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ORIGINAL ARTICLE

Relationship between periodontal condition and arterial properties in an adult population in Japan

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OBJECTIVE: This study addressed the relationship between periodontal condition and second derivative of the finger photoplethysmogram (SDPTG) in Japanese adults.
SUBJECT AND METHODS: The Community Periodontal Index (CPI) and SDPTG were recorded in 415 subjects (mean age: 44.0 years). For assessing SDPTG, we mainly focused on the ratio of the absolute value of the height of the early negative 'b' wave and ratio of the late re-decreasing 'd' wave to the height of the initial positive 'a' wave, namely the b/a and d/a ratios.
RESULTS: The CPI score was positively correlated with the b/a ratio ($P < 0.001$), and negatively correlated with the d/a ratio ($P < 0.001$). Logistic regression analysis showed that subjects with CPI scores ≥3 were more likely to have a higher level (male >−0.69, female >−0.64) of b/a ratio (Odds ratio = 1.7, $P = 0.026$) and lower level (male ≤−0.29, female ≤−0.32) of d/a ratio (Odds ratio = 2.2, $P = 0.001$) than those with CPI scores 0–2, after adjusting for age, gender, smoking status, pulse rate and presence of hypertension.
CONCLUSION: There was a statistical association between the CPI scores and SDPTG indices in Japanese adults.
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Keywords: periodontitis; the second derivate of the finger photoplethysmogram; CPI; a cross-sectional study

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Introduction

Periodontal disease is a chronic inflammatory disease of the tooth-supporting structures (Page *et al*, 1978; Pihlstrom *et al*, 2005). Studies have shown that periodontitis may influence risk markers for atherosclerotic disorders in humans. For instance, it is reported that data derived from a meta-analysis indicates that periodontal disease with elevated bacterial exposure was associated with carotid artery intima-medical thickness (IMT) (Mustapha *et al*, 2007). Clinical studies have also shown that periodontal treatment decreases serum inflammatory markers such as C-reactive protein (Marcaccini *et al*, 2009; Vidal *et al*, 2009), which could predict risk of atherosclerotic disorders (Calabrò *et al*, 2009). Thus, periodontal disease may augment risk markers related to atherosclerotic disorders.

Increased arterial stiffness has been associated with future development of atherosclerotic disorders (Laurent *et al*, 2001; Meaume *et al*, 2001). One of the non-invasive methods of assessing arterial stiffness is measurement of the finger photoplethysmogram (PTG) (Takazawa *et al*, 1998). The PTG expresses blood volume changes in the fingertip as pulse waves, but the PTG itself is used very rarely in the clinical field. Instead, the measurement of second derivative of the PTG (SDPTG) has been developed for more accurate recognition of the inflection points of PTG (Otsuka *et al*, 2006). The SDPTG is a simple, convenient and non-invasive indicator for pulse wave analysis, seemingly providing information about both central and peripheral arterial properties. In fact, there is a constant relationship between the index derived from SDPTG and the ascending aortic augmentation (Takazawa *et al*, 1993). Therefore, if the changes in SDPTG indices were correlated with periodontal condition, this information would strengthen the suggested association between periodontal disease and atherosclerotic disorders. However, to the best of our knowledge, the correlation between periodontal condition and SDPTG indices is unclear.

In this study, we hypothesized that the periodontal condition might affect the SDPTG indices in an adult population. The Community Periodontal Index (CPI) is often used for evaluation of the periodontal condition in public health (Cutress *et al*, 1987). Thus, we conducted a cross-sectional study in Japanese adults to assess the relationship between the CPI score and SDPTG indices.

Materials and methods

Subject recruitment
A total of 415 public employees, 339 males and 76 females, with a median age of 44.0 years (range: 20–60 years) were randomly recruited during the annual dental examination at the Kagawa Police Department, Kagawa Prefecture, Japan (Table 1). Subjects with a history or presence of dyslipidemia, coronary heart disease or diabetes mellitus were excluded from the study. We also excluded subjects who had taken anti-inflammatory drugs or medications for hypertension, dyslipidemia, or diabetes mellitus. The subjects with hypertension (systolic blood pressure: more than 140 mmHg or diastolic blood pressure: more than 90 mmHg), diagnosed by a medical examination preliminarily, were included. The study protocol was approved by the Ethical Committee of the Okayama University Graduate School of Medicine, Dentistry and Pharmaceutical Sciences. Verbal consent was obtained from all participants during the examination period.

