



The Hearing Function and Ambulatory Blood Pressure in Older Adults

Humberto Yévenes-Briones, PhD¹ ,
Francisco Félix Caballero, PhD¹ , Ellen A. Struijk, PhD¹ ,
Daniela B. Estrada-deLeón, PhD¹ ,
Jorge Rey-Martinez, MD, PhD² ,
Fernando Rodríguez-Artalejo, MD, PhD^{1,3} ,
José R. Banegas, MD, PhD¹ , and
Esther Lopez-Garcia, PhD^{1,3} 

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Abstract

Objective. To examine the association between hearing function, assessed with pure-tone average (PTA) of air conduction thresholds, and 24-hour ambulatory blood pressure (BP) in older adults.

Study Design. Cross-sectional study.

Setting. A total of 1404 community-dwelling individuals aged ≥65 years from the Seniors-ENRICA cohort were examined.

Methods. Hearing loss was defined as PTA > 40-AudCal hearing loss decibels (dB-aHL) in the better ear for standard frequency (0.5, 1, and 2 kHz), speech frequency (0.5, 1, 2, and 4 kHz), and high frequency (3, 4, and 8 kHz). Circadian BP patterns were calculated as the percentage decline in systolic BP during the night, and participants were classified as dipper, nondipper, and riser. Ambulatory hypertension was defined as BP ≥ 130/80 mm Hg (24 hour), ≥ 135/85 (daytime), and ≥ 120/70 (nighttime) or on antihypertensive treatment. Analyses were performed with linear- and logistic-regression models adjusted for the main confounders.

Results. In multivariable analyses, the PTA was associated with higher nighttime systolic BP [β coefficient per 20 dB-aHL increment standard frequency (95% confidence interval, CI): 2.41 mm Hg (0.87, 3.95); β (95% CI) per 20 dB-aHL increment speech frequency 2.17 mm Hg (0.70, 3.64)]. Among hypertensive patients, hearing loss at standard and high-frequency PTA was associated with the riser BP pattern [odds ratio: 2.01 (95% CI, 1.03–3.93) and 1.45 (1.00–2.09), respectively]; also, hearing loss at standard PTA was linked to uncontrolled nighttime BP [1.81 (1.01–3.24)].

Conclusion. PTA was associated with higher nighttime BP, and hearing loss with a riser BP pattern and uncontrolled BP in older hypertensives.

Keywords

24-hour blood pressure, BP control, hearing loss, hypertension

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Hypertension affects more than 1280 million people worldwide¹ and is a main risk factor for disability-adjusted life years and mortality.² The prevalence of hypertension worldwide has doubled in low and middle-income regions in the last 3 decades.³ Although in high-income countries this prevalence increase has not been observed, hypertension control has recently declined in the United States, and little improvement has been observed in recent years for many other countries.^{3,4} Prevention and management of hypertension is essential for healthy aging, and European and American hypertension clinical practice guidelines^{5,6} have periodically been released, with many considerations on pathological conditions associated with hypertension. However, these guidelines have not considered sensory limitations.

The relationship between hearing loss and blood pressure (BP) is unclear.^{7,8} On the one hand, it has been observed that increased systolic BP (SBP), diastolic BP (DBP), and hypertension were associated with hearing loss and impairment of auditory processing.^{9–13} On the contrary, other studies did not observe associations between hypertension and hearing loss,^{7,8,14,15} nor with cochlear deterioration.¹⁶

¹Department of Preventive Medicine and Public Health, School of Medicine, Universidad Autónoma de Madrid, CIBERESP (CIBER of Epidemiology and Public Health), Madrid, Spain

²Osakidetza Basque Health Service, Biodonostia Health Research Institute, San Sebastián-Donostia, Spain

³IMDEA-Food Institute, CEI UAM+CSIC, Madrid, Spain

Corresponding Author:

Humberto Yévenes-Briones, PhD, Department of Preventive Medicine and Public Health, School of Medicine, Universidad Autónoma de Madrid, C/Arzobispo Morcillo, s/n, 28029 Madrid, Spain.
Email: humberto.yevenes@uam.es

Some age-associated conditions, including disability,^{17,18} frailty,^{19,20} and dementia,^{21,22} have been associated with both hearing loss and hypertension, suggesting that they may have shared mechanisms. The pure-tone average (PTA) of air conduction thresholds is the gold standard measure for assessing hearing function in clinical and epidemiological settings.²³ Simultaneously, ambulatory BP monitoring (ABPM) is a better measure of the “true” (average) BP than an isolated clinical BP measurement.²⁴ Also, ABPM-derived parameters such as the night-to-day ratio of BP, which allow determining different BP patterns among hypertensive patients such as dipper, nondipper, or riser, have emerged as important predictors of cardiovascular disease, especially among older individuals.²⁵ A better characterization of the relationship between hearing loss and BP, considering patterns and uncontrolled hypertension with objective and more valid measures will probably allow to improve the interpretation of the possible association. Therefore, our objective was to examine the association between the PTA of air-conduction hearing thresholds in a wide range of frequencies and BP and BP control during a 24-hour period in hypertensive participants.

Methods

Study Design and Participants

The Seniors-ENRICA-2 study is a cohort of 3273 community-dwelling individuals aged ≥ 65 years, residing in Madrid and 4 large surrounding cities, and holding a national health card. Participants were recruited from

2015 to 2017 using random sampling stratified by sex and district. In 2019, a new data collection was conducted, updating baseline information and adding new measures, including the assessment of hearing function and ABPM. The study procedures, instruments, and questionnaires were like those used in the Seniors-ENRICA-1 study.^{19,26} Study participants provided informed written consent, and the clinical research ethics committee of La Paz University Hospital in Madrid approved the study.

A total of 1894 participants provided data in 2019. We selected those who had a hearing assessment, ABPM, and information for the covariates of interest, so the analytical sample was 1404 participants (**Figure 1**). Participants who refused audiological examination were older, had a higher prevalence of sedentary behavior, and had more comorbidities than those who agreed to be examined.

Hearing Assessment

Hearing was assessed with AudCal, an application for iPhone and iPad that determines air conduction thresholds at frequencies 0.5, 1, 2, 3, 4, and 8 kHz in both ears. The evaluation started with the frequency of 1 kHz at 0 AudCal hearing loss decibels (dB-aHL), increasing the sound in 5 dB-aHL intervals until the participant heard the stimulus. After the hearing threshold was identified at that frequency, the other frequencies were evaluated in 1 ear. The same procedure was used in the other ear.

