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Trends in Health Care Costs and Utilization Associated With Untreated Hearing Loss Over 10 Years

Nicholas S. Reed, AuD; Aylin Altan, PhD; Jennifer A. Deal, PhD; Charlotte Yeh, MD; Alexander D. Kravetz, PharmD; Margaret Wallhagen, RN, PhD; Frank R. Lin, MD, PhD

IMPORTANCE Nearly 38 million individuals in the United States have untreated hearing loss, which is associated with cognitive and functional decline. National initiatives to address hearing loss are currently under way.

OBJECTIVE To determine whether untreated hearing loss is associated with increased health care cost and utilization on the basis of data from a claims database.

DESIGN, SETTING, AND PARTICIPANTS Retrospective, propensity-matched cohort study of persons with and without untreated hearing loss based on claims for health services rendered between January 1, 1999, and December 31, 2016, from a large health insurance database. There were 154 414, 44 852, and 4728 participants at the 2-, 5-, and 10-year follow-up periods, respectively. The study was conceptualized and data were analyzed between September 2016 and November 2017.

EXPOSURES Untreated hearing loss (ie, hearing loss that has not been treated with hearing devices) was identified via claims measures.

MAIN OUTCOMES AND MEASURES Medical costs, inpatient hospitalizations, total days hospitalized, 30-day hospital readmission, emergency department visits, and days with at least 1 outpatient visit.

RESULTS Among 4728 matched adults (mean age at baseline, 61 years; 2280 women and 2448 men), untreated hearing loss was associated with $22 434 (95% CI, $18 219-$26 648) or 46% higher total health care costs over a 10-year period compared with costs for those without hearing loss. Persons with untreated hearing loss experienced more inpatient stays (incidence rate ratio, 1.47; 95% CI, 1.29-1.68) and were at greater risk for 30-day hospital readmission (relative risk, 1.44; 95% CI, 1.14-1.81) at 10 years postindex. Similar trends were observed at 2- and 5-year time points across measures.

CONCLUSIONS AND RELEVANCE Older adults with untreated hearing loss experience higher health care costs and utilization patterns compared with adults without hearing loss. To further define this association, additional research on mediators, such as treatment adherence, and mitigation strategies is needed.

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Author Affiliations: Department of Otolaryngology–Head & Neck Surgery, Johns Hopkins School of Medicine, Baltimore, Maryland (Reed, Lin); OptumLabs, Cambridge, Massachusetts (Reed, Altan, Kravetz); Cochlear Center for Hearing and Public Health, Johns Hopkins University Bloomberg School of Public Health, Baltimore, Maryland (Reed, Deal, Lin); Department of Epidemiology, Johns Hopkins Bloomberg School of Public Health, Baltimore, Maryland (Deal, Lin); AARP Services, Inc, Washington, DC (Yeh); University of California San Francisco School of Nursing, San Francisco (Wallhagen).

Corresponding Author: Nicholas S. Reed, AuD, Johns Hopkins University, Cochlear Center for Hearing and Public Health, 2024 E Monument Street, Baltimore, MD 21205 (nreed9@jhmi.edu).

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More than 38 million adults in the United States experience hearing loss, and the prevalence increases with age such that two-thirds of adults older than 70 years have clinically meaningful hearing loss.[1] Based on current aging population trends, the number of Americans with hearing loss is projected to increase to more than 73 million by 2060.[2] Importantly, hearing loss has been associated with negative health outcomes, including cognitive decline,[3] incident dementia,[4] falls,[5] depression,[6] reduced quality of life,[7] and an increased number of emergency department visits[8] and hospitalizations.[9] However, fewer than 20% of adults with hearing loss report using hearing aids.[10]

Hearing loss recently received recognition as a national public health concern.[11-15] Reports from the President's Council of Advisors on Science and Technology[12] and the National Academies of Science, Engineering, and Medicine[11] have called for policy changes to better understand the influence of hearing loss on health in the United States and to address the condition. These initiatives resulted in the passage of the Over-the-Counter Hearing Aid Act of 2017.[15] However, there remains a limited understanding of the broader influence that hearing loss may have on health care cost and resource utilization.[8,16,17]

This study investigates the association between untreated hearing loss (based on the lack of evidence of hearing device use in claims data and the assumption that relatively few persons with hearing loss use hearing aids[10]) and health care costs and utilization over a 10-year period using claims data from a large, deidentified administrative claims database from a geographically diverse US health insurance plan.

Key Points

Question Is untreated hearing loss associated with higher health care costs and utilization?

