Lipids in Health and Disease

RESEARCH

Open Access

Association between platelet to high-density lipoprotein cholesterol ratio (PHR) and hypertension: evidence from NHANES 2005–2018

Jia Chen[1†], Boyu Wang[1†], Changxing Liu[1†], Chengjia Li[1], Tianwei Meng[1], Jiameng Wang[1], Qingnan Liu[1], Zhiping Liu[2*] and Yabin Zhou[2*]

Abstract

Background The Platelet to High-Density Lipoprotein cholesterol Ratio (PHR) is a novel indicator of inflammatory response and metabolic disorders, linked to various chronic diseases. This study aims to investigate the relationship between PHR and hypertension.

Methods Data from the National Health and Nutrition Examination Survey (NHANES), collected across seven consecutive cycles from 2005 to 2018, were analyzed. The dataset included participants' hypertension status as reported by a doctor, their use of antihypertensive medications, and the average of three blood pressure measurements to identify hypertensive adults, along with complete information for PHR calculation. PHR was calculated based on Platelet (PLT) count and High-Density Lipoprotein cholesterol (HDL-C) using the following formula: PHR = [PLT (1000 cells/μL) / HDL-C (mmol/L)]. A multivariable logistic regression model was employed to assess the association between PHR and hypertension, and subgroup analyses were conducted to explore potential influencing factors. Additionally, Restricted Cubic Spline (RCS) curves were applied for threshold effect analysis to describe nonlinear relationships.

Results Higher PHR was associated with an increased prevalence of hypertension. After adjusting for various covariates, including race, education level, Family Poverty Income Ratio (PIR), smoking, alcohol consumption, sleep disturbances, waist circumference, diabetes, coronary heart disease, angina, heart attack, and stroke, the results remained significant (OR = 1.36; 95% CI, 1.32, 1.41, $P < 0.001$). Participants with the highest PHR levels had a 104% higher risk of hypertension compared to those with the lowest PHR levels (OR = 2.04; 95% CI, 1.89, 2.21, $P < 0.001$).

†Jia Chen, Boyu Wang and Changxing Liu contributed equally to this work.

*Correspondence:
Zhiping Liu
liuzhipingmedicine@163.com
Yabin Zhou
yabzhou@163.com

Full list of author information is available at the end of the article

© The Author(s) 2024. **Open Access** This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License, which permits any non-commercial use, sharing, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if you modified the licensed material. You do not have permission under this licence to share adapted material derived from this article or parts of it. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by-nc-nd/4.0/.

Conclusion Elevated PHR levels are strongly associated with an increased risk of hypertension. Specifically, when PHR is below 280, the risk of hypertension increases in proportion to PHR. This suggests that regular monitoring of PHR may help identify patients at risk of hypertension early, allowing for timely interventions to slow disease progression. Larger cohort studies are necessary to confirm these findings.

Keywords Platelet to high-density lipoprotein cholesterol ratio, Cross-sectional study, Hypertension, NHANES

Introduction

Hypertension is one of the most common chronic cardiovascular diseases globally. According to the World Health Organization, approximately 1.39 billion adults worldwide are affected by hypertension, with prevalence rates ranging from 30 to 45% [1]. The incidence and severity of hypertension increase with age; in the United States, the prevalence among individuals aged 65 and older reaches 70% [2]. The treatment of hypertension and its complications presents significant public health challenges, with direct and indirect costs exceeding $131 billion annually in the U.S [3]. Research indicates a positive correlation between the degree of elevated blood pressure and the incidence of severe complications [4]. For individuals diagnosed with hypertension, daily monitoring provides a simple method to assess increases in blood pressure. However, the majority of individuals without hypertension lack both the means and the awareness for regular monitoring. Consequently, there is a shortage of predictive factors related to hypertension, making it difficult to anticipate future cases. Identifying such factors is essential for early screening, risk stratification, and optimized management of high-risk populations to prevent serious outcomes.

The onset of hypertension is closely linked to the immune system and inflammatory responses [5, 6]. During inflammation, notable changes occur in neutrophil, platelet (PLT), lymphocyte levels, and acute-phase proteins [7]. PLT plays a key role in inflammatory processes by aggregating and releasing cytokines, which can accelerate inflammation to some extent [8]. Studies have demonstrated a correlation between platelet distribution width and the severity of hypertension in adults [9]. Additionally, High-Density Lipoprotein cholesterol (HDL-C) levels in the blood are associated with cardiovascular disease risk in hypertensive patients [10]. Research suggests a U-shaped relationship between HDL-C levels and cardiovascular event risk in patients with hypertension, and the triglyceride to HDL-C ratio is correlated with newly developed hypertension [11]. During Reverse Cholesterol Transport, HDL-C facilitates the efflux of free cholesterol from arterial walls, providing anti-inflammatory and antioxidant effects [12]. Thus, the combination of platelet count and HDL-C levels may serve as an estimator of hypertension risk. The Platelet to High-Density Lipoprotein cholesterol Ratio (PHR) combines platelet count and HDL-C levels, acting as a novel marker of inflammation and metabolic status. Recent studies have shown that PHR holds predictive and diagnostic value in various conditions, including newly developed metabolic syndrome, non-alcoholic fatty liver disease, hyperuricemia, depression, and kidney stones [13–18].

To date, no studies have reported a relationship between PHR and hypertension risk. This study hypothesizes that a correlation may exist between PHR and hypertension. Investigating the association between PHR levels and hypertension risk may assist in risk stratification and optimizing hypertension treatment. Furthermore, PHR can be easily calculated from routine blood tests using platelet counts and HDL-C levels, making it a practical tool for disease evaluation. Based on this premise, the current study conducted a cross-sectional analysis using data from the National Health and Nutrition Examination Survey (NHANES) from 2005 to 2018 to explore the association between PHR and hypertension risk.

Methods

Study population

The data for this study were sourced from the continuous NHANES surveys conducted between 2005 and 2018. NHANES is a nationwide, cross-sectional study managed by the National Center for Health Statistics (NCHS) of the United States, focusing on the health and nutritional status of the American population (https://www.cdc.gov/nchs/nhanes/index.htm). Each cycle of NHANES covers a broad range of survey content, including demographic data, socio-economic characteristics, medical indicators, and dietary and nutritional status. Detailed records of the health status of Americans are maintained across multiple dimensions in each cycle [19]. The NHANES survey process strictly adheres to ethical standards, ensuring informed consent from all participants and safeguarding data privacy.

