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The Relationship between Pulse Pressure and Periodontal Disease in Korean Populations with or without Hypertension

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Abstract: ***Aims*:** This study evaluated the relationship between pulse pressure (PP) and periodontal disease in Korean adults with or without hypertension (classified as HTN and non-HTN, respectively). ***Methods*:** Data on 3496 adults (≥20 years) were obtained from the Korean National Health and Nutrition Examination Survey (2015). We classified those with HTN as SBP ≥ 140 mmHg, DBP ≥ 90 mmHg, or current use of anti-hypertensive medications. ***Results*:** There were a few key findings: when logistic regression analysis was applied for periodontal disease (community periodontal index score ≥ 3), the odds ratios (OR) were significantly higher in the high PP (PP > 60 mmHg) than in the normal PP (PP ≤ 60 mmHg) in the HTN group (OR, 2.131; 95% confidence interval (CI), 1.579–2.876). However, periodontal disease was not associated with high PP in the non-HTN group and was not significant (OR, 0.866; 95% CI, 0.494–1.518). ***Conclusions*:** In Korean adults, periodontal disease was positively associated with PP in the HTN group but not in the non-HTN group.

Keywords: periodontal disease; community periodontal index scores; blood pressure; pulse pressure; hypertension

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1. Introduction

Hypertension (HTN) is one of the most urgent public health care problems worldwide and is defined as a diastolic blood pressure (DBP) of ≥ 90 mmHg or a systolic blood pressure (SBP) of ≥ 140 mmHg [1]. Risk factors for HTN include old age, chronic kidney disease (CKD), type 2 diabetes mellitus (T2DM), and obesity [2]. Pulse pressure (PP) is an important predictor of arterial stiffness and is an important risk factor for both cardiovascular disease and left ventricular hypertrophy [3,4]. The European blood pressure guidelines (2018) affirmed that a PP > 60 mm Hg in individuals with HTN was associated with cardiovascular risk [5]. In the Framingham Heart Study, an elevated PP was associated with increased and subsequent left ventricular hypertrophy, myocardial oxygen consumption, and left ventricular wall stress; an increase in PP levels of 10 mmHg increases the risk of coronary artery disease by 23% [6]. In particular, an increase in the PP of patients with HTN increases the incidence of myocardial stroke and infarction [7,8].

Periodontal disease is a strong cause of tooth loss and its prevalence ranges from 20% to 50% worldwide [9]. Periodontal disease is a multifactorial disease caused by immune mechanisms, genetic background, and pathogenic bacteria, and is associated with endothelial dysfunction and inflammation [10,11]. In addition, the resulting vascular stiffness and dysfunction that arises can contribute to the development of HTN [12,13].

Although several international studies on periodontal disease and HTN have been conducted, there are few studies on the association between PP and periodontal disease. Furthermore, findings are inconsistent across studies of different ethnicities and countries. In addition, when HTN is accompanied by high PP, few studies have examined their relationship with periodontal disease. Therefore, the purpose of this study was to investigate

the relationship between PP and periodontal disease in Korean adults with or without HTN. Data from the 6th Korean National Health and Nutrition Examination Survey (KNHANES VI-3) were used.

2. Methods

2.1. Study Participants

The KNHANES VI-3 is a cross-sectional survey conducted nationwide by the Division of Korean National Health and Welfare. This study analyzed data from the KNHANES VI-3 dataset. A total of 7380 individuals aged $\geq$ 1 year were sampled in the KNHANES VI-3 dataset. We limited the analyses to adults aged $\geq$ 20 years, with 5855 participants eligible for the current study. We then excluded 2359 participants with data that were missing for analytic variables, such as SBP, DBP, PP, community periodontal index (CPI), and various blood chemistry tests. This left a total of 3496 participants included in the statistical analysis. The KNHANES VI-3 study was conducted according to the principles expressed in the Declaration of Helsinki (Institutional Review Board No, 2015–01–02–6C). Participants in the study signed a written informed consent for this study. More detailed information can be found in "The KNHANES VI-3 Sample" on the KNHANES website.