Findings In this retrospective, propensity-matched cohort study of claims data, compared with no hearing loss, untreated hearing loss was associated with higher health care costs and a higher risk of 30-day hospital readmission over a 10-year period.

Meaning Untreated hearing loss may contribute to greater health care costs and utilization.

Methods

Data Source

This retrospective, propensity-matched cohort study used deidentified administrative claims data from the OptumLabs Data Warehouse (OLDW) to identify hearing products purchased or health services rendered between January 1, 1999, and December 31, 2016. Institutional review board approval and patient informed consent were not required because the deidentified data complies with the Health Insurance Portability and Accountability Act Privacy Rule. The OLDW includes deidentified claims data for more than 125 million privately insured and Medicare Advantage (MA) enrollees in a large, private, US health plan from 1993 to the present and represents a diverse population in terms of age, race/ethnicity, and US geographic region. The health plan provides comprehensive insurance coverage for physician, hospital, and prescription drug services, including Part D coverage for MA enrollees. The database includes socioeconomic information, such as race/ethnicity, household income, and education level, for approximately 73% of enrollees. This information was derived from a nationally recognized supplier of consumer marketing data and is a compilation of public data and derived predictive data. While the imputation methods used by this supplier are proprietary, imputation methods for race/ethnicity have been shown in previous studies to have moderate sensitivity (48%), excellent specificity (97%), and moderate positive predictive value (71%) for the purpose of identifying race.[18]

Outcome Variables

The primary outcome of this study was medical costs, measured as health plan–paid (HPP), out-of-pocket (OOP), and total paid (ie, the sum of all HPP and OOP) costs for all medical services reimbursed by health insurance during the follow-up period. Costs were adjusted to 2015 US dollars using the medical care component of the Consumer Price Index.[19] Secondary outcomes included medical costs not related to hearing services and measures of health care utilization, such as the number of inpatient hospitalizations, total days hospitalized, number of readmissions within 30 days of discharge, number of emergency department visits, and number of days with at least 1 outpatient visit (including visits for hearing-related services and visits for non–hearing-related services). Office visit days for hearing loss were defined as the total number of days during follow-up with at least 1 office visit related to hearing services.

Exposure

Older adults with and without hearing loss were identified from OLDW. Eligible participants were 50 years or older. Hearing loss status was determined by the presence of at least 2 claims separated by no more than 730 days with an *International Classification of Disease, 9th Revision, Clinical Modification* (*ICD-9-CM*) diagnosis code for hearing loss: V41.2 (problems with hearing), 388.01 (presbycusis), 389 (hearing loss), 389.1x (sensorineural hearing loss, excluding 389.12 [neural hearing loss, bilateral] and 389.14 [central hearing loss]), 389.2x (mixed conductive and sensorineural hearing loss) in any position during the identification period of January 1, 2000, to December 31, 2014. The date of the first claim was designated as the index date. To ensure that complete information was obtained, participants were required to have at least 12 months of continuous enrollment in the plan prior to the index date and at least 2 years of continuous enrollment after the index date. Exclusion criteria included evidence of hearing loss prior to the index date, first evidence of hearing loss experienced during an inpatient stay (indicating an acute issue), evidence of hearing device use via claims data before or within 2 years of the index date, and/or evidence of ototoxic drug use in the 12-month period prior to the index date. Furthermore, individuals were excluded if they had evidence of hearing loss secondary to correctable medical conditions (ie, via surgical measures) or hearing loss fundamentally different from typical peripheral age-related hearing loss (ie, central pathology) including

sudden hearing loss (*ICD-9-CM* code, 388.2), hyperacusis (*ICD-9-CM* code, 388.42), acoustic nerve disorders (*ICD-9-CM* code, 388.5), otorrhea (*ICD-9-CM* code, 388.6x), otalgia (*ICD-9-CM* code, 388.7x), conductive hearing loss (*ICD-9-CM* code, 389.0x), neural hearing loss (*ICD-9-CM* code, 389.12), and/or central hearing loss (*ICD-9-CM* code, 389.14). A pool of candidate participants with no evidence of hearing loss diagnosis at any point was selected, with the index date set to a random date of service within the capture window. Three nested samples were created, based on data availability for 2-, 5-, and 10-year follow-up periods. The resulting samples are nonmutually exclusive (ie, participants who qualified for the 10-year sample also qualified for the 5- and 2-year samples).

