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Original Research

Risk factors for hearing impairment among adults with diabetes: The Hispanic Community Health Study/Study of Latinos (HCHS/SOL)

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ABSTRACT

Aim: The aim was to examine risk factors for hearing impairment among Hispanic/Latino adults with diabetes.
Methods: Findings are based on 3384 participants aged 18–76 years with diagnosed or previously undetected diabetes who completed audiometric testing as part of the Hispanic Community Health Study/Study of Latinos. We defined hearing impairment as the pure-tone average (PTA) >25 decibels hearing level [dB HL] of pure-tone thresholds at high frequencies (3000, 4000, 6000, and 8000 Hz) in the worse ear and defined a second hearing impairment outcome with the additional requirement of PTA >25 dB HL of low/mid-frequency (500, 1000, and 2000 Hz) thresholds in the worse ear. We identified independent associations using logistic regression.
Results: Controlling for age and Hispanic/Latino background, prevalence ratios for hearing impairment in the high plus low/mid frequencies were 1.35 (95% CI 1.07, 1.71) for current smoking, 1.64 (1.14, 2.38) for alcohol consumption (≥14 drinks/week for men or ≥ 7 drinks/week for women), and 1.29 (1.06, 1.56) for triglycerides ≥ 150 mg/dL. For high-frequency only hearing impairment, the prevalence ratio for estimated glomerular filtration rate 30–59 mL/min/1.73 m^2 was 1.23 (1.03, 1.47) adjusted for age and sex. People with family income less than $20,000 had almost twice the prevalence of hearing impairment (PR = 1.93 (1.34, 2.78)) as people with income over $40,000.
Conclusions: Current smoking, alcohol consumption, high triglycerides, and chronic kidney disease are potentially preventable correlates of hearing impairment for persons with diabetes. Low income is a marker of increased likelihood of hearing impairment.

Introduction

Hearing impairment affects two-thirds of United States (U.S.) adults with diabetes limiting their ability to communicate with others [1]. Because an association between diabetes and hearing impairment has been observed among Hispanic/Latino adults [2,3], among whom one-fifth has diabetes [4], a large number of Hispanic/Latino adults may be at risk for hearing loss and its possible longer-term sequelae such as reduced health-related quality of life [5].

Among people with diabetes, hearing loss is thought to be of sensorineural origin, but the pathophysiological mechanisms have not been determined [6,7]. Diabetic complications, including coronary heart disease and nephropathy, have been associated with hearing impairment [8,9], and some evidence suggest that dyslipidemia, specifically low high-density lipoprotein cholesterol (HDL) [8], is associated with hearing impairment among people with diabetes. Other cardiovascular disease risk factors such as hypertension [10], smoking [2], and central adiposity [2] have been associated with hearing loss, but not specifically among adults with

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diabetes. Although level of glycemia has been associated with hearing impairment in Japanese [11] and U.S. community-based studies [12], its relationship to hearing loss in persons with diabetes is inconclusive [8,13].

The Hispanic Community Health Study/Study of Latinos (HCHS/SOL), a large, population-based cohort study of Hispanic/Latino adults residing in the United States, offers a unique opportunity to examine metabolic and cardiovascular correlates of hearing impairment among people with diabetes. The aim of this study was to examine whether hearing impairment was associated with cardiovascular disease, potentially modifiable cardiovascular risk factors, diabetic complications, and indicators of diabetes severity.

Subjects

Baseline data were collected between 2008 and 2011 as part of the Hispanic Community Health Study/Study of Latinos (HCHS/SOL), a multi-site population-based cohort study, with the target population designed to be all non-institutionalized Hispanic/Latino adults aged 18–74 years from geographically-defined communities in the Bronx, Chicago, Miami, and San Diego. Study design, rationale, and implementation have been reported in detail [14,15]. Briefly, stratified two-stage probability sampling for each site was implemented to generate a diverse sample with respect to Hispanic ethnicity and socio-economic status. A subsampling protocol produced an over-representation of adults 45–74 years of age. Of the 16,415 adults aged 18–74 years at screening, 15,526 (94.6%) had sufficient baseline audiometric data to be eligible for analysis; of those, 3384 individuals had diagnosed (n = 2151) or previously undetected (n = 1233) diabetes. Institutional review boards at each participating center approved the study protocol. Participants provided informed consent.

Materials and methods

Hearing impairment

Audiometric pure-tone air conduction hearing thresholds in decibels (hearing level) [dB HL] were obtained by certified and trained technicians for each ear at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz using calibrated GSI-61clinical audiometers with TDH-50 headphones in sound-attenuating booths. The protocol was a modified Hughson–Westlake procedure in accordance with the American Speech Language Association guidelines [16].

