

RESEARCH

Open Access



The association of periodontal disease and oral health with hypertension, NHANES 2009–2018

Yuting Li^{1,2†}, Xiaojing Yuan^{1,2†}, Qiutong Zheng^{1,2}, Fengxin Mo^{1,2}, Shiheng Zhu^{1,2}, Tianran Shen^{1,2}, Wenhan Yang^{1,2*} and Qingsong Chen^{1,2*}

Abstract

Background Hypertension is a worldwide public health problem. We sought to explore the interaction of oral health and smoking on hypertension, and periodontal disease and smoking on hypertension.

Methods We included 21,800 participants aged ≥ 30 years from the National Health and Nutrition Examination Survey (NHANES) 2009–2018. Information of oral health and periodontal disease were self-reported. Blood pressure was taken by trained personnel and/or physicians at mobile testing center. Multiple logistic regression was used to estimate the association between oral health, periodontal disease and the prevalence of hypertension. The effects of oral health and periodontal disease on hypertension under smoking status and age were analyzed by stratified and interaction analysis.

Results A total of 21,800 participants were investigated, including 11,017 (50.54%) in hypertensive group and 10,783 (49.46%) in non-hypertensive group. Compared with the excellent/very good of oral health, the multivariable-adjusted OR of good, fair, and poor were 1.13 (95% CI, 1.02–1.27), 1.30 (95% CI, 1.15–1.47), and 1.48 (95% CI, 1.22–1.79) (p for trend < 0.001) for hypertension, respectively. Compared without periodontal disease group, the multivariable-adjusted OR of periodontal disease for hypertension was 1.21 (95% CI, 1.09–1.35) (p for trend < 0.001). Furthermore, we found the interactions between periodontal disease and smoking, oral health and smoking, periodontal disease and age, oral health and age were $p < 0.001$.

Conclusions An association between oral health and periodontal disease with the prevalence of hypertension was identified. There exists interactive effect of periodontal disease and smoking, oral health and smoking, periodontal disease and age, oral health and age on hypertension in American population over 30 years of age and older.

Keywords Oral health, Periodontal disease, Smoking, Hypertension

[†]Yuting Li and Xiaojing Yuan contributed equally to this work.

*Correspondence:

Wenhan Yang
wenhan-yang@gdpu.edu.cn
Qingsong Chen
qingsongchen@aliyun.com

¹School of Public Health, Guangdong Pharmaceutical University, Guangzhou 510006, Guangdong Province, China

²Guangdong Provincial Engineering Research Center of Public Health Detection and Assessment(2019GCZX012), Guangdong Pharmaceutical University, Guangzhou 510310, Guangdong Province, China



© The Author(s) 2023. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, 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 changes were made. 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/4.0/>. The Creative Commons Public Domain Dedication waiver (<http://creativecommons.org/publicdomain/zero/1.0/>) applies to the data made available in this article, unless otherwise stated in a credit line to the data.

Introduction

Hypertension is a common chronic noncommunicable disease that affects the health of people worldwide and causes 10.4 million deaths each year [1]. About a third of the world's population is reported to be affected by high blood pressure, and premature deaths due to it have risen 56.1% in the past decade [2]. According to 2017 American College of Cardiology/American Heart Association guidelines, the overall crude prevalence of hypertension in American adults was 45.6% [3]. Hypertension is not only a high morbidity and mortality rate, but also a serious consumption of medical and social resources and a heavy economic burden on families and society [4].

Unhealth oral conditions and periodontal disease are important factors that affect the risk of high blood pressure [5–7]. Periodontal disease are common oral diseases with high prevalence worldwide [8]. Most studies show that there is a significant positive correlation between periodontal disease and hypertension [9–11]. Furthermore, there is a consistent association between cardiovascular disease (CVD) and oral health. One possible biological mechanism for this association is that the inflammatory mediators released into the local environment as a result of periodontitis could enter the blood stream and contribute to a systemic low-grade chronic inflammation known to be associated with an increased risk for future CVD [12]. This is mainly related to the low-grade systemic inflammation associated with poor periodontal health—characterized by increased C-reactive protein (CRP), interleukin-6 (IL-6), and fibrinogen levels [13].

It is well known that smoking is a risk for several diseases, including cardiovascular diseases [14] and oral diseases, especially periodontal diseases [15]. Epidemiological examinations reveal a strong correlation between smoking and inflammatory diseases of gingival and periodontal tissues and the mucosal surfaces [16]. Cigarette smoke has been shown to augment the production of pro-inflammatory cytokines such as tumor necrosis factor- α (TNF- α), interleukin (IL)-1, IL-6 and IL-8 and to decrease the levels of anti-inflammatory cytokines such as IL-10 [17]. Periodontitis is a chronic inflammatory disease, studies have shown that inflammation is the driving force behind neutrophil-mediated tissue degradation and alveolar bone loss in *P. gingivalis*-induced periodontitis [18]. Smoking increases the susceptibility of patients to infection of periodontopathogens and accelerates the progression of periodontitis via accelerating the destruction of periodontal supporting tissues, which increases the severity of periodontitis [19]. Pro-inflammatory T cell-derived cytokines such as interferon (IFN)- γ and TNF- α and IL-17 A exacerbate hypertensive responses mediating both endothelial dysfunction and cardiac injury [20]. The inflammatory response associated with

periodontitis is also considered to be an important factor affecting the regulation of blood pressure [21].