2.2. General Characteristics and Blood Chemistry

Participants were classified by gender, regular exercise (no or yes), smoking status (non-smoker or current smoker), and alcohol status (no or yes). Regular exercise was indicated as "yes" for participants who had exercised on a regular basis regardless of whether this was indoors or outdoors. This was defined as 30 min at a time for 5 times/week in the case of moderate exercise, such as doubles tennis, badminton, volleyball, swimming slowly, and carrying light objects; and for 20 min at a time for 3 times/week in the case of vigorous exercise, such as climbing, running, swimming fast, cycling fast, squash, singles tennis, football, skipping, basketball, and carrying heavy objects. In the smoking category, participants who never smoked and those who smoked more than one cigarette a day were classified as non-smokers and current smokers, respectively. Alcohol status was indicated as "yes" for participants who had consumed at least one glass of alcoholic drink every month. Anthropometric measurements included waist circumference (WC), body mass index (BMI), DBP, and SBP. Blood chemistry included measurements of high-density lipoprotein cholesterol (HDL-C), triglycerides (TGs), total cholesterol (TC), fasting blood glucose (FBG), and high sensitivity C reactive protein (hs-CRP).

2.3. High PP, Hypertension, and Periodontal Disease

The CPI was used to define periodontal disease and assess its severity, as described previously [14]. Six sextants were examined (anterior mandible, anterior maxilla, posterior left maxilla, posterior right maxilla, posterior left mandible, and posterior right mandible). CPI was determined as the sum of the anterior mandible, anterior maxilla, posterior left maxilla, posterior right maxilla, posterior left mandible, and posterior right mandible. It is well known that the CPI score is used to record periodontal conditions. The CPI scores ranged from 0 to 4, with score 0 representing healthy status; score 1, bleeding on probing; score 2, calculus or conditions for dental plaque retention; score 3, 4 mm to 5 mm pocket depth; and score 4, $\geq$6 mm pocket depth. Periodontitis was defined as a CPI score $\geq$ 3 [15]. HTN was defined as the use of HTN medications, DBP $\geq$ 90 mmHg, or SBP $\geq$ 140 mmHg [1]. High PP was classified as >60 mmHg [16].

3. Statistical Analysis

The data were statistically analyzed using SPSS (version 18.0, IBM, Armonk, NY, USA). The distributions of characteristics were converted into percentages (%), and the successive data were presented as averages and standard deviations (M $\pm$ SD). The distribution and average difference in general characteristics according to the non-HTN and HTN groups were calculated using chi-square and *t*-tests (Table 1). The distribution and average

difference in clinical characteristics according to periodontitis in non-HTN and HTN groups were calculated using chi-square and *t*-tests (Table 2). A multiple linear regression analysis model was constructed for CPI after adjusting for gender, age, regular exercising, drinking, smoking, BMI, WC, TC, HDL-C, TGs, FBG, hs-CRP, and PP (Table 3). When an analysis of covariance test was performed for CPI scores, the four models constructed were: (1) adjusted for gender and age; (2) further adjusted for smoking, regular exercise, and drinking; (3) Model 2 further adjusted for BMI and WC; and (4) Model 3 further adjusted for TGs, HDL-C, TC, hs-CRP, and FBG (Table 4). When a logistic regression was performed for the OR of periodontitis, the four models constructed were: (1) non-adjusted; (2) adjusted for gender and age; (3) further adjusted for smoking, regular exercise, and drinking; and (4) further adjusted for BMI, WC, HDL-C, TGs, TC, hs-CRP, and FBG (Table 5). The significance level for all statistical data was set at $p < 0.05$.

Table 1. General clinical characteristics. *n* (%), Mean ± SD.