For each individual and ear, we averaged pure-tone thresholds measured at 500, 1000, and 2000 Hz to produce a pure-tone average (PTA), as a measure of low/mid-frequency hearing sensitivity. We averaged pure-tone thresholds measured at 3000, 4000, 6000, and 8000 Hz to produce a PTA as a measure of high-frequency hearing sensitivity. By defining hearing impairment based on the PTA in the worse ear, we identified participants with impairment in at least one ear. A PTA greater than 25 dB HL defined hearing impairment of at least mild severity, consistent with previous reports on diabetes and hearing [1,8]. In this cohort, less than 1% percent of persons with diabetes had a low/mid-frequency hearing impairment without high-frequency involvement. We defined two outcomes: high-frequency hearing impairment (PTA > 25 dB HL of pure-tone thresholds measured at 3000, 4000, 6000, and 8000 Hz) and a combined high-frequency plus low/mid-frequency hearing impairment which included the subset who also had PTA > 25 dB HL of pure tone thresholds measured at 500, 1000, and 2000 Hz. We did not consider low/mid-frequency hearing impairment alone as an outcome.

Diabetes and related characteristics

Diagnosed diabetes was based on self-report of medically-diagnosed diabetes (other than during pregnancy) at baseline. Among persons with no diagnosed diabetes, previously undetected diabetes was defined by indicators of glucose metabolism: a fasting plasma glucose ≥126 mg/dl, a 2-hour postload plasma glucose ≥200 mg/dl, or HbA1c ≥6.5% [17]. Plasma glucose was measured by a hexokinase enzymatic method (Roche Diagnostics, Indianapolis, IN). Family history of diabetes was defined as a parent or sibling with diabetes. Diabetes duration was defined for those with previously diagnosed diabetes from self-reported age at diagnosis. HbA1c was assessed in whole blood using a Tosoh G7 Automated High Performance Liquid Chromatography Analyzer (Tosoh Bioscience, Inc., South San Francisco, CA). Glycemic control was defined as HbA1c <7% [18]. Reported use of glycemic medications was validated from prescriptions brought to the interview. Reported use of glycemic medications that was not validated (n = 12) resulted in a missing value.

Covariate definitions

Age, gender, Hispanic background (Mexican, Cuban, Puerto Rican, Dominican, Central American, South American), marital status, educational level, and annual family income were ascertained by questionnaire in English or Spanish. Cigarette use was categorized as never, former (among those who had smoked 100 cigarettes in a lifetime), and current. Alcohol consumption was categorized according to gender-specific number of drinks/week. Males who consumed ≥14 drinks per week and females who consumed ≥7 drinks per week were considered at high risk for developing an alcohol use disorder [19]. Former drinkers were categorized separately from non-drinkers, because former drinkers might represent people who had a past level of consumption consistent with high alcohol use disorder risk. Leisure-time noise exposure was assessed by asking whether, outside of work, the participant had been exposed to loud noise (such as from power tools or loud music) for an average of at least once per month for a year. Degree of current occupational noise exposure was assessed by asking during what proportion of work time it was necessary to speak in a raised voice to be heard.

The HCHS/SOL measured multiple cardiovascular disease risk factors: body mass index (BMI), calculated as weight in kilograms divided by height in meters squared; central adiposity, defined as a waist measurement ≥102 cm for men or ≥88 cm for women; hypertension, defined as systolic blood pressure ≥140 mm Hg, diastolic blood pressure ≥90 mm Hg, or report of current antihypertensive medication use [20]; serum HDL cholesterol (HDL) measured using a direct magnesium/dextran sulfate method (Roche Diagnostics, Indianapolis, IN) and low HDL cholesterol defined as HDL < 40 mg/dL for males and <50 mg/dL for females in accordance with the current standards of medical care [20]; serum LDL cholesterol (LDL) categorized as <100, 100–129, 130–159, and ≥160 mg/dL [21]; total serum cholesterol, measured using a cholesterol oxidase enzymatic method (Roche Diagnostics, Indianapolis, IN) and categorized with cutpoints ≥200 and ≥240 mg/dL [21]; serum triglycerides measured on a Roche Modular P Chemistry analyzer using a glycerol blanking enzymatic method (Roche Diagnostics, Indianapolis, IN) and high triglycerides defined as ≥150 mg/dL [20,21]. Two composite cholesterol measures were examined. Adverse cholesterol was defined as total serum cholesterol ≥240 mg/dL, LDL cholesterol ≥160 mg/dL, HDL cholesterol <40 mg/dL or use of lipid-lowering medication confirmed during interview. Dyslipidemia was defined as any of HDL <40 mg/dL, LDL ≥160 mg/dL, or triglycerides ≥ 150 mg/dL.

Stage of chronic kidney disease was based on estimated glomerular filtration rate [22] with cutpoints: ≥90 mL/min/1.73 m^2 (normal), 60–89 mL/min/1.73 m^2 (mild), 30–59 mL/min/1.73 m^2 (moderate), and <30 mL/min/1.73 m^2 (severe or end-stage). Coronary heart disease was assessed by participant report of whether they had been told by a medical professional that they had coronary heart disease or if they reported a history of coronary revascularization. Participants also reported whether they had cerebrovascular disease (or carotid revascularization). Intermittent claudication was determined from report of pain or discomfort when walking among those 45 years or older. Ankle brachial index (ABI), the ratio of systolic blood pressure of either the posterior tibial or the dorsalis pedis artery in the right or left ankle to that of the corresponding brachial artery, was assessed in persons aged 45–74 years. ABI cutpoints were defined as <0.90 (low), 0.90–0.99 (borderline), 1.00–1.39 (normal), and ≥1.4 (high) for each leg. Peripheral arterial disease was defined as an ankle brachial index <0.90 in either leg. High ABI was defined as an ankle brachial index ≥1.4 in either leg. Otherwise, borderline and normal ABI were based on the minimum of the left and right side [23].