The evaluation was carried out at the home of the participants, face-to-face with the trained evaluator in a quiet environment, with the mobile screen visible only to the evaluator. The headphones used were wired in-ear

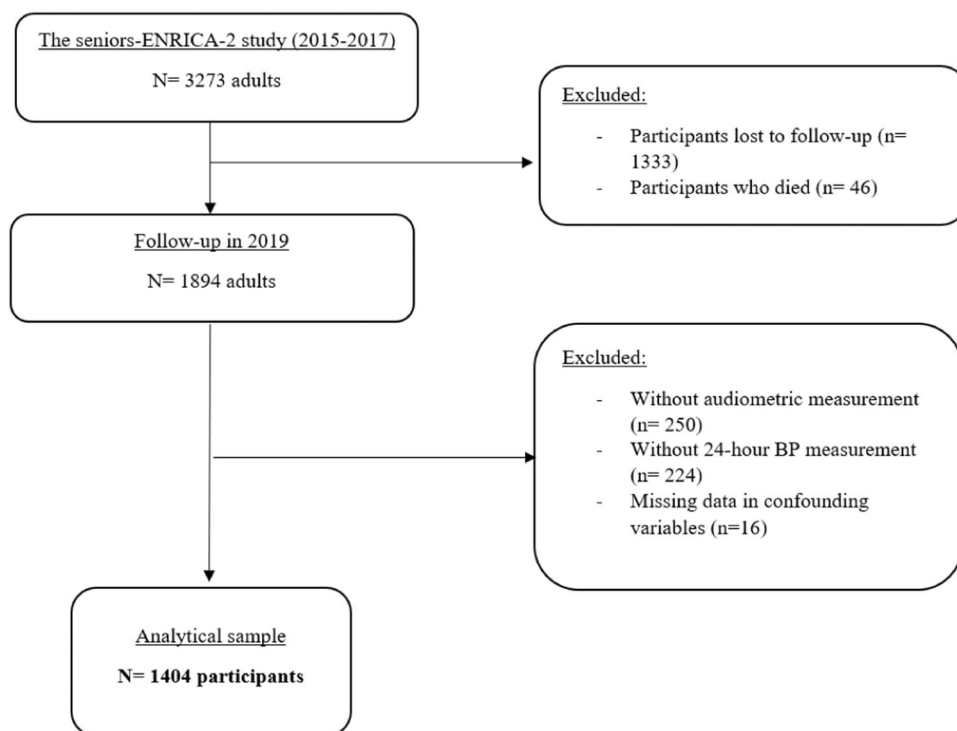


Figure 1. Participants flowchart. BP, blood pressure.

headphones, distributed in iPhone packages (EarPods). The earbuds were fitted under the standard headphones. AudCal has shown high sensitivity and specificity in both ears with respect to the standard test (tonal audiometry in a soundproof booth) and has shown a high intraclass correlation ($r = .93$) with the standard evaluation using an International Organization for Standardization standard audiometer and standard headphones in the Spanish population.²⁷ Based on this validation study evidence we also define for this research the *dB-aHL* term, to clarify that the hearing thresholds have been measured for this study with a sound magnitude that experimentally has a high correlation with the clinical gold standard hearing loss decibels magnitude.²⁷

We calculated 3 PTAs according to different frequency ranges: (1) standard PTA (0.5, 1, and 2 kHz); (2) speech frequency PTA (0.5, 1, 2, and 4 kHz); and high-frequency PTA (3, 4, and 8 kHz), and defined hearing loss as having a PTA > 40 dB-aHL, which corresponds to a moderate to profound hearing loss, according to the American Speech-Language-Hearing Association.²⁸ We considered the hearing threshold of the better ear, following the World Health Organization recommendations.²⁹

BP Measurement

We used the Mobil-O-Graph 24-hour PWA monitor (IEM; Mediscan/España) to measure ABPM, which recorded BP for 24 hours at 20-minute intervals during the day and 30-minute intervals at night. The registries were obtained with the participants doing their usual activities on preferably working days and advising them to keep the arm extended and immobile at the time of cuff inflation. The monitor was removed by study personnel the next day.

Registries were considered valid when they met these pre-established criteria: (1) 24-hour duration and at least 70% of successful recordings during the daytime and nighttime periods; or (2) at least 20 recordings during the daytime and 7 recordings during the nighttime. The daytime and nighttime periods of each participant were defined through self-reported bedtime and wake-up times.³⁰

Night-to-day ratios for SBP and DBP were calculated, and circadian patterns were defined by calculating the percentage decline in SBP during the night, using the formula: $[(\text{daytime SBP} - \text{night-time SBP}) / \text{daytime SBP}] \times 100$. According to this, participants were classified as nondippers when SBP decline was <10%, dipper when SBP decline was between $\geq 10\%$ and $\leq 20\%$, and riser when nighttime SBP was higher than daytime SBP.²⁵ We also defined ambulatory hypertension as a 24-hour average BP $\geq 130/80$ mm Hg or being under antihypertensive treatment, which is an agreed BP threshold for the definition of ABPM-based hypertension in adults.³¹

Other Variables

Participants reported their gender, age, educational level, and consumption of tobacco, alcohol, and coffee. Diet

quality was defined as adherence to the Mediterranean dietary pattern, evaluated with the Mediterranean diet adherence screener (MEDAS), whose score ranges from 0 (lowest adherence) to 14 (highest adherence).³² Physical activity (as equivalent metabolic tasks per h/wk) was assessed with an accelerometer (ActiGraph GT9X; ActiGraph LLC) for 7 consecutive days.³³ We measured weight and height under standardized conditions; body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. The number of daily hours of sleep was obtained with the question: "How many hours do you usually sleep per day?". The question included sleep at night and during the day.³⁴ Sedentary behavior was estimated from the reported time spent watching TV (h/wk). In addition, diabetes was defined as fasting glucose levels ≥ 126 mg/dL (to convert to millimoles per liter, multiplied by 0.0555) or the use of antidiabetic medication. Participants reported if they had received a physician-based diagnosis of cancer and cardiovascular diseases (myocardial infarction, stroke, heart failure, or atrial fibrillation). We also evaluated the cognitive status of the participants with the Mini-Mental State Examination (MMSE), in which orientation, memory, fixation, calculation, and language construction were measured; the score range is 0 to 30, and a higher figure reflects better cognitive performance.³⁵ Lastly, exposure to a noisy workplace or loud music exposure, use of a hearing aid, and the presence of tinnitus were reported by the participants.