Clinical measurements
Six experienced dentists conducted periodontal examinations using a CPI probe (YDM Co., Tokyo, Japan) according to the protocol of the WHO standardized methodology (Vered *et al*, 2008; Esaki *et al*, 2009). Six sextants were evaluated for each mouth. If less than two functional teeth were present, the sextant was defined as edentulous. The index teeth were 17, 16, 11, 26, and 27 in the upper jaw, and 37, 36, 31, 46, and 47 in the lower jaw. Each sextant was designated as either healthy (score 0), bleeding after probing (score 1), calculus detected but no pockets (score 2), pockets of 4–5 mm (score 3), and pockets of 6 mm or more (score 4) according to the highest score recorded at the indexed teeth. The highest score in the six sextants was used as individual CPI score. The number of teeth present in each participant was also examined. The intra- and inter-examiner agreement, evaluated with kappa statistics, of the CPI score was more than 0.9. Subjects with a CPI score of 0–2 were considered as controls and those with a CPI score ≥3 were considered to have periodontitis (Ekuni *et al*, 2008).

Table 1 Age and gender distribution of subjects

Age group (years)	*Male (n)*	*Female (n)*	*Total (n)*
20–29	56	15	71
30–39	56	22	78
40–49	153	27	180
50–59	67	12	79
60	7	0	7
Total	339	76	415

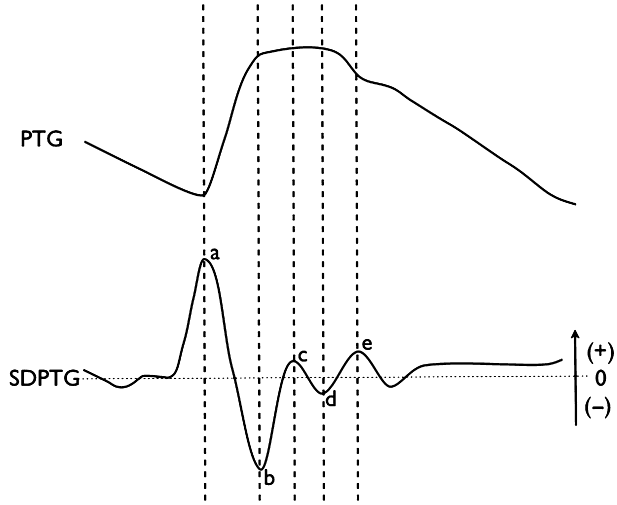

Figure 1 Representative recordings of finger photoplethysmogram (PTG) and the second derivative of PTG (SDPTG). The SDPTG consists of five waves: the first positive and negative waves (‘a’ and ‘b’ waves) in early systole, the second positive and negative wave (‘c’ and ‘d’ waves) in late systole, and the third positive wave (‘e’ wave) in diastole

Measurements of SDPTG indices
The SDPTG was obtained in the supine position using a SDPTG photosensor (TAS9; YKC Co., Tokyo, Japan), after the subject had been resting in a sitting position for more than 5 min. A transducer was placed on the cuticle of the index finger of the left hand and the signal of the blood volume changes in the peripheral circulation, which indicated PTG, was sent to the photoplethysmometer. The PTG expresses changes in the absorption of light by hemoglobin using a waveform according to the Lambert-Beer law (Jespersen and Pedersen, 1986). The SDPTG is, in general, obtained to specify inflection points on PTG waves.

Five waves per pulse were recorded automatically on the SDPTG, the first positive wave ‘a’, first negative wave ‘b’, second positive wave ‘c’, second negative wave ‘d’, and third positive wave ‘e’ (Figure 1). The ‘a’ and ‘b’ waves on the SDPTG are included in the early systolic phase of the PTG, whereas the ‘c’ and ‘d’ waves are included in the late systolic phase. The height of each wave from the baseline was automatically measured by the photoplethysmometer and the ratios of the height of the ‘b’ and ‘d’ waves to that of the ‘a’ wave (b/a and d/a) were calculated (Otsuka *et al*, 2006). We divided the subjects with high or low SDPTG indices (b/a and d/a ratios) as follows: high b/a ratio (male >-0.69, female >-0.64) or low b/a ratio (male ≤-0.69, female ≤-0.64), and high d/a ratio (male >-0.29, female >-0.32) or low d/a ratio (male ≤-0.29, female ≤-0.32). These cut-off values for the SDPTG indices were based on the median of the present results. It is reported that the b/a ratio was positively correlated, whereas the d/a ratio inversely correlated with the risk of atherosclerotic disorders (Otsuka *et al*, 2006). Therefore, high b/a ratio and low d/a ratio indicate high risk of atherosclerotic disorders.