A total of seven consecutive NHANES datasets were included in this analysis. From 2005 to 2018, 70,190 individuals participated in the NHANES survey. The exclusion criteria were as follows: (1) individuals under 20 years of age (n=30,441); (2) individuals without a hypertension diagnosis (n=7,124); (3) individuals with incomplete records for platelet count and HDL-C (n=1,863); and (4) individuals with missing relevant covariates (n=1,452). Ultimately, 29,310 participants were included in the final analysis (Fig. 1).

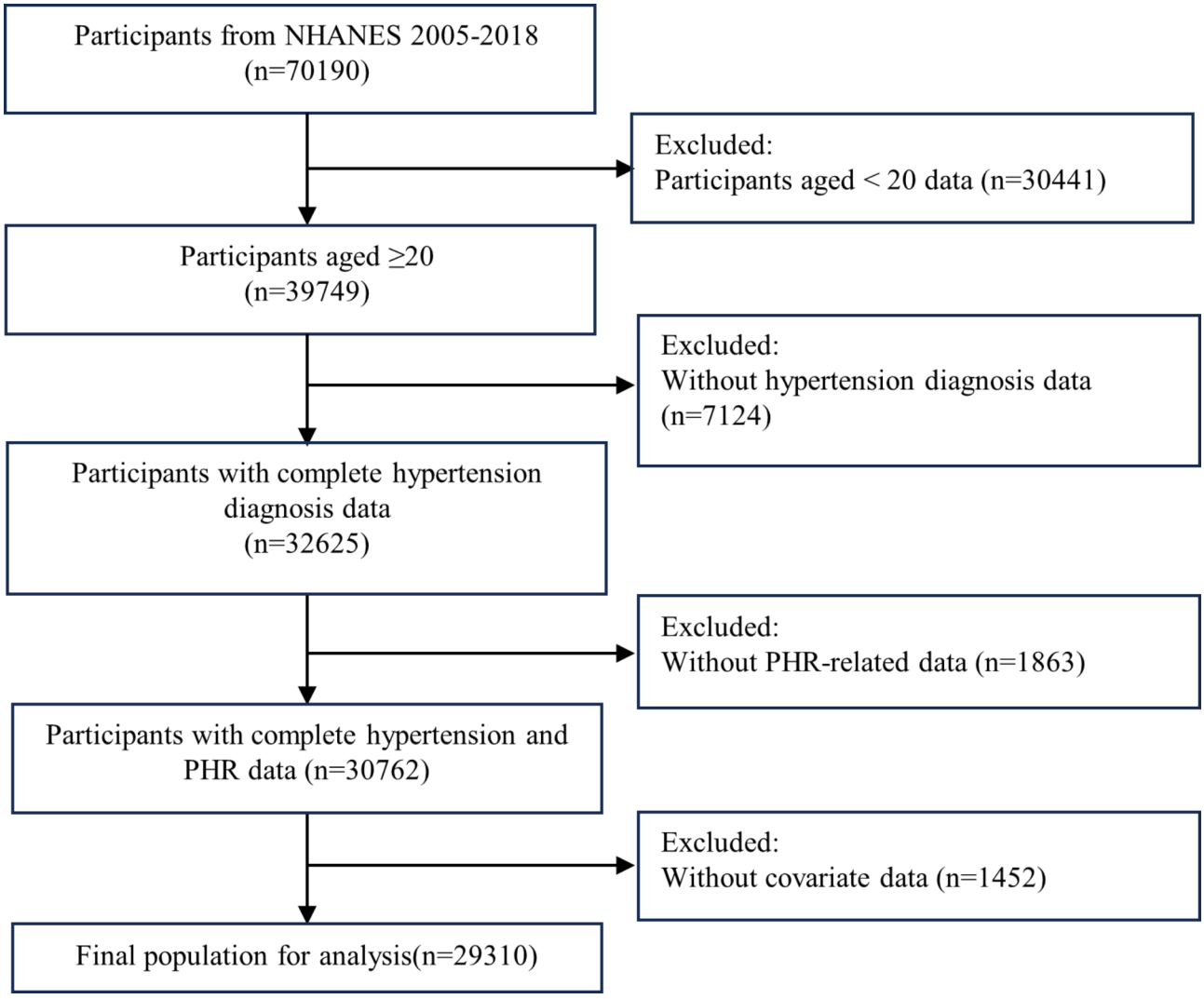

Fig. 1 Diagram of participant enrollment process

Exposure variable: PHR

PHR was calculated based on the patient's platelet count and HDL-C. The specific formula is as follows:

$$PHR = [PLT\,(1000cells/\mu L)/HDL - C\,(mmol/L)]$$

Blood and lipid indices for participants were extracted from the NHANES system and calculated using this formula, with PHR serving as the exposure variable [18].

Definition of hypertension as outcome measure

Hypertension was defined based on whether a doctor had diagnosed the individual with hypertension, whether the individual was taking prescribed antihypertensive medications, and the average of three blood pressure measurements. Blood pressure was measured by trained examiners following standardized protocols. After participants rested for 5 min, their maximum blood pressure was determined, and blood pressure values were measured as objective indices for diagnosing hypertension. Individuals with an average systolic blood pressure (SBP) of ≥140 mmHg or diastolic blood pressure (DBP) of ≥90 mmHg, based on three measurements, were classified as hypertensive, regardless of meeting the criteria of "doctor-diagnosed hypertension" or "prescribed antihypertensive medication." Additionally, individuals with an average SBP of <140 mmHg and DBP of <90 mmHg, but who met the criteria of "doctor-diagnosed hypertension" or "prescribed antihypertensive medication," were also considered hypertensive. Previous studies have validated the use of this method to determine hypertension in NHANES participants, and it is widely accepted [20, 21].

Covariates

To investigate the independent association between PHR and hypertension, covariates with potential relevance

to both PHR and hypertension were selected based on clinical significance. These covariates included gender, age, race, educational level, Family Poverty Income Ratio (PIR), smoking status, alcohol consumption, sleep disorders, waist circumference, diabetes, coronary heart disease, angina, myocardial infarction, and stroke [22, 23]. Detailed classifications of all data are available on the NHANES website. For sociodemographic covariates, race was categorized into Mexican American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, and Other race. Educational levels were grouped into the following categories: Less Than 9th Grade, 9-11th Grade (including 12th grade with no diploma), High School Graduate/General Educational Development (GED) or equivalent, Some College or Associate degree, and College Graduate or above. Smoking status was classified as "no" for participants who had smoked fewer than 100 cigarettes in their lifetime, and "yes" for those who had smoked more than 100 cigarettes in their lifetime. Alcohol consumption was classified as "no" for participants who had consumed fewer than one alcoholic drink in the past 12 months, and "yes" for those who had consumed more than one alcoholic drink in the past 12 months [24]. Among the health-related covariates, diabetes was defined based on fasting blood glucose measurements, doctor diagnosis, use of glucose-lowering medication, and insulin use. Participants were classified as having diabetes if they met any of the following criteria: fasting blood glucose > 7 mmol/L, being told by a physician that they have diabetes, taking glucose-lowering medication, or using insulin. Participants were classified as not having diabetes if they met al.l of the following criteria: fasting blood glucose ≤ 7 mmol/L, had not been diagnosed with diabetes by a physician, were not taking glucose-lowering medication, and were not using insulin. Fasting blood glucose measurement required at least 9 h of fasting prior to sample collection. Serum samples were processed and analyzed by professionals at the University of Missouri-Columbia under appropriate storage conditions (–30 °C). Data on coronary heart disease, angina, heart attack, and stroke were obtained from self-reported information collected through relevant questionnaires.

