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Original Investigation

Influence of Age at Revision Cochlear Implantation on Speech Perception Outcomes

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IMPORTANCE This study reviewed whether advanced age should be a consideration when revision cochlear implantation is warranted.

OBJECTIVE To examine whether age at revision cochlear implantation is related to postrevision speech perception performance.

DESIGN, SETTING, AND PARTICIPANTS A retrospective analysis was performed in an academic tertiary care center. Participants included 14 younger adults (<65 years) and 15 older adults (≥65 years) who underwent revision cochlear implantation.

INTERVENTION Revision cochlear implantation.

MAIN OUTCOMES AND MEASURES Speech perception performance, as measured with consonant-nucleus-consonant [CNC] words in quiet, at the best prerevision interval as well as the 3- and 6-month postrevision intervals were compared between the 2 cohorts. The CNC word test consists of 10 lists of 50 phonemically balanced monosyllabic words, scored with a range of 0% to 100% correct.

RESULTS Both cohorts experienced a restoration in speech perception scores after revision cochlear implantation compared with their best performance before the revision (mean [SD] CNC word test scores for the younger cohort: 43.9% [25.6%] before revision and 47.7% [21.3%] at 3 months and 47.6% [19.8%] at 6 months after revision; for the older cohort: 36.3% [19.1%] before revision and 35.3% [17.2%] at 3 months and 39.9% [16.3%] at 6 months after revision; $F_{2,54}$ = 0.93; P = .40). There was no interaction between age at revision surgery and speech perception performance at each assessment interval ($F_{2,54}$ = 0.51; P = .60).

CONCLUSIONS AND RELEVANCE In this study, age at revision cochlear implantation was not related to postrevision speech perception performance. Advanced age should not be considered a contraindication to revision cochlear implantation.

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With an appropriate indication, cochlear implantation provides significantly improved speech perception compared with conventional amplification. Cases of device failure or medical complications may require revision surgery and reimplantation to resolve the issue and/or restore speech perception performance. A clear understanding of the implications and the timeline of revision surgery, especially regarding speech perception, can benefit patient counseling and set expectations to a realistic level. To date, the influence of age on the postoperative course after revision surgery remains relatively unknown.

Revision surgery may be warranted in cases of internal device failure, which includes hard failures or signs of soft failure. A hard failure is an inability to present electric stimulation and may result from head trauma, loss of hermetic seal, or other electrode malfunctions. Reported signs of soft failure include pain or shocking, unusual auditory sensations, or reduced speech perception abilities compared with previous performance with electric stimulation.[1,2] For hard and soft failure cases, revision surgery may resolve the associated issues and restore speech perception abilities.

The incidence of revision cochlear implantation is low[3-6]; however, speech perception performance with the replace-

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ment device compared with the initial device is variable. Reports on speech perception abilities with the revised device range from those finding improved outcomes[7] to those describing speech perception as similar or worse than with the initial device.[8,9] This variation may result from a compromised cochlea or trauma during the revision surgery, whether the failure was hard vs soft, improvement in external speech processor technology, and internal device differences in technology and placement.

What is relatively unknown is whether advanced age at revision surgery is an indicator for postrevision success. A recent retrospective analysis by Mahtani et al[10] evaluated the best speech perception scores before and after revision. The investigators found no correlation between age at revision surgery and change in speech perception performance. Trends within the initial postrevision intervals could not be determined since this analysis included the best speech perception performance score obtained at variable postrevision intervals. The present study examined prerevision and postrevision speech perception abilities of younger and older adults, concentrating on performance outcomes within the first 6 months after revision.

Methods

This review was approved by the University of North Carolina at Chapel Hill institutional review board. A retrospective analysis was conducted on speech perception outcomes in adults who underwent revision cochlear implantation. Informed consent was not required as the data were part of a database and were deidentified before analysis.

Speech perception performance was evaluated with consonant-nucleus-consonant (CNC) words[11] in quiet since this test was used consistently in the routine assessment for most patients. The CNC word test consists of 10 lists of 50 phonemically balanced monosyllabic words, scored with a range of 0% to 100% correct. Recorded materials were presented in the sound field, with the listener seated 1 m from the sound source facing 0° azimuth.