Statistical Analysis

We assessed differences in sociodemographic characteristics, lifestyle, comorbidity, and cognitive function across categories of hearing status using the unpaired Student's *t* test and the χ^2 test for continuous or categorical variables, respectively. Then, we used linear regression models to estimate nonstandardized β coefficients and their 95% confidence interval (CI) for the association between PTA and BP. Three models were built to adjust for potential confounders: model 1 was adjusted for age and gender; model 2 was additionally adjusted for educational level (primary or less, secondary and university), smoking status (current smoker, former smoker, never smoker), current alcohol drinking (yes/no), habitual coffee consumption (yes/no), adherence to the MEDAS (tertiles of the score), physical activity (tertiles of METs-h/wk), BMI (tertiles of kg/m²), hours of daily sleep (tertiles, h/d), and time viewing television (tertiles, h/wk); model 3 was further adjusted for diabetes, cancer, cardiovascular disease, cognitive status (tertiles of MMSE score), having a noisy workplace (yes/no), exposure to loud music (yes/no), use of hearing aid (yes/no), and presence of tinnitus (yes/no). We also used adjusted logistic regression models to calculate odds ratios (ORs) for the association between moderate to profound hearing loss and circadian BP patterns and uncontrolled hypertension, considering

In this study of community-dwelling older adults, standard and speech frequencies of PTA were associated with higher nighttime BP, independently of sociodemographic and

Table 1. Prevalence of Hypertension in Study Participants According to Hearing Loss, by Gender

	All participants			Males			Females		
	Standard PTA (0.5, 1, 2 kHz)	Speech frequency PTA (0.5, 1, 2, 4 kHz)	High-frequency PTA (3, 4, 8 kHz)	Standard PTA (0.5, 1, 2 kHz)	Speech frequency PTA (0.5, 1, 2, 4 kHz)	High-frequency PTA (3, 4, 8 kHz)	Standard PTA (0.5, 1, 2 kHz)	Speech frequency PTA (0.5, 1, 2, 4 kHz)	High-frequency PTA (3, 4, 8 kHz)
24 h hypertension, ^b % (n = 1015)	71.7	76.2	76.0	65.2	74.0	75.8	80.4	79.2	76.2
Daytime hypertension, ^c % (n = 1044)	76.7	79.6	77.5	71.0	77.9	77.0	84.3	81.8	78.1
Nighttime hypertension, ^d % (n = 1095)	78.3	79.6	80.7	73.9	78.9	82.3	84.3	80.5	78.5

[†]Defined as nighttime BP $\geq 120/70$ mm Hg or being under antihypertensive treatment.

Table 2. Participants' Characteristics at Different Pure-Tone Average (PTA) Frequency Ranges

	Hearing status ^a					
	Standard PTA (0.5, 1, 2 kHz)		Speech frequency (PTA 0.5, 1, 2, 4 kHz)		High-frequency (PTA 3, 4, 8 kHz)	
	Normal	Hearing loss	Normal	Hearing loss	Normal	Hearing loss
N	1284	120	1223	181	783	621
Female, %	48.0	42.5	48.2	42.5	51.3	42.7
Age, y	73.4 ± 4.1	76.5 ± 4.7	73.3 ± 4.1	76.1 ± 4.8	72.6 ± 3.8	75.0 ± 4.4
Educational level; primary or less, %	59.3	64.2	59.9	58.6	58.1	61.7
Current smoker, %	8.3	5.8	8.5	5.0	8.2	7.9
Current alcohol drinker, %	34.0	31.7	33.7	34.3	34.6	32.7
Habitual coffee consumption, %	83.6	82.5	83.7	82.9	83.3	83.9
Adherence to the MEDAS score, points	7.2 ± 1.7	6.9 ± 1.6	7.3 ± 1.7	6.9 ± 1.6	7.3 ± 1.7	7.1 ± 1.7
Physical activity, METs-h/wk	23.8 ± 8.7	21.9 ± 9.4	24.0 ± 8.7	21.1 ± 9.1	24.7 ± 8.5	22.2 ± 8.9
Body mass index, kg/m ²	27.5 ± 4.3	27.8 ± 4.9	27.5 ± 4.2	28.0 ± 4.8	27.4 ± 4.4	27.7 ± 4.2
Hours of daily sleep	6.7 ± 1.3	6.6 ± 1.4	6.7 ± 1.3	6.6 ± 1.4	6.7 ± 1.2	6.7 ± 1.4
Television viewing, h/wk	24.4 ± 12.7	28.2 ± 15.3	24.4 ± 12.5	27.0 ± 15.2	24.1 ± 12.4	25.6 ± 13.5
Chronic diseases						
Diabetes, %	22.3	27.5	21.8	28.7	19.9	26.3
Cancer, %	10.7	11.7	10.8	10.5	11.0	10.5
Cardiovascular disease, ^b %	6.9	8.3	6.5	9.9	6.1	8.1
MMSE score	28.3 ± 1.8	27.8 ± 2.1	28.3 ± 1.8	27.9 ± 2.1	28.4 ± 1.8	28.1 ± 1.9
Hearing variables						
Noisy workplace, %	24.2	30.0	24.2	28.2	23.6	26.1
Loud music exposure, %	6.2	5.0	6.4	4.4	7.8	4.0
Use of hearing aid, %	4.1	60.8	3.2	48.1	1.4	18.5
Tinnitus, %	18.9	26.7	18.9	24.3	18.5	20.9

N = 1404.

Values are means ± SD unless otherwise indicated.

Abbreviations: dB-aHL, AudCal hearing loss decibels; MEDAS, Mediterranean diet adherence screener; METs, metabolic equivalent tasks; MMSE, Mini-Mental State Examination.

^aDefined as normal (PTA ≤ 40 dB-aHL) and as moderate to profound hearing loss (PTA > 40 dB-aHL) in the better ear.^bIncludes: heart attack, stroke, heart failure, and atrial fibrillation.

lifestyle characteristics, comorbidity, cognitive impairment, and hearing-related variables. Furthermore, among hypertensive participants, hearing loss at standard and speech frequencies was associated with a riser pattern, and hearing loss at standard PTA, with uncontrolled nighttime hypertension.

