Factors Influencing Time to Cochlear Implantation

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Objective: To determine demographic and audiologic factors associated with time to treatment with cochlear implantation.
Methods: Retrospective review of a prospectively maintained adult cochlear implant database. A total of 492 patients were implanted from 2012 to 2017. Time to implantation, preimplantation audiologic outcomes, and demographic data were collected. Multivariate analysis was undertaken to establish demographic/audiologic factors that predict time to cochlear implantation.
Results: Using multivariate analysis, nonwhite race (hazard ratio 0.157, $p = 0.038$) and increased age (hazard ratio 0.970, $p = 0.038$) were associated with increased time to cochlear implantation. Nonwhite patients had significantly higher pure-tone averages and lower speech recognition scores (consonant–nucleus–consonant words and AzBio sentences in quiet) and were less likely to use hearing aids as compared with white patients (all $p < 0.001$). Sex ($p = 0.188$), health insurance type ($p = 0.255$), preoperative hearing aid use ($p = 0.174$), and audiologic outcomes were not significant predictors of time to implantation.
Conclusion: Nonwhite patients have poorer preoperative hearing and speech recognition and lower hearing aid use and are at risk for delay in referral and treatment for severe to profound sensorineural hearing loss. Other demographic factors, notably health insurance status, did not significantly predict time to cochlear implantation. Given the observed hearing healthcare disparities, special outreach programs may be needed to ensure timely cochlear implantation and effective hearing screening and rehabilitation. **Key Words:** Cochlear implant—Healthcare disparity—Race—Treatment delay.

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Approximately 38 million Americans 12 years of age or over have some form of bilateral hearing loss. Of these, approximately 2 million adults have severe to profound bilateral sensorineural hearing loss and may be candidates for cochlear implantation (1). Metaanalyses have shown consistent improvement in quality of life (2,3) and speech recognition following cochlear implantation. Multiple cost-effectiveness studies have cited implantation as having a positive benefit-to-cost ratio (4–7). Paralleling these results and technological innovations, including the approval of electric-acoustic stimulation (EAS) and hybrid cochlear implants, the United States (US) Food and Drug Administration candidacy criteria for traditional implantation have expanded from total deafness in the 1980s to the present criteria of <50% open-set sentence recognition with properly fitted hearing aids, and 10–60% consonant–nucleus–consonant (CNC)-aided word recognition for EAS and hybrid implantation (6,7). Nevertheless, cochlear implantation in the US remains underutilized compared with similar industrialized nations, with studies citing approximately 6–10% usage in the candidate population (8,9).

Reasons for this underutilization are unclear and may include limited knowledge of candidacy criteria by primary care providers, poor patient understanding of expected cochlear implant outcomes, long travel distances to cochlear implant centers, and/or financial burdens related to device and other implantation-related costs. Disparity in reimbursement for implantation is a commonly cited concern, with reports of hospital reimbursement by Medicaid as low as 10% of device cost, and hospitals reporting losses of up to $10,000 per implant with Medicaid coverage (8–10). As such, demographic and socioeconomic factors can impact hearing healthcare access and the ability to provide timely cochlear implantation.

Delay in implantation not only prolongs patient disability but also may predict poorer outcomes. Early intervention with cochlear implants is one of the few

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consistent predictors of improvements in speech recognition following implantation (11–14). Thus, delays in cochlear implantation may represent a modifiable risk factor for cochlear implant candidates. The aims of the present study are to identify demographic and audiologic factors that may be associated with increased time before cochlear implantation. We hypothesize that demographic factors such as age, sex, and race; audiologic factors, such as magnitude of hearing loss; and socioeconomic factors, such as health insurance status, predict longer delays in cochlear implantation.

MATERIALS AND METHODS

Patients

The present study was approved by our Institutional Review Board. A retrospective review of a prospectively maintained database was performed for adult patients undergoing unilateral cochlear implantation for bilateral sensorineural hearing loss between January 2012 and August 2017. Evaluation for candidacy and surgery was performed at a tertiary university-based otology practice. Inclusion criteria included documented history of postlingual onset of hearing loss and age ≥18 years. Exclusion criteria were initial cochlear implant surgery at another institution (thus, history before cochlear implantation was not available), incomplete audiometric data, revision cochlear implantation, second-sided cochlear implantation, and implantation for single-sided deafness. Table 1 includes the demographics of the 492 patients who met inclusion/exclusion criteria.

