to assess whether the changes in speech recognition after implantation were the same for word recognition vs sentence recognition for patients who had completed both tests. The test demonstrated that there was a statistically significant difference between the changes in speech recognition scores (d = −1.33; 95% CI, −1.60 to −1.06; P<.001).

Substantial floor effects were observed for preoperative word and sentence recognition scores. Across the 3 measures, 211 patients (68.3%) had preoperative word scores of less than 10%, 160 patients (62.0%) had sentence in quiet scores of less than 10%, and 16 patients (38.1%) had sentence in noise scores of less than 10%. A ceiling effect (postoperative score of 100%) for sentence testing in quiet occurred in 1 patient. No other test demonstrated ceiling effects.

Figure 2 displays preoperative and postoperative change in speech recognition scores plotted against preoperative aided scores. Patients who demonstrated equivalent postoperative scores with respect to preoperative scores had preoperative scores of 0%-58% for word recognition and 0%-56% sentence recognition testing. Thus, preoperative aided scores were only fairly correlated with changes in postoperative scores (r = -0.34; 95% CI, −0.43 to -0.23 for word recognition, r = -0.38; 95% CI, -0.48 to -0.27 for sentence recognition, and r = -0.35; 95% CI, -0.59 to -0.06 for sentence in noise recognition). Similarly, preoperative aided scores and postoperative scores were poorly to fairly correlated (r = 0.21; 95% CI, 0.10-0.31 for word recognition, r = 0.14; 95% CI, 0.02-0.25 for sentence recognition, and r = 0.34; 95% CI, 0.04-0.59 for sentence in noise recognition). For word recognition, patients with the poorest aided preoperative scores (0%-20%) were most likely to achieve significant and large improvements. Many patients with somewhat better aided preoperative scores (20%-40%) improved significantly, but scores

Figure 2. Change in Speech Recognition Scores Based on Preoperative Aided Scores for 3 Groups



Preoperative and postoperative change in speech recognition score plotted against aided preoperative score for word recognition, sentence recognition, and sentence in noise recognition.

improved by only 20 to 40 percentage points. Fewer patients with preoperative aided word and sentence recognition scores greater than 40% achieved significant postoperative improvement (word recognition, 14%; sentence recognition, 11%). Unfortunately, because of the small sample sizes for patients with higher preoperative scores, it is difficult to make more definitive statements. For sentence recognition in noise, all patients with preoperative scores of 10% or less significantly improved after cochlear implantation. Similar to results for word recognition measures, patients who obtained no significant improvement in sentence recognition in noise were fairly evenly distributed along preoperative aided scores greater than 11%. Overall, Figure 2 shows the large variability for individual patients in postoperative speech recognition outcomes and lack of association with preoperative aided scores. For example, patients whose preoperative aided sentence recognition was 0% achieved postoperative scores ranging from 0% to 100%.

The eTable in the Supplement reports the percentage of patients in each of the three 95% CI groups at 6 months and 12 months after implantation. For word recognition, there was no difference in the percentage of patients who achieved significant improvement and no significant change (d = 0.18; 95% CI, -0.19 to 0.54). For sentence recognition, slightly more patients achieved significant improvement rather than no significant change at 12 months than at 6 months after implantation (d = 0.45; 95% CI, 0.01-0.89). For sentence recognition in noise, no difference was found between the 2 time points (d = 0.51; 95% CI, −0.34 to 1.35).

Discussion

In this cross-sectional study, data from a large number of patients who received cochlear implants under current Food and Drug Administration candidacy criteria were analyzed. Using published CNC and AzBio 95% CIs,[14,17] the study found that cochlear implantation was effective for the treatment of moderate to profound sensorineural hearing loss. Most patients had significant improvement in all speech recognition tests postoperatively beyond measurement error: 262 (84.8%) for word recognition, 226 (87.6%) for sentence recognition, and 33 (78.6%) for sentence recognition in noise (Table 3). However, a small but important percentage of patients (14.5% for CNC, 10.9% for AzBio Quiet, and 21.4% for AzBio +10) had equivalent preoperative and postoperative scores, and for these patients, preoperative aided scores were quite variable. Four patients (0.85%) in this sample had significantly poorer speech recognition after implantation compared to their preoperative aided scores.