Statistical Analysis

Because of suspected underlying differences in persons with and without hearing loss, matched cohorts were created for each of the 3 follow-up times using a 2-stage process. First, participants with untreated hearing loss were block-matched to persons with no evidence of hearing loss within the cohort year (2, 5, or 10), insurance type (commercial or MA), and cost deciles. Subsequently, nearest-neighbor 1:1 caliper-based greedy propensity score matching without replacement was used, with the following variables measured during the 1 year prior to the index date included in the propensity model: age,[2] sex, census geographic region, net worth, race/ethnicity, education level, Charlson Comorbidity Index,[20] number of office visits (natural log transformed, both linear and quadratic terms), number of inpatient stays, inpatient length of stay, number of emergency department visits, dementia, mild cognitive impairment, depression, stroke, myocardial infarction, coronary artery disease, breast cancer, prostate cancer, renal cell carcinoma, colorectal cancer, and baseline medical costs (evidence of any costs and total medical costs). Block matching on cost deciles was required owing to the skewed nature of cost, which can result in poorly matched cost distributions. Within each block, caliper matching was used to match persons with untreated hearing loss to the closest person without hearing loss with a propensity score within 0.2 SDs. Unmatched participants were excluded from analysis. The quality of the matched cohorts was assessed using absolute standardized differences (ASD). Following matching, no variable exhibited an ASD greater than 10%, indicating that persons with or without untreated hearing loss were balanced on baseline variables, including follow-up time.

Descriptive statistics were reported for all study measures and baseline covariates. Univariate comparisons were conducted according to the distribution of the data, using *t* tests, χ^2 tests, and Mann-Whitney *U* tests when appropriate. Statistical significance was assessed at the 2-sided 5% level unless otherwise indicated. Given the large sample size, it was expected a priori that formal statistical tests would show evidence of statistically significant but not clinically significant differences in baseline variables between patients with and without hearing loss even after matching.

Differences in means and proportions and associated 95% CIs are reported. The output of event modeling is also presented as incidence rate ratios, risk ratios, and absolute risk differences.[21] In addition to specifications with the cohort indicator only, multivariable analysis was conducted on the matched cohorts to evaluate whether residual confounding remained after matching. Covariates in these models included sociodemographics (eg, age, sex, geographic region, race/ethnicity, net worth), insurance type, and indicators of comorbidity and health-service use measured during the 12-month baseline period. Medical cost variables were analyzed using generalized linear models, assuming a gamma-distributed error and log link.[22] This assumption was tested using the modified Park test. The incremental cost of untreated hearing loss was calculated using recycled predictions to facilitate interpretation.[23] Negative binomial regression was used to model the number of inpatient hospitalizations and total days hospitalized. The 30-day hospital readmission and emergency department visits were modeled using a modified Poisson regression with robust standard errors and are presented as relative risks (RRs) with 95% CIs.[24] Marginal effects, standard errors, and 95% CIs for all multivariable models were calculated using the delta method.[25]

Analytic files were created using SAS software, version 9.4 (SAS Institute). All analyses were performed using R 3.3.2 (R Core Team, 2016), including R packages ggplot2, data.table, tableone, Rcpp, Zelig, attribrisk, lmtest, sandwich, modmarg, car, ggfortify, and survival; additional R code was custom created. Matching was done in C++ and R; the code is original and was written by one of us (A.D.K).

Results

Matching

Prior to propensity score matching, there were 77 310 participants with untreated hearing loss and 3 251 863 potential participants without hearing loss. Prior to matching, a greater proportion of persons in the untreated hearing loss cohort were MA enrollees, had greater net worth and education levels, and exhibited a greater level of comorbidity during the 12-month baseline period compared with persons with no evidence of hearing loss. These differences agree with previous research on characteristics of persons with hearing loss and access to hearing care.[1] Differences between cohorts were resolved via the matching process. All but 103 persons with hearing loss were matched, and unused data from 3 174 656 unexposed potential participants were dropped. Compared with persons who were included in the study, those persons without hearing loss who were excluded from the study were less likely to be MA enrollees (31.1% vs 17.5%), were younger (63.8 vs 59.5 years), were less likely to be in the highest net-worth bracket (25.5% vs 19.9%), were less likely to be white (60.4% vs 54.5%), and were less likely to be college educated (15.4%, vs 12.0%). Excluded individuals also had fewer office visits on average (13.4 vs 18.6 visits) and lower average medical costs ($7799 vs $8480) during the baseline year than retained participants had.