At present, there are many researches on the influencing factors of hypertension at home and abroad, but there are few reports on the interaction between the influencing factors of hypertension. The risk factors of disease do not exist alone, but are the result of many factors working together. Due to the interaction of various factors, when multiple factors work together on a result, the influence of a single factor may be enhanced or diminished. Therefore, through the interaction between factors, the real relationship between factors and results can be reflected [22]. This study aimed to: (1) investigate the association between oral health and periodontal disease with the prevalence of hypertension; (2) explore the interaction effect of oral health, periodontal disease and smoking on hypertension based on the National Health and Nutrition Examination Survey (NHANES) database in the United States.

Materials and methods

Study population

NHANES data by the centers for disease control and prevention, national center for health statistics web site at <https://www.cdc.gov/nchs/nhanes>. It a regular survey conducted by the National Center for Health Statistics at the U.S. Centers for Disease Control and Prevention. For analysis, we used data from the 2009–2018 National Health and Nutrition Examination Survey (NHANES), a cross-sectional, nationally representative sample of the non-institutionalized U.S. adult population. During interviews, trained staff conducted questionnaires to collect self-reported information on social demographic and health-related behaviors and prescription drug use. During the clinical examination, trained technicians measured height, weight and blood pressure, and collected blood and urine samples for laboratory tests. All participants provided informed consent.

Because periodontal assessment was only performed in people over 30 years of age and older during this survey. We finally included 21,800 participants after excluded those without the blood pressure ($n=19,398$), information for smoking, oral health, and periodontal disease ($n=1,090$).

Definition of variables

Blood pressure measurement

Blood pressure measurements were taken by trained personnel and/or physicians and all measurements were taken at mobile testing center. After resting in a sitting position for 5 min, blood pressure was measured with a mercury sphygmomanometer. A cuff of appropriate size was placed on the exposed right arm to obtain three consecutive blood pressure readings, and a fourth was

performed if the blood pressure measurement was interrupted or incomplete. In our analysis, we calculated an average of these measurements for each participant. The reasons participants were thought to have high blood pressure were defined by any affirmative answer of the following questions: “Have you ever been told by a doctor or other health professional that you have hypertension, also called high blood pressure?”; “are you now taking prescribed medicine for high blood pressure?”; or if they had a high biological measurement value (systolic blood pressure ≥ 140 mm Hg and/or diastolic blood pressure ≥ 90 mm Hg) [23].

Oral health and periodontal disease

In recent years, self-reported health status assessing systemic diseases and health-related conditions are widely used in populational investigations. Previous studies have shown that self-reported oral health questions and self-reported periodontal disease have good validity in larger populations [24–26]. Self-reported periodontal screening questions were adequately performed in identifying clinically periodontal disease [27]. Self-reported oral health is also an indicator with high reliability and validity, comparable to the results of an oral examination performed by a dentist [28, 29]. In conclusion, self-reported measures performed well in predicting oral health. However, the clinical measurement of periodontal disease only detects periodontitis as a single disease in NHANES study. The questionnaire defined periodontal disease as reflected by gum disease, including multiple gum diseases such as swollen gums, receding gums, sore or infected gums or loose teeth. Therefore, our study selected NHANES questionnaire data from 2009 to 2018 to reflect the relationship between oral health, periodontal disease and hypertension.

Oral health assessment uses the questionnaire survey results to conduct self-assessment through the following question: “Overall, how would you rate the health of your teeth and gums?” The answers were as follows: excellent, very good, good, fair and poor [30]. The oral health questionnaire was done before the physical examination, using the Computer-Assisted Personal Interviewing-CAPI (interviewer administered) system at home.

Periodontal disease assessment uses the questions: “Do you think you might have gum disease?” We treated this variable as a binary outcome: “self-aware of gum disease” (yes/no). If the answer to this question is yes, they are considered to have periodontal disease. Gum disease involves swollen gums, receding gums, sore or infected gums or loose teeth [31].

Covariates

Potential confounding factors for adjustment were age (continuous), sex, race (mexican American, other

hispanic, non-hispanic white, non-hispanic black and other race-including multi-racial), education (<high school, high school, > high school), body mass index (<18.5, 18.5~24.9, 25~29.9, ≥ 30), alcohol consumption (no drinks, ≤ 1 drink/week, > 1 drink/week), smoking (yes/no), physical activity (active or inactive), sleep duration (<7 h a night, 7 to 9 h a night, > 9 h a night), total cholesterol, HbA1c, creatinine, HDL, and triglycerides, sodium, fat, history of CVD (yes/no), diabetes (yes/no). Missing values for these covariates were treated as additional missing categories and their indicators dummy variables were included into the model.

Statistical analysis

Participants were divided into two groups in accordance with their hypertension status: group with and without hypertension. We analyzed all the data using survey weights, strata, and primary sampling units created by NCHS to allow for national estimates according to NHANES analytic guidelines [32]. Means and standard errors (SE) were used to describe quantitative variables (age, etc.) and inter-group comparisons were performed using the T-test. The number (n) and percentage (%) of categorical data were calculated, and the comparison between groups was performed by Chi-square (χ^2) test. Logistic regression models were used to assess the association between smoking, oral health, periodontal disease and the prevalence of hypertension. We conducted the sensitivity analysis on hypertension defined by measured blood pressure only (undiagnosed hypertension) and defined by physician diagnosed or treated disease. The effects of oral health and periodontal disease on hypertension under smoking status and age were analyzed by stratified analysis and interaction. We used SAS version 9.4 software (SAS Institute Inc, Cary, NC, USA) in all statistical analyses. Two-tailed *p*-values of <0.05 were considered statistically significant.

Results

Table 1 shows the general demographic characteristics of 21,800 participants. There are 48.40% male and 51.60% female. Of that, 11,017 (50.54%) were with hypertension and 10,783 (49.46%) without hypertension. Compared to persons without hypertension, persons in hypertension group tended to be older, smoke, have periodontal disease and fair/poor oral health, be more obese, have higher triglyceride, creatinine, HbA1c, and lower total-cholesterol and HDL.