When patients were analyzed as a group (Table 2), large mean increases from preoperative aided to postoperative scores were observed for each of the 3 speech recognition tasks (34%-46%), which is consistent with previous studies.[6-8] However, the group means presented in Table 2 are not reflective of individual patient improvements and therefore do not provide the information needed to predict postimplantation outcomes for individual patients. Rather, these results describe improvements for the average patient. Figure 1 and Figure 2 show large variability in what potential cochlear implant candidates may expect based on their aided scores, even among patients who have significant improvement. As shown in Figure 2, although a large number of patients may be assured that their speech recognition will significantly improve with cochlear implantation, it is not possible from preoperative aided scores to identify the magnitude of the improvement (eg, 6%-100%). Although the overall results are extremely encouraging, there was a small but important percentage of patients (11%-15% for words and sentences in quiet and 21% for sentences in noise) whose postoperative scores did not significantly improve when considering the CIs of the 3 speech recognition measures. Importantly, results for these patients are not typically recognized or discussed when analyzing group-level mean outcomes. By contrasting the well-known large mean improvements (Table 2) with large degrees of individual variability in postoperative scores (Figure 2), these data highlight the importance of patient counseling with respect to realistic and individualized expectations for postimplantation speech recognition outcomes.

Using the 95% CIs for each speech recognition score provides a means to analyze individual outcomes while accounting for the inherent variability of these tests. Percent-correct speech recognition tests are descriptors of probability, specifically the probability that a patient will correctly identify each item in a list of words or sentences. These characteristics of speech recognition tests were first examined in a study published by Thornton and Raffin.[14] They found that speech recognition scores were subject to 95% CIs within which changes in score were nonsignificant or equivalent, that these CIs varied for each initial score between 0% and 100% along a bimodal distribution curve, and that they also varied by the number of items in the list (eg, CIs widen as the number of items in the list decreases). Scores at the extremes of the range, such as near 0% and 100%, had smaller CIs. As a result, preoperative scores of 10% or less that improve with CIs even by only a few percentage points would be considered significant improvements. Clearly, such small improvements in scores, even if significant, would not be an appropriate reflection of a true improvement in patients' functional abilities. Preoperative aided scores in the middle of the distribution have larger CIs, so only somewhat larger improvements in scores are considered significant, but again significance levels may not necessarily relate to functional abilities with cochlear implants. In both cases, as mentioned earlier, large individual differences were seen within groups of patients whose preoperative and postoperative changes in scores were considered significant or nonsignificant (Figure 2). These characteristics are true of all tests using binomial outcomes (most commonly encountered with tests scored as correct or incorrect and reported as percentage correct) and are a first step in assessing the true effect of interventions for individual patients.

Cochlear implantation is a safe and effective treatment for moderate to profound sensorineural hearing loss in adults. As candidacy criteria broaden, many patients whose speech recognition scores are at or near the upper limit of candidacy must decide between their current and future hearing aid benefit and the unknown benefit of cochlear implantation. There is limited evidence that can be used to determine individual patients' likely benefit from cochlear implantation from their preoperative aided speech recognition abilities or other patient-related factors.[22]

The definition of success of cochlear implantation remains ambiguous. Whereas some studies[6-8,23] consider increases in speech recognition scores after implantation to be the goal, others[24-26] have found these improvements to be too narrow to assess all the functional abilities affected by implantation. The current results show equivalent preoperative aided and postoperative cochlear implant speech recognition scores for a small, but important, number of patients (11%-15% of patients for words and sentences in quiet and 21% of patients for sentences in noise). As discussed below, the definition of success after implantation determines whether implantations in individuals with equivalvent preoperative and postoperative scores are considered failures or successes.