Statistical analysis

To address potential complexities in the research design, such as oversampling specific groups and correcting for response bias due to survey non-responses, NHANES employs a sophisticated weighting system to ensure the accuracy and reliability of the data. In this study, appropriate sampling weights were applied to all statistical processes. The basic characteristics of the individuals included in the study were categorized based on their hypertension status. Continuous data were reported as mean ± standard deviation, while categorical data were presented as percentages. Differences between baseline continuous and categorical variables were compared using weighted linear regression and weighted chi-squared tests, respectively. Multivariate logistic regression models were employed to examine the association between PHR and hypertension. Three models were used for the analysis: Model 1 (unadjusted variables), Model 2 (adjusted for covariates including gender, age, race, education level, and Family PIR), and Model 3 (adjusted for all covariates). Additionally, subgroup analyses were conducted to explore potential heterogeneity within subgroups based on gender, age, race, education level, Family PIR, smoking status, alcohol consumption, sleep disorders, waist circumference, diabetes, coronary heart disease, angina, heart attack, and stroke. Interaction terms were included to test for heterogeneity among subgroups. All statistical analyses were performed using R (version 4.2.1) and Empower Stats (version 2.0). All P-values < 0.05 were considered statistically significant.

Results

Baseline characteristics

A total of 29,310 adults met the inclusion and exclusion criteria for this study (Table 1). The participants had an average age of 48.85 ± 17.47 years. Of the total, 11,489 (49.43%) were male, and 14,821 (50.57%) were female. In terms of ethnic distribution, 15.89% of participants were Mexican American, 9.95% were Other Hispanic, 42.6% were Non-Hispanic White, 20.34% were Non-Hispanic Black, and 11.23% belonged to other races. The average HDL-C level was 1.37 ± 0.42 mmol/L, and the mean PLT count was 246.27 ± 65.23 (1000 cells/μL). The prevalence of hypertension in the study population was 35.9%, with an average SBP of 122.55 ± 16.83 mmHg and an average DBP of 70.48 ± 11.39 mmHg.

Association between PHR and hypertension

The results of the study indicate a significant association between higher PHR and the incidence of hypertension (Table 2). In Model 1 (unadjusted for covariates), this association was significant (OR = 1.07; 95% CI, 1.04, 1.10, P < 0.001). Model 2, which adjusted for sex, age, race, educational level, and Family Poverty Income Ratio, also demonstrated a significant association (OR = 1.36; 95% CI, 1.32, 1.41, P < 0.001). Model 3, further adjusting for smoking, alcohol consumption, sleep disorders, waist circumference, diabetes, coronary heart disease, angina, myocardial infarction, and stroke, confirmed the association (OR = 1.13; 95% CI, 1.09, 1.17, P < 0.001). Additionally, the study examined the association between PHR and both SBP and DBP. A significant association was observed between PHR and SBP in Model 2 (OR = 1.00; 95% CI, 0.78, 1.21, P < 0.001) and Model 3 (OR = 0.32; 95% CI, 0.09, 0.54, P = 0.0056). Similarly, significant

Table 1 Clinical characteristics of the study participants

Hypertension	Overall	With Hypertension	Without Hypertension	*P*-value
N	29,310	10,549	18,761	
Age	48.85 ± 17.47	58.68 ± 14.89	43.33 ± 16.34	< 0.001
PIR	2.51 ± 1.57	2.47 ± 1.54	2.53 ± 1.58	0.002
Waist circumference(cm)	99.20 ± 16.17	105.35 ± 15.79	95.75 ± 15.34	< 0.001
SBP (mmHg)	122.55 ± 16.83	133.19 ± 19.54	116.56 ± 11.34	< 0.001
DBP (mmHg)	70.48 ± 11.39	73.24 ± 13.60	68.93 ± 9.59	< 0.001
HDL-C(mmol/L)	1.37 ± 0.42	1.34 ± 0.42	1.39 ± 0.41	< 0.001
PLT	246.27 ± 65.23	243.89 ± 68.53	247.61 ± 63.25	< 0.001
Gender				< 0.001
male	11,489 (49.43%)	5358 (50.79%)	9131 (48.67%)	
female	14,821 (50.57%)	5191 (49.21%)	9630 (51.33%)	
Race				< 0.001
Mexican, American	4658 (15.89%)	1281 (12.14%)	3377 (18.00%)	
Other, Hispanic	2915 (9.95%)	958 (9.08%)	1957 (10.43%)	
Non-Hispanic White	12,485 (42.6%)	4629 (43.88%)	7856 (41.87%)	
Non-Hispanic, Black	5961 (20.34%)	2735 (25.93%)	3226 (17.20%)	
Other race	3291 (11.23%)	946 (8.97%)	2345 (12.50%)	
Education				< 0.001
Less Than 9th Grade	3299 (11.26%)	1231 (11.67%)	2068 (11.02%)	
9-11th Grade	5620 (19.17%)	2233 (21.17%)	3387 (18.05%)	
High School Grad/GED or Equivalent	7455 (25.44%)	2802 (26.56%)	4653 (24.80%)	
Some College or AA degree	7040 (24.02%)	2556 (24.23%)	4484 (23.90%)	
College Graduate or above	5896 (20.12%)	1727 (16.37%)	4169 (22.22%)	
Drink				< 0.001
Yes	28,527 (97.33%)	10,147 (96.19%)	18,380 (97.97%)	
No	783 (2.67%)	402 (3.81%)	381 (2.03%)	
Sleep disorders				< 0.001
Yes	7363 (25.12%)	3654 (34.64%)	3709 (19.77%)	
No	21,947 (74.88%)	6895 (65.36%)	15,052 (80.23%)	
Smoking				< 0.001
Yes	13,056 (44.54%)	5252 (49.79%)	7804 (41.60%)	
No	16,254 (55.46%)	5297 (50.21%)	10,957 (58.40%)	
Diabetes				< 0.001
Yes	4166 (14.21%)	2789 (26.44%)	1377 (7.34%)	
No	25,144 (85.54%)	7760 (73.56%)	17,384 (92.66%)	
Coronary Heart Disease				< 0.001
Yes	1131 (3.86%)	863 (8.18%)	268 (1.43%)	
No	28,179 (96.14%)	9686 (91.82%)	18,493 (98.57%)	
Angina pectoris				< 0.001
Yes	705 (2.41%)	537 (5.09%)	168 (0.90%)	
No	28,605 (97.49%)	10,012 (94.91%)	18,593 (99.10%)	
Heart Attack				< 0.001
Yes	1131 (3.86%)	828 (7.85%)	303 (1.62%)	
No	28,179 (96.14%)	9721 (92.15%)	18,458 (98.38%)	
Stroke				< 0.001
Yes	975 (3.33%)	739 (7.01%)	236 (1.26%)	
No	28,335 (96.67%)	9810 (92.99%)	18,525 (98.74%)	

