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ORIGINAL ARTICLE

Oral Health and Blood Pressure: The IPC Cohort

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BACKGROUND
Chronic periodontal diseases involve bacteria-induced inflammation of the tissues supporting the teeth. An inflammatory origin for hypertension has been proposed, and periodontal diseases are associated with an increased risk of vascular disease. The present study was performed to assess whether oral health conditions were associated with the risk of hypertension in adult population.

METHODS
The sample comprised 102,330 subjects, who underwent medical and oral examinations between 2002 and 2011. A full-mouth clinical examination was performed using simplified plaque index, calculus index, and simplified modified gingival index to assess dental plaque, dental calculus and gingival inflammation. The number of teeth was recorded. Biological parameters, including blood pressure were assessed. A subset analysis according to age (<65 or ≥65 years) was conducted. The association between blood pressure and oral conditions was explored using a logistic regression approach.

RESULTS
In the sample of subject ≥65 years, no significant association was found between oral variables and the risk of hypertension. In subset <65 years, oral variables and risk of hypertension were associated. Insufficient masticatory function and missing teeth (>10) showed odds ratio (OR) = 1.20 [95% CI = 1.08–1.32] and OR = 1.17 [95% CI = 1.04–1.31], respectively. Hypertension was also associated with high level of dental plaque [OR = 1.90, 95% CI = 1.55–2.33], dental calculus [OR = 1.18, 95% CI = 1.07–1.29] and gingival inflammation [OR = 1.56, 95% CI = 1.35–1.80] Moreover, in this subset <65 years, the risk of hypertension increases with the number of dental exposure.

CONCLUSIONS
The present study indicates that insufficient masticatory function, poor oral hygiene, and oral inflammation are associated with hypertension in subject <65.

Keywords: cardiovascular diseases, dental occlusion, high blood pressure, hypertension, oral hygiene, periodontal diseases, tooth loss.

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The worldwide prevalence of hypertension is forecast to reach 29.2% by 2025.[1] Cardiovascular diseases (CVD), particularly ischemic heart disease and stroke, were among the leading causes of death worldwide between 2002 and 2012.[2] According to WHO projections for 2030, this trend will likely continue.[3] Several lines of evidence show that low-grade inflammation plays a key role in increasing CVD,[4] and hypertension can be considered a state of systemic inflammation. However, it is difficult to determine whether the proinflammatory state associated with hypertension is a cause or a consequence of CVD.[5] Poor oral health has been associated with higher levels of low-grade inflammation and CVD risk.[6,23,24] The present observational study aimed to investigate if there is an association between oral status and the risk of hypertension in a large French subject cohort.

METHODS

Study population

The population analysis comprised 102,330 participants (mean age 43.7 ± 12.7 years) who had undergone medical and dental examinations between January 2002 and December 2011, in Parisian medical centers subsidized by the French National Healthcare System (*Centre d'Investigations Préventives et Cliniques:* IPC). The sample was split according to age, one subset was <65 years (n = 96,435; male 63.3%), and the other was ≥65 (n = 5,895; male 53.9%).

Clinical and biological investigations

Each subject underwent biological and morphometric examination. The subjects were placed in the supine position. After 10 minutes of rest, blood pressure measurements were recorded by a trained nurse, three times consecutively with an electronic device (TM-2541 hemodynamometer A&D Company, Tokyo, Japan). The mean of the second and third measurements was used for analysis. Hypertension was defined as systolic blood pressure (SBP) higher than 140 mm Hg and/or diastolic blood pressure (DBP) higher than 90 mm Hg. Normal blood pressure was defined in three classes: SBP <120 mm Hg and DBP <80 mm Hg, SBP of 120–129 mm Hg and DBP of 80–84 mm Hg, SBP of 130–139 mm Hg and DBP of 85–89 mm Hg.[7] Body

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mass index (BMI) was calculated. Glycemia, total plasma cholesterol, and triglycerides were measured under fasting conditions. Gamma-glutamyl transpeptidase (gamma-GT) was used as a surrogate index for alcohol consumption. Tobacco consumption was self- reported (former smokers, current smokers, or nonsmokers). Socioeconomic deprivation was assessed using the Evaluation de la Précarité et des Inégalités de santé pour les Centres d'Examen de Santé (EPICES score). At the subject level, this score considers the multidimensional aspects of socioeconomic deprivation (Supplementary Data).[8]