Limitations

This study has limitations. First, equivalent preoperative and postoperative scores could be considered a failure if the goal of cochlear implantation is to improve patients' speech recognition relative to their preoperative aided ability. By this definition, only scores that are higher than the upper 95% CI would be considered successful outcomes. However, when using 95% CIs for speech recognition measures based on the binomial model, it is important to keep in mind that CIs vary according to the initial score (preoperative scores in this case), with the widest CIs for initial scores near the middle of the score range (approximately 50%) and the narrowest CIs for initial scores near 0% and 100%. Consider 3 patients. Patient 1's speech recognition improves from 0% with hearing aids to 6% with cochlear implants, whereas scores for patient 2 improve from 46% with hearing aids to 52% with cochlear implants. Patient 3 improves from 0% with hearing aids to 70% with cochlear implants. On the basis of the narrower CIs with lower scores, patient 1 has a statistically significant improvement, unlike patient 2. Using the first interpretation, patient 1's outcome is considered successful, whereas patient 2's outcome is considered a failure. From a practical standpoint, however, both of these outcomes could be considered failures given the small, and likely clinically insignificant, improvements. This interpretation becomes even less valid if one considers that patient 1 and patient 3, whose speech recognition improves from 0% to 70%, would be defined in the same success category.

A second potential interpretation is that the extent to which cochlear implants may preserve preoperative aided speech recognition ability (as in the case of patient 2) can also be considered a successful outcome. Sensorineural hearing loss is often progressive; therefore, hearing aid users can expect an increase in hearing thresholds over time.[27] Therefore, even a nonsignificant improvement in speech recognition after cochlear implantation that is maintained over time would be considered a successful outcome. The primary limitation of this interpretation is cases in which speech recognition abilities with a cochlear implant are relatively poor and the cochlear implant provides little functional benefit.

Clearly, determinants of success in cochlear implantation are more complex than can be assessed by simply comparing preoperative and postoperative speech recognition ability. Moreover, decisions about successful outcomes with cochlear implants are incomplete without considering patient-reported outcomes. Multiple authors have reported low correlations between cochlear implant users' speech recognition scores and self-reported communication ability and quality of life.[2,28-30] Therefore, in future studies, patient-reported outcome measures should be added to the set of criteria used in determining the success of cochlear implantation.

In addition to patient-reported outcome measures, future research will also include analysis of demographic and hearing-related factors that may be associated with patients obtaining significant improvement or no change in speech recognition ability after cochlear implantation. This study characterized benefit in cochlear implant-only settings; thus, the benefit of cochlear implants in bilaterally aided conditions needs further study. The current study also included many patients with very poor preoperative aided speech recognition, which may be indicative of delayed cochlear implantation referral patterns. Inclusion of such patients limited the range of aided scores available to assess the association between preoperative aided scores and postoperative scores (particularly preoperative aided word and sentence recognition scores >40%) (Figure 1 and Figure 2). Finally, the current results may have been affected by limiting the postoperative follow-up to 6 or 12 months, given evidence of continued improvement in speech recognition up to 2 years after implantation.[31]

Conclusions

Postoperative speech recognition compared with preoperative aided speech recognition for individual patients is largely encouraging. However, individual preoperative aided and postoperative scores are subject to a large degree of variability that may not be adequately represented in groupwise analyses and reporting of mean scores. Presenting individual patient data from a large sample of cochlear implant users provides a better understanding of individual differences in speech recognition outcomes and contributes to more complete interpretations of successful outcomes after cochlear implantation.

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Acquisition, analysis, or interpretation of data: Reddy, Schvartz-Leyzac, Dubno, McRackan.
Drafting of the manuscript: Dornhoffer, Reddy, Schvartz-Leyzac, Dubno, McRackan.
Critical revision of the manuscript for important intellectual content: Reddy, Meyer, Schvartz-Leyzac, Dubno, McRackan.
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Conflict of Interest Disclosures: Dr McRackan reported serving on the medical advisory board for Envoy Medical. Dr McRackan reported receiving grants from the National Institutes of Health/National Institute on Deafness and Other Communication Disorders and grants from the American Cochlear Implant Alliance during the conduct of the study; and serves on the advisory board of Envoy Medical outside the submitted work. Dr Dubno reported receiving an American Cochlear Implant Alliance Grant paid to the Medical University of South Carolina, Charleston, during the conduct of the study. No other disclosures were reported.

