Received: 6 December 2017 | Revised: 23 April 2018 | Accepted: 8 May 2018

DOI: 10.1111/jcpe.12920

EPIDEMIOLOGY (COHORT STUDY OR CASE-CONTROL STUDY)

WILEY Journal of Clinical Periodontology

Effect of lifestyle on 6-year periodontitis incidence or progression and tooth loss in older adults

Masanori Iwasaki[1,2] | Wenche S. Borgnakke[3] | Hiroshi Ogawa[1] | Takayuki Yamaga[1] | Misuzu Sato[1] | Kumiko Minagawa[1] | Toshihiro Ansai[2] | Akihiro Yoshihara[4] | Hideo Miyazaki[1]

[1]Department of Oral Health Science, Division of Preventive Dentistry, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan

[2]Division of Community Oral Health Development, Kyushu Dental University, Kitakyushu, Japan

[3]Department of Periodontics and Oral Medicine, University of Michigan School of Dentistry, Ann Arbor, Michigan

[4]Department of Oral Health and Welfare, Division of Oral Science for Health Promotion, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan

Correspondence
Masanori Iwasaki, Division of Community Oral Health Development, Kyushu Dental University, 2-6-1 Manazuru, Kokurakita-ku, Kitakyushu 803-8580 Japan.
Email: r14iwasaki@fa.kyu-dent.ac.jp

Funding information
This work was supported by a Grant-in-Aid from the Ministry of Health and Welfare of Japan (H10-Iryo-001, H13-Iryo-001 and H16-Iryo-020) and a Grant-in-Aid for Young Scientists (B) (26861827).

Abstract

Aim: To evaluate the longitudinal association of combined healthy lifestyle factors with incidence or progression of periodontitis and tooth loss in older adults.

Materials and methods: This 6-year study included 374 Japanese 70-year olds with 7,157 teeth, from a source eligible baseline population of 554 individuals. Four lifestyle factors—cigarette smoking, physical activity, relative weight, and dietary quality—were scored as healthy (1 point) or unhealthy (0 point). Adding the individual scores generated the "healthy lifestyle score" (0–4 points). Multilevel mixed-effects logistic regression models were applied to evaluate tooth-specific associations between the baseline healthy lifestyle score and the incidence or progression of periodontitis (increase in clinical attachment loss ≥3 mm) and tooth loss.

Results: After 6 years, 19.0% of the teeth exhibited periodontitis incidence or progression and 8.2% were lost. Compared with a healthy lifestyle score of 0–1 (least healthy), the highest score (4 points) was associated with a significantly lower tooth-specific risk of periodontitis (adjusted odds ratio = 0.32; 95% confidence interval: 0.16–0.62) and tooth loss (adjusted odds ratio = 0.42; 95% confidence interval: 0.23–0.77).

Conclusions: Simultaneous adherence to multiple healthy lifestyle factors significantly lowers the risk of incidence or progression of periodontitis and tooth loss in older adults.

KEYWORDS
aged, epidemiology, health behavior, life style, longitudinal studies, oral health, periodontal diseases, tooth loss

1 | INTRODUCTION

Although tooth loss has decreased over the last several decades, both missing teeth (Kassebaum et al., 2014a,b) and periodontitis (Eke et al., 2015; Kassebaum et al., 2014a) remain common chronic conditions, particularly in older adults whose life expectancy increases and who keep their teeth longer (Eke et al., 2016). A national survey of dental disease conducted in 2011 in Japan showed that 57.3% of individuals aged ≥70 years exhibited periodontitis, defined as community periodontal index codes of 3 or 4, accompanied by a loss of 13.4 teeth on average (The Ministry of Health, Labour, and Welfare, 2011).

Oral disease, including periodontitis and tooth loss, is *one of the most common public health issues worldwide* (Jin et al., 2016) and

poses significant health problems among older adults (Eke et al., 2016) that can have a major adverse impact on general health and quality of life (Buset et al., 2016; Griffin, Jones, Brunson, Griffin, & Bailey, 2012; Tan, Peres, & Peres, 2016), as shown among older Japanese (Matsuyama et al., 2017). Furthermore, it has been suggested that poor oral health predicts declining function in older adults (Zhang, Wu, & Wu, 2017) with tooth loss as a predictor of shortened longevity (Friedman & Lamster, 2016). Oral disease is also associated with increased healthcare costs among the elderly (Iwasaki, Sato, Yoshihara, Ansai, & Miyazaki, 2017; Sato, Iwasaki, Yoshihara, & Miyazaki, 2016). To decrease the burden of these oral diseases and establish more effective preventive strategies, it is necessary to investigate and understand the role of modifiable risk factors in detailed studies.

Previous studies have demonstrated that modifiable lifestyle factors such as cigarette smoking, physical inactivity, obesity/underweight, and an unhealthy diet are associated with various chronic systemic diseases (Ford et al., 2009; Jiao et al., 2009; Kirkegaard et al., 2010; Sasazuki et al., 2012), as well as periodontitis (Borgnakke, 2016). Health effects of these individual risk factors have been studied (Al-Zahrani, Borawski, & Bissada, 2005a; Bawadi, Khader, Haroun, Al-Omari, & Tayyem, 2011; Jenzsch, Eick, Rassoul, Purschwitz, & Jentsch, 2009; Johnson & Hill, 2004; Merchant, Pitiphat, Rimm, & Joshipura, 2003; Moynihan & Petersen, 2004; Saito, Shimazaki, & Sakamoto, 1998). However, despite the underlying assumption that the identification of modifiable risk factors can lead to intervention and ultimately improved health, their combined effects on oral health remain unclear. In particular, data from longitudinal studies are limited, which prevents assessment of causality.

Therefore, we designed a longitudinal study to explore the association between lifestyle, measured as the combination of four healthy lifestyle factors, and the development of new periodontitis or its progression and tooth loss risks in older adults. To achieve our aim, we scored study participants at baseline according to their simultaneous adherence to the following four healthy lifestyle factors that were selected based on previous research investigating the effects of healthy lifestyle factors on chronic disease risk (Ford et al., 2009): not smoking, engaging in good physical activity levels, having a healthy body mass index (BMI), and taking in a high-quality diet. We hypothesized that a higher combined healthy lifestyle score would be associated with a lower risk for incidence or progression of periodontitis as well as for tooth loss.

Clinical Relevance

Scientific rationale for the study: Reduction of common, modifiable lifestyle risk factors is assumed to be effective for oral diseases, but their longitudinal combined effect on periodontitis and tooth loss remains unclear.
Principal findings: Significant linear decreases in the 6-year risk of incidence or progression of periodontitis and tooth loss was found in participants with the following four healthy baseline lifestyle factors: no smoking, good physical activity level, healthy body mass index, and high-quality diet.
Practical implications: Adherence to multiple healthy lifestyle factors may be effective in preventing periodontitis and tooth loss in older adults and should be encouraged.

2 | MATERIALS AND METHODS

2.1 | Study design, setting, and participants

Data for the current investigation were sourced from the Niigata Study, a community-based cohort study investigating factors that affect oral health in older individuals. Details regarding sampling and data collection procedures have been described previously (Hirotomi et al., 2006). Briefly, a random sample of men and women aged 70 years was drawn from a database of the citizens of Niigata City, Japan. In total, 600 individuals (306 men and 294 women) were enrolled for baseline examinations conducted in 1998, which comprised dental and medical examinations, anthropometric evaluations, and responding to questionnaires. Follow-up dental examinations were conducted after 6 years.