Statistical methods

Age is strongly correlated with hearing impairment and with the majority of the cardiovascular disease risk factors. To control for the confounding effect of age in the bivariable analysis, we computed age-standardized prevalence estimates of high-frequency hearing impairment and high-frequency plus low/mid-frequency hearing impairment (the combined outcome) for each stratum of the independent variables. Our method was a direct standardization to the U.S. standard population from the year 2000 with the following age groups: 18–26, 27–35, 36–44, 45–49, 50–54, 55–59, 60–64, 65–69, and 70–74 years. Age eligibility for intermittent claudication and ankle brachial index began at 45 years, thus we used five year age groups beginning with 45–49 years for the age standardization. Because few participants younger than 45 years had chronic kidney disease, cardiovascular disease, or cerebrovascular disease, we used the same truncated series of age groups for the age standardization. Age-standardized prevalence estimates were stratified by socio-demographic factors, diabetic complications and characteristics (e.g. disease duration and glycemic medication use), and cardiovascular disease risk factors. We used a logit transformation to compute 95% confidence limits to maintain the range between 0 and 1; significant differences were identified by non-overlapping confidence limits. Characteristics independently associated with a greater prevalence of hearing impairment were identified from prevalence odds ratios and 95% confidence intervals estimated from multiple logistic regression models. Because prevalence odds ratios are poor estimates of risk ratios for common outcomes [24], adjusted prevalence ratios and 95% confidence limits were computed as a function of average marginal predictions [25], which allows for comparisons of predicted outcomes between groups and controls for differences in covariate distributions [26]. Analyses were performed using SAS version 9.4 (SAS corporation, Cary, NC) and SUDAAN version 11.0.0 (Research Triangle Institute, Research Triangle Park, NC) incorporating sample weights, which were calibrated to age, gender, and Hispanic/Latino background distributions from the 2010 U.S. census. These sample weights accounted for the complex sample design and the probability of differential non-response.

Results

Characteristics of the HCHS/SOL study population with diabetes are presented in Table 1. Over one-third (37.3%) of the study population was of Mexican background, 22.2% was Cuban and

Table 1
Age standardized[a] weighted prevalence of hearing impairment among people with diabetes age 18–76 years by socio-demographic characteristics (Hispanic Community Health Study/Study of Latinos, n = 3384)

Socio-demographic characteristic	Weighted %	Prevalence (95% CI) High-frequency[b] (n = 1870)	Prevalence (95% CI) High-frequency plus low/mid-frequency[c] (n = 655)
All, mean age = 53.8 years (unadjusted)	100.0	59.3 (56.6, 61.9)	21.6 (19.2, 24.1)
Hispanic/Latino group (%)			
Mexican	37.3	37.0 (33.8, 40.3)	11.3 (9.1 , 14.0)
Cuban	22.2	34.6 (30.1, 39.3)	11.4 (8.8 , 14.7)
Puerto Rican	20.2	40.6 (34.4, 47.1)	17.1 (12.9 , 22.4)
Dominican	10.1	40.4 (30.7, 50.8)	9.9 (6.0 , 16.0)
Central American	6.9	37.9 (30.7, 45.7)	9.0 (6.8 , 11.7)
South American	3.3	Not estimated[d]	Not estimated[d]
Sex (%)			
Female	54.5	32.0 (28.8, 35.3)	12.7 (10.1 , 15.8)
Male	45.5	44.8 (40.6, 49.1)	11.8 (9.9 , 14.0)
Marital status (%)			
Single	21.5	40.7 (35.7, 45.9)	13.6 (11.5 , 16.0)
Married/living with partner	52.0	36.4 (33.4, 39.5)	12.3 (10.1 , 14.9)
Separated, divorced, or widowed	26.4	34.6 (29.1, 40.6)	10.9 (8.4 , 14.0)
Educational level (%)			
Less than high school	45.6	40.8 (36.6, 45.1)	13.0 (11.2 , 15.1)
High school graduate	22.6	38.1 (32.3, 44.1)	12.4 (8.8 , 17.2)
More than high school	31.8	35.2 (31.3, 39.2)	9.9 (7.4 , 13.1)
Annual family income, $ (%)			
<20,000	54.3	39.6 (35.7, 43.8)	14.8 (12.0 , 18.1)
20,000–40,000	30.6	37.7 (33.7, 42.0)	10.9 (8.4 , 14.1)
>40,000	15.1	30.9 (25.7, 36.7)	7.1 (5.2 , 9.6)

[a] Age standardized to 18–26, 27–35, 36–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74 years.
[b] $PTA_{(3000,\ 4000,\ 6000,\ 8000\ Hz)}$ >25 dB in the worse ear.
[c] $PTA_{(3000,\ 4000,\ 6000,\ 8000\ Hz)}$ >25 dB in the worse ear and $PTA_{(500,\ 1000,\ 2000)}$ >25 dB in the worse ear.
[d] Age-standardized estimates not estimated due to insufficient data.
CI = Confidence Interval.