Table 2 shows the association between oral health, periodontal disease and the prevalence of hypertension. Compared with the excellent/very good of oral health, the multivariable-adjusted OR of good, fair, and poor were 1.13 (95% CI, 1.02–1.27), 1.30 (95% CI, 1.15–1.47), and 1.48 (95% CI, 1.22–1.79) (*p* for trend <0.001) for

Table 1 Characteristics of overall participants according to hypertension status in NHANES, 2009–2018. (N = 21,800)

Variables	Non-hypertension	Hypertension	p-value
No. of participants	10,783(49.46)	11,017(50.54)	
Age, y, mean (SE)	47.95(0.24)	59.04(0.21)	< 0.001
Sex, N (%)			0.015
Male	5140(46.74)	5412(48.93)	
Female	5643(53.26)	5606(51.07)	
Race/ethnicity, N(%)			< 0.001
Mexican American	1753(9.21)	1283(5.90)	
Other Hispanic	1193(6.14)	1060(4.90)	
Non-Hispanic White	4363(67.38)	4469(68.23)	
Non-Hispanic Black	1742(8.35)	2964(13.68)	
Other Race-Including Multi-Racial	1732(8.91)	1241(7.29)	
Smoking, N(%)			< 0.001
Yes	4520(42.01)	5398(49.76)	
No	6263(57.99)	5619(50.24)	
Periodontal disease, N(%)			< 0.001
Yes	1905(16.47)	2178(19.92)	
No	8878(83.53)	8839(80.08)	
Oral Health, N(%)			< 0.001
Excellent/Very good	3584(40.87)	3185(34.83)	
Good	3779(34.00)	3757(34.00)	
Fair	2374(17.53)	2620(19.91)	
Poor	1046(7.60)	1455(11.27)	
Education, N(%)			< 0.001
<High school	2374(13.77)	2923(17.13)	
High school	2147(19.45)	2669(25.11)	
>High school	6252(66.74)	5407(57.66)	
Missing	10(0.01)	18(0.11)	
BMI, N(%)			< 0.001
< 18.5	232(1.83)	312(2.41)	
18.5 ~ 24.9	3330(31.28)	1949(16.17)	
25 ~ 29.9	3757(35.15)	3450(31.41)	
≥ 30	3440(31.51)	5286(49.83)	
Missing	24(0.23)	20(0.18)	
Sleep duration, N(%)			< 0.001
< 7	7679(68.23)	7672(67.52)	
7 ~ 9	2737(28.93)	2747(27.53)	
> 9	367(2.84)	598(4.95)	
Alcohol consumption, N(%)			< 0.001
No drinks	337(3.07)	615(4.87)	
≤ 1 drink/week	4745(45.21)	4039(39.46)	
> 1 drink/week	2145(25.24)	2072(23.82)	
Missing	3556(26.48)	4291(31.84)	
Physical activity, N(%)			< 0.001
Inactive	4390(44.76)	3976(41.37)	
Active	6384(55.20)	7037(58.62)	
Missing	9(0.05)	4(0.01)	
Total cholesterol, mg/dl, mean (SE)	197.71(0.67)	195.03(0.80)	< 0.001
Triglyceride, mg/dl, mean (SE)	146.27(1.85)	172.62(1.90)	< 0.001
Creatinine, mg/dl, mean (SE)	0.85(0.00)	0.95(0.01)	< 0.001
HDL, mg/dl, mean (SE)	55.11(0.31)	52.64(0.29)	< 0.001
HbA1c, mg/dl, mean (SE)	5.55(0.01)	5.98(0.01)	< 0.001
Sodium, mg, mean (SE)	3575.03(25.86)	3476.48(25.77)	< 0.001

Table 1 (continued)

Variables	Non-hypertension	Hypertension	p-value
Fat, g, mean (SE)	85.55(0.66)	81.87(0.63)	< 0.001
History of CVD, N(%)			< 0.001
Yes	537(4.31)	2257(17.90)	
No	10,218(95.53)	8681(81.54)	
Missing	28(0.16)	79(0.55)	
Diabetes, N(%)			< 0.001
Yes	874(5.79)	2872(21.86)	
No	732(6.93)	1232(12.00)	
Missing	9177(87.28)	6913(66.14)	

All N are analytic sample N

SE, standard error of mean

All % and mean (SE) are weighted in order to represent the USA population

BMI, body mass index; HbA1c, glycohemoglobin A1c;

HDL, high-density lipoprotein

hypertension, respectively. Compared without periodontal disease group, the multivariable-adjusted OR of periodontal disease for hypertension was 1.21 (95% CI, 1.09–1.35) (p for trend < 0.001). In the smoking group, compared with the excellent/very good of oral health, the multivariable-adjusted OR of good, fair, and poor were 1.13 (95% CI, 0.96–1.33), 1.11 (95% CI, 0.93–1.32), 1.31 (95% CI, 1.03–1.67) (p for trend = 0.013) for hypertension, respectively, and the multivariable-adjusted OR of periodontal disease for hypertension was 1.16 (95% CI, 0.98–1.37) (p for trend = 0.080), compared without periodontal disease. In the non-smoking group, compared with the excellent/very good of oral health, the multivariable-adjusted OR of good, fair, and poor were 1.12 (95% CI, 0.98–1.27), 1.49 (95% CI, 1.26–1.77), 1.62 (95% CI, 1.24–2.12) (p for trend = 0.032), and the multivariable-adjusted OR of periodontal disease for hypertension was 1.22 (95% CI, 1.01–1.47) (p for trend = 0.041), compared without periodontal disease group. The stratified analyses by the smoking shows the interactions between periodontal disease and smoking, oral health and smoking were $p < 0.001$. After subsequent adjustment for confounding's, we found the effect of oral health and periodontal disease on hypertension was more significant among non-smoking persons.