Because the primary analyses were performed at the person- and tooth-level, exclusion criteria were based on both levels. Accordingly, participants were excluded from our analysis if they were edentulous at baseline or did not have complete data. Teeth were excluded from our analyses if data on their clinical attachment loss (CAL) could not be obtained at both time points.

All participants provided informed consent prior to enrolment, and the study was approved by the Ethics Committee of the Faculty of Dentistry, Niigata University (Approval number: 12-R1-4-21). The STROBE statement was applied for reporting.

2.2 | Data collection

Using sufficient artificial illumination, four trained dentists assessed tooth status (sound, decayed, or filled), type (anterior or posterior), and position (maxillary or mandibular jaw) as well as probing depth and recession (for calculation of CAL) at six sites for all natural teeth. Furthermore, the use of each tooth as an abutment for a dental bridge or a removable denture was recorded (World Health Organization, 1997).

In all, 10 patients at the Niigata University Medical & Dental Hospital volunteered for pre-study calibration. Cohen's kappa statistic (exact and within 1 mm of CAL) was used to assess inter-examiner reliability for each pair of examiners, which ranged from 0.79 to 0.93.

Data regarding oral health behavior, income, education, living situation, cigarette smoking status, physical activity levels, dietary habits, and medical conditions were obtained using a self-administered questionnaire. Fasting blood samples were collected for albumin

assessment. Weight and height were measured with the participant wearing light clothing, but no shoes.

The oral examination was repeated 6 years later by the same dentists.

2.3 | Principal exposure variable: "healthy lifestyle score"

We selected the four baseline lifestyle factors—cigarette smoking, physical activity, healthy BMI, and dietary quality—based on a priori knowledge of risk factors for periodontitis and tooth loss (Al-Zahrani et al., 2005a; Borgnakke, 2016; Johnson & Hill, 2004; Merchant et al., 2003; Moynihan & Petersen, 2004; Saito et al., 1998).

Using a self-administered questionnaire, participants provided information on smoking status and physical activity levels based on the average time spent per day performing three types of physical activity: heavy physical work or strenuous exercise, standing or walking, and sitting. The metabolic equivalent (MET)-hours/week was estimated by multiplying the time spent per week on each activity by the MET intensity level of that activity (Sasazuki et al., 2012). MET has been validated for use in physical activity assessments (Aadahl & Jorgensen, 2003). The Japanese Ministry of Health, Labour and Welfare recommends ≥10 MET-hr/week of physical activity for individuals aged ≥65 years (The Ministry of Health, Labour, and Welfare, 2013). The BMI was computed by dividing the weight in kilograms by the squared height in meters. A global consensus is lacking regarding a lower, evidence-based BMI threshold to define being overweight among Japanese seniors due to suggested generational, genetic, metabolic, ethnic, and environmental factors among Asians (American Diabetes Association, 2017, Kubota, Iso, & Tamakoshi, 2015). Thus, we used the generally applied BMI cutoff value of 25 kg/m^2 for overweight (World Health Organization, 2017). Based on the values reported by previous studies (Murayama et al., 2015; Nagai et al., 2010), a BMI cutoff value of 18.5 kg/m^2 was used for underweight. Dietary quality was measured with the dietary variety score (DVS) (Kumagai et al., 2003) previously used in epidemiologic studies among older adults (Kwon, Suzuki, Kumagai, Shinkai, & Yukawa, 2006). Participants completed a food frequency questionnaire covering the 10 main food groups: meat, fish and shellfish, eggs, milk, soybean products, potatoes, green/yellow vegetables, fruits, seaweed, and fat and oils. For each food group, a score of 1 was assigned if consumed daily or 0 if not consumed daily. Adding the scores for each food group, the total score ranged from 0 to 10, with higher scores indicating greater dietary variety.

Each participant was allocated 1 point for being a non-smoker (never smoked or quit smoking) (Kirkegaard et al., 2010), 1 point for a good physical activity level (≥10 MET-hr/week) (The Ministry of Health, Labour, and Welfare, 2013), 1 point for a healthy BMI (18.5–25 kg/m^2) (The Ministry of Health, Labour, and Welfare, 2012), and 1 point for a diverse, high-quality diet (greater than the group median DVS of 6). Scores of 0 were assigned for these factors if the participants did not meet the above specifications (Table 1).

TABLE 1 Distribution of healthy lifestyle scores at baseline for Japanese participants aged 70 years (*N* = 374)

Healthy Lifestyle Score	Number (%) Participants
Smoking	
0 (current smoker)	68 (18.2)
1 (non-smoker)	306 (81.8)
Physical activity	
0 (<10 MET-hr/week)	85 (22.7)
1 (≥10 MET-hr/week)	289 (77.3)
BMI	
0 (<18.5 or ≥25 kg/m^2)	109 (29.1)
1 (18.5–25 kg/m^2)	265 (70.9)
Diet	
0 (≤6 [group median for DVS])	209 (55.9)
1 (>6 [group median for DVS])	165 (44.1)

Note. BMI, body mass index; DVS, dietary variety score; MET, metabolic equivalent.

The principal exposure variable—"healthy lifestyle score"— was generated by adding the points for each of the four factors and hence ranged from 0 (least healthy) to 4 (most healthy). Participants were categorized into four groups according to their healthy lifestyle score of 0–1, 2, 3, and 4. Combining participants with scores of 0 and 1 into the same group was performed to achieve sufficient numbers of participants in each group.

2.4 | Outcome variables

The primary outcome variable was defined as tooth-specific progression of CAL (≥1 site exhibiting a ≥ 3 mm increase in CAL) at 6 years after baseline (Hirotomi, Yoshihara, Ogawa, & Miyazaki, 2010; Zhan et al., 2014). We have considered this variable to include (a) "periodontitis incidence," that is, development of periodontitis involving a tooth without any sites qualifying for a periodontitis case definition (CAL ≥3 mm) at baseline, but with ≥1 sites with CAL ≥3 mm at follow-up, as well as (b) "periodontitis progression," which indicates a tooth that already had ≥1 site with CAL ≥3 mm at baseline and exhibited an additional increase in CAL of ≥3 mm at follow-up. We combined both into one main outcome variable, "tooth-specific incidence or progression of periodontitis." The secondary outcome was tooth-specific incidence of tooth loss.

2.5 | Covariates

The description of covariates is included in the Supporting Information Appendix S1.

2.6 | Statistical analyses

Baseline tooth- and person-based factors were compared among the different groups based on the healthy lifestyle score using analysis

of variance, Kruskal–Wallis tests, or Chi-square tests, as appropriate. Associations among the four healthy lifestyle factors were studied using the Chi-square test.