Data Acquisition

The following data were extracted from our adult cochlear implant database: age at implantation, sex, race/ethnicity, history of hearing aid use, health insurance provider, time to implantation, and preoperative audiometric data. Audiometric data were obtained for the best aided ear and included aided pure-tone average (PTA) using thresholds at 500, 1000, and 2000 Hz, speech recognition threshold, and best aided speech recognition scores using CNC words, AzBio sentences in quiet, and AzBio sentences in noise at a +10 dB signal-to-noise ratio (AzBio +10) (15–17). AzBio +10 was used for patients obtaining ≥50% AzBio quiet scores. Preimplantation speech recognition was measured with hearing aids (personal or stock aids) fitted to National Acoustics Laboratory-Revised Linear (NAL-RL) targets (18). All speech recognition testing was performed in a sound-treated room in the sound field with speech presented at 60 dB SPL (0° azimuth).

Time to implantation was defined by self-report as the number of years with hearing loss before implantation. Preoperative hearing aid use was defined as the patient's self-reported active hearing aid use at the time of the cochlear implant evaluation (yes/no). Race/ethnicity was defined as white and nonwhite, with white including non-Hispanic white patients. Owing to small numbers of patients in certain racial/ethnic groups, nonwhite included African-American, Hispanic, Asian, and Native American patients (89.1% of patients in the nonwhite group were African-American). For insurance status, patients were grouped into 2 insurance provider categories, private and public. Private insurance included patients enrolled in any privately held or employee-acquired healthcare plan or pension. Public insurance included patients enrolled in Medicaid, Medicare, VA, or Tricare plans.

TABLE 1. *Patient demographic data*

	All	White	Nonwhite[b]	*p* Value
N	492	391	101	
Age in years (SD)	61.2 (18.1)	63.9 (17.1)	50.7 (18.2)	**<0.001**
Sex				0.014
Male (%)	260 (52.8)	218 (55.8)	42 (41.6)	
Female (%)	232 (47.2)	173 (44.3)	59 (58.4)	
Health insurance				0.091
Private (%)	152 (30.9)	128 (32.7)	24 (23.8)	
Public[a] (%)	340 (69.1)	263 (67.3)	77 (76.2)	

Bold indicates significant relationships.
SD indicates standard deviation.
[a]Public insurance includes Medicare, Medicaid, VA, or Tricare plans.
[b]Nonwhite cohort includes African-American patients (89.1%), and Hispanic, Asian, and Native American Patients.

Data Analysis

Analyses were performed with SPSS 25.0 (IBMCorp., Armonk, NY). Continuous variables were tested for normal distribution as determined by the Kolmogorov–Smirnov test. Nominal variables (sex, racial group, hearing aid use, insurance) were summarized by frequency, percentage, and/or range. Continuous variables (age at implantation, time to implantation, audiometric outcomes) were summarized by mean (standard deviation) where appropriate. Analysis between racial groups was performed using Chi-square analysis or Fisher exact test for nominal data and a Student's *t* test or Mann–Whitney *U* test for quantitative data.

A Cox regression was performed for multivariate analysis of all demographic and audiometric covariates to determine the independent relationship of the variable with time to implantation while controlling for possible confounding effects. For nominal covariates the largest cohort was designated as the reference category. A *p*-value of ≤0.05 was used as the measure for statistical significance for all statistical tests.

RESULTS

Patient Demographics

Demographics of the 492 patients included in this study are included in Table 1. Mean age at implantation was 61.2 years ± 18.1 years; 52.8% of patients were male. Most patients were non-Hispanic white (79.5%) or African-American (18.3%). Hispanic (1.0%), Asian (1.0%), and Native American (0.2%) patients made of the remainder of the study population. A majority of patients were enrolled in some form of public health insurance (69.1%). Meantime with hearing loss before implantation was 24.2 ± 17.2 years and most patients (61.8%) were using hearing aids at the time of the cochlear implant evaluation. Audiological data are detailed in Table 2.

Multivariate Analysis of Demographic and Audiometric Covariates

To assess the effects of multiple covariates on time before implantation, a Cox regression was performed and results are included in Table 3. Hazard ratio denotes a relative incidence of implantation at any point in time as modified by each covariate. A hazard ratio less than 1

TABLE 2. *Patient audiologic data*

	All Patients	White	Nonwhite[a]	p Value
Hearing aid use				**<0.001**
Yes (%)	304 (61.8)	264 (67.5)	40 (39.6)	
No (%)	179 (36.4)	121 (31.0)	58 (57.4)	
Unknown (%)	9 (1.8)	6 (1.5)	3 (3.0)	
Audiometric outcomes (aided)				
PTA-dB HL (SD)	39.0 (15.7)	36.3 (11.1)	41.9 (17.3)	**0.007**
SRT-dB HL (SD)	35.8 (10.5)	35.7 (10.5)	36.2 (11.0)	0.728
CNCw—%correct (SD)	17.4 (20.1)	19.3 (21.0)	9.4 (13.2)	**<0.001**
AzBio quiet—%correct (SD)	20.3 (23.2)	22.9 (24.2)	11.4 (16.4)	**<0.001**
AzBio quiet—%correct for those undergoing AzBio +10 testing (SD)	61.6 (22.4)	61.5 (22.9)	63.5 (6.4)	0.756
AzBio +10—%correct (SD)	35.1 (21.1)	35.0 (21.5)	38.2 (9.3)	0.511