Variables	Category	Overall (*n* = 3496)	Non-HTN (*n* = 2415)	HTN (*n* = 1081)	*p*
Age (years)		51.47 ± 16.13	46.69 ± 15.38	62.14 ± 12.16	0.945
Gender	Men	1515 (43.3)	992 (41.1)	523 (48.4)	<0.001
Drinking	Current drinker	1838 (52.6)	1301 (53.9)	537 (49.7)	0.022
Smoking	Current smoker	581 (16.6)	400 (16.6)	181 (16.7)	0.895
Exercising	Regular exerciser	353 (10.1)	264 (40.9)	89 (8.2)	0.014
SBP (mmHg)		118.54 ± 16.68	112.03 ± 11.82	133.08 ± 16.80	<0.001
DBP (mmHg)		75.05 ± 10.16	72.75 ± 8.12	80.19 ± 12.17	<0.001
PP (mmHg)		43.49 ± 13.15	39.28 ± 9.28	52.88 ± 15.45	<0.001
	Normal PP	3117 (89.2)	2341 (96.9)	776 (71.8)	<0.001
	High PP	379 (10.8)	74 (3.1)	305 (28.2)	
BMI (kg/m^2)		23.97 ± 3.49	23.41 ± 3.36	25.23 ± 3.43	<0.001
WC (cm)		82.84 ± 10.04	80.80 ± 9.67	87.39 ± 9.34	<0.001
TC (mg/dL)		190.75 ± 36.18	191.04 ± 34.99	190.11 ± 38.72	0.483
TGs (mg/dL)		136.25 ± 104.63	126.69 ± 100.59	157.62 ± 110.24	<0.001
HDL-C (mg/dL)		50.90 ± 12.77	52.01 ± 12.77	48.43 ± 12.41	<0.001
FBG (mg/dL)		100.69 ± 23.13	97.94 ± 22.19	106.81 ± 24.02	<0.001
hs-CRP (mg/L)		1.30 ± 2.40	1.21 ± 2.33	1.48 ± 2.55	0.003
CPI	CPI-UM	0.31 ± 0.82	0.74 ± 1.25	0.92 ± 1.34	<0.001
	CPI-LM	1.16 ± 1.02	0.27 ± 0.76	0.41 ± 0.94	<0.001
	CPI-UR	0.79 ± 1.28	0.63 ± 1.17	0.88 ± 1.31	<0.001
	CPI-UL	0.71 ± 1.22	0.58 ± 1.07	0.89 ± 1.26	<0.001
	CPI-LR	0.68 ± 1.14	1.11 ± 1.01	1.26 ± 1.02	<0.001
	CPI-LL	0.58 ± 1.07	0.51 ± 1.01	0.72 ± 1.18	<0.001
CPI scores		4.22 ± 4.90	3.84 ± 4.63	5.08 ± 5.38	<0.001
	CPI < 3	2498 (71.5)	1792 (74.2)	706 (65.3)	<0.001
	CPI ≥ 3	998 (28.5)	623 (25.8)	375 (34.7)	

Non-HTN, SBP < 140 mmHg or DBP < 90 mmHg; HTN, SBP ≥ 140 mmHg, DBP ≥ 90 mmHg, or HTN medications; SBP, systolic blood pressure; DBP, diastolic blood pressure; PP, pulse pressure; Normal PP, PP ≤ 60 mmHg; High PP, PP > 60 mmHg; BMI, body mass index; WC, waist circumference; TC, total Cholesterol; TGs, triglycerides; HDL-C, high density lipoprotein cholesterol; FBG, fasting blood glucose; hs-CRP, high sensitivity C reactive protein; CPI, Community periodontal Index; CPI-UM, anterior maxilla; CPI-LM, anterior mandible; CPI-UR, posterior right maxilla; CPI-UL, posterior left maxilla; CPI-LR, posterior right mandible; CPI-LL, posterior left mandible.

Table 2. General clinical characteristics according to periodontal disease in overall, non-HTN, and HTN groups.