Multilevel mixed-effects logistic regression models were used to calculate (sex-combined and sex-stratified) odds ratios (ORs) for the tooth-specific incidence or progression of periodontitis and tooth loss. Because our analyses were performed at the tooth level (the tooth was the unit of analysis), multilevel models were used to account for correlations between teeth in the same participant. First, we evaluated the association between individual healthy lifestyle factors and the tooth-specific risk of periodontitis incidence or progression and tooth loss, respectively. Second, we evaluated the same risk by comparing the combined healthy lifestyle scores to the least healthy group (score 0–1). A *p* value for the linear trend was further calculated using the model in which the healthy lifestyle score was included as a continuous variable. The multivariable models were adjusted for tooth-based (tooth status, tooth type, tooth location, use as an abutment, and greatest CAL) and person-based (sex [in sex-combined model], regular dental check-ups, brushing frequency, use of interdental cleaning devices, income, education level, living

TABLE 2 Baseline characteristics of the study population (*N* = 374) and their teeth (*N* = 7,157) by baseline healthy lifestyle score

		Healthy Lifestyle Score				
	Total	**0–1**	**2**	**3**	**4**	***p****
Person-based factors	*N* = 374 100%	*n* = 41 11.0%	*n* = 94 25.1%	*n* = 151 40.4%	*n* = 88 23.5%	
Number of teeth, median (IQR)	22 (13–26)	19 (8–26)	20 (12–25)	23 (12–26)	23 (15–27)	0.15
Denture use, *n* (%)	200 (53.5)	21 (51.2)	53 (56.4)	77 (51.0)	49 (55.7)	0.81
Mean CAL (mm), median (IQR)	2.9 (2.3–3.5)	3.2 (2.9–4.0)	3.2 (2.5–3.7)	2.6 (2.2–3.3)	2.8 (2.3–3.3)	<0.01
Men, *n* (%)	201 (53.7)	34 (82.9)	63 (67.0)	67 (44.4)	37 (42.1)	<0.01
Regular dental check-ups ≥1/year, *n* (%)	76 (20.3)	2 (4.9)	15 (16.0)	36 (23.8)	23 (26.1)	0.02
Tooth brushing frequency, ≥2 times/day, *n* (%)	255 (68.2)	25 (61.0)	60 (63.8)	102 (67.6)	68 (77.3)	0.16
Use of devices for interdental cleaning, *n* (%)	137 (36.6)	8 (19.5)	34 (36.2)	58 (38.4)	37 (42.1)	0.09
Annual household income, <2,000,000 JPY, *n* (%)	49 (13.1)	5 (12.2)	13 (13.8)	22 (14.6)	9 (10.2)	0.80
Years of education, ≤9 years, *n* (%)	156 (41.7)	21 (51.2)	40 (42.6)	62 (41.1)	33 (37.5)	0.53
Living alone, *n* (%)	33 (8.8)	4 (9.8)	8 (8.5)	12 (8.0)	9 (10.2)	0.94
Hypoalbuminemia, *n* (%)	24 (6.4)	3 (7.3)	10 (10.6)	7 (4.6)	4 (4.6)	0.25
High fasting blood glucose level, *n* (%)	51 (13.6)	4 (9.8)	14 (14.9)	19 (12.6)	14 (15.9)	0.76
Tooth-based factors	*N* = 7,157 100%	*n* = 697 9.7%	*n* = 1,701 23.8%	*n* = 2,965 41.4%	*n* = 1,794 25.1%	
Tooth status, *n* (%)						
Sound	3,320 (46.4)	324 (46.5)	786 (46.2)	1,389 (46.9)	821 (45.8)	0.11
Filled	3,729 (52.1)	362 (51.9)	876 (51.5)	1,540 (51.9)	951 (53.0)	
Decayed	108 (1.5)	11 (1.6)	39 (2.3)	36 (1.2)	22 (1.2)	
Tooth type, *n* (%)						
Anterior	3,407 (47.6)	335 (48.1)	897 (52.7)	1,423 (48.0)	845 (47.1)	0.92
Posterior	3,750 (52.4)	362 (51.9)	804 (47.3)	1,542 (52.0)	949 (52.9)	
Jaw, *n* (%)						
Maxilla	3,389 (47.4)	319 (45.8)	778 (45.7)	1,419 (47.9)	873 (48.7)	0.26
Mandible	3,768 (52.6)	378 (54.2)	923 (54.3)	1,546 (52.1)	921 (51.3)	
Used as an abutment, *n* (%)						
For fixed bridge	790 (11.0)	69 (9.9)	174 (10.2)	359 (12.1)	188 (10.5)	0.11
For a removable denture	658 (9.2)	67 (9.6)	173 (10.2)	255 (8.6)	163 (9.1)	0.34
Highest CAL (mm), median (IQR)	4 (3–4)	4 (3–4)	4 (3–4)	4 (3–4)	4 (3–4)	0.09

Notes. CAL, clinical attachment loss; IQR, interquartile range; JPY, Japanese Yen. **p* value for comparisons among groups.

situation, hypoalbuminemia, and high fasting blood glucose level) factors.

Inverse probability weighting (IPW) was used to adjust for selection bias due to the loss to follow-up (Hernan, Hernandez-Diaz, & Robins, 2004). Weights were calculated using baseline characteristics; number of teeth, sex, use of regular dental care, annual household income, years of school education, and smoking status.

All statistical analyses were performed using commercially available software (STATA version 14.2; StataCorp., College Station, TX). All p values were calculated using two-tailed tests with $p < 0.05$ considered statistically significant.

3 | RESULTS

At baseline, 45 individuals (44 edentulous and 1 with incomplete data) from the 600 participants in the original Niigata study population were excluded, leaving 554 eligible participants, of whom 180 were lost to follow-up over a period of 6 years. Subsequently, our final cohort comprised 374 individuals with 7,157 teeth. Of these, 6,443 teeth were available for risk analyses of the tooth-specific periodontitis incidence or progression. At the follow-up examination, 587 (8.2%) of the 7,157 teeth were lost. Additionally, incidence or progression of periodontitis was observed to involve 19.0% (1,226/6,443) of the teeth. The process of selection of the

TABLE 3 Risk of periodontitis incidence or progression and tooth loss by baseline person-based and tooth-based factors

Predictors	OR (95% CI)[a]	
	Tooth-specific periodontitis incidence/progression (N = 6,443 teeth)	Tooth-specific tooth loss (N = 7,157 teeth)
Person-based factors		
Male sex (versus female sex)	**1.97 (1.38–2.81)**	1.42 (0.94–2.15)
Regular dental check-ups ≥1/year[b]	0.67 (0.45–1.01)	**0.47 (0.28–0.79)**
Brushing frequency ≥2 times/day[b]	0.69 (0.47–1.02)	**0.64 (0.41–0.99)**
Use of devices for interdental cleaning[b]	0.75 (0.52–1.07)	**0.48 (0.31–0.74)**
Annual household income <2,000,000 JPY[b]	0.70 (0.43–1.13)	1.13 (0.66–1.93)
Years of school education ≤ 9 years[b]	1.10 (0.76–1.58)	1.15 (0.77–1.74)
Living alone[b]	0.61 (0.36–1.04)	1.40 (0.78–2.51)
Hypoalbuminemia[b]	1.64 (0.75–3.59)	1.21 (0.47–3.11)
High fasting blood glucose level[b]	1.83 (0.87–3.84)	1.49 (0.83–2.67)
Tooth-based factors		
Tooth status (versus sound)		
Decayed	1.78 (0.99–3.18)	**7.50 (3.96–14.19)**
Filled	**1.83 (1.54–2.18)**	**4.75 (3.49–6.46)**
Tooth type (versus anterior)		
Posterior	**1.36 (1.15–1.59)**	**2.47 (1.88–3.24)**
Tooth position (versus mandible)		
Maxilla	**1.72 (1.40–2.12)**	**1.37 (1.04–1.81)**
Use as an abutment		
For fixed bridge[b]	**1.61 (1.24–2.10)**	**1.84 (1.26–2.67)**
For removable denture[b]	**1.93 (1.43–2.60)**	**4.53 (3.26–6.29)**
Greatest CAL (per 1 mm increase)	**1.15 (1.08–1.24)**	**1.71 (1.58–1.85)**

Notes. CAL, clinical attachment loss; CI, confidence interval; JPY, Japanese Yen; OR, odds ratio. [a]Applying inverse probability weighting. [b]Versus no/not. Bold text highlights statistically significant findings ($p < 0.05$).