We presented the stratified analyses on hypertension defined by measured blood pressure only and defined by physician diagnosed or treated disease in Supplemental table I and table II. We still found a positive association between oral health and undiagnosed hypertension or physician diagnosed and treated hypertension, but the periodontal disease is only associated with physician diagnosed and treated hypertension.

Table 3 shows multivariable odds ratios (ORs, 95%CI) of prevalence of hypertension according to oral health, periodontal disease status, and stratified by age. We found the interactions between oral health and age or

between periodontal disease and age were $p < 0.001$. In the group younger than 45, compared with the excellent/very good of oral health, the multivariable-adjusted OR of good, fair, and poor were 1.11 (95% CI, 0.93–1.33), 1.27 (95% CI, 1.05–1.53), 1.71 (95% CI, 1.29–2.28) (p for trend < 0.001) for hypertension, respectively, and the multivariable-adjusted OR of periodontal disease for hypertension was 1.51 (95% CI, 1.27–1.79) (p for trend < 0.001), compared without periodontal disease. In the group older than 45, compared with the excellent/very good of oral health, the multivariable-adjusted OR of good, fair, and poor were 1.10 (95% CI, 0.98–1.24), 1.25 (95% CI, 1.07–1.46), 1.29 (95% CI, 1.07–1.55) (p for trend = 0.001), and the multivariable-adjusted OR of periodontal disease for hypertension was 1.05 (95% CI, 0.92–1.20) (p for trend = 0.444), compared without periodontal disease group. The interactions between periodontal disease and age, oral health and age were $p < 0.001$. After subsequent adjustment for confounding's, we found the effect of oral health and periodontal disease on hypertension was more significant among the group younger than 45.

Discussion

In this study of nationally representative data from NHANES 2009 to 2018 on people over the age of 30 in the United States, we found a positive association between oral health and periodontal disease with hypertension. After subsequent adjustment for confounding's, those with poor oral health or periodontal disease had a higher ORs for hypertension. And the effect of oral health and periodontal disease on hypertension was more significant among non-smoking persons and the group younger than 45. We also identified the interaction between periodontal disease and smoking, oral health and smoking, periodontal disease and age, oral health and age on hypertension.

Table 2 Multivariable odds ratios (ORs, 95%CI) of prevalence of hypertension and stratified by smoking status

	Cases/total participants	OR (95% CI)		
		Model 1	Model 2	Model 3
Oral health				
Excellent/Very good	3185/6769	1.00	1.00	1.00
Good	3757/7536	1.23(1.12–1.35)	1.14(1.03–1.26)	1.13(1.02–1.27)
Fair	2620/4994	1.48(1.32–1.65)	1.32(1.17–1.49)	1.30(1.15–1.47)
Poor	1455/2501	1.84(1.58–2.15)	1.49(1.24–1.79)	1.48(1.22–1.79)
P-trend		< 0.001	< 0.001	< 0.001
Non-Smoking				
Excellent/Very good	1801/4151	1.00	1.00	1.00
Good	2004/4320	1.19(1.03–1.38)	1.12(0.99–1.27)	1.12(0.98–1.27)
Fair	1293/2529	1.20(1.02–1.42)	1.51(1.27–1.79)	1.49(1.26–1.77)
Poor	521/882	1.49(1.22–1.82)	1.67(1.29–2.16)	1.62(1.24–2.12)
P-trend		< 0.001	< 0.001	0.032
Smoking				
Excellent/Very good	1384/2618	1.00	1.00	1.00
Good	1753/3216	1.22(1.07–1.38)	1.12(0.96–1.31)	1.13(0.96–1.33)
Fair	1327/2465	1.73(1.49–2.02)	1.11(0.94–1.30)	1.11(0.93–1.32)
Poor	934/1619	2.33(1.88–2.89)	1.29(1.02–1.63)	1.31(1.03–1.67)
P-trend		< 0.001	0.03	0.013
P-interaction	< 0.001			
Periodontal disease				
No	8839/17,717	1.00	1.00	1.00
Yes	2178/4083	1.35(1.22–1.49)	1.20(1.08–1.34)	1.21(1.09–1.35)
P-trend		< 0.001	< 0.001	< 0.001
Non-Smoking				
No	4664/10,018	1.00	1.00	1.00
Yes	955/1864	1.41(1.20–1.66)	1.19(0.99–1.44)	1.22(1.01–1.47)
P-trend		< 0.001	0.066	0.041
Smoking				
No	4175/7699	1.00	1.00	1.00
Yes	1223/2219	1.24(1.06–1.44)	1.14(0.98–1.34)	1.16(0.98–1.37)
P-trend		0.006	0.097	0.080
P-interaction	< 0.001			

Model 1: adjusted for age, sex, race/ethnicity, education

Model 2: Model 1 plus BMI, sleep duration, alcohol intake, physical activity, history of CVD, diabetes, sodium, fat

Model 3: Model 2 plus total cholesterol, creatinine, triglyceride, HbA1c, HDL.