In this population, the prevalence of 24-hour hypertension ranged between 71.7% and 76.2%, depending on the PTA used to define hearing loss. These figures were higher than those reported by Lin et al¹⁴ using NHANES data, who found a 60.4% prevalence of hypertension in participants with hearing loss. These discrepancies could be explained by differences between the US and Spanish populations, different methods to measure BP, and different study times. In any case, the magnitude of ambulatory hypertension was always huge.

We found no association between PTA and 24-hour or daytime BP. This is consistent with a cross-sectional study

by Umesawa et al⁷ who found no association between hypertension (based on clinic BP measurement) and moderate to severe hearing loss among Japanese workers, and with Mick et al¹⁵ who did not find a cross-sectional association between hypertension (again clinic BP) and PTA at frequencies from 1000 to 4000 Hz in middle-aged and older Canadian adults. Lastly, another study with data from the Korea National Health and Nutrition Examination Surveys did not observe an association between hearing loss and hypertension in participants with normal otoscopy.⁸ In contrast, Ramage-Morin et al⁹ reported an association between hypertension and hearing health problems in adults between the ages of 19 and 79; however, the definition also included tinnitus; when tinnitus was excluded, the association was not observed. Furthermore, Rigtters et al¹⁰ using data from the Population-Based Rotterdam Study, evidenced an association between SBP and hearing loss (0.03 dB loss

Table 3. β Regression Coefficients (95% Confidence Interval) for the Association Between Pure-Total Average (PTA) (Per 20 dB-aHL Increment) and Ambulatory Blood Pressure

Blood pressure, mm Hg	Frequency ranges		
	Standard PTA (0.5, 1, 2 kHz)	Speech frequency PTA (0.5, 2, 4 kHz)	High-frequency PTA (3, 4, 8 kHz)
24-h systolic			
Model 1	1.02 (−0.12, 2.15)	0.86 (−0.23, 1.96)	0.35 (−0.46, 1.17)
Model 2	1.03 (−0.10, 2.16)	0.83 (−0.26, 1.90)	0.24 (−0.57, 1.06)
Model 3	1.01 (−0.31, 2.33)	0.75 (−0.51, 2.01)	0.08 (−0.80, 0.97)
24-h diastolic			
Model 1	0.29 (−0.41, 0.99)	0.33 (−0.34, 1.00)	0.17 (−0.33, 0.67)
Model 2	0.35 (−0.35, 1.05)	0.35 (−0.32, 1.02)	0.12 (−0.38, 0.62)
Model 3	0.42 (−0.40, 1.24)	0.44 (−0.34, 1.21)	0.13 (−0.42, 0.68)
Daytime systolic			
Model 1	0.64 (−0.54, 1.81)	0.47 (−0.66, 1.59)	0.09 (−0.76, 0.93)
Model 2	0.69 (−0.47, 1.85)	0.47 (−0.65, 1.58)	0.00 (−0.83, 0.83)
Model 3	0.59 (−0.77, 1.95)	0.31 (−0.99, 1.60)	−0.18 (−1.09, 0.73)
Daytime diastolic			
Model 1	−0.05 (−0.78, 0.69)	0.00 (−0.70, 0.70)	−0.04 (−0.56, 0.49)
Model 2	0.04 (−0.70, 0.77)	0.04 (−0.66, 0.74)	−0.07 (−0.60, 0.45)
Model 3	0.09 (−0.77, 0.95)	0.11 (−0.71, 0.92)	−0.06 (−0.63, 0.52)
Nighttime systolic			
Model 1	2.28 (0.95, 3.62)	2.15 (0.88, 3.43)	1.20 (0.25, 2.16)
Model 2	2.18 (0.86, 3.50)	2.00 (0.74, 3.27)	1.02 (0.07, 1.97)
Model 3	2.41 (0.87, 3.95)	2.17 (0.70, 3.64)	0.89 (−0.14, 1.93)
Nighttime diastolic			
Model 1	1.37 (0.53, 2.19)	1.42 (0.64, 2.21)	0.86 (0.27, 1.45)
Model 2	1.36 (0.54, 2.18)	1.38 (0.59, 2.17)	0.78 (0.19, 1.37)
Model 3	1.56 (0.60, 2.52)	1.60 (0.68, 2.52)	0.78 (0.14, 1.43)

p values less than .05 were considered statistically significant in bold.

N = 1404.

PTA in the better ear.

Model 1: Adjusted for age and gender.

Model 2: Additionally, adjusted for educational level (primary or less, secondary and university), smoking status (current smoker, former smoker, never smoker), current alcohol drinker (yes, no), habitual coffee consumption (yes/no), MEDAS (tertiles of score), physical activity (tertiles of METs-h/wk, BMI (tertiles of kg/m²), sleep (tertiles, h/d), and time viewing television (tertiles, h/wk).

Model 3: Additionally, adjusted for diabetes, cancer, cardiovascular diseases, cognitive status (tertiles of MMSE score), noisy workplace (yes/no), loud music exposure (yes/no), use of hearing aid (yes/no), and tinnitus (yes/no).

Abbreviations: dB-aHL, AudCal hearing loss decibels; MEDAS, Mediterranean diet adherence screener; METs, metabolic equivalent tasks; MMSE, Mini-Mental State Examination.

per increase in 1 mm Hg of BP). In another study with an African-American population, SBP and hypertension were statistically predictive of auditory processing impairment.¹¹ Additionally, Helzner et al¹³ observed no correlation between hearing loss and hypertension in adults between 73 and 84 years old but observed an association between a 10 mm Hg increase in SBP and hearing loss in a subsample (white men). Also, an association between hypertension and SBP and hearing loss in low frequencies has been observed in women.¹²

We found an association between PTA and nighttime BP, which can only be detected with ABPM, and we also observed that PTA was more strongly associated with nocturnal SBP. However, in fully adjusted models, the association between high-frequency PTA and nocturnal SBP was not observed, probably because the

chronic diseases adjusted for in model 3 are linked to inflammatory mechanisms associated with both high-frequency hearing loss and hypertension,^{36,37} possibly partly mediating the association. To the best of our knowledge, this is the first study to examine this association. Previous studies have found that BP at nighttime increased the risk of mortality³⁸ and cardiovascular events³⁹; therefore, the fact that hearing loss is associated with higher BP at nighttime although not at daytime is highly relevant, since nighttime BP is generally reported as a better predictor of cardiovascular and all-cause mortality, coronary disease, and stroke than daytime BP, in both sexes and over a broad age range.⁴⁰ Changes in nighttime SBP of about 2.2 to 2.4 mm Hg per 20 dB-aHL standard PTA increment could have clinical importance. In fact, the magnitude of this association is