Demographic Characteristics

Table 1 lists the characteristics of the matched cohorts at 2-, 5-, and 10-year time points. Between 2000 and 2014, there

Table 1. Participant Baseline Characteristics

Characteristic	No. (%)[a]					
	2-y Cohort		5-y Cohort		10-y Cohort	
	Untreated Hearing Loss (n = 77 207)	No Hearing Loss (n = 77 207)	Untreated Hearing Loss (n = 22 426)	No Hearing Loss (n = 22 426)	Untreated Hearing Loss (n = 2364)	No Hearing Loss (n = 2364)
Age, mean (SD)	63.80 (9.74)	63.79 (9.70)	61.71 (9.22)	61.70 (9.20)	61.03 (9.30)	61.05 (9.28)
Female	37 309 (48.3)	37 155 (48.1)	10 792 (48.1)	10 671 (47.6)	1150 (48.6)	1130 (47.8)
Race						
Asian	1707 (2.2)	1626 (2.1)	385 (1.7)	352 (1.6)	39 (1.6)	34 (1.4)
Black	4367 (5.7)	4420 (5.7)	1312 (5.9)	1373 (6.1)	144 (6.1)	162 (6.9)
Hispanic	3933 (5.1)	4039 (5.2)	1061 (4.7)	1050 (4.7)	89 (3.8)	95 (4.0)
Unknown	20 428 (26.5)	20 452 (26.5)	6282 (28.0)	6389 (28.5)	605 (25.6)	642 (27.2)
White	46 772 (60.6)	46 670 (60.4)	13 386 (59.7)	13 262 (59.1)	1487 (62.9)	1431 (60.5)
Region						
Midwest	21 896 (28.4)	21 951 (28.4)	6903 (30.8)	6796 (30.3)	861 (36.4)	830 (35.1)
Northeast	14 536 (18.8)	14 323 (18.6)	3966 (17.7)	3906 (17.4)	418 (17.7)	436 (18.4)
South	31 820 (41.2)	31 929 (41.4)	9205 (41.0)	9329 (41.6)	882 (37.3)	899 (38.0)
West	8955 (11.6)	9004 (11.7)	2352 (10.5)	2395 (10.7)	203 (8.6)	199 (8.4)
Net worth, $						
Unknown	22 874 (29.6)	22 951 (29.7)	6978 (31.1)	7137 (31.8)	673 (28.5)	718 (30.4)
<25 000	2771 (3.6)	2707 (3.5)	729 (3.3)	682 (3.0)	80 (3.4)	77 (3.3)
24 000-149 000	7610 (9.9)	7447 (9.6)	2038 (9.1)	1998 (8.9)	206 (8.7)	185 (7.8)
150 000-249 000	7678 (9.9)	7815 (10.1)	2047 (9.1)	2043 (9.1)	195 (8.2)	193 (8.2)
250 000-499 000	16 404 (21.2)	16 564 (21.5)	4745 (21.2)	4738 (21.1)	558 (23.6)	560 (23.7)
≥500 000	19 870 (25.7)	19 723 (25.5)	5889 (26.3)	5828 (26.0)	652 (27.6)	631 (26.7)
Education						
<12th grade	231 (0.3)	219 (0.3)	39 (0.2)	37 (0.2)	Masked data[b]	Masked data[b]
High school diploma	14 647 (19.0)	14 568 (18.9)	3937 (17.6)	3890 (17.3)	380 (16.1)	386 (16.3)
<Bachelor's degree	31 981 (41.4)	32 166 (41.7)	9139 (40.8)	9072 (40.5)	992 (42.0)	965 (40.8)
≥Bachelor's degree	12 068 (15.6)	11 886 (15.4)	3621 (16.1)	3594 (16.0)	444 (18.8)	430 (18.2)
Unknown	18 280 (23.7)	18 368 (23.8)	5690 (25.4)	5833 (26.0)	<546	<585
Medicare	24 028 (31.1)	24 028 (31.1)	6025 (26.9)	6025 (26.9)	755 (31.9)	755 (31.9)
Baseline utilization, mean (SD)						
Inpatient stays	0.14 (0.47)	0.14 (0.43)	0.12 (0.42)	0.12 (0.39)	0.10 (0.34)	0.10 (0.33)
Total inpatient, d	0.79 (4.94)	0.82 (4.30)	0.61 (3.31)	0.64 (3.22)	0.54 (2.49)	0.54 (2.36)
Outpatient encounters	18.73 (18.18)	18.63 (17.84)	17.17 (16.07)	17.13 (15.67)	15.55 (14.35)	14.91 (13.33)
ED visits	0.32 (0.77)	0.32 (0.75)	0.27 (0.69)	0.27 (0.66)	0.24 (0.59)	0.22 (0.54)
Medical costs, $	8311.24 (20 645.18)	8479.90 (19 165.55)	7418.90 (17 586.02)	7536.63 (15 933.56)	6365.09 (14 413.20)	6272.95 (11 928.82)
Baseline comorbidities						
Charlson Comorbidity Index, mean (SD)	1.12 (1.71)	1.12 (1.68)	0.89 (1.48)	0.90 (1.47)	0.69 (1.24)	0.68 (1.20)
Acute myocardial infarction, No. (%)	324 (0.4)	301 (0.4)	87 (0.4)	76 (0.3)	13 (0.5)	14 (0.6)
Depression	8358 (10.8)	8325 (10.8)	2147 (9.6)	2109 (9.4)	201 (8.5)	192 (8.1)
Dementia	2104 (2.7)	2189 (2.8)	381 (1.7)	411 (1.8)	14 (0.6)	18 (0.8)
Stroke	1963 (2.5)	1953 (2.5)	466 (2.1)	437 (1.9)	35 (1.5)	30 (1.3)
Mild cognitive impairment	107 (0.1)	113 (0.1)	Masked data[b]	Masked data[b]	Masked data[b]	Masked data[b]
Coronary artery disease	8744 (11.3)	8850 (11.5)	2119 (9.4)	2195 (9.8)	208 (8.8)	224 (9.5)