Statistical analysis
Continuous variables and categorical data were expressed as the median (25% percentile, 75% percentile) and the number of subjects (as a percentage), respectively. The statistical significance of associations among variables was determined using the Spearman's rank correlation coefficient. Because the data were skewed, the Mann–Whitney *U*-test was used to compare parameters (age, number of teeth present and pulse rate) between the female and male subjects, between the subjects with high b/a ratio and those with low b/a ratio, or between the subjects with high d/a ratio and those with low d/a ratio. The chi-square test was also used to compare the CPI score, percentage of smokers, and the number of subjects with hypertension between females and males, between the subjects with high b/a ratio and those with low b/a ratio, or between the subjects with high d/a ratio and those with low d/a ratio. Furthermore, logistic regression analysis was used to determine the characteristics of subjects with high and low levels of SDPTG indices. Using the data of all subjects, the SDPTG indices (b/a ratio: high = 1, low = 0; d/a ratio: high = 0, low = 1) were used as the dependent variables, and age, gender, number of teeth present, smoking status, pulse rate, presence of hypertension and CPI score were regarded as the independent variables. Age, gender, pulse rate and presence of hypertension were selected as the independent variables, because a previous study reported that these factors were associated with the SDPTG indices in the general population (Otsuka *et al*, 2006). Furthermore, the logistic regression models were reviewed for goodness of fit and validated by means of the Hosmer-Lemeshow statistic (Ekuni *et al*, 2008).

All analyses were performed using a software program (SPSS 15.0J for Windows; SPSS Japan, Tokyo, Japan). A value of $P < 0.05$ was considered to be statistically significant.

Results

Of the total subjects, 3.1% demonstrated healthy gingival tissue (CPI score 0), 58.8% had, at worst, presence of bleeding or calculus (CPI scores 1 and 2), and 38.1% exhibited shallow and deep periodontal pockets (CPI scores 3 and 4) (Table 2). Significant differences in the parameters of age, CPI score, b/a ratio, and percentage of smokers were found between male and female subjects ($P < 0.05$).

The b/a ratio was positively correlated with age ($P < 0.001$) and CPI score ($P = 0.001$), and negatively correlated with the number of teeth present ($P = 0.019$) and pulse rate ($P = 0.003$) (Table 3). The d/a ratio was negatively correlated with age ($P < 0.001$) and the CPI score ($P < 0.001$), and positively correlated with the number of teeth present ($P < 0.001$).

The male subjects with high b/a ratio (> −0.69) had higher age ($P < 0.001$), higher CPI score ($P < 0.001$), higher number of subjects with hypertension ($P = 0.035$), lower number of teeth present ($P = 0.039$) and lower pulse rate ($P = 0.034$), compared with those with low b/a ratio (≤−0.69) (Table 4). On the other hand, the male subjects with high d/a ratio

Table 3 Correlations between the SDPTG indices (b/a and d/a) and other parameters in all subjects ($n = 415$)

	b/a		*d/a*	
Indicators	r^a	P-*value*	r	P-*value*
Age (years)	0.449	< 0.001	−0.469	< 0.001
Number of teeth present	−0.115	0.019	0.179	< 0.001
CPI score	0.164	0.001	−0.266	< 0.001
Pulse rate (per minute)	−0.145	0.003	0.036	0.462

[a]Spearman's rank correlation coefficient.