Evaluation intervals included before revision as well as 3 and 6 months after revision surgery. The prerevision interval was defined as the duration of listening experience since the initial surgical procedure when the patients achieved their highest CNC word score. **Table 1** lists the prerevision interval and associated CNC word score for each participant. Clinicians followed the "medical/audiological assessment in verbal patients" recommendations[1(p816)] when tracking suspected soft failure cases before revision cochlear implantation.

A query of the adult cochlear implantation database included the following inclusion criteria: postlingually deafened, history of revision cochlear implantation, and CNC word testing results completed before revision and approximately 3 and 6 months after revision. Patients were excluded if there was a history of multiple revision surgical procedures in the same ear or if CNC word testing was not conducted at the defined intervals.

Statistical analysis was completed using SPSS, version 21 (SPSS Inc). A repeated-measures analysis of variance was conducted, adopting a significance level of $P < .05$.

Results

Twenty-nine individuals met the criteria set by the database query. Revision surgery was performed in 14 patients younger than 65 years and in 15 individuals 65 years or older. The mean (SD) prerevision best CNC word score was 43.9% (25.6%; range, 0%-80%) for the younger cohort and 36.3% (19.1%; range, 8%-74%) for the older cohort. There was no significant difference ($P = .38$) in the prerevision best CNC word score between the 2 cohorts. The mean duration of listening experience at the best prerevision interval was 2.5 years (3.6; range, 0.1-14.0 years) for the younger cohort and 2.7 years (2.0; range, 0.1-7.0 years) for the older cohort. There was no significant difference ($P = .86$) in the duration of listening experience at the best prerevision interval between the 2 cohorts.

Demographic information for each cohort regarding age at initial implantation, initial device, indication for revision surgery, and revised device are documented in **Table 2**. For the younger cohort, revision surgery was warranted for 11 cases of soft failure and 3 cases of hard failure. The older cohort had 13 cases of soft failure and 2 cases of hard failure. The duration of listening experience with the initial device at the time of revision surgery was 4.9 years (3.7; range, 1.5-14.0 years) for the younger cohort and 4.4 years (2.6; range, 1.4-8.9 years) for the older cohort. There was no significant difference ($P = .70$) in the duration of listening experience with the initial device at the time of revision between the 2 cohorts.

Figure 1 plots the speech perception performance scores before revision surgery and 3 and 6 months after initial activation of the revised device. There was no significant difference ($F_{2,54} = 0.93$; $P = .40$; $\eta_p^2 = 0.033$) in CNC word scores across the intervals, indicating a restoration in speech perception abilities for both cohorts after revision. There was no interaction ($F_{2,54} = 0.51$; $P = .60$; $\eta_p^2 = 0.019$) between the assessment interval and age at revision surgery. This result was consistent, with both cohorts experiencing a similar restoration in postrevision speech perception abilities.

In **Figure 2**, data are plotted as the change in speech perception performance on CNC words between the best prerevision interval and the 6-month postrevision interval by the age at revision surgery. A bivariate Pearson correlation found no relationship ($r_{27} = -0.01$; $P = .96$) between the performance difference and age at revision cochlear implantation.

Discussion

The adults evaluated in the present study experienced a restoration in speech perception abilities within the first months of listening with the revised device. These findings are in line with previous investigations[12,13] that reported similar or improved speech perception abilities after revision cochlear implantation. The rate of speech perception acquisition could not

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Table 1. CNC Word Scores by Interval for the Younger and Older Adult Cohorts