Dental and periodontal examination

The participants received a full-mouth clinical examination, from one of five examiners who had been trained to perform a standardized examination. Dental plaque and supragingival calculus were visually assessed and rated using a 3-point ordinal scale. A simplified plaque index based on the Silness and Loe plaque index[9] was used and included the following ratings: low amount (plaque cannot be seen with the naked eye), moderate amount (limited quantity of plaque can be seen), and high amount (abundance of soft matter within tooth and/or gingival margin). Similarly, the calculus index was rated: low amount (no supragingival calculus covering not more than one-third of the tooth surface), moderate amount (supragingival calculus covering more than one-third but not more than two-thirds of the tooth surface and/or the presence of individual flecks of subgingival calculus around the cervical portion of the tooth) and high amount (supragingival calculus covering more than two-thirds of the tooth surface). Gingival inflammation was evaluated using a simplified modified gingival index (MGI) that was based on that described by Lobene *et al.*[10] Gingival inflammation was rated as low (absence of inflammation or mild inflammation), moderate (inflammation, including the preceding criteria, in all portions of the gingival marginal or papillary tissue), or high (erythema, edema, or spontaneous bleeding). The number of teeth, with the exception of the third molars, was recorded. The masticatory efficiency was evaluated by the number of functional occlusal units defined by pairs of natural or prosthetic opposing premolars and molars. Data were stored using custom-designed software (Buccodent 7.03 Ac version; Cetaf (Centre technique d'appui et de formation des centres d'examens de santé), Paris, France).

Ethics

Following the authorization of the *Commission Nationale Informatique et Libertés* (CNIL), the IPC center performed analyses of data collected during health check-ups. All volunteers signed an informed consent.

Statistical analysis

Groups were compared using a general linear model with variance analysis (ANOVA). The dependent variable was high blood pressure. The independent variables included dental plaque, dental calculus, gingival inflammation, tooth loss, and occlusal units. For masticatory efficiency analysis, the participants were pooled into two groups (sufficient vs. insufficient depending on the number of occlusal units >5 or <5).

The sample was split into subsets according to age <65 or ≥65 years. Subjects with antihypertensive medications and/or incomplete dental data were excluded from the analysis. Summary statistics are presented as mean (±SD or SEM) for continuous variables, and as percentage for categorical variables. Differences between groups were performed using unpaired ANOVA. Post hoc analysis used Ducan's test for quantitative variables. Chi square was used for qualitative variables. Logistic regression models were used in each subset to calculate the odds ratios (ORs) and corresponding 95% confidence intervals (CIs) for the risk of high blood pressure in presence of high dental plaque, high dental calculus, high gingival inflammation, tooth loss (>10), and occlusal units (<5). The results were adjusted for age, gender, BMI, smoking status, glycaemia, gamma-GT, cholesterol, and deprivation score. Then, each subset was divided into four groups depending on their cumulative exposure to dental variables, defined as following: 0: no dental exposure (reference group), 1: one dental exposure, 2: two dental exposures, and ≥3: three or more dental exposures. A concordance rate between examiners was calculated and was 100% for dental calculus and masticatory efficiency, 86.7% for dental plaque, and 80% for gingival inflammation. All *P* values were two-sided and those <0.05 were considered statistically significant. Statistical analyses were performed using the SAS statistical software (8.2 version; SAS Institute Inc., Cary, NC).

RESULTS

Table 1 shows that the major characteristics of the sample were significantly different among the blood pressure categories ($P < 0.0001$). However, differences between deprivation score among two blood pressure categories (SBP < 120 mm Hg/DBP < 80 mm Hg and SBP: 120–129 mm Hg/DBP: 80–84 mm Hg) were not significantly different. Data show a statistically significant relationship ($P < 0.0001$) between high blood pressure and poor oral hygiene parameters and gingival inflammation. Table 2 shows blood pressure variations according to oral parameters. Subjects with a high amount of dental plaque had higher SBP and DBP than those with a low amount (mean difference 2.5 and 2.3 mm Hg, respectively). A significant difference was also found for dental calculus. Regarding high gingival inflammation, the SBP and DBP were also significantly higher by 2.1 and 1.8 mm Hg, respectively.

Participants with >10 missing teeth had higher SBP by 2.3 mm Hg, whereas no significant difference in DBP was observed. Regarding masticatory efficiency, the mean SBP and DBP values were significantly higher in subjects with masticatory units <5, by 1 and 1.2 mm Hg, respectively.