Variables	Overall (*n* = 3496)		*p*	Non-HTN (*n* = 2415)		*p*	HTN (*n* = 1081)		*p*
	Non-Periodontal Disease (*n* = 2498)	Periodontal Disease (*n* = 998)		Non-Periodontal Disease (*n* = 1792)	Periodontal Disease (*n* = 623)		Non-Periodontal Disease (*n* = 706)	Periodontal Disease (*n* = 375)	
CPI	1.88 ± 2.39	10.08 ± 4.68	<0.001	1.80 ± 2.36	9.71 ± 4.53	<0.001	2.09 ± 2.45	10.70 ± 4.87	<0.001
Age (years)	50.84 ± 15.92	53.04 ± 4.68	<0.001	46.71 ± 15.20	46.66 ± 15.89	0.946	61.34 ± 12.54	63.65 ± 11.30	0.003
Men	1093 (43.8)	422 (42.3)	0.428	754 (42.1)	238 (38.2)	0.090	339 (48.0)	184 (49.1)	0.742
Current drinker	1338 (53.6)s	500 (50.1)	0.064	979 (54.6)	322 (51.7)	0.204	359 (50.8)	178 (47.5)	0.290
Current smoker	436 (17.6)	142 (14.2)	0.016	308 (17.2)	92 (14.8)	0.162	131 (18.6)	50 (13.3)	0.029
Regular exerciser	250 (10.0)	103 (10.3)	0.782	191 (72.3)	73 (11.7)	0.466	59 (8.4)	30 (8.0)	0.839
SBP (mmHg)	117.20 ± 15.41	121.87 ± 15.41	<0.001	111.96 ± 1.79	112.21 ± 11.91	0.659	130.50 ± 15.53	137.93 ± 18.01	<0.001
DBP (mmHg)	74.69 ± 9.91	75.94 ± 10.70	0.001	72.71 ± 8.17	72.87 ± 7.99	0.663	79.75 ± 11.96	81.04 ± 12.53	0.097
PP (mmHg)	42.51 ± 12.17	45.93 ± 15.06	<0.001	39.26 ± 9.18	39.34 ± 9.58	0.856	50.76 ± 14.67	56.89 ± 16.09	<0.001
High PP	216 (8.6)	163 (16.3)	<0.001	56 (3.1)	18 (2.9)	0.769	160 (22.7)	145 (48.5)	<0.001
BMI (kg/m^2)	23.92 ± 3.48	24.10 ± 3.52	0.185	23.39 ± 3.35	23.46 ± 3.40	0.668	25.28 ± 14.67	25.16 ± 3.46	0.591
WC (cm)	82.62 ± 9.97	83.39 ± 10.20	0.039	80.72 ± 9.56	81.02 ± 10.00	0.511	87.42 ± 9.38	87.34 ± 9.28	0.885
TC (mg/dL)	190.88 ± 36.39	190.44 ± 35.68	0.747	191.29 ± 35.40	190.30 ± 33.82	0.538	189.81 ± 38.81	190.68 ± 38.61	0.725
TGs (mg/dL)	136.79 ± 107.27	134.89 ± 97.75	0.626	127.90 ± 102.16	123.20 ± 95.92	0.315	159.39 ± 116.33	154.30 ± 97.81	0.470
HDL-C (mg/dL)	52.93 ± 12.66	50.83 ± 13.04	0.829	51.87 ± 12.71	52.41 ± 12.96	0.365	48.55 ± 12.22	48.20 ± 12.77	0.661
FBG (mg/dL)	100.27 ± 21.98	101.73 ± 25.78	0.090	97.62 ± 20.59	98.89 ± 26.26	0.218	106.99 ± 23.90	106.46 ± 24.27	0.728
hs-CRP (mg/L)	1.29 ± 2.43	1.31 ± 2.24	0.776	1.19 ± 2.31	1.29 ± 2.39	0.347	1.54 ± 2.70	1.35 ± 2.26	0.244

Non-periodontal disease, CPI scores < 3; Periodontal disease, CPI scores ≥ 3; High PP, PP > 60 mmHg.

Table 3. Linear regression analysis of independent factors determining community periodontal index scores.