	Prerevision CNC Word Score, %		Postrevision CNC Word Score, %	
Patient No.	Best Performance	Interval, y	3 mo	6 mo
Younger Adults (<65 y)				
Y1	80	14.0	72	72
Y2	48	5.1	18	28
Y3	0	3.0	18	28
Y4	46	1.2	42	54
Y5	66	1.3	74	74
Y6	0	2.7	18	28
Y7	80	1.1	72	72
Y8	68	0.6	66	56
Y9	30	0.4	56	42
Y10	34	1.1	44	28
Y11	34	1.2	48	32
Y12	60	0.1	70	66
Y13	42	0.7	28	22
Y14	26	3.1	42	64
Mean (SD) [range]	43.9 (25.6) [80.0-0.0]	2.5 (3.6) [14.0-0.1]	47.7 (21.3) [74.0-18.0]	47.6 (19.8) [74.0-22.0]
Older Adults (≥65 y)				
O1	62	3.4	48	62
O2	18	1.2	16	36
O3	56	1.0	44	64
O4	8	1.5	38	36
O5	36	6.3	32	38
O6	24	1.1	46	48
O7	20	4.2	30	14
O8	22	7.0	34	34
O9	74	4.0	70	60
O10	24	0.1	16	32
O11	30	1.9	22	18
O12	58	3.0	40	38
O13	46	3.3	40	44
O14	26	0.6	0	16
O15	40	2.5	54	58
Mean (SD) [range]	36.3 (19.1) [74.0-8.0]	2.7 (2.0) [7.0-0.1]	35.3 (17.2) [70.0-0.0]	39.9 (16.3) [64.0-14.0]

Abbreviation: CNC, consonant-nucleus-consonant.

be evaluated in the present study since speech perception was not routinely assessed at intervals earlier than 3 months after revision.

There was no significant difference in speech perception performance outcomes between the 2 cohorts when assessing the influence of age at revision cochlear implantation. A consideration of this analysis is the sample size for each cohort. Partial eta-squared (η_p^2) was calculated to assess the effect size for interval and age at revision surgery; the value for each analysis was small, indicating that a minor proportion of the variance in speech perception performance was explained by the reviewed intervals and age at revision cochlear implantation. An analysis including larger sample sizes may provide further insight into the possible relationship between these variables. It is challenging to obtain larger sample sizes, however, considering the low incidence of revision cochlear implantation.[3-6]

Previous analysis of age at revision cochlear implantation has been limited, although some studies have suggested that advanced age may negatively influence postrevision outcomes. Rivas et al[12] described 4 individuals whose speech perception did not return to its best prerevision performance after approximately 10 months of listening experience with the revised device. These patients were older than those in the remaining cohort; therefore, age was suspected as a potential influence. From the cohort reviewed here, advanced age at revision cochlear implantation did not negatively influence the older adult cohort's ability to achieve speech perception scores similar to their best scores with the initial device.

Although advanced age did not appear to be a strong indicator of postrevision speech perception performance, there may be other factors that influence outcomes. In the cohort reviewed here, previous listening experience may have influenced the restoration in speech perception abilities to be simi-

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Table 2. Demographic Information for the Younger and Older Adult Cohorts