Table 4. Odds Ratios (95% Confidence Interval) for the Association Between Moderate-to-Profound Hearing Loss and BP Patterns Among Hypertensive Participants

	Hearing loss, standard (PTA 0.5, 1, 2 kHz)	Hearing loss, speech frequency (PTA 0.5, 1, 2, 4 kHz)	Hearing loss, high-frequency (PTA 3, 4, 8 kHz)
N	86	138	472
Dipper pattern ^a			
Number of cases	28	45	134
Model 1	1.10 (0.68, 1.79)	1.10 (0.74, 1.63)	0.75 (0.57, 0.99)
Model 2	1.19 (0.73, 1.95)	1.16 (0.78, 1.73)	0.75 (0.57, 0.99)
Model 3	1.09 (0.61, 1.95)	1.10 (0.69, 1.75)	0.72 (0.54, 0.97)
Nondipper pattern ^b			
Number of cases	34	57	222
Model 1	0.76 (0.48, 1.21)	0.80 (0.55, 1.17)	1.08 (0.83, 1.40)
Model 2	0.72 (0.45, 1.16)	0.78 (0.53, 1.14)	1.10 (0.84, 1.42)
Model 3	0.63 (0.36, 1.09)	0.71 (0.46, 1.10)	1.10 (0.84, 1.44)
Riser pattern ^c			
Number of cases	22	32	95
Model 1	1.55 (0.91, 2.65)	1.43 (0.91, 2.24)	1.43 (1.02, 2.02)
Model 2	1.47 (0.85, 2.55)	1.35 (0.85, 2.16)	1.38 (0.97, 1.96)
Model 3	2.01 (1.03, 3.93)	1.70 (0.99, 2.93)	1.45 (1.00, 2.09)

p values less than .05 were considered statistically significant in bold.

N = 1015.

Hearing loss is defined as PTA > 40 dB-aHL in the better ear.

Model 1: Adjusted for age and gender.

Model 2: Additionally, adjusted for educational level (primary or less, secondary and university), smoking status (current smoker, former smoker, never smoker), current alcohol drinker (yes, no), habitual coffee consumption (yes/no), MEDAS (tertiles of score), physical activity (tertiles of METs-h/wk, BMI (tertiles of kg/m²), sleep (tertiles, h/d), and time viewing television (tertiles, h/wk).

Model 3: Additionally, adjusted for diabetes, cancer, cardiovascular diseases, cognitive status (tertiles of MMSE score), noisy workplace (yes/no), loud music exposure (yes/no), use of hearing aid (yes/no) and tinnitus (yes/no).

Abbreviations: BP, blood pressure; dB-aHL, AudCal hearing loss decibels; MEDAS, Mediterranean diet adherence screener; METs, metabolic equivalent tasks; MMSE, Mini-Mental State Examination; PTA, pure-total average.

^aDefined as difference between daytime systolic BP and nighttime systolic between BP ≥10% and ≤20%.

^bDefined as difference between daytime systolic BP and nighttime systolic BP < 10%.

^cDefined as nighttime systolic BP greater than daytime systolic BP.

comparable to that of some single lifestyle interventions on nocturnal fall in mean BP.⁴¹

Our results on the association of hearing loss at standard and high frequencies with the riser BP pattern among hypertensive individuals are also of potential importance because a riser pattern is associated with a higher risk of cognitive impairment among patients with heart failure⁴²; also, this BP pattern is more common in older⁴³ and frail people⁴⁴ and is associated with a higher risk of cardiovascular events.⁴⁵ Our finding of an association between hearing loss at standard frequency and nighttime uncontrolled hypertension seems novel, and it is in concordance with our other findings on the association between hearing loss and nighttime BP.

Aging, exposure to high-intensity noise, treatment with ototoxic drugs, and gene mutations are the main risk factors for hearing loss.⁴⁶ Although the mechanisms that explain hearing loss are not fully elucidated, inflammation could play a role.⁴⁷ Melatonin treatment in animal models significantly improves hearing by reducing the expression of inflammatory cytokines.⁴⁸ In addition, in older people, inflammatory markers, including C-reactive protein and

white blood cell counts, could contribute to hearing impairment.^{49,50} Another evidence supporting this mechanism is that anti-inflammatory corticosteroids have shown efficacy in the treatment of sudden sensorineural hearing loss. Furthermore, the neutrophil-to-lymphocyte ratio and the monocyte-to-lymphocyte ratio have been linked to hearing loss in middle-aged adults, reaffirming the plausibility of this mechanism.⁵¹ On the other hand, inflammation is increasingly recognized within the pathogenesis of hypertension.^{52,53} Also, in longitudinal epidemiological studies, inflammatory markers are associated with an increased risk of hypertension.⁵⁴ The role that inflammation plays in both hearing loss and hypertension, added to the fact that both health conditions are associated with other diseases where inflammation is one of the pathogenic mechanisms,^{19,22} suggests that this may well be the link that supports our results.

Finally, the differences between the associations depending on the frequency range of hearing loss and the different patterns and untreated hypertension could be explained in part by the critical role of microvascularization, since there is a decrease in flow in the capillaries

Table 5. Odds Ratios (95% Confidence Interval) for the Association Between Moderate to Profound Hearing Loss and Uncontrolled Hypertension Among Hypertensive Participants

	Hearing loss, standard (PTA 0.5, 1, 2 kHz)	Hearing loss, speech frequency (PTA 0.5, 1, 2, 4 kHz)	Hearing loss, high-frequency (PTA 3, 4, 8 kHz)
N	86	138	472
Uncontrolled 24-h hypertension ^a			
Number of cases	19	29	77
Model 1	1.90 (1.08, 3.34)	1.78 (1.12, 2.87)	1.32 (0.92, 1.90)
Model 2	1.94 (1.09, 3.46)	1.74 (1.08, 2.82)	1.27 (0.88, 1.84)
Model 3	1.87 (0.93, 3.72)	1.73 (0.99, 3.02)	1.21 (0.83, 1.79)
Uncontrolled daytime hypertension ^b			
Number of cases	12	17	49
Model 1	1.64 (0.84, 3.22)	1.35 (0.76, 2.40)	1.04 (0.68, 1.59)
Model 2	1.74 (0.87, 3.48)	1.33 (0.74, 2.39)	0.99 (0.64, 1.52)
Model 3	1.68 (0.74, 3.83)	1.32 (0.67, 2.63)	0.95 (0.61, 1.50)
Uncontrolled nighttime hypertension ^c			
Number of cases	32	46	138
Model 1	1.74 (1.08, 2.80)	1.44 (0.97, 2.15)	1.24 (0.93, 1.65)
Model 2	1.71 (1.05, 2.79)	1.40 (0.93, 2.11)	1.20 (0.89, 1.61)
Model 3	1.81 (1.01, 3.24)	1.39 (0.87, 2.23)	1.16 (0.85, 1.58)

p values less than .05 were considered statistically significant in bold.