Table 2
Age-standardized[a] weighted prevalence of hearing impairment among people with diabetes age 18–76 years by diabetic complications and characteristics (Hispanic Community Health Study/Study of Latinos, n = 3384)

Diabetic complications and characteristics	Weighted %	Prevalence (95% CI)	
		High-frequency[b] (n = 1870)	High-frequency plus low/mid-frequency[c] (n = 655)
Chronic kidney disease (%)§			
Normal (eGFR ≥ 90 mL/min/1.73 m^2)	39.1	64.1 (60.6, 67.5)	24.0 (20.7, 27.5)
Mild (eGFR 60–89 mL/min/1.73 m^2)	48.8	61.9 (58.2, 65.5)	22.5 (19.4, 26.1)
Moderate (eGFR 30–59 mL/min/1.73 m^2)	10.9	78.6 (68.0, 86.4)	33.7 (23.4, 45.9)
Severe/End-Stage (eGFR< 30 mL/min/1.73 m^2)	1.1	84.4 (60.9, 95.0)	20.40 (10.1, 36.9)
Coronary heart disease§ (%)			
No	90.0	64.0 (61.4, 66.5)	23.5 (20.9, 26.3)
Yes	10.0	64.2 (54.6, 72.8)	24.0 (18.4, 30.6)
Cerebrovascular disease§ (%)			
No	92.3	64.1 (61.6, 66.5)	23.7 (21.0, 26.5)
Yes	7.7	68.3 (57.1, 77.7)	24.4 (17.6, 32.8)
Intermittent claudication§ (%)			
No	65.8	64.1 (61.2, 66.9)	21.8 (19.3, 24.5)
Yes	34.2	63.9 (59.3, 68.2)	27.0 (22.3, 32.2)
Ankle Brachial Index§ (%)			
Low/Peripheral arterial disease	7.8	64.2 (56.8, 71.0)	26.2 (18.6, 35.5)
Borderline	14.9	63.8 (58.2, 69.2)	27.4 (22.4, 33.1)
Normal	75.8	63.7 (60.8, 66.4)	22.2 (19.6, 25.0)
High	1.6	78.1 (60.5, 89.3)	24.6 (15.3, 37.0)
Previously diagnosed diabetes (%)			
No	37.0	37.4 (34.0, 41.0)	12.1 (9.7, 15.1)
Yes	63.0	38.4 (34.9, 42.1)	12.1 (10.0, 14.6)
Family history of diabetes (%)			
No	39.2	39.4 (35.2, 43.8)	12.2 (9.8, 15.1)
Yes	60.8	37.5 (34.2, 40.9)	12.5 (10.4, 15.0)
Among the previously diagnosed with diabetes (n = 2151)			
Diabetes duration, years			
≤ 3	33.5	41.1 (35.8, 46.6)	12.4 (8.9, 17.0)
>3–5	13.8	36.6 (31.0, 42.6)	10.1 (7.5, 13.5)
>5–10	21.4	36.4 (29.9, 43.5)	13.2 (9.3, 18.3)
>10	31.3	33.1 (27.9, 38.9)	11.2 (9.4, 13.4)
A1c<7% (%)			
No	46.7	38.1 (34.7, 41.5)	12.9 (10.7, 15.4)
Yes	53.3	38.0 (34.1, 42.0)	11.9 (9.5, 14.8)
Glycemic medication use (%)			
No	55.8	38.0 (34.6, 41.5)	11.8 (9.7, 14.4)
Yes	44.2	37.8 (34.0, 41.8)	12.4 (10.4, 14.8)

[a] Age standardized to 18–26, 27–35, 36–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74 years; chronic kidney disease, coronary heart disease, cerebrovascular disease, intermittent claudication, and ankle brachial index were age standardized to 45–49, 50–54, 55–59, 60–64, 65–69, 70–74 years.
[b] $PTA_{(3000, 4000, 6000, 8000 Hz)}$ >25 dB in the worse ear.
[c] $PTA_{(3000, 4000, 6000, 8000 Hz)}$ >25 dB in the worse ear and $PTA_{(500, 1000, 2000)}$ >25 dB in the worse ear.
§ Measured among participants 45–76 years.
CI = Confidence Interval; eGFR = estimated glomerular filtration rate.

one-fifth (20.2%) was Puerto-Rican. The mean age was 53.8 years, 54.5% were female, and over one-half (52.0%) was married or living with a partner. The majority (45.6%) had less than a high school education and over half (54.3%) had an annual family income of less than $20,000.