TABLE 4 Risk of periodontitis incidence or progression and tooth loss by the four baseline individual healthy lifestyle factors

	Tooth-specific periodontitis incidence/progression (*N* = 6,443 teeth)		
	Number (%) of events	Model 1[a] OR (95% CI)	Model 2[b] OR (95% CI)
Smoking			
0 (current smoker)	342 (31.8)	1	1
1 (non-smoker)	884 (16.5)	**0.46 (0.29–0.76)**	**0.54 (0.33–0.89)**
Physical activity			
0 (<10 MET-hr/week)	334 (26.6)	1	1
1 (≥10 MET-hr/week)	892 (17.2)	**0.61 (0.39–0.95)**	0.68 (0.43–1.08)
BMI			
0 (<18.5 or ≥25 kg/m^2)	382 (20.6)	1	1
1 (18.5–25 kg/m^2)	844 (18.4)	0.83 (0.57–1.20)	0.91 (0.63–1.31)
Diet			
0 (≤6 [group median for DVS])	669 (19.5)	1	1
1 (>6 [group median for DVS])	557 (18.5)	0.94 (0.66–1.33)	0.90 (0.64–1.27)
	Tooth-specific tooth loss (*N* = 7,157 teeth)		
	Number (%) of events	Model 1[a] OR (95% CI)	Model 2[b] OR (95% CI)
Smoking			
0 (current smoker)	145 (11.7)	1	1
1 (non-smoker)	442 (7.5)	**0.53 (0.31–0.90)**	0.68 (0.43–1.07)
Physical activity			
0 (<10 MET-hr/week)	166 (11.3)	1	1
1 (≥10 MET-hr/week)	421 (7.4)	0.65 (0.39–1.08)	0.80 (0.52–1.23)
BMI			
0 (<18.5 or ≥25 kg/m^2)	181 (8.7)	1	1
1 (18.5–25 kg/m^2)	406 (8.0)	0.84 (0.55–1.30)	0.82 (0.56–1.18)
Diet			
0 (≤6 [group median for DVS])	350 (9.1)	1	1
1 (>6 [group median for DVS])	237 (7.2)	0.67 (0.45–1.00)	0.80 (0.57–1.13)

Notes. BMI, body mass index; CI, confidence interval; DVS, dietary variety score; MET, metabolic equivalent; OR, odds ratio. [a]Model 1: Applying inverse probability weighting and adjusting for all listed healthy lifestyle factors. [b]Model 2: Additionally adjusting for tooth status, tooth type, tooth location, abutment tooth, highest clinical attachment loss, sex, use of regular dental care, brushing frequency, use of devices for interdental cleaning, annual household income, years of school education, living situation, hypoalbuminemia, and high fasting blood glucose level. Bold text highlights statistically significant findings ($p < 0.05$).

respondents is described in detail in the Supporting Information Appendix 1 & S1.

Among the 374 study participants, 306 (81.8%) were non-smokers, 289 (77.3%) were physically active, 265 (70.9%) maintained a healthy BMI, and 165 (44.1%) had a high-quality diet intake at baseline (Table 1).

Table 2 shows the baseline characteristics of the study population and their teeth according to the baseline healthy lifestyle score. The median number of teeth in the entire cohort was 22 (interquartile range, 13–26), and 201 (53.7%) of the participants were men. The baseline healthy lifestyle score was 0–1 for 41 (11.0%) participants, 2 for 94 (25.1%), 3 for 151 (40.4%), and 4 for 88 (23.5%).

Participants with a lower baseline healthy lifestyle score were more likely to be men, had a greater mean CAL, and were less likely to visit dentists for regular check-ups. On the contrary, none of the tooth-based factors were found to associate with healthy lifestyle scores.

Physically active individuals tended to be non-smokers and had diverse, high-quality diets (Appendix 2).

Associations of baseline person-based and tooth-based factors with the risk of periodontitis and tooth loss are presented in Table 3. Among person-based factors, male sex was associated with significantly higher odds for periodontitis incidence/progression, whereas regular dental check-ups, tooth brushing ≥2 times daily, and the use of interdental cleaning devices were associated with significantly

(a) Tooth-specific periodontitis incidence/progression (*N* = 6,443 teeth)

	Number (%) of events	Model 1† ORs (95% CI)	Model 2‡ ORs (95% CI)
Healthy lifestyle score			
0–1	163 (27.7)	1	1
2	402 (27.0)	0.80 (0.40–1.60)	0.75 (0.38–1.52)
3	468 (17.2)	**0.53 (0.26–1.10)**	0.56 (0.27–1.14)
4	193 (11.7)	**0.30 (0.15–0.59)**	**0.32 (0.16–0.62)**
P_{trend}§		<0.01	<0.01

(b) Tooth-specific tooth loss (*N* = 7,157 teeth)

	Number (%) of events	Model 1† ORs (95% CI)	Model 2‡ ORs (95% CI)
Healthy lifestyle score			
0–1	90 (12.9)	1	1
2	184 (10.8)	0.76 (0.38–1.51)	0.73 (0.41–1.31)
3	204 (6.9)	**0.33 (0.17–0.63)**	**0.49 (0.28–0.86)**
4	109 (6.1)	**0.31 (0.15–0.61)**	**0.42 (0.23–0.77)**
P_{trend}§		<0.01	<0.01

Bold text highlights statistically significant findings ($P<0.05$).

CI, confidence interval; OR, odds ratio

*Four lifestyle factors (cigarette smoking, physical activity, relative weight, and dietary quality) were allocated a score of healthy (1 point) or unhealthy (0 points). The healthy lifestyle score (0–4 points) was generated by adding the individual scores for the four factors.

†Applying inverse probability weighting.

‡Applying inverse probability weighting and adjusting for tooth status, tooth type, tooth location, abutment tooth, highest clinical attachment loss, sex, use of regular dental care, brushing frequency, use of devices for interdental cleaning, annual household income, years of school education, living situation, hypoalbuminemia, and high fasting blood glucose level.