Our result was consistent with the previous studies. In a large prospective cohort of 32,285 participants in France with a median follow-up of 8 years showed that arterial hypertension was associated with self-reported periodontal health, severe periodontitis (mPESS \geq 5) at baseline was an independent predictor of arterial hypertension development, the multivariable HR (95% CI) was 1.84 (1.66–2.03) compared with mPESS less than 5 [33]. A 12-year longitudinal health-examinee cohort study in South Korea showed that periodontal disease was significantly positively related to hypertension compared with normal hypertension (OR=1.04, 95% CI=1.01–1.07, $p<0.014$) after adjustment for sex, age, household income, insurance status, residence area, health status, and smoking status [34]. However, in

another prospective cohort of 31,543 male professionals (dentists, pharmacists, optometrists, podiatrists, osteopaths, and veterinarians) aged 40–75 years in the United States, there was no significant relationship between self-reported periodontal disease at baseline and the occurrence of hypertension at 20 years of follow-up (RR=1.04, 95% CI=0.98–1.10) [35]. Unlike this study, our results showed a significant positive relationship between periodontal disease and hypertension. The differences with our study may be explained by the differences in baseline age (>30 years old vs. 40–75 years old) and the study population (Americans over the age of 30 vs. male health professionals).

It has been indicated that smoking and age are important factors in the pathogenesis of hypertension [3, 6].

Table 3 Multivariable odds ratios (ORs, 95%CI) of prevalence of hypertension and stratified by age

	Cases/total participants	OR (95% CI)		
		Model 1	Model 2	Model 3
Oral health				
Age < 45				
Excellent/Very good	415/2053	1.00	1.00	1.00
Good	552/2298	1.23(1.04–1.46)	1.12(0.94–1.34)	1.11(0.93–1.33)
Fair	438/1598	1.50(1.25–1.80)	1.32(1.11–1.58)	1.27(1.05–1.53)
Poor	218/640	2.14(1.60–2.86)	1.81(1.35–2.41)	1.71(1.29–2.28)
P-trend		< 0.001	< 0.001	< 0.001
Age ≥ 45				
Excellent/Very good	2770/4716	1.00	1.00	1.00
Good	3205/5238	1.16(1.05–1.29)	1.11(0.99–1.24)	1.10(0.98–1.24)
Fair	2182/3396	1.33(1.15–1.53)	1.26(1.08–1.45)	1.25(1.07–1.46)
Poor	1237/1861	1.45(1.25–1.68)	1.31(1.11–1.54)	1.29(1.07–1.55)
P-trend		< 0.001	< 0.001	0.001
P-interaction	< 0.001			
Periodontal disease				
Age < 45				
No	1243/5381	1.00	1.00	1.00
Yes	380/1208	1.71(1.43–2.04)	1.52(1.29–1.81)	1.51(1.27–1.79)
P-trend		< 0.001	< 0.001	< 0.001
Age ≥ 45				
No	7596/12,336	1.00	1.00	1.00
Yes	1798/2875	1.08(0.96–1.21)	1.05(0.93–1.18)	1.05(0.92–1.20)
P-trend		0.21	0.444	0.444
P-interaction	< 0.001			

Model 1: adjusted for sex, race/ethnicity, education

Model 2: Model 1 plus BMI, sleep duration, alcohol intake, physical activity, smoking

Model 3: Model 2 plus total cholesterol, creatinine, triglyceride, HbA1c, HDL.

We stratified our analyses by the smoking status and age. Interestingly, the persons with poor oral health and periodontal disease in the non-smoking group and the group younger than 45 had a higher prevalence of hypertension in present study. This may be due to the following reasons: for smokers, it may be possible to follow dental advice longer after the diagnosis of poor oral health to increase oral health awareness, improve oral hygiene and smoking risk behaviors, which may lead smokers to subsequently reduce smoking or quit smoking and thus reduce the prevalence of hypertension; another explanation may be due to the statistical results only reflecting the large sample size (powers) or accidental findings. Participants in smoking group reported excellent oral health possibly because they were light smokers. However, some inevitable misclassification could have happened. But we still can observe a real association between oral health and hypertension among non-smokers. A cross-sectional study from Taiwan on Cardiorespiratory Fitness and Hospitalization Events in Armed Forces showed that systolic and diastolic blood pressure in 1,123 military participants were not associated with the risk of stage II/III periodontitis [36], which was contrary to our study. The differences may be explained by the differences in the

study population (military VS general population) and definition of periodontitis (clinical measurement VS self-reported). The effects of smoking on oral health range from life threatening conditions like oral cancer to tooth staining with potential jeopardies to oral health morbidity and tooth mortality. Various studies have shown smoking as a risk factor leading to an increase in the incidence and progression of periodontitis, contributing to tooth loss and edentulism as compared to non-smokers [37–39]. Therefore, reducing or not smoking will further improve oral health and reduce the prevalence of hypertension [40].

Our findings also in line with the previous study which is showed the association between dental calculus and hypertension (HTN) in Taiwanese military personnel aged 19–45 years. The study showed that poor oral health manifested by dental calculus was associated with a greater likelihood of CHTN (combined HTN) in young adults, and that there was a dose-dependent relationship between the number of teeth with any dental calculus and total HTN and CHTN [41]. A few studies revealed that the presence of dental calculus represents poor oral hygiene and is related to the greater risk of HTN [7]. In

other words, the worse the oral health, the higher the prevalence of hypertension.