N = 1015.

Hearing loss is defined as PTA > 40 dB-aHL in the better ear.

Model 1: Adjusted for age and gender.

Model 2: Additionally, adjusted for educational level (primary or less, secondary and university), smoking status (current smoker, former smoker, never smoker), current alcohol drinker (yes, no), habitual coffee consumption (yes/no), MEDAS (tertiles of score), physical activity (tertiles of METs-h/wk, BMI (tertiles of kg/m²), sleep (tertiles, h/d), and time viewing television (tertiles, h/wk).

Model 3: Additionally, adjusted for diabetes, cancer, cardiovascular diseases, cognitive status (tertiles of MMSE score), noisy workplace (yes/no), loud music exposure (yes/no), use of hearing aid (yes/no) and tinnitus (yes/no).

Abbreviations: BP, blood pressure; dB-aHL, AudCal hearing loss decibels; MEDAS, Mediterranean diet adherence screener; METs, metabolic equivalent tasks; MMSE, Mini-Mental State Examination; PTA, pure-total average.

^a24-hour BP ≥ 130/80 mm Hg or being under antihypertensive treatment.

^bDaytime BP ≥ 135/85 mm Hg or being under antihypertensive treatment.

^cNighttime BP ≥ 120/70 mm Hg or being under antihypertensive treatment.

of the basal turn with aging⁵⁵; this is added to the consequences of hypertension in those patients, including anomalies of the blood components, the vascular wall (dysfunction or endothelial damage) and of the blood flow,^{56,57} which could affect both basal areas of the cochlea (high frequencies) and apical areas (low frequencies), but in different ways.

The strength of our study lies in the use of PTA (gold standard) for measurements of auditory function, and ABPM, a tool that better predicts clinical outcomes than isolated clinical BP measurements and measures BP in everyday life. Also, the analyses were adjusted for main potential confounders, including lifestyles, comorbidities, cognitive impairment, and hearing variables. The study also has several limitations, including the cross-sectional design, so we could not attribute directionality to the observed associations with certainty. In addition, the measurement of the hearing function was carried out with a portable device in the participants' homes; therefore, the bias related to environmental noise and the interviewer's

performance, as well as the bias related to the instrument, cannot be eliminated.

In conclusion, in older adults PTA was associated with higher nighttime BP, and hearing loss was linked to a riser BP pattern and uncontrolled BP among hypertensive individuals. Longitudinal studies are needed to further support the associations between PTA and nighttime BP.

Authors Contributions

Humberto Yévenes-Briones, designed the research, performed the statistical analyses, contributed to the interpretation of the results, drafted the manuscript, reviewed the manuscript for important intellectual content, and read and approved the final manuscript; **Francisco Félix Caballero**, designed the research, contributed to interpretation of the results, drafted the manuscript, reviewed the manuscript for important intellectual content, and read and approved the final manuscript; **Ellen A. Struijk**, **Daniela B. Estrada-deLeón**, **Jorge Rey-Martínez**, and

Fernando Rodríguez-Artalejo, contributed to interpretation of the results, reviewed the manuscript for important intellectual content, and read and approved the final manuscript; **José R. Banegas**, designed the research, contributed to interpretation of the results, reviewed the manuscript for important intellectual content, and read and approved the final manuscript; **Esther Lopez-Garcia**, designed the research, contributed to interpretation of the results, drafted the manuscript, had primary responsibility for final content, reviewed the manuscript for important intellectual content, and read and approved the final manuscript.


Disclosures



Competing interests: The authors have no conflicts. All authors have read the manuscript, agree that the work is ready for submission to a journal, and accept responsibility for the manuscript content.



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
ORCID iD

Humberto Yévenes-Briones  <http://orcid.org/0000-0002-3431-7247>

Francisco Félix Caballero  <https://orcid.org/0000-0001-9609-3579>

Ellen A. Struijk  <https://orcid.org/0000-0002-9302-9616>
 Daniela B. Estrada-deLeón  <https://orcid.org/0000-0002-9397-540X>

Jorge Rey-Martinez  <https://orcid.org/0000-0001-7649-3823>
 Fernando Rodríguez-Artalejo  <https://orcid.org/0000-0001-9317-5755>