§*P*-values for a linear trend

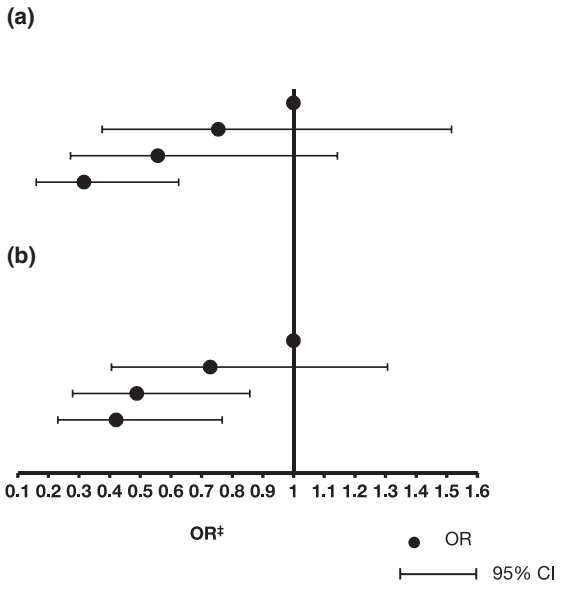

FIGURE 1 Risk of periodontitis incidence or progression (a) and tooth loss (b) over 6 years by baseline combined healthy lifestyle score for Japanese participants who were aged 70 years at baseline (*N* = 374). The healthy lifestyle score showed a significant linear relation with the odds for the tooth-specific incidence or progression of periodontitis and tooth loss. The adjusted odds ratios for the tooth-specific incidence or progression of periodontitis were 1 (reference), 0.75 (95% confidence interval [CI]: 0.38–1.52), 0.56 (95% CI: 0.27–1.14), and 0.32 (95% CI: 0.16–0.62) for individuals with a baseline healthy lifestyle score of 0–1, 2, 3, and 4, respectively ($p_{trend} < 0.01$). The adjusted ORs for the tooth-specific incidence of tooth loss were 1 (reference), 0.73 (95% CI: 0.41–1.31), 0.49 (95% CI: 0.28–0.86), and 0.42 (95% CI: 0.23–0.77) for individuals with a baseline healthy lifestyle score of 0–1, 2, 3, and 4, respectively ($p_{trend} < 0.01$)

lower odds for tooth loss. Among tooth-based factors, filled teeth, posterior teeth, maxillary teeth, abutment teeth, and a higher CAL were all associated with significantly higher odds for periodontitis incidence/progression. Decayed, filled, posterior, maxillary, and abutment teeth, as well as a higher CAL were associated with significantly higher odds for tooth loss.

The effects of individual healthy lifestyle factors on the risk of periodontitis incidence or progression and tooth loss are presented in Table 4. After applying IPW and adjusting for confounding variables, no smoking was associated with significantly lower odds for periodontitis incidence/progression (adjusted OR [aOR] = 0.54; 95% confidence interval [CI]: 0.33–0.89).

The table in Figure 1 displays the risks for tooth-specific periodontitis incidence or progression and tooth loss, respectively, in relation to the baseline combined healthy lifestyle score. The aORs are additionally visualized as a forest plot. Compared to the reference group with the least healthy lifestyle (scores 0–1), the aORs for tooth-specific periodontitis incidence or progression were 0.75 (95% CI: 0.38–1.52), 0.56 (95% CI: 0.27–1.14), and 0.32 (95% CI: 0.16–0.62) for participants with baseline healthy lifestyle scores of 2, 3, and 4, respectively, with a significant trend ($p < 0.01$). The corresponding values for the tooth-specific tooth loss were 0.73 (95% CI: 0.41–1.31), 0.49 (95% CI: 0.28–0.86), and 0.42 (95% CI: 0.23–0.77), respectively, with a significant trend ($p < 0.01$). Results of sex-stratified analyses were similar to those for both sexes combined (Appendix 3).

4 | DISCUSSION

In this longitudinal study among community-dwelling older adults, we investigated the combined effects of healthy lifestyle factors on the risk of oral diseases, specifically development of new periodontitis or progression of existing periodontitis and tooth loss. Compared with the least healthy lifestyle (scores 0–1) at baseline, the healthiest lifestyle (score 4) was significantly associated with a lower risk of incidence or progression of periodontitis and tooth loss over 6 years. There was also a significant linear trend between increasingly healthier lifestyle scores and decreased odds for periodontitis incidence or progression as well as for tooth loss.

Our findings are in agreement with previous findings from the cross-sectional study of 12,110 US adults participating in the third National Health and Nutrition Examination Survey that reported participants engaging in a combination of three health-enhancing behaviors (healthy BMI, good physical activity levels,

and a high-quality diet) had a lower prevalence of periodontitis compared to those who did not (Al-Zahrani, Borawski, & Bissada, 2005b).

A unique strength of the current study is the longitudinal design. To our knowledge, this is the first study to examine the temporal association between four simultaneous healthy lifestyle factors and the risk of periodontitis incidence or progression and tooth loss in older adults.

Another distinction is our adjustment of the multilevel analyses for tooth-based factors. Both person-based and tooth-based factors were significantly associated with risks of oral disease incidence. Our findings that periodontitis incidence or progression occurs significantly more often among molars and in the maxilla agree with a recent study (Teles et al., 2017). The longitudinal association between the combined healthy lifestyle score and the risk of incidence or progression of periodontitis and tooth loss remained significant after adjusting for these person-based and tooth-based factors.

The observed association between an overall healthy lifestyle, measured by the combined four factors, and oral diseases appears biologically plausible. The underlying mechanisms likely involve multiple pathways, including those of inflammation and immune function. Each healthy lifestyle factor investigated in the current study is believed to play a role in the amelioration of inflammation (Ertek & Cicero, 2012; Sotos-Prieto et al., 2016) and the maintenance of immune function (Kohut & Senchina, 2004; Milner & Beck, 2012; Sopori & Kozak, 1998; Wardwell, Chapman-Novakofski, Herrel, & Woods, 2008). Inflammation and immune function have been suggested to play a key role in the pathogenesis of periodontal disease (Cekici, Kantarci, Hasturk, & Van Dyke, 2014). Overall, a healthy lifestyle can prevent periodontitis by reducing inflammation and maintaining healthy immune function. Second, a healthy lifestyle can minimize the risk of physical disability (Jacob et al., 2016), a risk factor for oral disease (Avlund, Holm-Pedersen, & Schroll, 2001; Hatipoglu, Canbaz Kabay, Gungor Hatipoglu, & Ozden, 2016; Jette, Feldman, & Douglass, 1993). Compared with participants with a higher healthy lifestyle score, those with lower scores were less likely to visit the dentist for regular check-ups. A non-significant trend was also observed between the healthy lifestyle score and interdental cleaning habits ($p = 0.09$). These findings suggest an association between a healthy lifestyle and oral health behavior, as indicated previously (Sakki, Knuuttila, & Anttila, 1998). However, the observed association between combined healthy lifestyle factors and oral diseases was independent of oral health behavior. This suggests that a healthy lifestyle involves positive effects other than good oral health behavior, which may promote reduced inflammation and maintain healthy immune function as discussed above.

A study investigating causes of tooth extractions in Japan revealed that periodontitis was the leading cause among individuals aged ≥65 years (Aida et al., 2006). A healthy lifestyle may contribute to a decreased risk of tooth loss by lessening the risk of periodontitis. Unfortunately, a limitation of our study is the unavailability of the reason for tooth loss.