The biologic mechanisms for oral health or periodontal disease and hypertension are not well understood. Some studies have found that patients with primary arterial hypertension in poor oral status are more susceptible to oxidative stress, which may result in increased levels of reactive metabolites of oxygen, lipid peroxidation, total antioxidant capacity. This could result in the inactivation of prostacyclin and NO. Hence, an enhancement of peripheral vascular resistance and hypertension [42, 43]. Periodontitis is a chronic infection that causes inflammation, particularly, the inflammatory response accompanying periodontitis has been proposed as an important factor that may exert adverse effects on the regulation of BP [21]. It is reported that periodontitis attenuates endothelium - dependent vasodilation in rats [44, 45]. The causes were increased systemic inflammatory biomarkers (CRP and IL-6), increased production of vascular superoxide free radicals, worsening lipid status, and decreased expression of vascular nitric oxide synthase-3 (NOS-3) [45]. However, periodontitis may also lead to an increased systemic immune response in patients [44]. A cross-sectional study found a positive correlation between gingival fluid TNF- α levels and blood pressure ($p < 0.05$), inducing a double inflammatory effect in patients with both periodontitis and hypertension [46]. Thus, inflammatory mediators such as C-reactive protein (CRP), tumor necrosis factor - α (TNF- α) and interleukin-6 (IL-6) may be the link between periodontitis and hypertension, and smoking may promote the co-occurrence and development of the two diseases as a common risk factor.

Dentists have been reported to be effective in motivating patients to quit smoking, with brief, repeated motivational interventions by physicians and other health professionals (including dentists) achieve long-term cessation success rates of about 16–20% [47]. A cross-sectional study using a theoretical model to study the importance of periodontal status on oral health-related quality of life in 195 adults with systemic arterial hypertension. The results showed that poor oral health-related quality of life was directly predicted by smoking ($\beta = 0.172$), more lost teeth ($\beta = 0.273$), more decayed teeth ($\beta = 0.198$) and worse periodontal status ($\beta = 0.293$) [48]. A cohort study of 8,139 participants with a median follow-up time of 6.59 years, 1,215 incident hypertension cases were identified. After adjustment for potential confounders, they found that brushing teeth once a day was associated with a 23% reduction in risk of hypertension (HR: 0.77, 95% CI: 0.60–0.98, $p < 0.05$), while brushing teeth at least twice a day was associated with a 45% reduction (HR: 0.55, 95% CI: 0.42–0.73, $p < 0.001$) [49]. Therefore, we can reduce the prevalence of hypertension by quitting smoking and taking regular oral hygiene care.

The strengths of our study are found in the following aspects. First, we used five cycles of high-quality, representative data on Americans from NHANES, which was large and multi-stage [50]. Secondly, previous studies have shown that periodontal disease and oral health are risk factors for hypertension, but no studies have shown that there is an interaction between them and smoking on hypertension. Here, we report for the first time an interactive effect of oral health and smoking, periodontal disease and smoking on the prevalence of hypertension in individuals over 30 years in the United States. Finally, self-rated oral health has the advantage of embodying the perspective of the participant and is considered to be a valid, reliable, and inexpensive way to measure overall oral health [51].

We declare several potential limitations in our study. Firstly, the oral health assessment in this study, the measure of periodontal disease was self-reported, it was subjective rather than objective, and there were individual differences [30, 31]. Self-reported measures may underestimate or overestimate the association between oral health/periodontal disease and hypertension. Secondly, this was a cross-sectional survey with poor accuracy and universality, so we cannot determine causality or exclude a two-way relationship. Finally, the study only included people over 30 years old, 18–29 people were not included in the analysis, and the results could not cover this population. Now the behavior of smoking is gradually becoming younger, because NHANES periodontal examination is conducted in people over 30 years of age and older, so this problem is inevitable in this study.

Conclusion

We found an association between oral health and periodontal disease and the prevalence of hypertension. There exists interactive effect of periodontal disease and smoking, oral health and smoking, periodontal disease and age, oral health and age on hypertension in American population over 30 years of age and older, and the effect of oral health and periodontal disease on hypertension was more significant among non-smoking persons and the group younger than 45.

Abbreviations

BP	Blood pressure
CRP	C-reactive protein
CVD	Cardiovascular disease
HbA1c	Glycosylated Hemoglobin
HDL	High density lipoprotein
HR	Hazard ratio
IFN	Interferon
IL-6	Interleukin-6
IL	Interleukin
mPSS	Severe periodontitis
N	Number
NCHS	National Center for Health Statistics
NHANES	National Health and Nutrition Examination Survey
NOS-3	Nitric oxide synthase-3

OR Odds ratio
SE Means and standard errors
TNF- α Factor- α
U.S. United States

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12889-023-16012-z>.

Supplementary Material 1

Acknowledgements

The authors would like to acknowledge the support from all the team members and Guangdong Pharmaceutical University.

Authors' contributions

Qingsong Chen has full access to all of the data in this study and assumes responsibility for study supervision. Qingsong Chen and Wenhan Yang conceptualized and designed the study, collected and analyzed data, carried out the initial analyses, reviewed and revised the manuscript. Yuting Li, Xiaojing Yuan, Qiutong Zheng, Fengxin Mo, Shiheng Zhu and Tianran Shen acquired, analyzed, and interpreted the data, and drafted the initial manuscript. All authors critically revised manuscripts of significant intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work. Yuting Li and Xiaojing Yuan contributed equally to this work.

Funding

No specific funding for this work.

Data Availability

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: <https://www.cdc.gov/nchs/nhanes>.

Declarations

Ethics approval and consent to participate

Data collection for the NHANES was approved by the NCHS Research Ethics Review Board (ERB). An individual investigator utilizing the publicly available NHANES data do not need to file the institution internal review board (IRB).

Consent for publication

Not applicable.