Continuous measurement data were reported as mean ± standard deviation, and categorical data were described as percentages

PIR: Poverty income ratio, SBP: systolic blood pressure, DBP: diastolic blood pressure, HDL-C: High-Density Lipoprotein cholesterol, PLT: platelet

Table 2 Association between PHR and Hypertension and blood pressure levels

Exposure	Non-adjusted(Model I)	Adjust I(Model II)	Adjust II(Model III)
Hypertension			
PHR	1.07 (1.04, 1.10) < 0.001	1.36 (1.32, 1.41) < 0.001	1.13 (1.09, 1.17) < 0.001
PHR quartile			
Q1(0.02–1.40)	1	1	1
Q2(1.41–1.82)	0.97 (0.91, 1.04) 0.366	1.22 (1.13, 1.31) < 0.001	1.05 (0.97, 1.14) 0.231
Q3(1.83–2.35)	1.03 (0.96, 1.10) 0.382	1.49 (1.38, 1.61) < 0.001	1.13 (1.04, 1.23) 0.004
Q4(1.83–2.35)	1.16 (1.08, 1.24) < 0.001	2.04 (1.89, 2.21) < 0.001	1.35 (1.24, 1.46) < 0.001
SBP			
PHR	-0.07 (-0.31, 0.16) 0.548	1.00 (0.78, 1.21) < 0.001	0.32 (0.09, 0.54) 0.0056
PHR quartile			
Q1(0.02–1.40)	0	0	0
Q2(1.41–1.82)	-0.87 (-1.42, -0.33) 0.002	0.30 (-0.19, 0.78) 0.233	-0.25 (-0.73, 0.24) 0.316
Q3(1.83–2.35)	-0.68 (-1.23, -0.14) 0.014	0.93 (0.45, 1.42) 0.001	-0.10 (-0.59, 0.40) 0.700
Q4(1.83–2.35)	-0.28 (-0.83, 0.26) 0.312	2.22 (1.73, 2.72) < 0.001	0.67 (0.15, 1.18) 0.011
DBP			
PHR	0.90 (0.74, 1.06) < 0.001	0.92 (0.76, 1.08) < 0.001	0.50 (0.33, 0.67) < 0.001
PHR quartile			
Q1(0.02–1.40)	0	0	0
Q2(1.41–1.82)	0.72 (0.35, 1.09) 0.001	0.69 (0.33, 1.06) 0.001	0.38 (0.02, 0.74) 0.040
Q3(1.83–2.35)	1.57 (1.20, 1.94) < 0.001	1.56 (1.20, 1.93) < 0.001	0.93 (0.56, 1.30) < 0.001
Q4(1.83–2.35)	2.33 (1.96, 2.70) 2.34 < 0.001	2.35 (1.99, 2.73) 2.36 < 0.001	1.43 (1.04, 1.81) < 0.001

Model I: unadjusted for any covariates; Model II: adjusted for sex, age, race, educational level, and Family PIR; Model III: adjusted for sex, age, race, educational level, Family PIR, smoking, alcohol consumption, sleep disorders, waist circumference, diabetes, coronary heart disease, angina, myocardial infarction, and stroke

associations were found between PHR and DBP in Model 1 (OR=0.90; 95% CI, 0.74, 1.06, $P<0.001$), Model 2 (OR=0.92; 95% CI, 0.76, 1.08, $P<0.001$), and Model 3 (OR=0.50; 95% CI, 0.33, 0.67, $P<0.001$). The findings suggest that for every unit increase in PHR, the risk of developing hypertension increases by 13%, while SBP increases by 0.32 units and DBP by 0.50 units. To assess the robustness of the association between PHR and blood pressure, PHR was categorized into quartiles (Q1, Q2, Q3, Q4) for sensitivity analysis. The results showed that participants with the highest PHR levels had a 104% greater risk of hypertension compared to those with the lowest PHR levels (OR=2.04; 95% CI, 1.89, 2.21, $P<0.001$), accompanied by an increase of 2.22 units in SBP (OR=2.22; 95% CI, 1.73, 2.72, $P<0.001$) and an increase of 2.36 units in DBP (OR=2.36; 95% CI, 1.99, 2.73, $P<0.001$).

RCS curve plotting and threshold effect analysis

To further investigate the relationship between PHR and hypertension, Restricted Cubic Spline (RCS) curve plotting and threshold effect analysis were performed (Table 3; Fig. 2). The results indicated a non-linear association between PHR and hypertension, with a breakpoint identified at a PHR level of 280. Specifically, when PHR<280, there was a significant positive correlation between PHR and hypertension (OR=1.19; 95% CI, 1.13, 1.26, $P<0.001$). However, when PHR>280, no significant association was found between PHR and hypertension (OR=1.03; 95% CI, 0.95, 1.12, $P=0.466$). Similarly, a non-linear relationship was observed between PHR and SBP, with a breakpoint at PHR 129. When PHR>129, SBP increased with higher PHR levels (OR=0.54; 95% CI, 0.29, 0.79, $P<0.001$). Additionally, a non-linear relationship was also found between PHR and DBP. When PHR<341, DBP increased as PHR levels rose (OR=0.81; 95% CI, 0.60, 1.02, $P<0.001$). Detailed illustrations