Several other study limitations should be acknowledged. First, lifestyle factors other than BMI were self-reported. We confirmed that no study participant was diagnosed with dementia. Nonetheless, the healthy lifestyle score used in this study was subject to recall bias and misclassification. Second, only baseline information was available for generating the healthy lifestyle score and we therefore could not take into account subsequent lifestyle changes. Similarly, only information on smoking habits at baseline was collected, and thus, past smoking habits were not taken into account. Third, because the present study population only included Japanese adults aged 70 years at baseline, the results may not be generalizable to other populations. Fourth, the healthy lifestyle score used in this study did not include all possible lifestyle factors. Although each factor has been studied in terms of its association with oral diseases (Al-Zahrani et al., 2005a; Bawadi et al., 2011; Jenzsch et al., 2009; Johnson & Hill, 2004; Merchant et al., 2003; Moynihan & Petersen, 2004; Saito et al., 1998), other factors such as alcohol consumption (Tezal, Grossi, Ho, & Genco, 2001) and sleep duration (Romandini et al., 2017) are also possibly associated with disease risk. Furthermore, the healthy lifestyle factors investigated in this study can be measured and scored in multiple different ways. For example, quality of diet can be measured in terms of total calories or by sugar consumption. Overnutrition is associated with chronic inflammation (Lionetti et al., 2009), which can contribute to periodontitis. With regard to the risk of tooth loss, excessive sugar consumption can have significant effects as an essential risk factor for caries (Bernabe, Vehkalahti, Sheiham, Lundqvist, & Suominen, 2016), the second leading cause of tooth extraction among older adults in Japan (Aida et al., 2006). However, we were not able to obtain information regarding individual nutrients, nor were we able to assess the caries status at baseline or caries incidence during the study. Finally, although our analyses were adjusted for various potential confounding variables evaluated, residual confounding due to unmeasured variables, such as history of cigarette smoking and depression, or due to unexpected confounding, may exist. Our findings should therefore be verified in future studies that include collection of such data and be conducted in other geographic areas and age groups.

Within its limitations, our study demonstrates that a healthy lifestyle—defined as simultaneous adherence to the four healthy lifestyle factors: not smoking, a good physical activity level, a healthy BMI, and a high-quality diet—is associated with a lower risk of incidence or progression of periodontitis, and tooth loss over 6 years in elderly Japanese men and women. These findings validate the general expectations of positive effects of modifying risk factors for periodontitis and tooth loss. To prevent oral diseases and promote oral health in older adults, the public health community, clinicians, and other stakeholders should place more emphasis on comprehensive approaches to enhance simultaneous adherence to multiple healthy lifestyle components for the benefit of both oral and general health—and ultimately to enhance quality of life.

CONTRIBUTIONS

Research concepts and study design: MI; data acquisition: MI, HO, TY, MS, KM, AY, and HM; data analysis/interpretation: MI and WSB; statistical analysis: MI; supervision: TA and HM. Each author contributed important intellectual content during manuscript drafting or revision and accepts accountability for the overall work by ensuring that questions pertaining to the accuracy or integrity of any portion of the work are appropriately investigated and resolved. MI takes responsibility for the fact that this study has been reported honestly, accurately, and transparently; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

CONFLICT OF INTEREST

The authors have no conflicts of interest to declare.

ORCID

Masanori Iwasaki http://orcid.org/0000-0002-5739-2936
Wenche S. Borgnakke http://orcid.org/0000-0003-3593-093X
Akihiro Yoshihara http://orcid.org/0000-0002-0424-8228

REFERENCES

Aadahl, M., & Jorgensen, T. (2003). Validation of a new self-report instrument for measuring physical activity. *Medicine & Science in Sports & Exercise*, *35*, 1196–1202. https://doi.org/10.1249/01.mss.0000074446.02192.14

Aida, J., Ando, Y., Akhter, R., Aoyama, H., Masui, M., & Morita, M. (2006). Reasons for permanent tooth extractions in Japan. *Journal of Epidemiology*, *16*, 214–219. https://doi.org/10.2188/jea.16.214

Al-Zahrani, M. S., Borawski, E. A., & Bissada, N. F. (2005a). Increased physical activity reduces prevalence of periodontitis. *Journal of Dentistry*, *33*, 703–710. https://doi.org/10.1016/j.jdent.2005.01.004

Al-Zahrani, M. S., Borawski, E. A., & Bissada, N. F. (2005b). Periodontitis and three health-enhancing behaviors: Maintaining normal weight, engaging in recommended level of exercise, and consuming a high-quality diet. *Journal of Periodontology*, *76*, 1362–1366. https://doi.org/10.1902/jop.2005.76.8.1362

American Diabetes Association (2017). 2. Classification and diagnosis of diabetes. *Diabetes Care*, *40*, S11–S24. https://doi.org/10.2337/dc17-S005

Avlund, K., Holm-Pedersen, P., & Schroll, M. (2001). Functional ability and oral health among older people: A longitudinal study from age 75 to 80. *Journal of the American Geriatrics Society*, *49*, 954–962. https://doi.org/10.1046/j.1532-5415.2001.49187.x

Bawadi, H. A., Khader, Y. S., Haroun, T. F., Al-Omari, M., & Tayyem, R. F. (2011). The association between periodontal disease, physical activity and healthy diet among adults in Jordan. *Journal of Periodontal Research*, *46*, 74–81. https://doi.org/10.1111/j.1600-0765.2010.01314.x

Bernabe, E., Vehkalahti, M. M., Sheiham, A., Lundqvist, A., & Suominen, A. L. (2016). The shape of the dose-response relationship between sugars and caries in adults. *Journal of Dental Research*, *95*, 167–172. https://doi.org/10.1177/0022034515616572

Borgnakke, W. S. (2016). Modifiable risk factors for periodontitis and diabetes. *Current Oral Health Reports*, *3*, 254–269. https://doi.org/10.1007/s40496-016-0099-6

Buset, S. L., Walter, C., Friedmann, A., Weiger, R., Borgnakke, W. S., & Zitzmann, N. U. (2016). Are periodontal diseases really silent? A systematic review of their effect on quality of life. *Journal of Clinical Periodontology*, *43*, 333–344. https://doi.org/10.1111/jcpe.12517

Cekici, A., Kantarci, A., Hasturk, H., & Van Dyke, T. E. (2014). Inflammatory and immune pathways in the pathogenesis of periodontal disease. *Periodontology 2000*, *64*, 57–80. https://doi.org/10.1111/prd.12002

Eke, P. I., Dye, B. A., Wei, L., Slade, G. D., Thornton-Evans, G. O., Borgnakke, W. S., … Genco, R. J. (2015). Update on prevalence of periodontitis in adults in the United States: NHANES 2009 to 2012. *Journal of Periodontology*, *86*, 611–622. https://doi.org/10.1902/jop.2015.140520

Eke, P. I., Wei, L., Borgnakke, W. S., Thornton-Evans, G., Zhang, X., Lu, H., … Genco, R. J. (2016). Periodontitis prevalence in adults ≥ 65 years of age, in the USA. *Periodontology 2000*, *72*, 76–95. https://doi.org/10.1111/prd.12145

Ertek, S., & Cicero, A. (2012). Impact of physical activity on inflammation: Effects on cardiovascular disease risk and other inflammatory conditions. *Archives of Medical Science*, *8*, 794–804. https://doi.org/10.5114/aoms.2012.31614

Ford, E. S., Bergmann, M. M., Kroger, J., Schienkiewitz, A., Weikert, C., & Boeing, H. (2009). Healthy living is the best revenge: Findings from the European Prospective Investigation Into Cancer and Nutrition-Potsdam study. *Archives of Internal Medicine*, *169*, 1355–1362. https://doi.org/10.1001/archinternmed.2009.237

Friedman, P. K., & Lamster, I. B. (2016). Tooth loss as a predictor of shortened longevity: Exploring the hypothesis. *Periodontology 2000*, *72*, 142–152. https://doi.org/10.1111/prd.12128

Griffin, S. O., Jones, J. A., Brunson, D., Griffin, P. M., & Bailey, W. D. (2012). Burden of oral disease among older adults and implications for public health priorities. *American Journal of Public Health*, *102*, 411–418. https://doi.org/10.2105/ajph.2011.300362