Table 1 gives unadjusted prevalence estimates for high-frequency and the combined (high- plus low/mid-frequency) hearing impairment and age-standardized prevalence estimates for these outcomes by socio-demographic characteristics. Among all Hispanic/Latino adults with diabetes, we observed a 59.3% (n = 1870) unadjusted prevalence of high-frequency hearing impairment and a 21.6% (n = 655) unadjusted prevalence of high-frequency plus low/mid-frequency hearing impairment (the combined outcome). Adults of Puerto Rican background had a significantly greater prevalence of high- plus low/mid-frequency hearing loss than those of Central American background. Due to the age distribution of the South American subgroup which was skewed older, age-standardized prevalence estimates could not be computed. Males with diabetes had a significantly greater prevalence of high-frequency hearing impairment than females, but this sex difference did not manifest among those with low/mid-frequency hearing impairment. We observed a strong association between family income and the combined high- plus low/mid-frequency hearing impairment. The age-standardized prevalence among those with annual family income less than $20,000 was twice the prevalence of those in the upper income category (14.8% versus 7.1%). A similar pattern was also found for educational level. We observed no prevalence difference by leisure-time or occupational noise exposure (data not shown).

Frequency differences in characteristics and complications of diabetes are provided in Table 2. Slightly less than half (48.8%) of Hispanic/Latino adults with diabetes had evidence of mild chronic kidney disease. Hispanic/Latino adults with diabetes who also had moderate chronic kidney disease had a significantly greater age-standardized prevalence of high-frequency hearing impairment than people with mild chronic kidney disease or normal kidney function. Chronic kidney disease was not associated with the combined high- plus low/mid-frequency hearing impairment. Ten percent of these Hispanic/Latino adults reported having coronary heart disease, and 7.7% reported cerebrovascular disease. Over one-third (34%) reported symptoms of intermittent claudication and 7.8% had peripheral arterial disease. We found no greater prevalence of hearing

Table 3
Age-standardized[a] weighted prevalence of hearing impairment among people with diabetes age 18–76 years by cardiovascular disease risk factors (Hispanic Community Health Study/Study of Latinos, n = 3384)

Cardiovascular disease risk factors	Weighted %	Prevalence (95% CI) High-frequency[b] (n = 1870)	High-frequency plus low/mid-frequency[c] (n = 655)
BMI (%)			
Normal	9.9	40.2 (31.7, 49.3)	11.4 (8.6, 15.0)
Overweight	33.7	34.3 (30.7, 38.0)	12.0 (9.5, 15.1)
Obese	56.4	39.7 (36.2, 43.2)	12.3 (10.1, 15.0)
Central adiposity (%)			
No	25.2	40.2 (35.2, 45.4)	11.6 (9.3, 14.4)
Yes	74.8	37.9 (34.7, 41.1)	12.4 (10.3, 14.7)
Hypertension (%)			
No	42.4	37.4 (34.3, 40.6)	10.9 (8.8, 13.6)
Yes	57.6	38.9 (33.4, 44.6)	11.7 (9.9, 13.9)
Total cholesterol, mg/dL (%)			
<200	51.3	36.0 (33.0, 39.1)	13.4 (11.2, 16.0)
200–< 240	28.0	41.1 (35.0, 47.6)	10.4 (7.8, 13.7)
≥240	20.7	40.5 (33.5, 47.9)	12.3 (8.3, 17.8)
HDL-C, mg/dL (%)			
≥ 40 (males) or ≥ 50 (females)	51.1	36.4 (33.1, 39.9)	11.2 (9.3, 13.3)
<40 (males) or <50 (females)	48.9	38.7 (35.1, 42.4)	13.0 (10.6, 15.7)
LDL-C, mg/dL (%)			
<100	30.7	35.3 (31.7, 39.1)	12.2 (9.8, 15.0)
≥100–< 130	28.8	35.4 (31.2, 39.8)	13.6 (10.4, 17.6)
≥130–< 160	24.6	43.9 (36.7, 51.3)	10.3 (8.3, 12.8)
≥160	15.8	34.3 (28.3, 41.0)	10.4 (7.9, 13.7)
Lipid-lowering medications			
No	66.3	38.6 (35.7, 41.6)	12.0 (10.2, 14.2)
Yes	33.7	34.0 (29.6, 38.6)	12.5 (9.3, 16.5)
Adverse cholesterol, includes lipid medication use[d]			
No	33.4	36.0 (32.5, 39.6)	10.7 (8.4, 13.6)
Yes	66.6	39.4 (35.8, 43.2)	12.9 (10.8, 15.4)
Triglycerides, mg/dL (%)			
<150	53.4	34.5 (31.4, 37.8)	11.1 (9.2, 13.5)
≥ 150	46.6	42.0 (37.5, 46.5)	13.6 (11.0, 16.7)
Dyslipidemia[e] (%)			
No	50.7	33.9 (31.0, 36.8)	10.4 (8.6, 12.7)
Yes	49.3	41.2 (37.4, 45.0)	14.2 (11.7, 17.1)
Cigarette use (%)			
Never	56.1	35.6 (32.3, 39.2)	12.0 (9.9, 14.3)
Former	25.4	42.0 (36.3, 47.9)	9.6 (8.1, 11.4)
Current	18.6	39.8 (34.6, 45.4)	15.9 (11.9, 21.0)
Alcohol use, drinks/week (%)			
0	23.7	38.7 (31.0, 47.1)	15.8 (10.1, 23.8)
1–13 (males) or 1–6 (females)	32.8	38.4 (34.1, 42.9)	9.0 (7.3, 11.1)
≥14 (males) or ≥7 (females)	4.4	48.4 (37.9, 59.0)	15.7 (10.6, 22.7)
Former drinker	39.1	35.7 (32.6, 38.8)	13.3 (11.1, 15.8)