The risk of having hypertension according to oral parameters was analyzed (Table 3).

The results indicate a lack of significant association between hypertension and oral variables for subset ≥65 years. However, in subset <65 years hypertension was associated with all parameters including dental plaque (OR = 1.90, 95% CI = 1.55–2.33), dental calculus (OR = 1.18,

Table 1. Demographic, biological, and dental characteristics of the overall sample population according to systolic and diastolic blood pressure[a]

	SBP < 120 mm Hg, DBP < 80 mm Hg	SBP: 120–129 mm Hg, DBP: 80–84 mm Hg	SBP: 130–139 mm Hg, DBP: 85–89 mm Hg	SBP ≥ 140 mm Hg, DBP ≥ 90 mm Hg	Total
Population, *n* (%)	37,594 (36.8)	33,296 (32.5)	17,787 (17.4)	13,653 (13.3)	102,330 (100)
Gender male, *n* (%)	18,383 (48.9)	23,040 (69.2)	12,985 (73.0)	10,021 (73.4)	64,429 (63.0)
Smokers, *n* (%)	12,256 (32.6)	9,456 (28.4)	4,713 (26.6)	3,393 (24.9)	29,817 (29.1)
Age, y[b]	39.8 (12.4)	44.1 (12.8)	47.1 (13.2)	51.9 (12.3)	43.7 (12.7)
BMI, kg/m^2	23.9 ± 0.02[c]	25.3 ± 0.02[c]	25.9 ± 0.03[c]	26.96 ± 0.04[c]	25.1 ± 4.1[b]
Deprivation score	29.1 ± 0.14[c,d]	29.5 ± 0.15[c,d]	31.0 ± 0.20[c]	34.1 ± 0.25[c]	30.1 ± 22.8[b]
Glycaemia (mg/dl)	94.1 ± 0.10[c]	95.1 ± 0.10 [c]	96.8 ± 0.13 [c]	99.7 ± 0.15[c]	95.8 ± 17.0[b]
Cholesterol (mg/dl)	201.1 ± 0.20[c]	206.2 ± 0.22 [c]	208.4 ± 0.30 [c]	212.6 ± 0.35[c]	205.6 ± 38.0[b]
Gamma_GT (UI/l)	30.0 ± 0.30[c]	33.3 ± 0.30[c]	37.6 ± 0.40[c]	48.2 ± 0.50[c]	34.8 ± 56.1[b]
SBP (mm Hg)	111.7 ± 0.06[c]	127.8 ± 0.05[c]	137.3 ± 0.07[c]	155.3 ± 0.08[c]	128.1 ± 9.1[b]
DBP (mm Hg)	68.0 ± 0.05[c]	76.8 ± 0.04[c]	80.9 ± 0.06[c]	91.5 ± 0.07[c]	76.7 ± 7.8[b]
Dental plaque, *n* (%)					
Low	34,098 (90.7)	29,467 (88.5)	15,475 (87.0)	11,482 (84.1)	90,522 (88.5)
Moderate	3,045 (8.1)	3,230 (9.7)	1,921 (10.8)	1,720 (12.6)	9,916 (9.7)
High	451 (1.2)	599 (1.8)	391 (2.2)	451 (3.3)	1,892 (1.8)
Dental calculus, *n* (%)					
Low	14,888 (39.6)	10,388 (31.2)	5,212 (29.3)	3,604 (26.4)	34,092 (33.3)
Moderate	19,962 (53.1)	19,745 (59.3)	10,707 (60.2)	8,301 (60.8)	58,715 (57.4)
High	2,744 (7.3)	3,163 (9.5)	1,868 (10.5)	1,748 (12.8)	9,523 (9.3)
Gingival inflammation, *n* (%)					
Low	29,474 (78.4)	23,940 (71.9)	12,255 (68.9)	8,601 (63.0)	74,270 (72.6)
Moderate	7,030 (18.7)	8,058 (24.2)	4,678 (26.3)	4,151 (30.4)	23,917 (23.4)
High	1,090 (2.9)	1,298 (3.9)	854 (4.8)	901 (6.6)	4,143 (4.0)
>10 missing teeth, *n* (%)	1,955 (5.2)	2,597 (7.8)	1,974 (11.1)	2,130 (15.6)	8,656 (8.5)
<5 functional masticatory units, *n* (%)	2,594 (6.9)	2,697 (8.1)	1,690 (9.5)	1,802 (13.2)	8,783 (8.6)

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure.
[a]WHO Blood pressure classes.
[b]Data are shown as mean (SD).
[c]Data are shown as mean ± SEM.
P < 0.0001 except for the footnote designator "d."