Table 2 Characteristics of subjects in each sex

Indicators	*Male* (n = *339*)	*Female* (n = *76*)	*Total* (n = *415*)	P-*value*
Age (years)[a]	44.0 (34.0, 49.0)	40.0 (32.0, 47.8)	44.0 (34.0, 49.0)	0.040
Number of teeth present[a]	28.0 (28.0, 30.0)	28.0 (28.0, 29.2)	28.0 (28.0, 30.0)	0.597
CPI score [*n* (%)][b]				
0	12 (3.5)	1 (1.3)	13 (3.1)	0.007
1	48 (14.2)	16 (21.1)	64 (15.4)	
2	137 (40.4)	43 (56.6)	180 (43.4)	
3	138 (40.7)	16 (21.1)	154 (37.1)	
4	4 (1.2)	0 (0.0)	4 (1.0)	
SDPTG indices[a]				
b/a	−0.69 (−0.79, −0.59)	−0.64 (−0.71, −0.50)	−0.68 (−0.78, −0.57)	< 0.001
d/a	−0.29 (−0.40, −0.19)	−0.32 (−0.47, −0.22)	−0.29 (−0.41, −0.20)	0.089
Pulse rate (per minute)[a]	69.0 (62.0, 77.0)	68.5 (63.3, 76.8)	69.0 (62.0, 77.0)	0.759
Smokers [*n* (%)][b]	194 (56.9)	3 (5.3)	197 (47.5)	< 0.001
Hypertension [*n* (%)][b]	12 (3.5)	2 (2.6)	14 (3.4)	0.692

The differences were analyzed using the Mann–Whitney *U*-test.
[a]Median (25%, 75%).
[b]The differences were analyzed using the chi-square test or the Fisher's exact test for hypertension.

Table 4 Comparison of each parameter between the subjects with high and those with low levels of SDPTG indices

	b/a						*d/a*					
	Male			*Female*			*Male*			*Female*		
Indicators	*Subject with* $b/a \le -0.69$ (n = *168*)	*Subject with* $b/a > -0.69$ (n = *171*)	P-*value*	*Subject with* $b/a \le -0.64$ (n = *38*)	*Subject with* $b/a > -0.64$ (n = *38*)	P-*value*	*Subject with* $d/a \le -0.29$ (n = *173*)	*Subject with* $d/a > -0.29$ (n = *166*)	P-*value*	*Subject with* $d/a \le -0.32$ (n = *38*)	*Subject with* $d/a > -0.32$ (n = *38*)	P-*value*
Age (years)[a]	40.5 (29.0, 46.0)	47.0 (42.0, 50.0)	< 0.001	35.0 (28.0, 43.0)	45.5 (36.8, 49.0)	< 0.001	47.0 (43.0, 50.0)	37.0 (29.0, 47.0)	< 0.001	45.5 (37.5, 50.5)	35.0 (28.0, 43.0)	< 0.001
Number of teeth present[a]	28.0 (28.0, 30.0)	28.0 (28.0, 29.0)	0.039	28.0 (28.0, 29.3)	28.0 (27.8, 29.3)	0.724	28.0 (28.0, 29.0)	28.0 (28.0, 30.0)	0.009	28.0 (28.0, 29.0)	28.5 (28.0, 30.0)	0.234
CPI score [*n* (%)][b]			< 0.001			0.735			< 0.001			0.295
0	10 (6.0)	2 (1.2)		1 (2.6)	0 (0.0)		3 (1.7)	9 (5.4)		0 (0.0)	1 (2.6)	
1	26 (15.5)	22 (12.9)		7 (18.4)	9 (23.7)		15 (8.7)	33 (19.9)		7 (18.4)	9 (23.7)	
2	79 (47.0)	58 (33.9)		22 (57.9)	21 (55.3)		59 (34.1)	78 (47.0)		20 (52.6)	23 (60.5)	
3	53 (31.5)	85 (49.7)		8 (21.1)	8 (21.1)		85 (49.1)	53 (31.9)		11 (28.9)	5 (13.2)	
4	0 (0.0)	4 (2.3)		0 (0.0)	0 (0.0)		4 (2.3)	0 (0.0)		0 (0.0)	0 (0.0)	
Smoking [*n* **(%)**][b]			0.177			0.524			0.025			0.240
Never	78 (46.4)	67 (39.2)		35 (92.1)	38 (100.0)		62 (35.8)	83 (50.0)		38 (100.0)	35 (92.1)	
Past	35 (20.8)	50 (29.2)		3 (7.9)	0 (0.0)		52 (30.1)	33 (19.9)		0 (0.0)	3 (7.9)	
Current	55 (32.7)	54 (31.6)		0 (0.0)	0 (0.0)		52 (30.1)	57 (34.3)		0 (0.0)	0 (0.0)	
Pulse rate (per minute)[a]	70.0 (63.0, 79.0)	69.0 (61.0, 75.0)	0.034	71.5 (68.8, 79.2)	66.5 (59.0, 72.8)	0.004	70.0 (61.0, 77.3)	68.0 (62.0, 76.0)	0.495	68.0 (61.0, 75.3)	70.5 (66.0, 78.0)	0.165
Hypertension [n **(%)**][b]	2 (1.2)	10 (5.8)	0.035	0 (0.0)	2 (5.3)	0.493	6 (3.5)	6 (3.6)	0.942	2 (5.3)	0 (0.0)	0.493

The differences were analyzed using the Mann–Whitney *U*-test.
[a]Median (25%, 75%).
[b]The differences were analyzed using the chi-square test or the Fisher's exact test for hypertension.