Variables	Community Periodontal Index (CPI) Scores											
	Overall (*n* = 3496)				Non-HTN (*n* = 2415)				HTN (*n* = 1081)			
	β	SE	*p*	95% CI	*β*	SE	*p*	95% CI	*β*	SE	*p*	95% CI
Age (years)	−0.018	0.007	0.438	−0.019–0.008	−0.035	0.008	0.174	−0.026–0.005	−0.006	0.019	0.893	−0.040–0.035
Men	0.019	0.226	0.406	−0.256–0.632	0.035	0.265	0.225	−0.198–0.841	−0.033	0.444	0.428	−1.223–0.519
Current drinker	0.025	0.016	0.237	−0.012–0.050	0.040	0.019	0.111	−0.007–0.066	−0.025	0.031	0.547	−0.080–0.043
Current smoker	−0.036	0.252	0.081	−0.934–0.055	−0.045	0.292	0.070	−1.102–0.043	−0.010	0.502	0.795	−1.115–0.855
Regular exerciser	0.009	0.282	0.606	−0.408–0.699	0.021	0.313	0.325	−0.036–0.921	−0.021	0.618	0.550	−1.583–0.844
BMI (kg/m^2)	0.055	0.021	0.217	−0.016–0.068	0.058	0.025	0.272	−0.022–0.077	0.047	0.043	0.527	−0.055–0.108
WC (cm)	−0.016	0.056	0.699	−0.131–0.088	−0.029	0.065	0.544	−0.166–0.088	0.001	0.110	0.999	−0.216–0.217
TC (mg/dL)	0.019	0.003	0.366	−0.003–0.008	0.015	0.003	0.537	−0.004–0.009	0.035	0.005	0.369	−0.006–0.015
TGs (mg/dL)	−0.031	0.001	0.176	−0.003–0.001	−0.019	0.001	0.473	−0.003–0.002	−0.059	0.002	0.164	−0.006–0.001
HDL-C (mg/dL)	−0.001	0.009	0.985	−0.017–0.017	0.001	0.010	0.994	−0.020–0.020	−0.001	0.018	0.976	−0.035–0.034
FBG (mg/dL)	0.036	0.004	0.069	−0.001–0.016	0.065	0.005	0.005	0.004–0.023	−0.021	0.008	0.554	−0.021–0.011
hs-CRP (mg/L)	0.017	0.037	0.346	−0.038–0.109	0.031	0.044	0.164	−0.025–0.148	−0.017	0.071	0.622	−0.175–0.105
PP (mmHg)	0.128	0.008	< 0.001	0.033–0.066	0.041	0.012	0.091	−0.003–0.045	0.173	0.014	<0.001	0.034–0.087

Table 4. Comparisons of the community periodontal index scores and pulse pressure in overall, non-HTN, and HTN groups.

Gender	Category	Community Periodontal Index (CPI) Scores			
		Model 1	Model 2	Model 3	Model 4
Overall (*n* = 3496)	Normal PP	4.05 ± 0.09 (3.88–4.22)	4.05 ± 0.09 (3.88–4.22)	4.05 ± 0.09 (3.88–4.22)	4.05 ± 0.09 (3.88–4.23)
	High PP	5.64 ± 0.27 (5.12–6.17)	5.64 ± 0.27 (5.12–6.17)	5.63 ± 0.27 (5.10–6.15)	5.61 ± 0.27 (5.09–6.14)
	p	<0.001	<0.001	<0.001	<0.001
Non-HTN (*n* = 2415)	Normal PP	3.84 ± 0.10 (3.65–4.02)	3.84 ± 0.10 (3.65–4.02)	3.84 ± 0.10 (3.65–4.02)	3.84 ± 0.10 (3.65–4.03)
	High PP	3.95 ± 0.55 (2.87–5.04)	3.95 ± 0.55 (2.86–5.03)	3.89 ± 0.55 (2.81–4.98)	3.84 ± 0.56 (2.75–4.93)
	p	0.835	0.842	0.919	0.999

Table 4. *Cont.*

Gender	Category	Community Periodontal Index (CPI) Scores			
		Model 1	Model 2	Model 3	Model 4
HTN (n = 1081)	Normal PP	4.63 ± 0.20 (4.25–5.02)	4.64 ± 0.20 (4.26–5.02)	4.64 ± 0.20 (4.25–5.02)	4.63 ± 0.20 (4.24–5.01)
	High PP	6.21 ± 0.32 (5.58–6.84)	6.20 ± 0.32 (5.57–6.80)	6.21 ± 0.32 (5.57–6.84)	6.23 ± 0.32 (5.59–6.87)
	p	<0.001	<0.001	<0.001	<0.001

Non-HTN, SBP < 140 mmHg or DBP < 90 mmHg; HTN, SBP ≥ 140 mmHg, DBP ≥ 90 mmHg, or HTN medications; Normal PP, PP ≤ 60 mmHg; High PP, PP > 60 mmHg. Model 1 [M ± SE, 95% CI], adjusted for gender and age; Model 2 [M ± SE, 95% CI], Model 1 further adjusted for regular exercising, smoking, and drinking; Model 3 [M ± SE, 95% CI], Model 2 further adjusted for BMI and WC; Model 4 [M ± SE, 95% CI], Model 3 further adjusted for TGs, TC, HDL-C, hs-CRP, and FBG.