95% CI = 1.07–1.29), gingival inflammation (OR = 1.56, 95% CI = 1.35–1.80), insufficient masticatory function (OR = 1.20, 95% CI = 1.08–1.32), and missing teeth >10 (OR = 1.17, 95% CI = 1.04–1.31).

Results in Table 4 indicate in subset <65 years a significant risk augmentation of hypertension depending on the number of dental exposure; ORs of hypertension in case of 1, 2 or ≥3 dental exposures were 1.15 (95% CI, 1.05–1.25), 1.28 [1.12–1.47], 1.88 [1.52–2.32], respectively. In subset ≥65 years, no results were significant.

DISCUSSION

Our study shows that in a subset <65 years in a French adult cohort, insufficient masticatory efficiency, missing teeth, poor oral hygiene, and gingival inflammation are significant independent variables associated with hypertension. Moreover, the risk of hypertension increases with the number of dental exposure in subjects <65 years. However, in a subset aged ≥65 years, our results did not show associations between the risk of hypertension and individual or cumulative dental variables. The present outcomes are in agreement with numerous cross-sectional studies.[11] However, our results seem different from those of Rivas-Tumanyan *et al.*[12] study. This difference must be carefully interpreted because of the discrepancy between the type of oral variables and the method (self-reported data vs. clinical measurements). We found a lack of association between oral health parameters and the risk of hypertension in patients aged ≥65; whereas, Iwashima *et al.*[13] showed in the same age group, a significant risk of hypertension when subjects had ≥3 oral markers (OR = 1.82, 95% CI = 1.23–2.72). This discrepancy between the outcomes may be associated with the number and the nature of the oral variables. In

the present study, we focused on the overall oral health, and not specifically on periodontal diseases, which was the aim of previous studies. Regarding our main result, it may be hypothesized that oral hygiene status and insufficient masticatory score have a greater impact on younger than on elderly subjects in terms of hypertension risk, as confirmed by a prospective cohort of Japanese manufacturing company employees.[14] In our study, inefficient masticatory efficiency and hypertension were significantly associated and these results could be related to changes in eating habits. The link between food choices and masticatory efficiency is well established.[15,16] In a randomized clinical trial, Appel *et al.*[17] showed that a diet rich in fruits, vegetables, and low-fat dairy foods, led to significantly decreased SBP and DBP levels in hypertensive and normotensive subjects. And it has been shown that dietary fiber intake was 1.2 times lower among subjects with reduced masticatory efficiency.[18] Therefore, our results suggest that tooth loss leads to impaired masticatory function and, consequently diet.

We used a threshold of five occlusal units for the measurement of masticatory efficiency. This was chosen based on the WHO recommendations indicating that the retention of 20 teeth minimum is sufficient for adequate masticatory efficiency.

In the subset ≥65 years, tooth loss was not significantly associated with hypertension, contrary to the subset <65 years. This finding is concordant with Peres *et al.*[19] study.

Our results revealed a significant relationship between oral hygiene parameters and hypertension. This result aligns with epidemiological studies showing an inverse association between frequency of tooth brushing and hypertension[20] or higher risk of CVD.[21] Plaque accumulation around teeth leads to gingivitis, and our findings indicated a significant association between gingival inflammation and hypertension. It is well accepted that good plaque control reduces gingival inflammation; consequently, it was unsurprising that we detected a relationship between gingival inflammation and hypertension. Our study had several strengths. We show a difference in the impact of oral health variables according to the age. Moreover, the sample size was large and based on a well-known cohort. Then, oral hygiene was clinically evaluated using plaque and calculus indices, which carefully evaluated the ability of the participants to eliminate dental plaque. Similarly, the number of occlusal units represents an objective approach to evaluate masticatory capacity. However, the present study also has several limitations. First, observational design is prone to bias, although useful in introducing new hypotheses. Thus, regarding the main outcome, it can be hypothesized that oral health prevention helps to prevent high blood pressure in population <65 years. Second, we only showed small clinical differences in blood pressure between groups. However, given the size and age of the studied population, a higher BP from 2.1 mm Hg could have a large impact in terms of public health, as shown by the well-known change of risk exposure for few millimeters of mercury in larges epidemiological studies or meta-analysis.[22] Our outcomes strengthen the evidence in support of a relationship between components of oral health and general health in persons aged <65 years. Consequently, we hypothesize that oral hygiene improvement and/or teeth replacement are important to prevent oral diseases but also high blood pressure. This may have implications in terms of