Table 3 Threshold effect analysis

PHR	HYPERTENSION	SBP	DBP
Model 1			
A straight-line effect	1.13 (1.09, 1.17) < 0.001	0.32 (0.09, 0.54) 0.0056	0.50 (0.33, 0.67) < 0.001
Model 2			
Fold points (K)	2.8	1.29	3.41
< K-segment effect 1	1.19 (1.13, 1.26) < 0.001	-2.64 (-4.08, -1.21) 0.0003	0.81 (0.60, 1.02) < 0.001
> K-segment effect 2	1.03 (0.95, 1.12) 0.466	0.54 (0.29, 0.79) < 0.001	-0.68 (-1.16, -0.20) 0.006
Effect size difference of 2 versus 1	0.87 (0.78, 0.97) 0.011	3.19 (1.66, 4.71) < 0.001	-1.49 (-2.06, -0.92) < 0.001
Equation predicted values at break points	-0.52 (-0.57, -0.47)	122.02 (121.72, 122.32)	72.45 (72.13, 72.78)
Log likelihood ratio tests	0.01	< 0.001	< 0.001

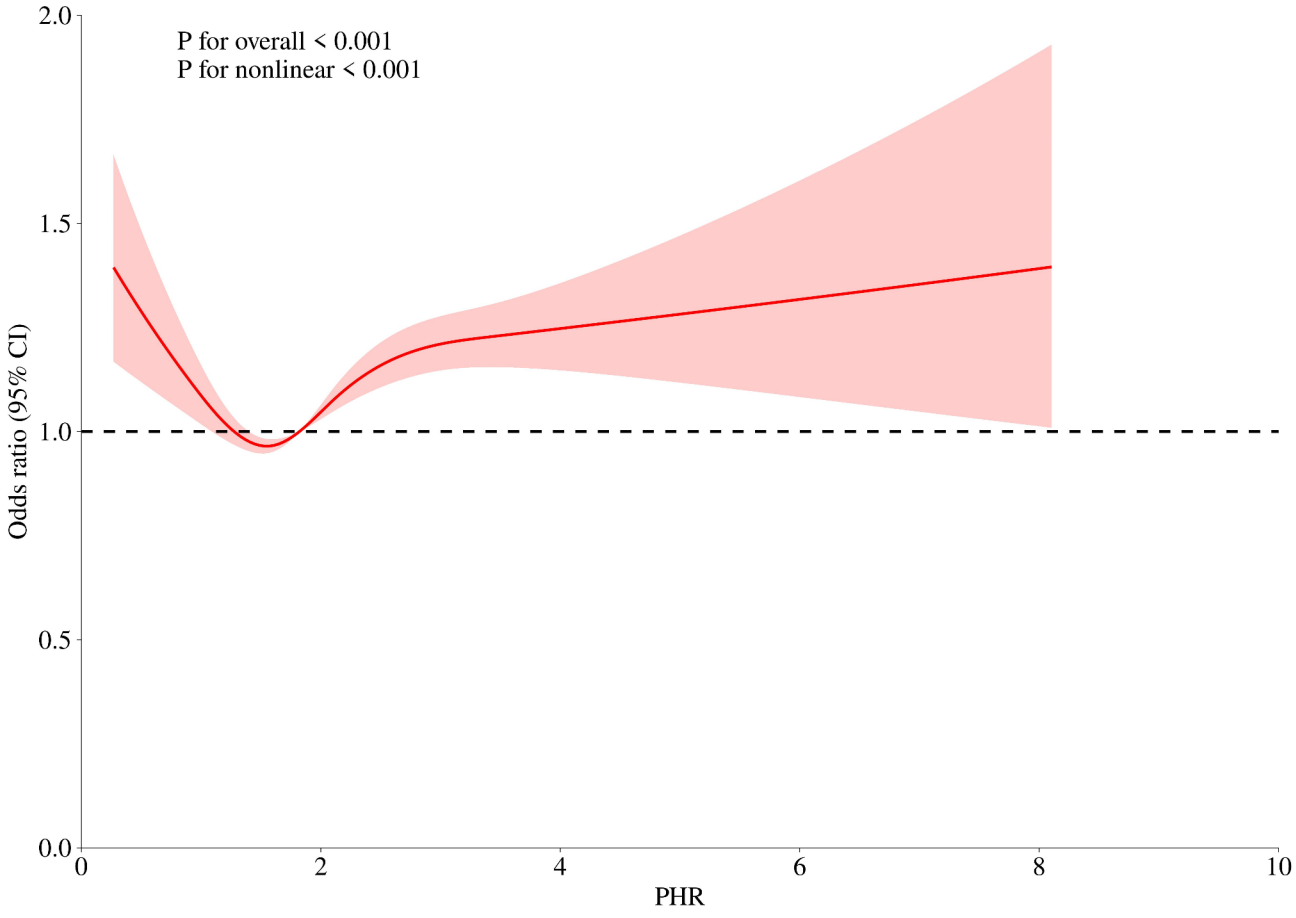

Fig. 2 The association between PHR and Hypertension

of these findings can be found in the supplementary materials.

The nonlinear relationship between the PHR and Hypertension. Adjusted for sex, age, race, educational level, Family PIR, smoking, alcohol consumption, sleep disorders, waist circumference, diabetes, coronary heart disease, angina, myocardial infarction, and stroke.

Subgroup analyses

To assess the stability of the association between PHR and hypertension across different subgroups, additional analyses were conducted based on previous research. Interaction tests revealed that the association between PHR and hypertension was not statistically significant in several subgroups, indicating that factors such as Family PIR, education level (Less Than 9th Grade, 9-11th Grade,

High School Grad/GED or Equivalent, Some College or AA degree, College Graduate or above), waist circumference (cm), alcohol consumption (yes/no), sleep status (yes/no), diabetes (yes/no), coronary heart disease (yes/no), angina (yes/no), heart attack (yes/no), and stroke (yes/no) did not significantly influence this positive association ($P>0.05$). However, significant interactions were found within subgroups based on gender (male/female), age, and race (Mexican American, Other Hispanic, Non-Hispanic White, Non-Hispanic Black, Other race) ($P<0.05$). Previous studies have shown that gender, age, and race are risk factors for hypertension, suggesting that the association between PHR and hypertension remains consistent across these subgroups (Fig. 3). Further analyses were conducted to explore the relationship between PHR and blood pressure levels (SBP and DBP) across subgroups. The results indicated that the interaction between PHR and blood pressure was not significant in subgroups based on race, Family PIR, education level, alcohol consumption, sleep status, coronary heart disease, and heart attack or stroke ($P>0.05$). Detailed illustrations of these findings are available in the supplementary materials.