Abbreviations: ASD, absolute standard difference; ED, emergency department.

[a] Absolute standard difference was less than 10% for all comparisons.

[b] Sample size masked owing to small sample size.

were 154 414, 44 852, and 4728 participants with and without untreated hearing loss who met study inclusion criteria and had 2, 5, and 10 years of follow-up, respectively. As detailed in Table 1, across the 3 samples of matched persons at 2-, 5-, and 10-year follow-up, the mean age range was 61 to 64 years, 47.6% to 48.6% of participants were women, and 59.1% to

Table 2. Postpropensity Score Matching, Unadjusted Health-Service Costs and Utilization for Untreated Hearing Loss vs No Hearing Loss Groups

Follow-up Measure	2-y Cohort		5-y Cohort		10-y Cohort	
	Untreated Hearing Loss (n = 77 207)	No Hearing Loss (n = 77 207)	Untreated Hearing Loss (n = 22 426)	No Hearing Loss (n = 22 426)	Untreated Hearing Loss (n = 2364)	No Hearing Loss (n = 2364)
Medical costs, mean (SD), $	18 744.36 (40 628.30)	14 892.70 (32 038.23)	41 386.64 (64 387.99)	30 239.23 (4259.55)	70 631.60 (84 918.08)	48 198.08 (60 954.44)
Difference (95% CI)	3851.70 (3486.82-4216.59)		11 147.4 (10 086.34-12 208.47)		22 433.52 (18 218.61-26 648.43)	
Non-hearing loss medical costs, mean (SD), $	18 362.40 (40 613.22)	14 892.70 (32 038.23)	40 916.95 (64 371.86)	30 239.23 (49 259.55)	70 075.82 (84 894.26)	48 198.08 (60 954.44)
Difference (95% CI)	3469.70 (3104.82-3834.59)		10 677.72 (9616.81-11 738.62)		21 877.74 (17 663.61-26 091.87)	
Inpatient stays, mean (SD)	0.28 (0.78)	0.24 (0.69)	0.62 (1.34)	0.48 (1.08)	1.24 (2.05)	0.86 (1.60)
Difference (95% CI)	0.04 (0.03-0.05)		0.14 (0.12-0.16)		0.38 (0.27-0.48)	
Inpatient days, mean (SD)	1.57 (6.78)	1.31 (5.43)	3.25 (9.83)	2.50 (8.25)	6.56 (14.81)	4.46 (10.88)
Difference (95% CI)	0.26 (0.20-0.33)		0.75 (0.58-0.92)		2.1 (1.36-2.84)	
Outpatient visit days, mean (SD)	40.18 (36.49)	32.72 (35.18)	90.76 (72.64)	68.62 (62.21)	168.05 (123.25)	115.85 (95.37)
Difference (95% CI)	7.47 (7.11-7.83)		22.14 (20.89-23.39)		52.19 (45.91-58.48)	
Non–hearing loss office visit days, mean (SD)	39.62 (36.17)	32.47 (35.00)	89.69 (71.99)	68.10 (61.76)	166.00 (121.14)	115.13 (94.79)
Difference (95% CI)	7.15 (6.80-7.51)		21.59 (20.35-22.83)		50.87 (44.67-57.07)	
ED visits, mean (SD)	0.64 (1.37)	0.52 (1.30)	1.39 (2.85)	1.10 (2.14)	2.61 (3.61)	1.81 (2.77)
Difference (95% CI)	0.11 (0.10-0.12)		0.29 (0.24-0.33)		0.8 (0.62-0.98)	
30-d Readmission, No. (%)	1542 (2.0)	1198 (1.6)	829 (3.7)	646 (2.9)	164 (6.9)	114 (4.8)
Difference (95% CI)	0.45 (0.31-0.58)		0.82 (0.48-1.15)		2.12 (0.73-3.50)	

Abbreviation: ED, emergency department.