Table 2. Systolic and diastolic blood pressure[a] according to oral parameters (n = 102,330)

	SBP, mm Hg	DBP, mm Hg
Dental plaque		
Low	126.6 ± 0.06	75.9 ± 0.04
Moderate	127.3 ± 0.18[b]	76.8 ± 0.12[b]
High	129.1 ± 0.43[b]	78.2 ± 0.28[b]
Dental calculus		
Low	126.5 ± 0.10	75.8 ± 0.06
Moderate	126.7 ± 0.07	76.0 ± 0.05
High	127.6 ± 0.19[b]	77.1 ± 0.12[b]
Gingival inflammation		
Low	126.4 ± 0.07	75.8 ± 0.04
Moderate	127.3 ± 0.12[b]	76.6 ± 0.08[b]
High	128.5 ± 0.29[b]	77.6 ± 0.19[b]
Missing teeth	≤10	>10
SBP (mm Hg)	126.5 ± 0.06	128.8 ± 0.23[b]
DBP (mm Hg)	76.0 ± 0.04	76.1 ± 0.15
Functional masticatory units	≥5	<5
SBP (mm Hg)	126.6 ± 0.06	127.6 ± 0.20[b]
DBP (mm Hg)	75.9 ± 0.04	77.1 ± 0.13[b]

[a]The results are shown as adjusted mean ± SEM. Adjustment for age, gender, body mass index, smokers, glycaemia, gamma_GT, cholesterol, deprivation score.
[b]P < 0.0001.

Table 3. Odds ratios[a] (OR) for high blood pressure (≥140 mm Hg) in case of high amount of dental plaque, dental calculus, gingival inflammation, and masticatory efficiency status in subset <65 years (n = 96,435) and ≥65 years (n = 5,895)

	OR (95% CI) subset <65	OR (95% CI) subset ≥65	P interaction
Dental plaque	1.90 (1.55–2.33)[c]	1.94 (0.91–4.17)	0.64
Dental calculus	1.18 (1.07–1.29)[b]	0.98 (0.68–1.43)	0.03
Gingival inflammation	1.56 (1.35–1.80)[c]	1.30 (0.78–2.15)	0.07
Functional masticatory units <5	1.20 (1.08–1.32)[b]	1.07 (0.78–1.48)	0.02
Missing teeth >10	1.17 (1.04–1.31)[b]	0.89 (0.69–1.14)	<0.0001

[a]Adjustment for age, gender, body mass index, current smokers, glycaemia, gamma_GT, cholesterol, and deprivation score.
[b]p < 0.01, [c]p < 0.001.

Table 4. Odds ratios[a] (OR) for high blood pressure (≥140 mm Hg) in subset <65 years and ≥65 years depending on cumulative dental exposure

Dental exposure	OR (95% CI) subset <65, *n* = 96,435	OR (95% CI) subset ≥65, *n* = 5,895	*P* interaction
0 (reference group)	1, *n* = 75,424 (78%)	1, *n* = 3,170 (54%)	—
1	1.15 (1.05–1.25)[b], *n* = 14,079 (15%)	1.09 (0.84–1.42), *n* = 2,004 (34%)	<0.0001
2	1.28 (1.12–1.47)[b], *n* = 4,879 (5%)	1.02 (0.68–1.54), *n* = 561 (10%)	0.01
≥3	1.88 (1.52–2.32)[c], *n* = 2,053 (2%)	1.09 (0.53–2.24), *n* = 160 (2%)	0.04

[a]Adjustment for age, gender, body mass index, current smokers, glycaemia, gamma_GT, cholesterol, and deprivation score.
[b]$p < 0.01$, [c]$p < 0.001$.

improving public health. Further interventional studies are needed to confirm this hypothesis.

SUPPLEMENTARY MATERIAL

Supplementary materials are available at *American Journal of Hypertension* (http://ajh.oxfordjournals.org).

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DISCLOSURE

The authors declared no conflict of interest.

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