Discussion

This study is the first to investigate the relationship between PHR and hypertension. The findings suggest that an increase in PHR levels, whether analyzed as a categorical or continuous variable, is associated with a higher risk of developing hypertension when PHR is below 280. Even after adjusting for various covariates, including age, gender, race, educational level, Family PIR, smoking, alcohol consumption, sleep status, waist circumference, diabetes, coronary heart disease, angina, myocardial infarction, and stroke, the positive association between PHR and hypertension remains consistent. Subgroup interaction tests further confirm the stability of this association. Additionally, the relationship between PHR and blood pressure levels (SBP and DBP) was explored, revealing a non-linear association. Specifically, when PHR exceeds 129, SBP rises with increasing PHR levels, and when PHR is below 341, DBP increases as PHR levels rise. These results support and extend the study's hypothesis, highlighting the complex interaction between PHR and blood pressure. This highlights the importance of considering both inflammatory and metabolic indicators in managing patients with hypertension.

In recent years, extensive research has explored the relationship between hypertension, inflammation, and metabolism. PHR has emerged as a new indicator of inflammatory response and metabolic status [18]. In this study, a clear correlation between PHR and hypertension is observed, which aligns with findings from previous research. Earlier studies have shown that hypertensive patients often exhibit elevated levels of inflammation-related markers, such as C-reactive protein, Interleukin-6, and Tumor Necrosis Factor. This suggests that dysregulated blood pressure is frequently accompanied by an inflammatory response. Additionally, during the onset and progression of hypertension, immune cells such as T cells, monocytes, and macrophages accumulate in target organs—including arteries, kidneys, heart, and brain—releasing inflammatory factors that exacerbate inflammation and cause organ damage [6]. Furthermore, inflammatory factors and chemokines can influence blood pressure regulation by promoting the release of inflammatory mediators, increasing vascular tension, stimulating the proliferation and migration of vascular smooth muscle cells, and impairing vascular endothelial function [7, 25]. Blood pressure fluctuations are primarily affected by vascular factors, and disturbances in lipid and glucose metabolism can impact vascular relaxation and contraction, leading to imbalances in blood pressure regulation. Previous studies have also identified obesity and insulin resistance as contributing factors to hypertension [26, 27]. Therefore, abnormal inflammatory responses and metabolic disturbances may jointly contribute to the risk of hypertension onset and progression. Given the positive correlation between PHR and both SBP and DBP within certain ranges, it is crucial to implement early health education and intervention strategies for individuals with elevated PHR. These measures can help reduce hypertension-related risks and support the stratified management of hypertension risk, which is essential for the prevention and treatment of the condition.

In this study, PHR demonstrated a significant association with the risk of hypertension and DBP levels, even before adjusting for covariates. This relationship remained stable after covariate adjustment, highlighting the reliability of PHR in predicting both hypertension risk and DBP levels. The consistency of this association was further confirmed through subgroup interaction tests, which showed that the positive correlation between PHR and hypertension persisted across various risk factors and habits, such as diabetes, coronary heart disease, heart attack, alcohol consumption, and sleep status, without being affected by intergroup differences. The subgroup interaction results also revealed notable variations in the relationship between PHR and hypertension risk based on gender, age, and race. Previous studies have shown differences in hypertension prevalence between males and females, largely due to endocrine factors. Estrogen, for instance, can influence the vascular system by inducing vasodilation, inhibiting vascular remodeling, and regulating the renin-angiotensin-aldosterone system and the sympathetic nervous system, thereby playing a protective role in blood pressure regulation in premenopausal women [28, 29]. The impact of age on