Patient No.	Age at Initial Surgery, y	Ear	Device Manufacturer	Duration of Listening Experience, y	Reason for Revision[a]	Age at Revision, y	Device Manufacturer
Younger Adults (<65 y)							
Y1	7.7	R	Advanced Bionics	14.0	Soft failure: loud popping, constant headaches, variable loudness	21.7	Cochlear
Y2	13.1	R	Advanced Bionics	9.0	Soft failure: decline in speech perception performance, headaches, neck pain	22.1	Advanced Bionics
Y3	16.9	L	Advanced Bionics	6.4	Soft failure: vertigo 6-8 wk postoperatively, little perceived benefit	23.3	Cochlear
Y4	36.8	R	Advanced Bionics	2.6	Hard failure: head trauma	39.4	MED-EL
Y5	29.6	R	Advanced Bionics	9.9	Soft failure: malfunctioning device	39.5	Advanced Bionics
Y6	38.5	R	Advanced Bionics	4.4	Soft failure: lack of progress	42.9	MED-EL
Y7	42.1	R	Advanced Bionics	4.2	Soft failure: loud sounds	46.3	MED-EL
Y8	47.2	R	MED-EL	2.6	Soft failure: suspected ground electrode migration, low-grade headache, scratching sound with jaw movement	49.8	MED-EL
Y9	49.9	L	Advanced Bionics	1.6	Soft failure: unusual auditory perceptions	51.5	MED-EL
Y10	51.0	R	MED-EL	1.5	Soft failure: facial pain	52.5	MED-EL
Y11	51.2	L	Advanced Bionics	2.1	Hard failure: no lock	53.3	Cochlear
Y12	52.6	L	Advanced Bionics	3.0	Hard failure: no lock	55.6	MED-EL
Y13	53.0	L	MED-EL	4.1	Soft failure: pain, little benefit	57.1	MED-EL
Y14	60.6	L	MED-EL	3.5	Soft failure: loud noises, intermittency, pain	64.1	MED-EL
Mean (SD) [range]	39.3 (16.6) [60.6-7.7]			4.9 (3.7) [14.0-1.5]		44.2 (13.6) [64.1-21.7]	
Older Adults (≥65 y)							
O1	59.1	L	MED-EL	5.8	Soft failure: decline in speech perception performance	64.9	MED-EL
O2	63.2	R	MED-EL	1.9	Soft failure: decline in speech perception performance	65.1	MED-EL
O3	66.5	R	MED-EL	1.4	Soft failure: high dissatisfaction with sound quality that could not be alleviated with mapping adjustments	67.9	MED-EL
O4	70.3	L	Advanced Bionics	1.7	Soft failure: vendor B device, little benefit	72.0	Advanced Bionics
O5	65.8	R	Advanced Bionics	7.3	Soft failure: decline in speech perception performance, atypical tinnitus	73.1	MED-EL
O6	74.5	L	Advanced Bionics	1.5	Soft failure: low speech perception performance, dissatisfaction with sound quality	76.0	MED-EL
O7	74.1	L	Advanced Bionics	4.8	Soft failure: poor pitch discrimination on apical electrodes	78.9	MED-EL
O8	71.8	L	Advanced Bionics	7.3	Hard failure: vendor B, hermetic seal failure	79.1	Advanced Bionics
O9	70.6	L	Advanced Bionics	8.9	Soft failure: insufficient external processor power	79.5	Advanced Bionics
O10	77.6	L	MED-EL	2.9	Soft failure: sudden pain at incision site and behind coil	80.5	MED-EL
O11	77.1	R	Advanced Bionics	3.6	Soft failure: continuous loud noise, decline in speech perception performance	80.7	MED-EL
O12	75.0	L	Advanced Bionics	6.0	Soft failure: decline in speech perception performance, poor sound quality	81.0	Cochlear
O13	73.5	R	Advanced Bionics	8.2	Soft failure: decline in speech perception performance	81.7	Cochlear
O14	81.9	L	Advanced Bionics	2.3	Soft failure: significant facial stimulation	84.2	MED-EL
O15	83.3	R	MED-EL	2.9	Hard failure: no lock	86.2	MED-EL
Mean (SD) [range]	72.3 (6.7) [83.3-59.1]			4.4 (2.6) [8.9-1.4]		76.7 (6.7) [86.2-64.9]	

Abbreviations: CNC, consonant-nucleus-consonant; L, left; R, right.

[a] Vendor B indicates a type of device that was revised owing to breakdowns in the hermetic seal.