Bold indicates significant relationships.
CNCw indicates consonant–nucleus–consonant words; PTA, pure tone threshold; SD, standard deviation; SRT, speech reception threshold.
[a]Nonwhite cohort includes African-American patients (89.1%), and Hispanic, Asian, and Native American Patients.

represents a decreased incidence at that point in time, and, in the case of this study, a delay in cochlear implantation. The lower the hazard ratio, the longer the delay in implantation. While controlling for effects of all other variables, nonwhite race was associated with a delay in cochlear implantation (hazard ratio = 0.157 (0.027–0.904), $p = 0.038$), meaning that white patients were approximately 6 times more likely to undergo implantation during each year of hearing loss as compared with nonwhite patients. Increased age was also significantly associated with a delay in implantation (hazard ratio 0.970 (0.942–0.998), $p = 0.038$); although statistically significant, hazard ratios near 1 represent very minor associations. That is, with each 1-year increase in age, the likelihood of obtaining a cochlear implant increased by only 3% over the study timeline. The remaining demographic and audiometric covariates were not significantly associated with time to cochlear implantation (all $p > 0.05$). Of note, several large hazard ratio ranges were observed, particularly in the demographic variables. This variance likely reflects differences in the size of the categorical variable groups. This is contrasted to hazard ratio intervals for continuous variables such as age or audiologic outcomes, which can be compared among the entire sample without concern for intragroup variance.

Additional analyses were performed to explore further racial/ethnic differences that may influence time to cochlear implantation (Tables 1 and 2). On average, nonwhite patients were younger than white patients (50.7 ± 18.2 versus 63.9 ± 17.1; $p < 0.001$) and had significantly higher PTAs (41.9 ± 17.3 versus 36.3 ± 11.1, $p = 0.007$) and lower word recognition scores in quiet (CNC: 9.4 ± 13.2 versus 19.3 ± 21.0; AzBio: 11.4 ± 16.4 versus 22.9 ± 24.2; all $p < 0.001$). Only patients with AzBio in quiet scores greater than 50% underwent AzBio +10 testing. As such, these borderline patients were fewer in number had better hearing scores in a much narrower range. Although their hearing was poorer, nonwhite patients reported a lower percentage of hearing aid use at the time of implantation evaluation than white patients (39.6 versus 67.5; $p < 0.001$). Unadjusted years to implantation was shorter in nonwhite patients (17.3 (15.9) versus 26.0 (17.4); $p < 0.001$); when adjusted using multivariate statistical methods for age at implantation, audiologic outcomes, and hearing aid usage, time

TABLE 3. *Demographic and audiological factors influencing time to cochlear implantation as indicated by hazard ratios*

Covariate	Hazard Ratio (95% Confidence Interval)	p Value
Demographics		
Age	0.97 (0.94–0.99)	**0.038**
Race (Nonwhite/white)	0.16 (0.03–0.90)	**0.038**
Sex (female/male)	0.59 (0.27–1.30)	0.188
Health insurance category (public/private)	1.80 (0.77–4.18)	0.255
Audiological data		
Hearing aid use (use/no use)	1.60 (0.71–3.57)	0.174
PTA	0.96 (0.90–1.04)	0.329
SRT	0.99 (0.94–1.04)	0.756
CNCw	0.99 (0.96–1.01)	0.270
AzBio quiet	1.00 (0.97–1.02)	0.688
AzBio +10	1.00 (0.98–1.02)	0.782

CNCw indicates consonant–nucleus–consonant words; PTA, pure tone threshold; SRT, speech reception threshold.
Bold indicates significant hazard ratios.

to implantation was longer in nonwhite than white patients. No other significant differences were noted between the 2 racial/ethnic groups.

DISCUSSION

Cochlear implantation is a well-tolerated and effective treatment for moderate to profound sensorineural hearing loss in adults, although more inclusive candidacy criteria have not increased utilization in the US (8,9). Possible reasons include centralization of cochlear implant centers in urban areas leading to long travel distances for some patients, poor primary care awareness of candidacy criteria, and inadequate insurance reimbursement, but little evidence is available to explain low utilization or access (8,9). To better understand hearing healthcare access and timely utilization by adult cochlear implant users, we assessed factors that may contribute to time with sensorineural hearing loss before cochlear implantation. We found a significant independent association between nonwhite race and increased time to implantation.