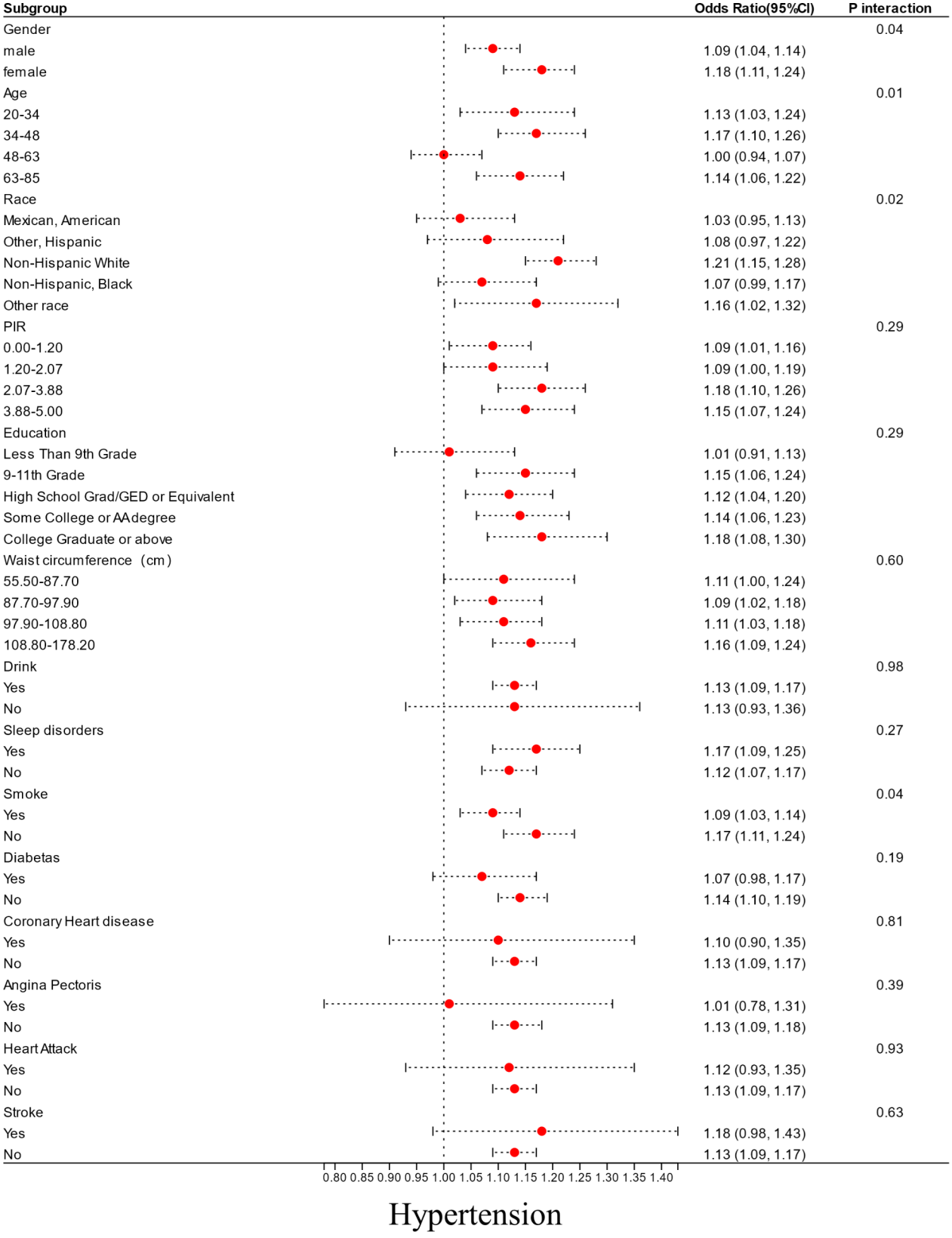

Fig. 3 Subgroup analysis for the association between PHR and Hypertension

blood pressure levels is likely related to reduced vascular elasticity and changes in hemodynamics [4]. Racial differences may stem from genetic polymorphisms and environmental factors, such as socioeconomic disparities, dietary habits, and access to healthcare services, which vary across ethnic groups [30]. These factors directly influence the risk of developing hypertension and contribute to the observed intergroup differences in the correlation between PHR and hypertension.

In the analysis of the correlation between PHR and SBP levels, no statistically significant association was observed without adjustment ($P>0.05$). However, as covariates were progressively included and adjusted, a significant correlation between PHR and SBP levels began to emerge. This suggests that uncontrolled confounding factors may have obscured the true relationship between PHR and SBP levels. These factors likely masked the potential association, which only became apparent after accounting for them. Further subgroup interaction analyses revealed significant interactions between PHR and SBP levels, particularly in subgroups defined by age, smoking status, and diabetes status. Previous research has shown that smoking increases platelet activity, leading to the release of pro-inflammatory and pro-thrombotic factors, such as thromboxane A2 and P-selectin, which cause vasoconstriction [31]. Additionally, nicotine intake during smoking activates the sympathetic nervous system, promoting the release of catecholamines like adrenaline and noradrenaline, contributing to vascular dysfunction and further influencing SBP levels [32].

In summary, the correlation between PHR and hypertension appears to be the result of a complex interplay of multiple factors. The specific molecular mechanisms and potential intervention strategies still require further investigation. This study highlights the potential role of inflammatory and metabolic factors in the development of hypertension, offering insights into early prevention and treatment measures to improve patient outcomes and reduce the risk of complications from elevated blood pressure. Future research should focus on the inflammatory and metabolic factors associated with hypertension risk to increase understanding and improve management of the condition.

Study strengths and limitations

This study conducted a cross-sectional analysis using data from the NHANES database on the American population, addressing a gap in predicting hypertension risk through novel inflammatory and metabolic indicators. It is the first to demonstrate a significant correlation between PHR and hypertension, suggesting that PHR could serve as a predictive marker for hypertension risk. The study strengthened the reliability of this association through multivariate logistic regression and subgroup analyses, which have important implications for early prevention, stratified management, and treatment of hypertension. However, this study has certain limitations. First, some of the data were collected from questionnaires, which may lack precision and completeness. Second, as with most cross-sectional studies, the data represent a specific point in time, which limits the ability to ensure timeliness and comprehensiveness. Rapid changes in sociodemographic factors and disease profiles may also affect the results, making it difficult to establish a causal relationship between PHR and blood pressure levels. To better understand the nature and causality of the relationship between PHR and hypertension, future large-scale cohort studies are needed to track dynamic changes in PHR over time and explore the chronological links in the pathophysiology of hypertension, improving the reliability of causal inference. Additionally, further exploration of the biomolecular mechanisms underlying the relationship between PHR and hypertension is needed. Experimental and clinical studies should focus on investigating the possible signaling pathways and mechanisms that link PHR to hypertension. This research will not only deepen the understanding of the complex relationship but also contribute to discovering potential prevention strategies and interventions for hypertension, offering new insights and approaches.

In conclusion, by analyzing the current limitations and potential directions for future research, this study anticipates that future investigations will provide more comprehensive insights and drive significant progress in the field of PHR and hypertension research.

Conclusion

The results of this study suggest a correlation between PHR and the risk of developing hypertension. Specifically, when PHR is below 280, the risk of hypertension rises as PHR values increase. This finding implies that by routinely monitoring PHR levels, physicians may be able to identify patients at risk for hypertension at an early stage, allowing for timely interventions to slow the progression of the disease. Additionally, larger cohort studies are needed to further validate these findings.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12944-024-02342-3.

Supplementary Material 1

Acknowledgements

We thank the participants of the NHANES and the NHANES staff.

Author contributions

Chen Jia, Wang Boyu and Liu Changxing participated in the design of the study, analysis of the data, and drafting of the manuscript. Li Chengjia and Meng Tianwei conceived of the study, participated in its design and revised

the manuscript. Wang Jiameng, Liu Qingnan, Zhou Yabin and Liu Zhiping participated in extracting, merging and cleaning data. Dr. Zhou Yabin and Liu Zhiping are the corresponding author. All authors read and approved the final manuscript.

Funding
This research was supported financially by the Heilongjiang Provincial Postdoctoral Science (LBH-Z22286).

Data availability
The National Health and Nutrition Examination Survey dataset is publicly available at the National Center for Health Statistics of the Centers for Disease Control and Prevention (https://www.cdc.gov/nchs/nhanes/index.htm).

Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
NHANES is conducted by the Centers for Disease Control and Prevention (CDC) and the National Center for Health Statistics (NCHS). The NCHS Research Ethics Review Committee reviewed and approved the NHANES study protocol.
All participants signed written informed consent.

Author details
[1]Heilongjiang University of Chinese Medicine, Harbin 150040, China
[2]The First Affiliated Hospital of Heilongjiang University of Chinese Medicine, Harbin 150040, China

Received: 13 September 2024 / Accepted: 22 October 2024
Published online: 26 October 2024