[a] Age standardized to 18–26, 27–35, 36–44, 45–49, 50–54, 55–59, 60–64, 65–69, 70–74 years.
[b] $PTA_{(3000, 4000, 6000, 8000 Hz)}$ >25 dB in the worse ear.
[c] $PTA_{(3000, 4000, 6000, 8000 Hz)}$ >25 dB in the worse ear and $PTA_{(500, 1000, 2000)}$ >25 dB in the worse ear.
[d] High cholesterol defined as total cholesterol ≥ 240 mg.dL, LDL ≥160 md/dL, HDL ≤ 40 mg/dL, or lipid-lowering medication use.
[e] Dyslipidemia defined as low HDL-C, high LDL-C, or high triglycerides.
CI = Confidence Interval.

impairment among those with coronary heart disease, cerebrovascular disease, or intermittent claudication. Sixty-three percent of these Hispanic/Latino individuals were previously diagnosed with diabetes; 60.8% had a family history of diabetes. Neither prior diagnosis nor family history of diabetes was associated with hearing impairment. The age-standardized prevalence of high-frequency hearing impairment among those with high ankle-brachial index (ABI) was much greater than among those whose ABI was in the normal range, but with only 1.6% of participants in this category, power to detect a significant difference was low.

Among the 2151 adults with previously diagnosed diabetes, one-third had a diabetes duration of up to three years, and almost as many (31.3%) had diabetes of over ten years duration. No significant difference in the prevalence of hearing impairment was observed by duration of diabetes, glycemic control, or use of glycemic medications.

Table 3 provides the frequency distributions of cardiovascular disease risk factors and the age-standardized prevalence of hearing impairment stratified by these factors. Over one-half of these diabetic adults were obese and three-quarters met the criteria for central adiposity. Anthropometric measures were not associated with hearing impairment. A majority of these Hispanic/Latino adults with diabetes had hypertension and almost one half had total cholesterol ≥200 mg/dL. Almost one-half had low HDL-C and 69.3% had LDL-C ≥ 100 mg/dL. One third was using lipid-lowering medication and two thirds had adverse cholesterol accounting for the use of medications. Forty-seven percent had high triglycerides, and this group had a higher prevalence of high-frequency hearing impairment, although the confidence intervals were overlapping. Dyslipidemia, exhibited by 49.3% of these Hispanic/Latino diabetic adults, was associated with a greater prevalence of high-frequency hearing impairment. Behavioral risk factors were associated with

Table 4
Independent associations between hearing impairment and its correlates among the HCHS-SOL sample with diabetes, age 18–76 years (n = 3384)

	High-frequency[a]		High-frequency plus low/mid-frequency[b]	
	Odds Ratio (95% CI)	Prevalence ratio (95% CI)	Odds Ratio (95% CI)	Prevalence ratio (95% CI)
Cigarette use				
Never	1.00	1.00	1.00	1.00
Former	1.46 (1.09, 1.96)	1.11 (1.03, 1.21)	0.92 (0.66, 1.28)	0.94 (0.75, 1.19)
Current	1.35 (0.99, 1.85)	1.09 (1.00, 1.19)	1.61 (1.10, 2.37)	1.35 (1.07, 1.71)
Alcohol use, drinks/week				
0	1.41 (0.97, 2.05)	1.10 (0.99, 1.22)	1.42 (0.94, 2.15)	1.28 (0.96, 1.71)
1–13 (males) or 1–6 (females)	1.00	1.00	1.00	1.00
≥14 (males) or ≥7 (females)	1.64 (0.93, 2.90)	1.15 (0.99, 1.32)	2.12 (1.16, 3.86)	1.64 (1.14, 2.38)
Former drinker	1.19 (0.90, 1.59)	1.05 (0.97, 1.15)	1.67 (1.20, 2.31)	1.42 (1.13, 1.78)
Triglycerides ≥ 150 mg/dL	–	–	1.46 (1.09, 1.97)	1.29 (1.06, 1.57)
Chronic kidney disease				
Normal (eGFR ≥ 90 mL/min/1.73 m^2)	1.00	1.00	–	–
Mild (eGFR 60–89 mL/min/1.73 m^2)	1.11 (0.84, 1.46)	1.03 (0.95, 1.12)	–	–
Moderate (eGFR 30–59 mL/min/1.73 m^2)	2.28 (1.04, 5.02)	1.23 (1.04, 1.47)	–	–
Severe/End-Stage (eGFR< 30 mL/min/1.73 m^2)	3.00 (0.44, 20.45)	1.30 (0.91, 1.87)	–	–
Annual family income, $				
$20,000 or less	1.55 (1.07, 2.25)	1.14 (1.01, 1.28)	2.49 (1.57, 3.96)	1.93 (1.34, 2.78)
$20,000–$40,000	1.42 (0.98, 2.05)	1.11 (0.99, 1.25)	1.62 (1.01, 2.61)	1.44 (0.99, 2.08)
>$40,000	1.00	1.00	1.00	1.00
Educational level				
Less than high school	1.39 (1.04, 1.85)	1.10 (1.01, 1.19)	1.43 (1.0, 2.1)	1.27 (0.99, 1.63)
High school	1.06 (0.77, 1.45)	1.02 (0.93, 1.12)	0.89 (0.57, 1.39)	0.92 (0.67, 1.27)
Greater than high school	1.00	1.00	1.00	1.00