Table 5 Relationship between CPI score and higher level of b/a ratio and lower level of d/a ratio

	High b/a ratio[a]			Low d/a ratio[b]		
Indicators	*Adjusted odds ratio*	*95% CI*	P-*value*	*Adjusted odds ratio*	*95% CI*	P-*value*
CPI score						
0–2	1			1		
≥3	1.7	1.1–2.7	0.026	2.2	1.3–3.5	0.001
Number of teeth present	1.0	0.9–1.1	0.774	1.0	0.9–1.2	0.666
Age (years)						
20–39	1			1		
40–	4.5	2.7–7.4	< 0.001	7.1	4.2–12.0	< 0.001
Gender						
Female	1			1		
Male	1.5	0.8–2.8	0.175	1.9	0.9–3.5	0.059
Smoking						
Never	1			1		
Past	1.0	0.6–1.8	0.962	1.3	0.7–2.4	0.348
Current	1.2	0.7–2.1	0.560	0.9	0.5–1.7	0.824
Pulse rate (per minute)	0.95	0.93–0.97	< 0.001	0.99	0.97–1.01	0.158
Hypertension						
No	1			1		
Yes	5.2	1.1–24.9	0.040	0.8	0.2–2.4	0.348

[a]High (male > −0.69, female > −0.64) or low (male ≤−0.69, female ≤−0.64) levels of b/a as the dependent variable.
[b]High (male > −0.29, female > −0.32) or low (male ≤−0.29, female ≤−0.32) levels of d/a as the dependent variable.

(> −0.29) had lower age ($P < 0.001$), lower CPI score ($P < 0.001$), higher number of teeth present ($P = 0.009$) and higher percentage of non-smokers ($P = 0.025$), compared with those with low d/a ratio (≤−0.29). In the female subjects, there were no significant differences in the number of teeth present and CPI score between high and low b/a ratios and between high and low d/a ratios.

After adjustment for the number of teeth present, age, gender, smoking status, pulse rate and presence of hypertension, the logistic regression analysis showed that the subjects who had CPI score ≥3 more likely had high b/a ratio (Odds ratio = 1.7, CI = 1.1–2.7, $P = 0.026$) (Table 5). In addition, the subjects who had a CPI score ≥3 were likely to have low d/a ratio (Odds ratio = 2.2, CI = 1.3–3.5, $P = 0.001$).

Discussion

To the best of our knowledge, this is the first epidemiological study to assess the relationship between the CPI score and SDPTG indices. The present results found a positive correlation between the b/a ratio and CPI score and a negative correlation between the d/a ratio and the CPI score. Furthermore, logistic regression analysis showed that the subjects with CPI scores ≥3 more likely had a higher (male > −0.69, female > −0.64) b/a ratio and lower (male ≤−0.29, female ≤−0.32) d/a ratio than those with CPI scores ≤2, after adjusting for age, gender, the number of teeth present, smoking status, pulse rate and presence of hypertension. These observations indicate that the periodontal condition would affect the changes in the SDPTG indices, such as the b/a and d/a ratios. In addition, the previous studies suggest that the b/a ratio and the d/a ratio represent the stiffness of large arteries (Imanaga *et al*, 1998) and peripheral vascular resistance (Takazawa *et al*, 1993; Kelly *et al*, 2001), respectively. An increased arterial stiffness as well as aging, smoking and hypertension is a risk factor for the development of atherosclerotic disorders (Laurent *et al*, 2001; Meaume *et al*, 2001). Our results further support the growing evidence of the association between periodontal disease and atherosclerotic disorders.

Several investigators have studied the association between periodontal condition and the development of early atherosclerotic vascular lesions. A previous report showed a significantly higher mean carotid artery IMT in periodontitis patients than in the control subjects (Söder *et al*, 2005). An epidemiological study also revealed that the overall periodontal bacterial burden was related to carotid IMT (Desvarieux *et al*, 2005). Moreover, arterial stiffness has been shown to correlate with the IMT significantly (Wykretowicz *et al*, 2009), as supported by the present results.