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REFERENCES

1. Gaylor JM, Raman G, Chung M, et al. Cochlear implantation in adults: a systematic review and meta-analysis. *JAMA Otolaryngol Head Neck Surg*. 2013;139(3):265-272. doi:10.1001/jamaoto.2013.1744

2. McRackan TR, Bauschard M, Hatch JL, et al. Meta-analysis of quality-of-life improvement after cochlear implantation and associations with speech recognition abilities. *Laryngoscope*. 2018;128(4):982-990. doi:10.1002/lary.26738

3. Eshraghi AA, Nazarian R, Telischi FF, Rajguru SM, Truy E, Gupta C. The cochlear implant: historical aspects and future prospects. *Anat Rec (Hoboken)*. 2012;295(11):1967-1980. doi:10.1002/ar.22580

4. Huinck WJ, Mylanus EAM, Snik AFM. Expanding unilateral cochlear implantation criteria for adults with bilateral acquired severe sensorineural hearing loss. *Eur Arch Otorhinolaryngol*. 2019;276(5):1313-1320. doi:10.1007/s00405-019-05358-z

5. Sladen DP, Gifford RH, Haynes D, et al. Evaluation of a revised indication for determining adult cochlear implant candidacy. *Laryngoscope*. 2017;127(10):2368-2374. doi:10.1002/lary.26513

6. Gifford RH, Dorman MF, Shallop JK, Sydlowski SA. Evidence for the expansion of adult cochlear implant candidacy. *Ear Hear*. 2010;31(2):186-194. doi:10.1097/AUD.0b013e3181c6b831

7. Hughes ML, Neff DL, Simmons JL, Moeller MP. Performance outcomes for borderline cochlear implant recipients with substantial preoperative residual hearing. *Otol Neurotol*. 2014;35(8):1373-1384. doi:10.1097/MAO.0000000000000367

8. Zhang E, Coelho DH. Beyond sentence recognition in quiet for older adults: implications for cochlear implant candidacy. *Otol Neurotol*. 2018;39(8):979-986. doi:10.1097/MAO.0000000000001885

9. Bassim MK, Buss E, Clark MS, et al. MED-EL Combi40+ cochlear implantation in adults. *Laryngoscope*. 2005;115(9):1568-1573. doi:10.1097/01.mlg.0000171023.72680.95

10. Blamey P, Artieres F, Başkent D, et al. Factors affecting auditory performance of postlinguistically deaf adults using cochlear implants: an update with 2251 patients. *Audiol Neurootol*. 2013;18(1):36-47. doi:10.1159/000343189

11. Leigh JR, Moran M, Hollow R, Dowell RC. Evidence-based guidelines for recommending cochlear implantation for postlingually deafened adults. *Int J Audiol*. 2016;55(suppl 2):S3-S8. doi:10.3109/14992027.2016.1146415

12. Snel-Bongers J, Netten AP, Boermans PBM, Rotteveel LJC, Briaire JJ, Frijns JHM. Evidence-based inclusion criteria for cochlear implantation in patients with postlingual deafness. *Ear Hear*. 2018;39(5):1008-1014. doi:10.1097/AUD.0000000000000568

13. Raman G, Lee J, Chung Met, et al. Cochlear implantation devices currently approved by the FDA. In: Sen S, ed. *Effectiveness of Cochlear Implants in Adults with Sensorineural Hearing Loss*. Agency for Healthcare Research and Quality; 2011.