[a] $PTA_{(3000,\ 4000,\ 6000,\ 8000\ Hz)}$ >25 dB in the worse ear – controlling for age and sex.
[b] $PTA_{(3000,\ 4000,\ 6000,\ 8000\ Hz)}$ >25 dB in the worse ear and $PTA_{(500,\ 1000,\ 2000)}$ >25 dB in the worse ear -controlling for age, and Hispanic/Latino group.
CI = Confidence Interval; eGFR = estimated glomerular filtration rate.

the combined high plus low/mid-frequency hearing impairment. The 18.6% Hispanic/Latino diabetic adults who were current smokers had a significantly greater prevalence of the combined high plus low/mid-frequency hearing impairment compared to former smokers. The thirty-nine percent of people who formerly consumed alcoholic beverages had a greater prevalence of high plus low/mid-frequency hearing impairment than those who consumed alcohol at levels consistent with a low risk of alcohol use disorder (<14 drinks per week for males or <7 drinks per week for females).

Independent associations for high-frequency hearing impairment and the combined (high- plus low/mid-frequency) hearing impairment are presented as odds ratios and prevalence ratios with corresponding confidence intervals in Table 4. Current or former use of cigarettes was associated with a 9–11% greater prevalence of high-frequency hearing impairment than never smokers. Current smokers had a 35% greater prevalence of the combined outcome than never smokers. Men who consumed ≥14 alcoholic drinks/week or women who consumed ≥7 alcoholic drinks/week were considered at high risk category of developing an alcohol use disorder. People in this category had a borderline increased prevalence of high-frequency hearing impairment and a 64% greater prevalence of the high- plus low/mid- frequency hearing impairment than those who consumed alcohol at more modest levels. Triglycerides ≥150 mg/dL was not associated with high-frequency hearing impairment but was associated with a 29% greater prevalence of high-frequency plus low/mid-frequency hearing impairment. Hispanic/Latino adults with severe or end-stage chronic kidney disease had a greater prevalence but the confidence intervals did not indicate a statistically significant difference from normal (PR1.30 (0.91, 1.87)). Hispanic/Latinos with diabetes who had chronic kidney complications of moderate severity had a 23% greater prevalence of high-frequency hearing impairment than those with normal kidney function. Compared with persons whose annual family income exceeded $40,000, those with an annual family income level below $20,000 had a 14% greater prevalence of high-frequency hearing impairment (PR 1.14 (1.01, 1.28)) and a 93% greater prevalence of high- plus low/mid-frequency hearing impairment (PR 1.93 (1.34, 2.78)). Hispanic/Latino adults with less than a high school education had 18% greater and 27% greater prevalence of high-frequency and high and low/mid-frequency hearing impairment, respectively, compared to those who had some education beyond high school.

Discussion

We examined two indicators of loss of hearing sensitivity: high-frequency hearing impairment and high-frequency in addition to low/mid-frequency hearing impairment, among a cohort of Hispanic/Latino adults with diabetes and identified cigarette smoking, high levels of alcohol consumption and high triglyceride levels as potentially modifiable factors associated with hearing impairment. We also observed that participants who had lower family income and lower educational attainment were more likely to have hearing impairment. Diabetes severity, as indicated by diabetes duration, suboptimal glycemic control, and use of glycemic medication were not associated with hearing impairment.

Hyperglycemia has been longitudinally associated with incident hearing loss in general populations [11,12], but cross-sectional analyses have not supported glycemia as a correlate of hearing impairment among people with diabetes [8,9]. With well-characterized relationships between glycemic control and microvascular complications of diabetes [27], we hypothesized that we would detect an association in this large cohort of adults with diabetes, if glycemia similarly affected the highly vascularized tissue of the inner ear. We did not, however, observe an association with suboptimal glycemic control (HbA1c ≥7%) indicating glycemia may not be causally related to hearing loss among people with diabetes. Because HbA1c indicates an average level of glycemia over the previous three months, if hearing loss onset or its progression are related to glycemia of longer duration or to episodic hyper- or hypoglycemia or to glycemic variability over time, our single measure of HbA1c would not have captured this variability. Cruickshanks et al. reported an elevated risk of hearing impairment in a general population occurred at an HbA1c threshold ≥12.5% [12], thus it may be that more severe glucose dysregulation is necessary for inducing elevated audiometric thresholds. Diabetes duration and use of glycemic medications were not associated with hearing impairment in the current study, findings consistent with previous cross-sectional and longitudinal evidence [28,29].