Table 5. Comparisons of periodontal disease and high pulse pressure in overall, non-HTN, and HTN groups.

Gender	Category	Periodontal Disease			
		Model 1	Model 2	Model 3	Model 4
Overall (n = 3496)	Normal PP	1	1	1	1
	High PP	2.062 (1.658–2.565)	1.937 (1.526–2.458)	1.940 (1.529–2.463)	1.921 (1.512–2.444)
Non-HTN (n = 2415)	Normal PP	1	1	1	1
	High PP	0.922 (0.538–1.581)	0.826 (0.540–1.637)	0.936 (0.537–1.630)	0.866 (0.494–1.518)
HTN (n = 1081)	Normal PP	1	1	1	1
	High PP	2.151 (1.638–2.825)	2.044 (1.523–2.743)	2.070 (1.540–2.782)	2.131 (1.579–2.876)

Periodontal disease, CPI scores ≥ 3; Non-HTN, SBP < 140 mmHg or DBP < 90 mmHg; HTN, SBP ≥ 140 mmHg, DBP ≥ 90 mmHg, or HTN medications; Normal PP, PP ≤ 60 mmHg; High PP, PP > 60 mmHg. Model 1 [OR, 95% CI], non-adjusted; Model 2 [OR, 95% CI], adjusted for gender and age; Model 3 [OR, 95% CI], Model 2 further adjusted for regular exercising, smoking, and drinking; Model 4 [OR, 95% CI], Model 3 further adjusted for BMI, WC, TGs, TC, HDL-C, hs-CRP, and FBG.

4. Results

4.1. Clinical Characteristics of Participants According to the Non-HTN and HTN

The clinical characteristics of participants in the non-HTN and HTN groups are presented in Table 1. The prevalence of high PP and periodontal disease in the overall population was 379 (10.8%) and 998 (28.5%), respectively. SBP, DBP, PP, CPI scores, high PP, and periodontal disease in the HTN group were higher than those in the non-HTN group (all, $p < 0.001$).

4.2. Clinical Characteristics of Participants According to Periodontal Disease

Clinical characteristics according to periodontal disease in the overall population, non-HTN group, and HTN group are presented in Table 2. In the overall population, SBP, DBP, PP, and high PP in the periodontal disease group were higher than in the non-periodontal disease group (all, $p < 0.001$). In the HTN group, SBP, PP, and high PP in the periodontal disease group were higher than in the non-periodontal disease group (all, $p < 0.001$). DBP ($p = 0.097$) was not significant. However, SBP ($p = 0.659$), DBP ($p = 0.663$), PP ($p = 0.856$), and high PP ($p = 0.769$) in both the non-periodontal disease and periodontal disease group were not significant.

4.3. Multiple Linear Regression Analysis for Independent Factors Determining CPI Scores

Multiple linear regression analysis results for independent factors determining CPI scores are presented in Table 3. CPI scores were positively associated with PP in the overall population (β, 0.128; 95% confidence interval (CI), 0.033 to 0.066) and HTN group (β, 0.173; 95% CI, 0.034 to 0.087). However, CPI was positively associated with PP in the non-HTN group (β, 0.041; 95% CI, −0.003 to 0.045).