62.9% of participants were white. The percentage of patients with MA insurance ranged from 26.9% to 31.9% (Table 1). Average Charlson comorbidity index scores ranged from 1.12 in the 2-year cohort to 0.68 in the 10-year cohort. Health care utilization was similar across the 3 samples, with the exception that the 10-year cohort had fewer outpatient encounters (mean, 15.55 in the untreated hearing loss group and 14.91 in the no hearing loss group) compared with the 2-year cohort (mean, 18.73 in the untreated hearing loss group and 18.63 in the no hearing loss group) and the 5-year cohort (mean, 17.17 in the untreated hearing loss group and 17.13 in the no hearing loss group).

Health Care Cost

Table 2 details the postmatching unadjusted mean health care cost and resource utilization at 2-, 5-, and 10-year time points, differences between cohorts, and associated 95% CIs. Compared with no hearing loss, untreated hearing loss was associated with higher medical costs across all 3 cohorts. Unadjusted total cumulative medical costs were 25.9%, 36.9%, and 46.5% higher over the 2-, 5-, and 10-year periods for individuals with untreated hearing loss compared with that of those without hearing loss. This amounted to a mean difference of $3852 (95% CI, $3487-$4217), $11 147 (95% CI, $10 086-$12 208), and $22 434 (95% CI, $18 219-$26 648) higher total health care costs for the individuals with untreated hearing loss compared with health care costs for those without hearing loss (**Figure 1** and **Table 3**). Unadjusted OOP costs were 19.1%, 23.3%, and 34.0% higher over the 2-, 5-, and 10-year periods, respectively, for patients with untreated hearing loss than for patients with no hearing loss. Notably, among the untreated hearing loss cohort, mean costs specifically related to hearing loss were relatively minor within health care expenditures of $382, $470, and $556 at 2, 5, and 10 years, respectively. Results from adjusted multivariable models were substantively unchanged.

Health Resource Utilization

Participants with untreated hearing loss experienced significantly more inpatient stays compared with participants without hearing loss at 2 years (incident rate ratio [IRR], 1.20; 95% CI, 1.15-1.25), 5 years (IRR, 1.30; 95% CI, 1.23-1.38), and 10 years (IRR, 1.47; 95% CI,1.29-1.68) following the index date. Moreover, participants with untreated hearing loss spent more days in the hospital on average with 0.26 (95% CI, 0.20-0.33), 0.75 (95% CI, 0.58-0.92), and 2.10 (95% CI, 1.36-2.84) more days spent in the hospital over the 2-, 5-, and 10-year periods, respectively (Table 2). Similar results were found for outpatient visits. Over the 2 years following the index date, participants with untreated hearing loss had an average of 7.5 (95% CI, 7.1-7.8) more outpatient visit days. By 10 years, patients with untreated hearing loss had 52.2 (95% CI, 45.9-58.5) more outpatient visit days. Participants with untreated hearing loss had a 16.9% increased risk of an emergency department visit within 2 years (RR, 1.17; 95% CI, 1.15-1.19), a 16.8% increased risk over 5 years (RR, 1.17; 95% CI, 1.15-1.19), and a 17.0% increased risk over 10 years (RR, 1.17; 95% CI, 1.12-1.22). **Figure 2** displays the unadjusted difference in risk of 30-day readmissions. Partici-

pants with untreated hearing loss had a 29% increased risk of a 30-day hospital readmission within 2 years (RR, 1.29; 95% CI, 1.19-1.39), a 28% increase in risk over 5 years (RR, 1.28; 95% CI, 1.16-1.42), and a 44% increase in risk over 10 years (RR, 1.44; 95% CI, 1.14-1.81). Results of the adjusted multivariable analysis were similar to those of the unadjusted analyses.