José R. Banegas  <https://orcid.org/0000-0001-6152-9862>

Esther Lopez-Garcia  <https://orcid.org/0000-0001-6202-4970>

References

1. World Health Organization (WHO). *Hypertension*. WHO; 2023. <https://www.who.int/es/news-room/fact-sheets/detail/hypertension>
2. GBD 2016 Risk Factors Collaborators. Global, regional, and national comparative risk assessment of 84 behavioral, environmental and occupational, and metabolic risks or clusters of risks, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016. *Lancet*. 2017;390(10100):1345-1422. doi:10.1016/S0140-6736(17)32366-8
3. Zhou B, Carrillo-Larco RM, Danaei G, et al. Worldwide trends in hypertension prevalence and progress in treatment and control from 1990 to 2019: a pooled analysis of 1201 population-representative studies with 104 million participants. *Lancet*. 2021;398(10304):957-980. doi:10.1016/S0140-6736(21)01330-1
4. Muntner P, Hardy ST, Fine LJ, et al. Trends in blood pressure control among US adults with hypertension, 1999-2000 to 2017-2018. *JAMA*. 2020;324(12):1190-1200. doi:10.1001/jama.2020.14545
5. Williams B, Mancia G, Spiering W, et al. 2018 ESC/ESH guidelines for the management of arterial hypertension. *Eur Heart J*. 2018;39(33):3021-3104. doi:10.1093/eurheartj/ehy339
6. Whelton PK, Carey RM, Aronow WS, et al. 2017 ACC/AHA/AAPA/ABC/ACPM/AGS/APhA/ASH/ASPC/NMA/PCNA guideline for the prevention, detection, evaluation, and management of high blood pressure in adults: executive summary: a report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Hypertension*. 2018;71(6):1269-1324. doi:10.1161/HYP.0000000000000066
7. Umesawa M, Sairenchi T, Haruyama Y, Nagao M, Kobashi G. Association between hypertension and hearing impairment in health check-ups among Japanese workers: a cross-sectional study. *BMJ Open*. 2019;9(4):e028392. doi:10.1136/bmjopen-2018-028392
8. Park HJ, Yoo MH, Woo SY, Kim SW, Cho YS. Prevalence of hearing loss and associated factors in subjects with normal otoscopy: a national cross-sectional study. *Int J Audiol*. 2017;56(12):951-957. doi:10.1080/14992027.2017.1373866
9. Ramage-Morin PL, Gilmour H, Banks R, Pineault D, Atrach M. Hypertension associated with hearing health problems among Canadian adults aged 19 to 79 years. *Health Rep*. 2021;32(10):14-26. doi:10.25318/82-003-x202101000002-eng
10. Rigtters SC, Metselaar M, Wieringa MH, Baatenburg de Jong RJ, Hofman A, Goedegebure A. Contributing determinants to hearing loss in elderly men and women: results from the population-based Rotterdam study. *Audiol Neurotol*. 2016;21(suppl 1):10-15. doi:10.1159/000448348
11. Smith E, Bishop CE, Spankovich C, Su D, Valle K, Schweinfurth J. The relationship of cardiometabolic risk and auditory processing among African Americans: The Jackson Heart Study. *Otolaryngol Head Neck Surg*. 2019;160(4):695-705. doi:10.1177/0194599818816090
12. Gates GA, Cobb JL, D'Agostino RB, Wolf PA. The relation of hearing in the elderly to the presence of cardiovascular disease and cardiovascular risk factors. *Arch Otolaryngol Head Neck Surg*. 1993;119(2):156-161. doi:10.1001/archotol.1993.01880140038006
13. Helzner EP, Cauley JA, Pratt SR, et al. Race and sex differences in age-related hearing loss: the Health, Aging and Body Composition Study. *J Am Geriatr Soc*. 2005;53(12):2119-2127. doi:10.1111/j.1532-5415.2005.00525.x
14. Lin FR, Thorpe R, Gordon-Salant S, Ferrucci L. Hearing loss prevalence and risk factors among older adults in the United States. *J Gerontol A Biol Sci Med Sci*. 2011;66(5):582-590. doi:10.1093/gerona/glr002
15. Mick PT, Kabir R, Pichora-Fuller MK, et al. Associations between cardiovascular risk factors and audiometric hearing:

- findings from the Canadian Longitudinal Study on Aging. *Ear Hear.* 2023;44(6):1332-1343. doi:10.1097/AUD.0000000000001370
16. Torre 3rd P, Cruickshanks KJ, Klein BEK, Klein R, Nondahl DM. The association between cardiovascular disease and cochlear function in older adults. *J Speech Lang Hear Res.* 2005;48(2):473-481. doi:10.1044/1092-4388(2005/032)
 17. GBD 2019 Hearing Loss Collaborators. Hearing loss prevalence and years lived with disability, 1990-2019: findings from the Global Burden of Disease Study 2019. *Lancet.* 2021;397(10278):996-1009. doi:10.1016/S0140-6736(21)00516-X
 18. Hajjar I, Lackland DT, Cupples LA, Lipsitz LA. Association between concurrent and remote blood pressure and disability in older adults. *Hypertension.* 2007;50(6):1026-1032. doi:10.1161/HYPERTENSIONAHA.107.097667
 19. Yévenes-Briones H, Caballero FF, Struijk EA, et al. Association between hearing loss and impaired physical function, frailty, and disability in older adults: a cross-sectional study. *JAMA Otolaryngol Head Neck Surg.* 2021;147(11):951-958. doi:10.1001/jamaoto.2021.2399
 20. Gijón-Conde T, Graciani A, López-García E, et al. Frailty, disability, and ambulatory blood pressure in older adults. *J Am Med Dir Assoc.* 2018;19(5):433-438. doi:10.1016/j.jamda.2017.11.014
 21. Liang Z, Li A, Xu Y, Qian X, Gao X. Hearing loss and dementia: a meta-analysis of prospective cohort studies. *Front Aging Neurosci.* 2021;13:695117. doi:10.3389/fnagi.2021.695117
 22. Livingston G, Sommerlad A, Orgeta V, et al. Dementia prevention, intervention, and care. *Lancet.* 2017;390(10113):2673-2734. doi:10.1016/S0140-6736(17)31363-6
 23. Lin FR, Reed NS. The pure-tone average as a universal metric-knowing your hearing. *JAMA Otolaryngol Head Neck Surg.* 2021;147(3):230-231. doi:10.1001/jamaoto.2020.4862
 24. Pickering TG, Shimbo D, Haas D. Ambulatory blood-pressure monitoring. *N Engl J Med.* 2006;354(22):2368-2374. doi:10.1056/NEJMr060433
 25. Burr ML, Dolan E, O'Brien EW, O'Brien ET, McCormack P. The value of ambulatory blood pressure in older adults: the Dublin outcome study. *Age Ageing.* 2008;37(2):201-206. doi:10.1093/ageing/afm193
 26. Rodríguez-Artalejo F, Graciani A, Guallar-Castillón P, et al. Justificación y métodos del estudio sobre nutrición y riesgo cardiovascular en España (ENRICA). *Rev Esp Cardiol.* 2011;64(10):876-882. doi:10.1016/j.recresp.2011.05.019
 27. Larrosa F, Rama-Lopez J, Benitez J, et al. Development and evaluation of an audiology app for iPhone/iPad mobile devices. *Acta Otolaryngol.* 2015;135(11):1119-1127. doi:10.3109/00016489.2015.1063786
 28. American Speech-Language-Hearing Association (ASHA). Degree of hearing loss. 2010. Accessed March 2, 2021. <https://www.asha.org/public/hearing/degree-of-hearing-loss/>
 29. World Health Organization. *WHO Report of the Informal Working Group on Prevention of Deafness and Hearing Impairment Programme Planning.* WHO; 1991. https://apps.who.int/iris/bitstream/handle/10665/58839/WHO_PDH_91.1.pdf?sequence=1&isAllowed=y
 30. Sánchez-Martínez M, López-García E, Guallar-Castillón P, et al. Home and ambulatory blood pressure levels below target range and clinical effort to detect this condition: a population-based study in older treated hypertensives. *Age Ageing.* 2022;51(2):afab236. doi:10.1093/ageing/afab236
 31. O'Brien E, Parati G, Stergiou G. Ambulatory blood pressure measurement: what is the international consensus. *Hypertension.* 2013;62(6):988-994. doi:10.1161/HYPERTENSIONAHA.113.02148
 32. Schröder H, Fitó M, Estruch R, et al. A short screener is valid for assessing Mediterranean diet adherence among older Spanish men and women. *J Nutr.* 2011;141(6):1140-1145. doi:10.3945/jn.110.135566
 33. Cabanas-Sánchez V, Esteban-Cornejo I, Migueles JH, et al. Twenty four-hour activity cycle in older adults using wrist-worn accelerometers: the seniors-ENRICA-2 study. *Scand J Med Sci Sports.* 2020;30(4):700-708. doi:10.1111/sms.13612
 34. Lana A, Struijk EA, Arias-Fernandez L, et al. Habitual meat consumption and changes in sleep duration and quality in older adults. *Aging Dis.* 2019;10(2):267-277. doi:10.14336/AD.2018.0503
 35. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state." A practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res.* 1975;12(3):189-198. doi:10.1016/0022-3956(75)90026-6
 36. Long L, Meng Z, Jia Z, Tang X. Exploring the association of leukocyte telomere length and hearing threshold shifts of adults in the United States. *Front Aging Neurosci.* 2022;14:770159. doi:10.3389/fnagi.2022.770159
 37. Tellechea ML, Pirola CJ. The impact of hypertension on leukocyte telomere length: a systematic review and meta-analysis of human studies. *J Hum Hypertens.* 2017;31(2):99-105. doi:10.1038/jhh.2016.45
 38. Yang WY, Melgarejo JD, Thijs L, et al. Association of office and ambulatory blood pressure with mortality and cardiovascular outcomes. *JAMA.* 2019;322(5):409-420. doi:10.1001/jama.2019.9811
 39. Kario K, Hoshida S, Mizuno H, et al. Nighttime blood pressure phenotype and cardiovascular prognosis: practitioner-based nationwide JAMP Study. *Circulation.* 2020;142(19):1810-1820. doi:10.1161/CIRCULATIONAHA.120.049730
 40. Fagard RH, Celis H, Thijs L, et al. Daytime and nighttime blood pressure as predictors of death and cause-specific cardiovascular events in hypertension. *Hypertension.* 2008;51(1):55-61. doi:10.1161/HYPERTENSIONAHA.107.100727
 41. Vij R, Peixoto AJ. Management of nocturnal hypertension. *Expert Rev Cardiovasc Ther.* 2009;7:607-618.
 42. Komori T, Eguchi K, Saito T, Nishimura Y, Hoshida S, Kario K. Riser blood pressure pattern is associated with mild cognitive impairment in heart failure patients. *Am J Hypertens.* 2016;29(2):194-201. doi:10.1093/ajh/hpv086
 43. Fukutomi M, Kario K. Aging and hypertension. *Expert Rev Cardiovasc Ther.* 2010;8(11):1531-1539. doi:10.1586/erc.10.78