The mechanisms by which periodontal condition affects arterial stiffness are not completely understood. However, two prevailing hypotheses may explain the relationship between periodontal condition and arterial stiffness: first, periodontal bacteria (e.g., *Porphyromonas gingivalis* and *Aggregatibacter actinomycetemcomitans*) may have a direct effect on the vasculature (Deshpande *et al*, 1998; Haraszthy *et al*, 2000); and, second, local periodontal inflammation causes an enhanced inflammatory response at distant sites without the spread of the infectious agent (Pouliot *et al*, 2000).

In our findings, the SDPTG indices showed no differences between the female subjects with CPI scores ≥3 and those with CPI scores ≤2, which is consistent with the previous results that indicated a relationship between long-term periodontitis and subclinical atherosclerosis in men but not women (Desvarieux *et al*, 2004). In this study, the percentage of subjects with a periodontal condition and CPI scores ≥3 was 41.9% in males and 21.1% in females. It is possible that females did not reach a threshold of inflammation that might have otherwise been associated with severe periodontal infections and carried on to increased arterial stiffness until a later age. Moreover, all female subjects were < 60 years. As females < 60 years seem to have no increased carotid plaque associated with periodontal disease but catch up with men as they age (Desvarieux *et al*, 2004), the possibility of a protective hormonal role cannot be excluded (Dias *et al*, 2005).

It has been reported that both active and passive smoking were associated with a consistent increase in the IMT (Diez-Roux *et al*, 1995). It has also been demonstrated that both active and passive cigarette smoke exposure was related to a decrease in vasodilatory function (Mayhan and Patel, 1997; Ijzerman *et al*, 2003). Therefore, smoking may also have influenced our results. In this study, the differences in smoking status influenced the d/a ratio in the male subjects. This is in agreement with a previous study showing that there were positive associations between atherosclerotic disorders, periodontitis, and smoking status (Wolfram *et al*, 2006). On the other hand, smoking status had little effect on the SDPTG indices in the female subjects. Because most of the female subjects were non-smokers, it is conceivable that the influence of smoking was minimal in this study.

Generally, it might be reasonable that the b/a is higher in male than in female subjects and that the d/a is lower in male than in female subjects, considering arterial properties and mean age of the subjects. However, our results showed that b/a ratio was higher in female than in male subjects. A previous study (Otsuka *et al*, 2006) also reported that b/a ratio was higher in female than in male subjects, which support our study. The reason remains unclear. Basically, female subjects might tend to show higher b/a ratio than male subjects when using this device.

It is reported that the cut-off value of b/a ratio which can discriminate coronary heart disease was −0.53 in male and −0.40 in female subjects (Otsuka *et al*, 2006). Similarly, in female subjects, the cut-off value of d/a ratio to discriminate coronary heart disease was −0.39 (Otsuka *et al*, 2006). However, in male subjects, the cut-off value of d/a ratio for discriminating coronary heart disease is still unclear. In addition, the aim of this study was to assess the relationship between periodontitis and atherosclerotic disorders at subclinical level, but not clinical level. Therefore, we used the median of the present results as the cut-off values for the SDPTG indices.

This study has some limitations. First, all subjects were recruited at the Kagawa Police Department. This may limit the ability to extrapolate these findings to the general population. Second, this study is not a longitudinal, but cross-sectional survey. It is, therefore, still uncertain as to whether periodontal disease is the cause or the result of increased arterial stiffness and reduced vascular resistance. Longitudinal studies will be needed to examine the causal relationship between the periodontal condition and SDPTG indices. Third, we did not use strict measures to control factors (body mass index and blood pressure) that might influence the SDPTG indices. Because the current study was performed at the annual dental examination and not medical examination, we could not collect these medical parameters. However, recent studies have shown that obesity is positively correlated with both atherosclerotic disorders (Rocha and Libby, 2009) and periodontitis (Pischon *et al*, 2007), suggesting that a close link exists between atherosclerotic disorders and periodontitis, with obesity suggested as the common confounding factor (Saito and Shimazaki, 2007). Therefore, although a previous study showed no association between body mass index and the SDPTG indices in the general population (Otsuka *et al*, 2006), further investigations might be needed to examine the relationship between CPI score and SDPTG indices after adjusting body mass index.

In conclusion, there appears to be a significant association between the CPI scores and SDPTG indices in Japanese adults. This information supports the suggested association between periodontal disease and atherosclerotic disorders.

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