Dalton et al. showed an association between severe diabetic nephropathy (proteinuria, renal transplant or dialysis) and hearing loss [9]. We used estimated glomerular filtration rate as the indicator of renal function and demonstrated that loss of hearing sensitivity is apparent at earlier stages of chronic kidney disease. This observation adds to recent evidence from Korea where mild chronic kidney disease (eGFR 60–90 mL/min/1.73 m^2) was associated with more severe hearing impairment [30]. Independent of diabetes, estimated glomerular filtration rate less than 60 mL/min/1.73 m^2 has been associated with hearing loss of mild severity in population-based studies conducted in Australia and Korea [10,31]. Reduced kidney function was not associated with high plus low/mid-frequency hearing loss in our study, a result that could be explained by loss from the cohort due to the mortality of people with advanced kidney disease [32].

In this relatively young cohort with diabetes, we found no associations of hearing impairment with coronary heart disease or cerebrovascular disease. As previously reported, current smoking was not associated with hearing impairment in the HCHS/SOL general population after adjusting for diabetes [2], yet when we defined hearing impairment in terms of both a high-frequency and a low/mid-frequency component, we found a greater prevalence among people with diabetes who smoke. Smoking has been linked to prevalent and incident hearing loss, among general populations [12,33], but the associations are not necessarily strong [34]. Our observations add to evidence that the toxic effects of smoking lead to hearing loss. Similarly, we documented a positive association between high triglycerides and high plus low/mid-frequency hearing impairment, evidence that agree with other cross-sectional studies [35,36]. The identification of an association between hearing impairment and atherogenic risk factors, such as smoking and triglycerides, lends credence to a vascular etiology for hearing loss. Thickened capillaries observed within the stria vascularis [37] and sclerosis of the internal auditory artery [38] among people known to have had diabetes provide pathophysiologic evidence of injury to the cochlea, the inner ear organ responsible for translating sound waves to nerve impulses for transmission to the brain. We infer from our findings that smoking and dyslipidemia may be markers of a progressive, atherosclerotic mechanism, possibly related to lipid oxidation, that damages the cochlea and reduces hearing sensitivity.

Moderate alcohol use has been associated with lower prevalence of hearing loss [39]. We found that alcohol consumption at higher levels is positively associated with hearing impairment consistent with recent evidence from a nationally representative sample of Korean adults [40]. With our large sample of diabetic adults, we were able to separate former drinkers from lifelong abstainers; we found a J-shaped association between alcohol consumption and hearing loss similar to what has been consistently reported between alcohol and heart disease [41]. This so-called cardioprotective effect of moderate alcohol consumption is thought to be related to decreased lipid oxidation. The association we report persists after controlling for dyslipidemia and may reflect a different mechanism.

We found family income and educational level were independently and negatively associated with both high-frequency and high plus low/mid-frequency hearing impairment. A previous examination of risk factors for hearing impairment among adults with diabetes found those with lower education had a higher prevalence of hearing loss but the association was not independent of diabetic complications including coronary heart disease, peripheral neuropathy, and reported poor health [8]. Rather, the social patterning observed in the present analysis is consistent with a lower likelihood of hearing impairment as education and income level increase among the general population in the Hispanic communities from which the sample was drawn [2]. More research is needed to determine what factors predispose people of lower socio-economic position to greater risk of hearing impairment [42].

Our analysis has limitations including the inability to distinguish type 1 from type 2 diabetes and no available data with which to test a neuropathic mechanism for hearing loss. Inferences regarding the temporal relationships between the covariates and hearing impairment are limited by the cross-sectional nature of the data. We undoubtedly have some errors in measurement. Cigarette and alcohol use are by self-report and are subject to recall bias, a bias unlikely to be differential with respect to hearing impairment. Last, findings from this cohort of community-dwelling Hispanic/Latinos within specific geographically-defined areas may not be generalizable to other demographic groups, including other Hispanic/Latino populations, within or outside the U.S.

Hearing impairment was experienced by 59.3% of these Hispanic/Latino adults with diabetes. Those who have lower family income and lower education are more likely to be affected. Hearing impairment was detected among people with earlier stages of diabetic nephropathy than previously documented. Our findings suggest an emphasis on smoking cessation, reduction of high levels of alcohol consumption, and lipid management may offer opportunities to lower the public health burden of hearing impairment among Hispanic/Latinos with diabetes.

Conflict of interest

KJC receives funding from the National Institutes of Health. The other authors declare they have no conflicts of interest.

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