Competing interests

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 22 October 2022 / Accepted: 29 May 2023

Published online: 12 June 2023

References

- Global regional et al. and national comparative risk assessment of 84 behavioural, environmental and occupational, and metabolic risks or clusters of risks for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *Lancet* 2018, 392(10159):1923–1994.
- Virani SS, Alonso A, Benjamin EJ, Bittencourt MS, Callaway CW, Carson AP, Chamberlain AM, Chang AR, Cheng S, Dellings FN, et al. Heart Disease and Stroke Statistics-2020 update: a Report from the American Heart Association. *Circulation*. 2020;141(9):e139–e596.
- Muntner P, Carey RM, Gidding S, Jones DW, Taler SJ, Wright JT, Whelton PK. Potential US Population Impact of the 2017 ACC/AHA high blood pressure Guideline. *Circulation*. 2018;137(2):109–18.
- Song J-J, Ma Z, Wang J, Chen L-X, Zhong J-C. Gender differences in hypertension. *J Cardiovasc Transl Res*. 2020;13(1):47–54.
- Kim J, Kim HJ, Jeon J, Song T-J. Association between oral health and cardiovascular outcomes in patients with hypertension: a nationwide cohort study. *J Hypertens*. 2022;40(2):374–81.
- Viridis A, Giannarelli C, Neves MF, Taddei S, Ghiadoni L. Cigarette smoking and hypertension. *Curr Pharm Des*. 2010;16(23):2518–25.
- Kim N-H, Lee G-Y, Park S-K, Kim Y-J, Lee M-Y, Kim C-B. Provision of oral hygiene services as a potential method for preventing periodontal disease and control hypertension and diabetes in a community health centre in Korea. *Health Soc Care Community*. 2018;26(3):e378–85.
- Petersen PE. The World Oral Health Report. 2003: continuous improvement of oral health in the 21st century—the approach of the WHO Global Oral Health Programme. *Community Dent Oral Epidemiol* 2003, 31 Suppl 1.
- Shin H-S. Association between the number of teeth and hypertension in a study based on 13,561 participants. *J Periodontol*. 2018;89(4):397–406.
- Rivas-Tumanyan S, Campos M, Zevallos JC, Joshipura KJ. Periodontal disease, hypertension, and blood pressure among older adults in Puerto Rico. *J Periodontol*. 2013;84(2):203–11.
- Muñoz Aguilera E, Suvan J, Buti J, Czesnikiewicz-Guzik M, Barbosa Ribeiro A, Orlandi M, Guzik TJ, Hingorani AD, Nart J, D'Aiuto F. Periodontitis is associated with hypertension: a systematic review and meta-analysis. *Cardiovasc Res*. 2020;116(1):28–39.
- Holmlund A, Lampa E, Lind L. Oral health and cardiovascular disease risk in a cohort of periodontitis patients. *Atherosclerosis*. 2017;262:101–6.
- Southerland JH, Taylor GW, Moss K, Beck JD, Offenbacher S. Commonality in chronic inflammatory diseases: periodontitis, diabetes, and coronary artery disease. *Periodontol* 2000. 2006;40:130–43.
- Ambrose JA, Barua RS. The pathophysiology of cigarette smoking and cardiovascular disease: an update. *J Am Coll Cardiol*. 2004;43(10):1731–7.
- Genco RJ, Borgnakke WS. Risk factors for periodontal disease. *Periodontol* 2000. 2013;62(1):59–94.
- Offenbacher S. Periodontal diseases: pathogenesis. *Ann Periodontol*. 1996;1(1):821–78.
- Arnsion Y, Shoenfeld Y, Amital H. Effects of tobacco smoke on immunity, inflammation and autoimmunity. *J Autoimmun*. 2010;34(3):J258–65.
- Serhan CN, Jain A, Marleau S, Clish C, Kantarci A, Behbehani B, Colgan SP, Stahl GL, Merched A, Petasis NA, et al. Reduced inflammation and tissue damage in transgenic rabbits overexpressing 15-lipoxygenase and endogenous anti-inflammatory lipid mediators. *J Immunol*. 2003;171(12):6856–65.
- Zhang J, Yu J, Dou J, Hu P, Guo Q. The impact of smoking on Subgingival Plaque and the development of Periodontitis: A literature review. *Front Oral Health*. 2021;2:751099.
- Mikolajczyk TP, Guzik TJ. Adaptive immunity in hypertension. *Curr Hypertens Rep*. 2019;21(9):68.
- Leong X-F, Ng C-Y, Badiah B, Das S. Association between hypertension and periodontitis: possible mechanisms. *ScientificWorldJournal* 2014, 2014:768237.
- Li A-I, Peng Q, Shao Y-Q, Fang X, Zhang Y-Y. The interaction on hypertension between family history and diabetes and other risk factors. *Sci Rep*. 2021;11(1):4716.
- Chobanian AV, Bakris GL, Black HR, Cushman WC, Green LA, Izzo JL, Jones DW, Materson BJ, Oparil S, Wright JT, et al. The Seventh Report of the Joint National Committee on Prevention, detection, evaluation, and treatment of high blood pressure: the JNC 7 report. *JAMA*. 2003;289(19):2560–72.
- Buhlin K, Gustafsson A, Andersson K, Håkansson J, Klinge B. Validity and limitations of self-reported periodontal health. *Community Dent Oral Epidemiol*. 2002;30(6):431–7.
- Eke PI, Dye BA, Wei L, Slade GD, Thornton-Evans GO, Beck JD, Taylor GW, Borgnakke WS, Page RC, Genco RJ. Self-reported measures for surveillance of periodontitis. *J Dent Res*. 2013;92(11):1041–7.
- Khader Y, Alhabashneh R, Alhersh F. Development and validation of a self-reported periodontal disease measure among Jordanians. *Int Dent J*. 2015;65(4):203–10.
- Foster Page LA, Thomson WM, Broadbent JM. Validity of self-reported periodontal questions in a New Zealand cohort. *Clin Oral Investig*. 2016;20(3):563–9.
- Joshipura KJ, Douglass CW, Garcia RI, Valachovic R, Willett WC. Validity of a self-reported periodontal disease measure. *J Public Health Dent*. 1996;56(4):205–12.
- Meisel P, Holtfreter B, Völzke H, Kocher T. Self-reported oral health predicts tooth loss after five and ten years in a population-based study. *J Clin Periodontol*. 2018;45(10):1164–72.