4.4. Comparisons of CPI Scores and High PP

Comparisons of CPI scores and high PP in the non-HTN group, HTN group, and overall population are presented in Table 4. In the overall population, after adjusting for related variables (age, regular exercise, smoking, alcohol drinking, WC, BMI, HDL-C, TGs, TC, hs-CRP, and FBG), the CPI scores (M ± SE, 95% CI) in the high PP group (5.61 ± 0.27, 5.09–6.14) were significantly higher ($p < 0.001$) than those in the normal PP group (4.05 ± 0.09, 3.88–4.23). In the HTN group, the CPI scores (M ± SE, 95% CI) in the high PP group (6.23 ± 0.32, 5.59–6.87) were significantly higher ($p < 0.001$) than those in the normal PP group (4.24 ± 0.20, 4.24–5.01). However, there was no significant difference ($p = 0.999$) in scores (M ± SE, 95% CI) between the high PP (3.84 ± 0.56, 2.75–4.93) and normal PP group (3.84 ± 0.10, 3.65–4.03).

4.5. Comparisons of Periodontal Disease and High PP

Comparisons of periodontal disease and high PP in the overall population, non-HTN group, and HTN group are presented in Table 5. After adjusting for the related variables, the ORs for periodontal disease were significantly higher in the high PP than the normal PP in the overall population (OR, 1.921; 95% CI, 1.512–2.444) and HTN group (OR, 2.131; 95% CI, 1.579–2.876). However, the results in the non-HTN group were not significant (OR, 0.866; 95% CI, 0.494–1.518).

5. Discussion

This study conducted the association between PP and periodontal disease in Korean adults with or without HTN. Periodontal disease was positively associated with high PP in Korean adults with HTN but not in those without HTN.

Higher SBP can induce chronic left ventricular overload, leading to myocardial wall stress and enhanced myocardial wall stress. In addition, lower DBP can reduce coronary perfusion pressure, which can decrease myocardial oxygen supply [17]. PP is well established as a predictor of atherosclerosis, coronary heart disease, and left ventricular hypertrophy [18–20]. Periodontal disease is a multifactorial disease involving chronic 'infectious/inflammatory' factors [21] and plays an important role in chronic inflammation [22]. Czesnikiewicz-Guzik et al. reported that levels of pro- and anti-inflammatory cytokines (IFN-γ, IL-17A, IL-6, and TNF-α) decreased in an intensive periodontal treatment group and that these are the cytokines associated with cardiovascular disease and systemic HTN [23]. Several studies have investigated the relationship between cardiovascular disease and periodontal disease [24–26]. In a study of 897 Japanese patients with cardiovascular disease, increased periodontal disease was found in coronary heart disease patients compared to non-coronary heart disease patients [24]. In a meta-analysis of nine cohort studies, periodontal disease increased the event of stroke (relative risk, 1.63; 95% CI, 1.25–2.00) [25]. In a cohort study of 8999 patients with periodontal disease, participants who were not active during periodontal disease treatment had an increased incidence of cardiovascular disease events (incidence rate (IR), 1.28; 95% CI, 1.07 to 1.53) compared with those who were active during periodontal treatment [26]. In addition, the results suggested that periodontal treatment can reduce the cardiovascular disease events.

Currently, periodontal disease and blood pressure are closely related—especially SBP. Machado et al. revealed that periodontal disease was positively associated with SBP ($p < 0.001$) but was not associated with DBP ($p = 0.082$) [27]. In a case–control study, periodontal disease was positively associated with SBP ($\beta = 3.46 \pm 1.25$, $p = 0.005$) and the odds of HTN (OR, 2.3; 95% CI, 1.15–4.60). In addition, they mentioned that the treatment of periodontal disease could help reduce the prevalence of HTN and its complications [28]. In our results, periodontal disease was associated with SBP (area under the curve (AUC), 0.636; 95% CI, 0.600–0.672; $p < 0.001$) in the HTN group but was not associated with DBP (AUC, 0.526; 95% CI, 0.489–0.562; $p = 0.167$). In addition, periodontal disease was not associated with both SBP (AUC, 0.503; 95% CI, 0.476–0.529; $p = 0.849$) and DBP (AUC, 0.508; 95% CI, 0.482–0.534; $p = 0.574$) in the non-HTN group (Supplementary Table S1).