44. Blauth FG, Vilar LAS, Pontes VCB, Moriguti JC, Ferriolli E, Lima NKC. The effect of frailty on the 24-hour blood pressure pattern in the very elderly. *J Clin Hyperten*. 2022; 24(1):67-73. doi:10.1111/jch.14409
45. Camafort M, Chung WJ, Shin JH. Role of ambulatory blood pressure monitoring in elderly hypertensive patients. *Clin Hypertens*. 2022;28(1):22. doi:10.1186/s40885-022-00205-6
46. Cunningham LL, Tucci DL. Hearing loss in adults. *N Engl J Med*. 2017;377(25):2465-2473. doi:10.1056/NEJMr1616601
47. Tu NC, Friedman RA. Age-related hearing loss: unraveling the pieces. *Laryngoscope Investig Otolaryngol*. 2018;3(2): 68-72. doi:10.1002/lio2.134
48. Liu J, Chen H, Lin X, et al. Melatonin suppresses cyclic GMP-AMP synthase-stimulator of interferon genes signaling and delays the development of hearing loss in the C57BL/6J presbycusis mouse model. *Neuroscience*. 2023; 517:84-95. doi:10.1016/j.neuroscience.2023.01.015
49. Verschuur CA, Dowell A, Syddall HE, et al. Markers of inflammatory status are associated with hearing threshold in older people: findings from the Hertfordshire Ageing Study. *Age Ageing*. 2012;41(1):92-97. doi:10.1093/ageing/afr140
50. Lassale C, Vullo P, Cadar D, Batty GD, Steptoe A, Zaninotto P. Association of inflammatory markers with hearing impairment: the English Longitudinal Study of Ageing. *Brain Behav Immun*. 2020;83:112-119. doi:10.1016/j.bbi.2019.09.020
51. Shapira U, Ben Assayag H, Ungar OJ, et al. Association of inflammatory markers with hearing loss in young adults. *Clin Otolaryngol*. 2023;48(2):220-225. doi:10.1111/coa.14026
52. Patrick DM, Van Beusecum JP, Kirabo A. The role of inflammation in hypertension: novel concepts. *Curr Opin Physiol*. 2021;19:92-98. doi:10.1016/j.cophys.2020.09.016
53. Idris-Khodja N, Mian MOR, Paradis P, Schiffrin EL. Dual opposing roles of adaptive immunity in hypertension. *Eur Heart J*. 2014;35(19):1238-1244. doi:10.1093/eurheartj/ehu119
54. Crouch SH, Botha-Le Roux S, Delles C, Graham LA, Schutte AE. Inflammation and hypertension development: a longitudinal analysis of the African-PREDICT study. *Int J Cardiol Hypertens*. 2020;7:100067. doi:10.1016/j.ijchy.2020.100067
55. Shi X. Physiopathology of the cochlear microcirculation. *Hear Res*. 2011;282(1-2):10-24. doi:10.1016/j.heares.2011.08.006
56. Beevers G. ABC of hypertension: the pathophysiology of hypertension. *BMJ*. 2001;322(7291):912-916. doi:10.1136/bmj.322.7291.912
57. Harrison DG, Coffman TM, Wilcox CS. Pathophysiology of hypertension: the mosaic theory and beyond. *Circ Res*. 2021;128(7):847-863. doi:10.1161/CIRCRESAHA.121.318082