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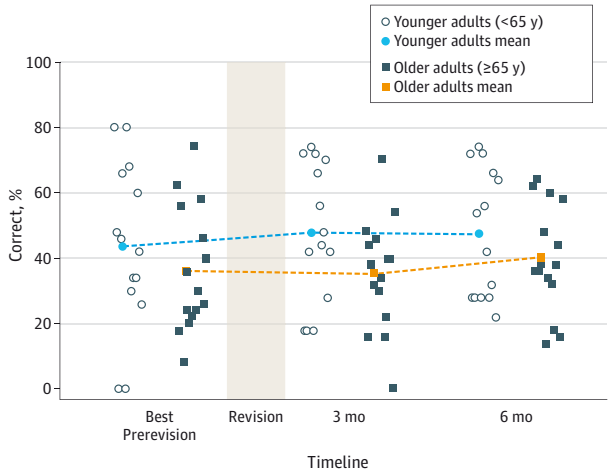
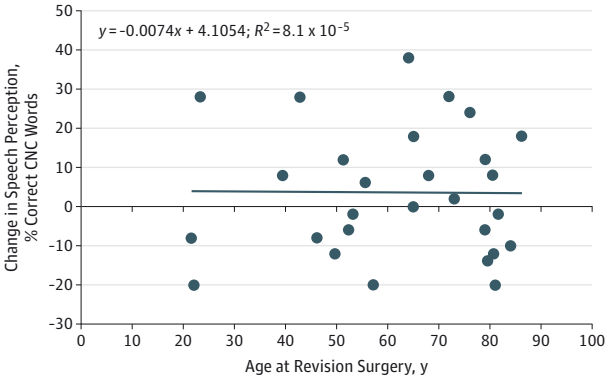
Figure 1. Consonant-Nucleus-Consonant (CNC) Word Scores Before and After Revision Surgery



Percentage correct on CNC words for the best prerevision interval and the 3- and 6-month follow-up intervals after initial activation of the revised device. Individual performance scores are plotted in addition to mean data at each interval. Participants are plotted from youngest to oldest for each cohort to observe individual variations over time.

Figure 2. Comparison Between Age at Revision Surgery and Change in Consonant-Nucleus-Consonant (CNC) Word Score



Comparison between age at revision surgery and difference between best prerevision and 6-month postrevision CNC word score. Data on 2 patients overlap.

lar to those of the younger cohort. Each group had a mean of more than 4 years of listening experience with the initial device at the time of revision cochlear implantation. This finding is in line with previous reports[6,14,15] indicating the incidence of revision surgery to be within the first 5 years of listening experience. The familiarity of the electric signal may have allowed for the fast-rate restoration in speech perception abilities for both groups. Further analysis of the relationship of duration of listening experience with the initial device and postrevision performance is needed to determine the strength of this variable as an indicator of postrevision outcomes.

Other potential influences on postrevision outcomes may include differences in the intracochlear position of the revised device, upgrades in internal and external technologies, and use of new signal coding strategies. Shin et al[14] discussed the complications associated with implanting an electrode different from the initial device, including incomplete insertion depth. Four of the 5 patients who received an electrode array different from the initial device experienced incomplete electrode insertions with variable postrevision speech perception outcomes. Furthermore, if patients switch cochlear implant manufacturers, postrevision speech perception may be influenced by variation in the signal coding strategies. In the sample reviewed here, 15 of 29 individuals received devices from a manufacturer different from that of the original device. When the total group was divided into those with a revised device from a different manufacturer vs the same manufacturer as the initial device, there was no interaction ($F_{2,54}$ = 0.51; P = .60) between speech perception scores and revised device. A review of these different variables in a larger group is needed.

In addition to analysis of variables influencing postrevision speech perception within the first months of listening experience, a review of long-term outcomes is needed. Older adult cochlear implant recipients have shown improvements in speech perception abilities beyond 12 months of listening experience with the initial device.[16] Although there was no significant difference in the postrevision speech perception abilities between the 2 cohorts in the present study, it could be that continued improvements are noted with long-term listening experience. Evaluation of long-term outcomes after revision surgery is needed to assess whether speech perception abilities remain stable or continue to improve in both cohorts.

Conclusions

Adult cochlear implant recipients who experience either a hard or soft internal device failure demonstrate a restoration in speech perception abilities after revision surgery. The restoration in speech perception abilities within 6 months of listening experience with the revised device was not influenced by the patient's age at revision implantation. Advanced age should not be a contraindication to revision cochlear implantation even in the setting of a suspected soft failure. Older adults experience gains in speech perception abilities after revision cochlear implantation that meet or exceed previous performance.

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Study concept and design: Dillon, O. F. Adunka, King, Buchman.
Acquisition, analysis, or interpretation of data: Dillon, O. F. Adunka, Anderson, M. C. Adunka,

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