Hatipoglu, H., Canbaz Kabay, S., Gungor Hatipoglu, M., & Ozden, H. (2016). Expanded disability status scale-based disability and dental-periodontal conditions in patients with multiple sclerosis. *Medical Principles and Practice*, *25*, 49–55. https://doi.org/10.1159/000440980

Hernan, M. A., Hernandez-Diaz, S., & Robins, J. M. (2004). A structural approach to selection bias. *Epidemiology*, *15*, 615–625. https://doi.org/10.1097/01.ede.0000135174.63482.43

Hirotomi, T., Yoshihara, A., Ogawa, H., Ito, K., Igarashi, A., & Miyazaki, H. (2006). A preliminary study on the relationship between stimulated saliva and periodontal conditions in community-dwelling elderly people. *Journal of Dentistry*, *34*, 692–698. https://doi.org/10.1016/j.jdent.2006.01.001

Hirotomi, T., Yoshihara, A., Ogawa, H., & Miyazaki, H. (2010). Tooth-related risk factors for periodontal disease in community-dwelling elderly people. *Journal of Clinical Periodontology*, *37*, 494–500. https://doi.org/10.1111/j.1600-051X.2010.01565.x

Hirotomi, T., Yoshihara, A., Ogawa, H., & Miyazaki, H. (2012). Tooth-related risk factors for tooth loss in community-dwelling elderly people. *Community Dentistry and Oral Epidemiology*, *40*, 154–163. https://doi.org/10.1111/j.1600-0528.2011.00648.x

Iwasaki, M., Sato, M., Yoshihara, A., Ansai, T., & Miyazaki, H. (2017). Association between tooth loss and medical costs related to stroke in healthy older adults aged over 75 years in Japan. *Geriatrics & Gerontology International*, *17*, 202–210. https://doi.org/10.1111/ggi.12687

Jacob, M. E., Yee, L. M., Diehr, P. H., Arnold, A. M., Thielke, S. M., Chaves, P. H., … Newman, A. B. (2016). Can a healthy lifestyle compress the disabled period in older adults? *Journal of the American Geriatrics Society*, *64*, 1952–1961. https://doi.org/10.1111/jgs.14314

Jenzsch, A., Eick, S., Rassoul, F., Purschwitz, R., & Jentsch, H. (2009). Nutritional intervention in patients with periodontal disease: Clinical, immunological and microbiological variables during 12 months.

British Journal of Nutrition, *101*, 879–885. https://doi.org/10.1017/s0007114508047776

Jette, A. M., Feldman, H. A., & Douglass, C. (1993). Oral disease and physical disability in community-dwelling older persons. *Journal of the American Geriatrics Society*, *41*, 1102–1108. https://doi.org/10.1111/j.1532-5415.1993.tb06459.x

Jiao, L., Mitrou, P. N., Reedy, J., Graubard, B. I., Hollenbeck, A. R., Schatzkin, A., & Stolzenberg-Solomon, R. (2009). A combined healthy lifestyle score and risk of pancreatic cancer in a large cohort study. *Archives of Internal Medicine*, *169*, 764–770. https://doi.org/10.1001/archinternmed.2009.46

Jin, L. J., Lamster, I. B., Greenspan, J. S., Pitts, N. B., Scully, C., & Warnakulasuriya, S. (2016). Global burden of oral diseases: Emerging concepts, management and interplay with systemic health. *Oral Diseases*, *22*, 609–619. https://doi.org/10.1111/odi.12428

Johnson, G. K., & Hill, M. (2004). Cigarette smoking and the periodontal patient. *Journal of Periodontology*, *75*, 196–209. https://doi.org/10.1902/jop.2004.75.2.196

Kassebaum, N. J., Bernabe, E., Dahiya, M., Bhandari, B., Murray, C. J., & Marcenes, W. (2014a). Global burden of severe periodontitis in 1990–2010: A systematic review and meta-regression. *Journal of Dental Research*, *93*, 1045–1053. https://doi.org/10.1177/0022034514552491

Kassebaum, N. J., Bernabe, E., Dahiya, M., Bhandari, B., Murray, C. J., & Marcenes, W. (2014b). Global burden of severe tooth loss: A systematic review and meta-analysis. *Journal of Dental Research*, *93*, 20S–28S. https://doi.org/10.1177/0022034514537828

Kirkegaard, H., Johnsen, N. F., Christensen, J., Frederiksen, K., Overvad, K., & Tjonneland, A. (2010). Association of adherence to lifestyle recommendations and risk of colorectal cancer: A prospective Danish cohort study. *British Medical Journal*, *341*, c5504. https://doi.org/10.1136/bmj.c5504

Kohut, M. L., & Senchina, D. S. (2004). Reversing age-associated immunosenescence via exercise. *Exercise Immunology Review*, *10*, 6–41.

Kubota, Y., Iso, H., & Tamakoshi, A. (2015). Association of body mass index and mortality in Japanese diabetic men and women based on self-reports: The Japan Collaborative Cohort (JACC) Study. *Journal of Epidemiology*, *25*, 553–558. https://doi.org/10.2188/jea.JE20150011

Kumagai, S., Watanabe, S., Shibata, H., Amano, H., Fujiwara, Y., Shinkai, S., … Haga, H. (2003). Effects of dietary variety on declines in high-level functional capacity in elderly people living in a community [in Japanese]. *Nihon Koshu Eisei Zasshi*, *50*, 1117–1124. https://doi.org/10.11236/jph.50.12_1117

Kwon, J., Suzuki, T., Kumagai, S., Shinkai, S., & Yukawa, H. (2006). Risk factors for dietary variety decline among Japanese elderly in a rural community: A 8-year follow-up study from TMIG-LISA. *European Journal of Clinical Nutrition*, *60*, 305–311. https://doi.org/10.1038/sj.ejcn.1602314

Lionetti, L., Mollica, M. P., Lombardi, A., Cavaliere, G., Gifuni, G., & Barletta, A. (2009). From chronic overnutrition to insulin resistance: The role of fat-storing capacity and inflammation. *Nutrition, Metabolism & Cardiovascular Diseases*, *19*, 146–152. https://doi.org/10.1016/j.numecd.2008.10.010

Matsuyama, Y., Aida, J., Watt, R. G., Tsuboya, T., Koyama, S., Sato, Y., … Osaka, K. (2017). Dental status and compression of life expectancy with disability. *Journal of Dental Research*, *96*, 1006–1013. https://doi.org/10.1177/0022034517713166

Merchant, A. T., Pitiphat, W., Rimm, E. B., & Joshipura, K. (2003). Increased physical activity decreases periodontitis risk in men. *European Journal of Epidemiology*, *18*, 891–898. https://doi.org/10.1023/A:1025622815579

Milner, J. J., & Beck, M. A. (2012). The impact of obesity on the immune response to infection. *Proceedings of the Nutrition Society*, *71*, 298–306. https://doi.org/10.1017/s0029665112000158

Moynihan, P., & Petersen, P. E. (2004). Diet, nutrition and the prevention of dental diseases. *Public Health Nutrition*, *7*, 201–226. https://doi.org/10.1079/PHN2003589

Murayama, H., Liang, J., Bennett, J. M., Shaw, B. A., Botoseneanu, A., Kobayashi, E., … Shinkai, S. (2015). Trajectories of body mass index and their associations with mortality among older Japanese: Do they differ from those of western populations? *American Journal of Epidemiology*, *182*, 597–605. https://doi.org/10.1093/aje/kwv107