Discussion

In a matched cohort study of up to 154 414 individuals in a large administrative claims database, untreated hearing loss was associated with higher health care costs, increased risk of 30-day hospital readmission, more inpatient and outpatient stays, increased risk of emergency department visits, and longer length of hospital stays at 2, 5, and 10 years following initial hearing loss diagnosis. Over a 10-year period, persons with untreated hearing loss incurred an average $22 434 more in health care costs than persons without evidence of hearing loss. Importantly, the magnitude of most of these associations appears to compound over time. These findings suggest that persons with untreated hearing loss experience significantly higher health care costs and higher health care utilization rates than those without hearing loss. To our knowledge, this is the first 10-year analysis of the association of untreated hearing loss with health care cost and utilization measures using real-world claims data.

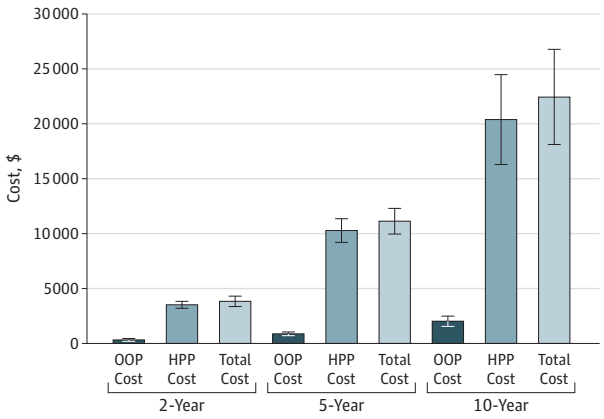
Research on health care costs related to hearing loss is sparse and varies because studies have often examined the overall societal economic influence of hearing loss on projected medical expenses and lost labor productivity rather than on the direct and indirect health care costs that were actually incurred.[16,26] On the basis of a simulated model from California Medicaid data, medical costs directly related to hearing loss diagnosis and treatment 1 year after diagnosis were $1292 per person older than 65 years with any type of hearing loss (ie, mild to functionally deaf).[27] Furthermore, according to data from the 2000 to 2010 Medical Expenditure Panel Surveys (pooled), which includes self-reported hearing loss, persons older than 65 years with hearing loss had, on average, an estimated $392 (95% CI, $277-$392) in excess medical expenditures.[8] These simulated results are relatively low compared with the present study's results.

In the only other, to our knowledge, claims-based study examining hearing loss and medical expenditures, health care costs in patients with hearing loss were substantially higher than those of patients without hearing loss.[17] Researchers conducted a matched analysis of 561 764 individuals with and without hearing loss claims (based on *ICD-9-CM* codes V41.2, V72.1x, 388.00, 388.01, 388.40, 388.43, 388.44, 388.5, 389.1x, and 389.2x) over an 18-month period using the Truven Health MarketScan database. They found that those with hearing loss spent more, on average, in health care costs ($14 165; 95% CI, $14 091-$14 239) than did persons without hearing loss ($10 629; 95% CI, $10 576-$10 681). The difference of $3536 over a 1.5-year period is relatively similar to the difference of $4764 over the 2-year period observed in the present study.

The association between hearing loss and health care service utilization remains mostly unexplored. Two studies found that hearing loss was associated with an increased risk of hospitalization based on objective audiometric measures and self-reported hospitalization rates.[9,28] In 1 study, individuals with hearing loss had a 16% (HR, 1.16; 95% CI, 1.04-1.29) and 21% (HR, 1.21; 95% CI, 1.06-1.38) greater risk of hospitalization compared with those without hearing loss.[9] In addition, the previously noted study of Medical Expenditure Panel Survey data reported increased odds of emergency department visits associated with hearing loss.[8] Our results are broadly consistent with those of these earlier studies and further suggest that hearing loss is associated with increased average length of hospital stay and risk of 30-day readmissions.

The observed associations between hearing loss and health care utilization and costs is possibly explained by the potential influence of hearing loss on cognitive (eg, particularly dementia),[3,4,29,30] physical (eg, falls),[5] and psychosocial[6,31] function. The association between hearing loss and health outcomes may be further mediated by the effects of hearing loss on patient-clinician communication.[32,33] Poor communication has previously been associated with poorer health care

Figure 1. Difference in Unadjusted Mean Patient-Paid, Plan-Paid, and Total Costs for Patients With Untreated Hearing Loss vs Patients With No Hearing Loss



Error bars represent the 95% CI. HPP indicates health plan–paid costs; OOP, out-of-pocket costs.