The relationship between periodontal disease and PP is not yet clear and the results in previous studies have been inconsistent. Franek et al. revealed that CPI was positively associated with aortic SBP (p = 0.03; 95% CI, 0.27 to 7.76) in patients with essential HTN but not with the left ventricular mass index (p = 0.06; 95% CI, −0.30 to 16.6) [29]. Łysek et al. reported that the OR of HTN (OR, 3.38; 95% CI, 1.30–9.42) in a periodontal disease group (CPI 3 + 4) was higher than in the normal group (CPI 1 + 2), whereas the OR of high PP (OR, 1.77; 95% CI, 0.65–4.90) was not [30]. By contrast, in a meta-analysis of seven cohort studies, the estimated relative risk of coronary heart disease for different categories of periodontal disease (including tooth loss, bone loss, gingivitis, and periodontitis) ranged from 1.24 to 1.34 [31]. Angeli et al. reported that periodontal disease in participants with HTN was positively associated with interventricular septum thickness, left ventricular internal diameter, and left ventricular posterior wall thickness (all, $p < 0.0001$) [32]. In addition, they suggested there is an association between the severity of the left ventricular mass and periodontitis in participants with essential HTN. We believe that these inconsistent results can be due to differences in the presence or absence of cardiovascular disease such as HTN. In our study, CPI or periodontal disease were positively associated with PP levels (β, 0.128; 95% CI, 0.033–0.066) or high PP (OR, 1.921; 95% CI, 1.512–2.444) in the overall population (Tables 3 and 5). However, when non-HTN and HTN groups were analyzed separately, the results for each group were different. In the HTN group, CPI or periodontal disease were positively associated with PP levels (β, 0.173; 95% CI, 0.034–0.087) or high PP (OR, 2.131; 95% CI, 1.579–2.876). However, in the non-HTN group, the associations of CPI or periodontal disease with PP levels (β, 0.041; 95% CI, −0.003–0.045) or high PP (OR, 0.866; 95% CI, 0.494–1.518) were not significant. Compared to normotensive populations, periodontitis in hypertensive populations can show alterations in endothelial and increased cardiovascular risk [33]. A decline in endothelial function is closely related to increases in aortic stiffness and PP [34]. On the contrary, the adverse effect of hypertension on periodontal tissues cannot be excluded. Alterations in microcirculation in subjects with HTN can lead to periodontal ischemia, which can cause periodontal disease [35].

PP is a predictor for atherosclerosis, coronary heart disease, and left ventricular hypertrophy, but may have poor predictive function with normotensive blood pressure. In the Systolic Hypertension Test in the Elderly Program trial, every 10 mmHg increase in PP in the HTN group increased the risk of heart failure by 32% and stroke by 24%; however, the incidence of coronary heart disease was not associated with PP in either the non-HTN or HTN groups [36]. In addition, Su et al. reported that elevated PP is strongly associated with carotid atherosclerosis in patients with HTN, but not in those with normal blood pressure [37]. The mechanism underpinning the association of periodontal disease and PP in population with HTN has not yet been established. However, in patients with HTN, hypertrophic heart and periodontal disease may share arteriolar and capillary rarefaction and microcirculatory dysfunction [38,39]. Pressure overload causes left ventricular hypertrophy to develop, which can narrow the lumen diameter of microvessels [40]. The limitation of the present study was that its cross-sectional design made it difficult to establish a causal relationship between PP and periodontal disease in the hypertensive population. Nevertheless, this study is the first reported study to determine the association of periodontal disease and PP in Korean adults with hypertension. Therefore, if a cohort study of their relationship was conducted, more generalizable and accurate results might be obtained.

6. Conclusions

We conducted a study on the association of PP with periodontal disease in Korean adults with or without HTN. PP was positively associated with periodontal disease in the HTN group but not in the non-HTN group. In the hypertensive population, periodontal disease was associated with an increase in PP, which may link periodontal disease with cardiovascular disease and coronary artery disease in the hypertensive population.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/app12104973/s1, Table S1: Receiver-operating characteristic curve analysis for SBP, DBP, and PP associated with the prevalence of periodontal disease.

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Data Availability Statement: The information can be found in relation to the KNHANES VI-3 Sample on the KDCA website. The data from KNHANES VI-3 is available on request by email if the applicant logs on to the KDCA website.

Conflicts of Interest: The authors state that they have no conflict of interest.

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