14. Thornton AR, Raffin MJ. Speech-discrimination scores modeled as a binomial variable. *J Speech Hear Res*. 1978;21(3):507-518. doi:10.1044/jshr.2103.507

15. Causey GD, Hood LJ, Hermanson CL, Bowling LS. The Maryland CNC Test: normative studies. *Audiology*. 1984;23(6):552-568. doi:10.3109/00206098409081538

16. Tillman TW, Carhart R. *An Expanded Test for Speech Discrimination Utilizing CNC Monosyllabic Words*. Northwestern University Auditory Test No. 6. SAM-TR-66-55. USAF School of Aerospace Medicine; 1966:1-12.

17. Spahr AJ, Dorman MF, Litvak LM, et al. Development and validation of the AzBio sentence lists. *Ear Hear*. 2012;33(1):112-117. doi:10.1097/AUD.0b013e31822c2549

18. Byrne D, Dillon H. The National Acoustic Laboratories' (NAL) new procedure for selecting the gain and frequency response of a hearing aid. *Ear Hear*. 1986;7(4):257-265. doi:10.1097/00003446-198608000-00007

19. Gifford RH, Shallop JK, Peterson AM. Speech recognition materials and ceiling effects: considerations for cochlear implant programs. *Audiol Neurootol*. 2008;13(3):193-205. doi:10.1159/000113510

20. Chan YH. Biostatistics 104: correlational analysis. *Singapore Med J*. 2003;44(12):614-619.

21. Sullivan GM, Feinn R. Using effect size-or why the *P* value is not enough. *J Grad Med Educ*. 2012;4(3):279-282. doi:10.4300/JGME-D-12-00156.1

22. Zhao EE, Dornhoffer JR, Loftus C, et al. Association of patient-related factors with adult cochlear implant speech recognition outcomes: a meta-analysis. *JAMA Otolaryngol Head Neck Surg*. 2020;146(7):613-620. doi:10.1001/jamaoto.2020.0662

23. Dunn C, Miller SE, Schafer EC, Silva C, Gifford RH, Grisel JJ. Benefits of a hearing registry: cochlear implant candidacy in quiet versus noise in 1,611 patients. *Am J Audiol*. 2020;1-11. doi:10.1044/2020_AJA-20-00055

24. Lassaletta L, Castro A, Bastarrica M, et al. Does music perception have an impact on quality of life following cochlear implantation? *Acta Otolaryngol*. 2007;127(7):682-686. doi:10.1080/00016480601002112

25. Sousa AF, Couto MIV, Martinho-Carvalho AC. Quality of life and cochlear implant: results in adults with postlingual hearing loss. *Braz J Otorhinolaryngol*. 2018;84(4):494-499. doi:10.1016/j.bjorl.2017.06.005

26. Vermeire K, Brokx JPL, Wuyts FL, Cochet E, Hofkens A, Van de Heyning PH. Quality-of-life benefit from cochlear implantation in the elderly. *Otol Neurotol*. 2005;26(2):188-195. doi:10.1097/00129492-200503000-00010

27. Shearer AE, Hildebrand MS, Smith RJH. Hereditary hearing loss and deafness overview. In: Adam MP, Ardinger HH, Pagon RA, Wallace SE, Bean LJH, Stephens K, Amemiya A, eds. *GeneReviews((R))*. University of Washington; 1993.

28. McRackan TR, Fabie JE, Bhenswala PN, NGuyen SA, Dubno JR. General health quality of life instruments underestimate the imparct of bilateral cochlear implantation. *Otol Neurotol*. 2019;40(6):745-754. doi:10.1097/MAO.0000000000002225

29. McRackan TR, Bauschard M, Hatch JL, et al. Meta-analysis of cochlear implantation outcomes evaluated with general health-related patient-reported outcome measures. *Otol Neurotol*. 2018;39(1):29-36. doi:10.1097/MAO.0000000000001620

30. Capretta NR, Moberly AC. Does quality of life depend on speech recognition performance for adult cochlear implant users? *Laryngoscope*. 2016;126(3):699-706. doi:10.1002/lary.25525

31. Ching TY, Dillon H. A brief overview of factors affecting speech intelligibility of people with hearing loss: implications for amplification. *Am J Audiol*. 2013;22(2):306-309. doi:10.1044/1059-0889(2013/12-0075)