Table 3. Difference in Unadjusted Mean Costs for Untreated Hearing Loss vs No Hearing Loss Groups

Cohort	Out-of-Pocket Costs (95% CI), $	Health Plan–Paid Costs (95% CI), $	Total Costs (95% CI), $
2-Year	334 (310-358)	3518 (3164-3871)	3852 (3487-4217)
5-Year	876 (792-961)	10 271 (9255-11 287)	11 147 (10 086-12 208)
10-Year	2030 (1624-2436)	20 403 (16 446-24 360)	22 434 (18 219-26 648)

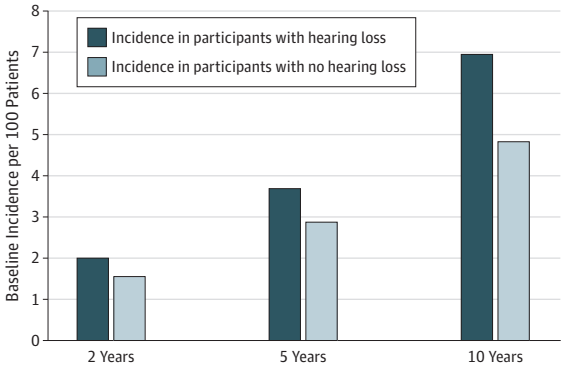
outcomes, poor treatment adherence, lower patient satisfaction, and increased health care costs.[34,35] This study supports the need for future research to understand the role of hearing loss on patient-clinician communication and the potential influence of hearing care, including devices and services, in mitigating the overall association between hearing loss and health care cost. Importantly, given the minimal risk involved and the potential reward, health care clinics and/or institutions could consider awareness and communication training for clinicians and screening programs to identify and address hearing loss as a potential communication barrier.

Limitations

This study used a large, deidentified, geographically diverse database of administrative claims that includes health encounter information for more than 125 million commercial and MA insurance enrollees in the United States. There are several limitations inherent to claims data, including its reliance on coding processes designed for billing purposes rather than research. Capturing the exposure (ie, untreated hearing loss) in a population is likely limited to individuals who feel that hearing loss is a great burden on their lifestyle, those with the means to seek and continuously maintain health care, and those with coverage for hearing services. Because of limitations in the coding and reimbursement for hearing care and hearing devices under some health plan policies, and because some individuals do not seek care for hearing loss, the group without hearing loss diagnosis may include individuals with uncoded hearing loss. However, such a bias would likely lead to underestimation of the differences between these cohorts. Furthermore, hearing device use as a covariate in these data would be unreliable given that many sales occur outside the medical claims data and that access is highly related to socioeconomic status; thus both cohorts may include individuals with treated hearing loss. Again, this resultant bias may underestimate the differences between cohorts. Finally, claims data do not account for indirect costs of untreated hearing loss, such as lost productivity and wages.

Other limitations not related to the data source exist. Though examination of ASDs suggests well-matched cohorts, after matching, a few statistically significant differences were still present between cohorts. However, these differences are to be expected based on the large sample size, and likely do not represent clinically meaningful differences between cohorts. As with most analyses of observational data, despite careful matching, it is possible that residual unmeasured confounding exists owing to a lack of randomized treatment allocation, prohibiting causal inferences from these data. Furthermore, findings may be affected by detection bias because individuals with hearing loss may have frequent interaction with the health care system. Finally, survival bias in the 10-year cohort and a lack of Medicaid and uninsured participants in the database may limit generalizability.

Figure 2. Unadjusted Difference in 30-Day Readmissions for Participants With Untreated Hearing Loss vs Participants With No Hearing Loss



Bar graph represents the unadjusted difference in baseline incidence of 30-day readmissions in the 2- (risk difference [RD], 0.45; 95% CI, 0.31-0.58), 5- (RD, 0.82; 95% CI, 0.49-1.15), and 10- (RD, 0.45; 95% CI, 0.49-1.15) year cohorts with untreated and no hearing loss.

Conclusions

The present study suggests that hearing loss is associated with increased health care expenditures and resource utilization. Notably, hearing loss was associated with an average 46.5% increase in health care costs and a 44% increase in risk of 30-day readmission over a 10-year period. Awareness of the burden that hearing loss places on individuals, insurers, and hospitals contributes to the growing evidence of hearing loss as a public health concern.

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Study concept and design: Reed, Yeh, Kravetz, Wallhagen, Lin.
Acquisition, analysis, or interpretation of data: Reed, Altan, Deal, Yeh, Kravetz, Wallhagen.
Drafting of the manuscript: Reed, Altan, Kravetz, Wallhagen.
Critical revision of the manuscript for important intellectual content: Reed, Altan, Deal, Yeh, Wallhagen, Lin.
Statistical analysis: Altan, Kravetz.
Administrative, technical, or material support: Altan, Yeh, Lin.
Study supervision: Reed, Altan, Yeh, Lin.

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