30. Hung M, Moffat R, Gill G, Lauren E, Ruiz-Negrón B, Rosales MN, Richey J, Licari FW. Oral health as a gateway to overall health and well-being: Surveillance of the geriatric population in the United States. *Spec Care Dentist*. 2019;39(4):354–61.
31. Luo H, Wu B. Self-awareness of “Gum Disease” among US adults. *J Public Health Manag Pract*. 2017;23(2):e1–e7.
32. National health and nutrition examination survey. Survey methods and analytic guidelines [<https://www.cdc.gov/nchs/nhanes/analyticguidelines.aspx>]
33. Carra MC, Fessi S, Detzen L, Darnaud C, Julia C, Hercberg S, Touvier M, Andreva VA, Bouchard P. Self-reported periodontal health and incident hypertension: longitudinal evidence from the NutriNet-Santé e-cohort. *J Hypertens*. 2021;39(12):2422–30.
34. Lee J-H, Oh J-Y, Youk T-M, Jeong S-N, Kim Y-T, Choi S-H. Association between periodontal disease and non-communicable diseases: a 12-year longitudinal health-examinee cohort study in South Korea. *Med (Baltim)*. 2017;96(26):e7398.
35. Rivas-Tumanyan S, Spiegelman D, Curhan GC, Forman JP, Joshipura KJ. Periodontal disease and incidence of hypertension in the health professionals follow-up study. *Am J Hypertens*. 2012;25(7):770–6.
36. Tsai K-Z, Su F-Y, Cheng W-C, Huang R-Y, Lin Y-P, Lin G-M. Associations between metabolic biomarkers and localized stage II/III periodontitis in young adults: the CHIEF oral health study. *J Clin Periodontol*. 2021;48(12):1549–58.
37. LaMonte MJ, Hovey KM, Millen AE, Genco RJ, Wactawski-Wende J. Accuracy of self-reported periodontal disease in the Women’s Health Initiative Observational Study. *J Periodontol*. 2014;85(8):1006–18.
38. Leite FRM, Nascimento GG, Scheutz F, López R. Effect of smoking on Periodontitis: a systematic review and Meta-regression. *Am J Prev Med*. 2018;54(6):831–41.
39. Haber J. Smoking is a major risk factor for periodontitis. *Curr Opin Periodontol* 1994:12–8.
40. Alexandridi F, Tsantila S, Pepelassi E. Smoking cessation and response to periodontal treatment. *Aust Dent J*. 2018;63(2):140–9.
41. Tsai K-Z, Huang R-Y, Cheng W-C, Han C-L, Huang W-C, Sui X, Lavie CJ, Lin G-M. Association between Dental Calculus and Hypertension phenotypes in highly fit adults: CHIEF oral health study. *Am J Hypertens*. 2023;36(2):102–8.
42. Kolesnikova LR, Dolgih VV, Kolesnikova LI, Vlasov BY, Natyaganova LV. [The impact of arterial hypertension in children on dental decay activity]. *Stomatologiya (Mosk)*. 2016;95(2):26–9.
43. Digiesi V, Oliviero C, Giannò V, Rossetti M, Fiorillo C, Oradei A, Lenuzza M, Nassi P. [Reactive metabolites of oxygen, lipid peroxidation, total antioxidant capacity and vitamin E in essential arterial hypertension]. *Clin Ter*. 1997;148(11):515–9.
44. Gomes MS, Blattner TC, Sant’Ana Filho M, Grecca FS, Hugo FN, Fouad AF, Reynolds MA. Can apical periodontitis modify systemic levels of inflammatory markers? A systematic review and meta-analysis. *J Endod*. 2013;39(10):1205–17.
45. Brito LCW, DalBó S, Striechen TM, Farias JM, Olchanheski LR, Mendes RT, Velloso JCR, Fávero GM, Sordi R, Assreuy J, et al. Experimental periodontitis promotes transient vascular inflammation and endothelial dysfunction. *Arch Oral Biol*. 2013;58(9):1187–98.
46. Khocht A, Rogers T, Janal MN, Brown M. Gingival Fluid inflammatory biomarkers and hypertension in African Americans. *JDR Clin Trans Res*. 2017;2(3):269–77.
47. Fiore MC. US public health service clinical practice guideline: treating tobacco use and dependence. *Respir Care*. 2000;45(10):1200–62.
48. Rebelo MAB, de Castro PHD, Rebelo Vieira JM, Robinson PG, Vettore MV. Low social position, Periodontal Disease, and poor oral health-related quality of life in adults with systemic arterial hypertension. *J Periodontol*. 2016;87(12):1379–87.
49. Wang Y, Jiang Y, Chen Y, Yu L, Zhou J, Wang N, Liu T, Fu C. Associations of oral hygiene with incident hypertension and type 2 diabetes mellitus: a population based cohort study in Southwest China. *J Clin Hypertens (Greenwich)*. 2022;24(4):483–92.
50. National health and nutrition examination survey. Questionnaires, Datasets, and, Documentation R. [<https://www.cdc.gov/nchs/nhanes/default.aspx>]
51. Pattussi MP, Peres KG, Boing AF, Peres MA, da Costa JSD. Self-rated oral health and associated factors in Brazilian elders. *Community Dent Oral Epidemiol*. 2010;38(4):348–59.

Publisher’s Note

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