References

1. Mills KT, Stefanescu A, He J. The global epidemiology of hypertension. Nat Rev Nephrol. 2020;16(4):223–37.
2. Alanaeme CJ, Ghazi L, Akinyelure OP, Wen Y, Christenson A, Poudel B, et al. Trends in the prevalence of multiple chronic conditions among US adults with hypertension from 1999–2000 through 2017–2020. Am J Hypertens. 2024;37(7):493–502.
3. Wierzejska E, Giernas B, Lipiak A, Karasiewicz M, Cofta M, Staszewski R. A global perspective on the costs of hypertension: a systematic review. Arch Med Sci. 2020;16(5):1078–91.
4. Wang C, Yuan Y, Zheng M, Pan A, Wang M, Zhao M, et al. Association of Age of Onset of Hypertension with Cardiovascular diseases and Mortality. J Am Coll Cardiol. 2020;75(23):2921–30.
5. Ferreira NS, Tostes RC, Paradis P, Schiffrin EL. Aldosterone, inflammation, Immune System, and hypertension. Am J Hypertens. 2021;34(1):15–27.
6. Guzik TJ, Nosalski R, Maffia P, Drummond GR. Immune and inflammatory mechanisms in hypertension. Nat Rev Cardiol. 2024;21(6):396–416.
7. Patrick DM, Van Beusecum JP, Kirabo A. The role of inflammation in hypertension: novel concepts. Curr Opin Physiol. 2021;19:92–8.
8. Zamora C, Canto E, Vidal S. The dual role of platelets in the Cardiovascular risk of chronic inflammation. Front Immunol. 2021;12:625181.
9. Mansoori A, Farizani Gohari NS, Etemad L, Poudineh M, Ahari RK, Mohammadyari F, et al. White blood cell and platelet distribution widths are associated with hypertension: data mining approaches. Hypertens Res. 2024;47(2):515–28.
10. Trimarco V, Izzo R, Morisco C, Mone P, Virginia Manzi M, Falco A, et al. High HDL (high-Density lipoprotein) cholesterol increases Cardiovascular Risk in Hypertensive patients. Hypertension. 2022;79(10):2355–63.
11. Liu D, Guan L, Zhao Y, Liu Y, Sun X, Li H, et al. Association of triglycerides to high-density lipoprotein-cholesterol ratio with risk of incident hypertension. Hypertens Res. 2020;43(9):948–55.
12. Crudele L, De Matteis C, Piccinin E, Gadaleta RM, Cariello M, Di Buduo E, et al. Low HDL-cholesterol levels predict hepatocellular carcinoma development in individuals with liver fibrosis. JHEP Rep. 2023;5(1):100627.
13. Lu CF, Cang XM, Liu WS, Wang LH, Huang HY, Sang SM, et al. Association between the platelet/high-density lipoprotein cholesterol ratio and nonalcoholic fatty liver disease: results from NHANES 2017–2020. Lipids Health Dis. 2023;22(1):130.
14. Ni J, Lv L, Wu P, Xu C. Associations between the platelet/high-density lipoprotein cholesterol ratio and likelihood of nephrolithiasis: a cross-sectional analysis in United States adults. Front Endocrinol (Lausanne). 2024;15:1289553.
15. Ni J, Wu P, Lu X, Xu C. Examining the cross-sectional relationship of platelet/high-density lipoprotein cholesterol ratio with depressive symptoms in adults in the United States. BMC Psychiatry. 2024;24(1):427.
16. Zhang H, Xu Y, Xu Y. The association of the platelet/high-density lipoprotein cholesterol ratio with self-reported stroke and cardiovascular mortality: a population-based observational study. Lipids Health Dis. 2024;23(1):121.
17. Huang C, Guan Y, Chen L, Xu Y, Yang H. The association of platelet count, high-density lipoprotein cholesterol, and platelet/high-density lipoprotein cholesterol ratio with serum soluble Klotho. Lipids Health Dis. 2024;23(1):251.
18. Jialal I, Jialal G, Adams-Huet B. The platelet to high density lipoprotein -cholesterol ratio is a valid biomarker of nascent metabolic syndrome. Diabetes Metab Res Rev. 2021;37(6):e3403.
19. Leroux A, Di J, Smirnova E, McGuffey EJ, Cao Q, Bayatmokhtari E, et al. Organizing and analyzing the activity data in NHANES. Stat Biosci. 2019;11(2):262–87.
20. Li C, Shang S. Relationship between Sleep and Hypertension: findings from the NHANES (2007–2014). Int J Environ Res Public Health. 2021;18:15.
21. Chen J, Liu Z, Yang L, Zhou J, Ma K, Peng Z, et al. Relationship between nocturia and hypertension: findings from the NHANES 2005–2016. Front Cardiovasc Med. 2023;10:1165092.
22. Zhang H, Xu Y, Xu Y. The value of the platelet/high-density lipoprotein cholesterol ratio in predicting depression and its cardiovascular disease mortality: a population-based observational study. Front Endocrinol (Lausanne). 2024;15:1402336.
23. Wu M, Si J, Liu Y, Kang L, Xu B. Association between composite dietary antioxidant index and hypertension: insights from NHANES. Clin Exp Hypertens. 2023;45(1):2233712.
24. Cai Y, Chen M, Zhai W, Wang C. Interaction between trouble sleeping and depression on hypertension in the NHANES 2005–2018. BMC Public Health. 2022;22(1):481.
25. Mikolajczyk TP, Szczepaniak P, Vidler F, Maffia P, Graham GJ, Guzik TJ. Role of inflammatory chemokines in hypertension. Pharmacol Ther. 2021;223:107799.
26. Hall JE, Mouton AJ, da Silva AA, Omoto ACM, Wang Z, Li X, et al. Obesity, kidney dysfunction, and inflammation: interactions in hypertension. Cardiovasc Res. 2021;117(8):1859–76.
27. Sasaki N, Ozono R, Higashi Y, Maeda R, Kihara Y. Association of Insulin Resistance, plasma glucose level, and serum insulin level with hypertension in a Population with different stages of impaired glucose metabolism. J Am Heart Assoc. 2020;9(7):e015546.
28. Sabbatini AR, Kararigas G. Estrogen-related mechanisms in sex differences of hypertension and target organ damage. Biol Sex Differ. 2020;11(1):31.
29. Connelly PJ, Currie G, Delles C. Sex differences in the prevalence, outcomes and Management of Hypertension. Curr Hypertens Rep. 2022;24(6):185–92.
30. Abrahamowicz AA, Ebinger J, Whelton SP, Commodore-Mensah Y, Yang E. Racial and ethnic disparities in hypertension: barriers and opportunities to improve blood pressure control. Curr Cardiol Rep. 2023;25(1):17–27.
31. Pujani M, Chauhan V, Singh K, Rastogi S, Agarwal C, Gera K. The effect and correlation of smoking with platelet indices, neutrophil lymphocyte ratio and platelet lymphocyte ratio. Hematol Transfus Cell Ther. 2021;43(4):424–9.
32. Dimitriadis K, Narkiewicz K, Leontsinis I, Konstantinidis D, Mihas C, Andrikou I et al. Acute effects of Electronic and Tobacco cigarette smoking on sympathetic nerve activity and blood pressure in humans. Int J Environ Res Public Health. 2022;19(6).

Publisher's note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.