The relationship of patient race to time to implantation is likely multifactorial and may be related to availability of hearing and healthcare services in minority communities and general socioeconomic considerations (19,20). A 2002 Institute of Medicine report showed that minority populations received substantially lower rates of routine care and procedures than white populations (21). Similarly, rates of aural rehabilitation in minority populations lag behind that of majority populations, with roughly 5% of African-Americans with severe hearing loss pursuing treatment compared with 40% of white patients with similar hearing loss (22,23). Such underutilization of hearing healthcare in minority populations may explain lower rates of hearing aid utilization in nonwhite patients in the present study. If minority patients bypass hearing aids, they may seek cochlear implantation at earlier ages, which may explain their earlier age at implantation. However, further research is needed to confirm this association. Studies have also shown some circumstantial evidence that hearing aid use before cochlear implantation may slow degradation of central auditory pathways. As such, lower rates of hearing aid before cochlear implantation use may partially explain poorer audiologic outcomes in nonwhite patients (11,12).

Commonly considered causes for discrepancies in hearing healthcare utilization are lack of routine hearing healthcare and education in minority communities, economic factors, and lack of minority physicians and providers (19–21). Geographic considerations may also act as barriers to timely cochlear implantation. Hixon et al (24) previously reported that rural cochlear implant recipients in Kentucky had lower income levels, were largely covered by public insurance, and had significantly longer commutes to cochlear implantation centers. In addition, this population had significantly longer times before implantation.

Another frequently considered barrier to cochlear implantation is public versus private health insurance. A common assumption is that public insurance presents a barrier to implantation through both lower physician compensation and more stringent candidacy criteria (8–10,20,25). Such barriers may exacerbate racial disparities in healthcare accessibility. In the present study, private/public insurance proportions were not significantly different for white and nonwhite patients (Table 1), which may not be the case nationally. Accordingly, race, and not insurance type, was significantly associated with time before cochlear implantation (Table 3). Fortnum et al (26) showed affluent children in the United Kingdom were more likely to obtain cochlear implants than less affluent children, despite a social medical system with high public funding. As such, factors beyond access to a certain type of health insurance, such as personal, financial, and other resources, may contribute to timely cochlear implantation.

The results of this study demonstrate that, despite similar insurance coverage, nonwhite patients underutilized hearing aids and/or cochlear implants. On average, nonwhite patients were younger than white patients at implantation, had poorer hearing at the time of the cochlear implant candidacy evaluation but also reported lower rates of hearing aid use. This shows a potentially disturbing trend toward overall underutilization of or lack of access to hearing healthcare by nonwhite patients. Effective screening, education, and more rapid intervention in minority communities are needed to achieve timely cochlear implantation.

Our study also showed a very small but significant association of increasing age and increased time to cochlear implantation, with each 1-year increase in age increasing by 3% the likelihood of obtaining a cochlear implant over the study timeline. Thus, although statistically significant, this result is unlikely to be of clinical significance, because a small change in age will yield only a negligible change in the likelihood of implantation.

The present study failed to show any significant association between health insurance type and time to cochlear implantation. Socioeconomic status and health insurance coverage remain major issues in healthcare policy. We have insufficient information to discuss the impact of specific private insurance policies on hearing healthcare access, nor can we claim that our results reflect the overall population of adult cochlear implant candidates in the US. In 2016, 67.5% of Americans held some form of private insurance and 37.3% were insured through government policies (27). The South Carolina adult population, from which the study data was drawn, held private and government policies at 61 and 38.5%, respectively (28). These figures differ from our study population, with 69.1% of patients holding government insurance policies and only 30.9% holding private insurance (Table 1). However, we note that the average age of our patient population is 61 years, close to the eligible age for Medicare of 65. Roughly 34% of Medicare beneficiaries enroll in private health insurance, which more closely matches rates of enrollment seen here and may explain the ratio of private to public insurance seen in this study (29). As noted earlier, these ratios did not differ by race (Table 1).

In this regard, 1 limitation of the present study is the single university-based sample, which may limit the generalizability of the results. Including community and private practices and a larger sample in future studies address these limitations. Another limitation is that 89.1% of our nonwhite patients were African-American with numbers of other nonwhite races too small to provide sufficient statistical power for subanalyses. A larger and more diverse sample is necessary to analyze the independent impact of other nonwhite patients on time to implantation. An additional limitation is the reliance on self-report estimates of patients' time to implantation, which was used because of the absence of serial audiograms. Nevertheless, patient-reported estimates of onset of hearing loss are commonly used and often reported in the literature (15,30,31).

CONCLUSION

Cochlear implantation is an effective therapeutic option for patients with moderate to profound sensorineural hearing loss, but utilization remains low. In the setting of a tertiary university-based otology practice, results from the present study suggest that nonwhite patients may be at risk for delay in referral for cochlear implantation, leading to increased time without treatment. Additional research is needed to investigate these findings in larger sample sizes and in community and private practice settings to determine the generalizability of these results.

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