Nagai, M., Kuriyama, S., Kakizaki, M., Ohmori-Matsuda, K., Sugawara, Y., Sone, T., … Tsuji, I. (2010). Effect of age on the association between body mass index and all-cause mortality: The Ohsaki cohort study. *Journal of Epidemiology*, *20*, 398–407. https://doi.org/10.2188/jea.JE20090204

Romandini, M., Gioco, G., Perfetti, G., Deli, G., Staderini, E., & Lafori, A. (2017). The association between periodontitis and sleep duration. *Journal of Clinical Periodontology*, *44*, 490–501. https://doi.org/10.1111/jcpe.12713

Saito, T., Shimazaki, Y., & Sakamoto, M. (1998). Obesity and periodontitis. *The New England Journal of Medicine*, *339*, 482–483. https://doi.org/10.1056/NEJM199808133390717

Sakki, T. K., Knuuttila, M. L., & Anttila, S. S. (1998). Lifestyle, gender and occupational status as determinants of dental health behavior. *Journal of Clinical Periodontology*, *25*, 566–570. https://doi.org/10.1111/j.1600-051X.1998.tb02489.x

Sasazuki, S., Inoue, M., Iwasaki, M., Sawada, N., Shimazu, T., Yamaji, T., & Tsugane, S. (2012). Combined impact of five lifestyle factors and subsequent risk of cancer: The Japan Public Health Center Study. *Preventive Medicine*, *54*, 112–116. https://doi.org/10.1016/j.ypmed.2011.11.003

Sato, M., Iwasaki, M., Yoshihara, A., & Miyazaki, H. (2016). Association between periodontitis and medical expenditure in older adults: A 33-month follow-up study. *Geriatrics & Gerontology International*, *16*, 856–864. https://doi.org/10.1111/ggi.12569

Sopori, M. L., & Kozak, W. (1998). Immunomodulatory effects of cigarette smoke. *Journal of Neuroimmunology*, *83*, 148–156. https://doi.org/10.1016/S0165-5728(97), 00231-2

Sotos-Prieto, M., Bhupathiraju, S. N., Falcon, L. M., Gao, X., Tucker, K. L., & Mattei, J. (2016). Association between a Healthy Lifestyle Score and inflammatory markers among Puerto Rican adults. *Nutrition, Metabolism & Cardiovascular Diseases*, *26*, 178–184. https://doi.org/10.1016/j.numecd.2015.12.004

Tan, H., Peres, K. G., & Peres, M. A. (2016). Retention of teeth and oral health-related quality of life. *Journal of Dental Research*, *95*, 1350–1357. https://doi.org/10.1177/0022034516657992

Teles, R., Moss, K., Preisser, J. S., Genco, R., Giannobile, W. V., Corby, P., … Cugini, M. (2017). Patterns of periodontal disease progression based on linear mixed models of clinical attachment loss. *Journal of Clinical Periodontology*, *45*, 15–25. https://doi.org/10.1111/jcpe.12827

Tezal, M., Grossi, S. G., Ho, A. W., & Genco, R. J. (2001). The effect of alcohol consumption on periodontal disease. *Journal of Periodontology*, *72*, 183–189. https://doi.org/10.1902/jop.2001.72.2.183

The Ministry of Health, Labour, and Welfare. (2011). *Survey of dental diseases*, *2011*. Retrieved from http://www.mhlw.go.jp/toukei/list/62-23.html

The Ministry of Health, Labour, and Welfare. (2012). *Health Japan 21 (the second term)*. Retrieved from http://www.mhlw.go.jp/seisakunitsuite/bunya/kenkou_iryou/kenkou/kenkounippon21/en/kenkounippon21/mokuhyou05.html

The Ministry of Health, Labour, and Welfare. (2013). *Exercise and physical activity reference for health promotion (EPAR) 2013*. Retrieved from http://www.mhlw.go.jp/stf/houdou/2r9852000002xple-att/2r9852000002xpqt.pdf

Wardwell, L., Chapman-Novakofski, K., Herrel, S., & Woods, J. (2008). Nutrient intake and immune function of elderly subjects. *Journal of the American Dietetic Association*, *108*, 2005–2012. https://doi.org/10.1016/j.jada.2008.09.003

World Health Organization. (1997). *Oral health surveys: Basic methods*. 4th edition. Retrieved from http://apps.who.int/iris/bitstream/10665/41905/1/9241544937.pdf

World Health Organization. (2017). *Obesity and overweight. Fact sheet Updated October 2017*. Retrieved from http://www.who.int/mediacentre/factsheets/fs311/en/

Zhan, Y., Samietz, S., Holtfreter, B., Hannemann, A., Meisel, P., Nauck, M., … Kocher, T. (2014). Prospective study of serum 25-hydroxy vitamin D and tooth loss. *Journal of Dental Research*, *93*, 639–644. https://doi.org/10.1177/0022034514534985

Zhang, W., Wu, Y. Y., & Wu, B. (2017). Does oral health predict functional status in late life? Findings from a national sample. *Journal of Aging and Health*. https://doi.org/10.1177/0898264317698552

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Iwasaki M, Borgnakke WS, Ogawa H, et al. Effect of lifestyle on 6-year periodontitis incidence or progression and tooth loss in older adults. *J Clin Periodontol*. 2018;45:896–908. https://doi.org/10.1111/jcpe.12920

APPENDIX 1

Comparison of characteristics between participants and non-completers

	Study participants	Non-completers[a]	
	n = 374	*n* = 180	*P**
Healthy lifestyle			
Healthy lifestyle score, *n* (%)			0.33
0–1	41 (11.0)	19 (10.6)	
2	94 (25.1)	57 (31.7)	
3	151 (40.4)	66 (36.7)	
4	88 (23.5)	38 (21.1)	
Non-smoker, *n* (%)	306 (81.8)	148 (82.2)	0.91
Good physical activity level (≥10 MET-hr/week), *n* (%)	289 (77.3)	140 (77.8)	0.89
Healthy BMI (18.5–25 kg/m^2), *n* (%)	265 (70.9)	123 (68.3)	0.54
Diverse, high-quality diet (DVS >6), *n* (%)	165 (44.1)	71 (39.4)	0.30
Other characteristics			
n of teeth, median (IQR)	22 (13–26)	19 (12–24.5)	0.06
Denture use, *n* (%)	200 (53.5)	108 (60.0)	0.15
Average CAL (mm), median (IQR)	2.9 (2.3–3.5)	2.9 (2.4–3.8)	0.55
Men, *n* (%)	201 (53.7)	82 (45.6)	0.07
Regular dental visits at least once a year, *n* (%)	76 (20.3)	30 (16.7)	0.31
Brushing frequency ≥2 times/day, *n* (%)	255 (68.2)	122 (67.8)	0.92
Using devices for interdental cleaning, *n* (%)	137 (36.6)	63 (35.0)	0.71
Annual household income <2,000,000 JPY, *n* (%)	49 (13.1)	31 (17.2)	0.20
Length of school education ≤9 years, *n* (%)	156 (41.7)	88 (48.9)	0.11
Living alone, *n* (%)	33 (8.8)	19 (10.6)	0.51
Hypoalbuminemia, *n* (%)	24 (6.4)	17 (9.4)	0.20
High fasting blood glucose level, *n* (%)	51 (13.6)	23 (12.8)	0.78

Notes. BMI, body mass index; CAL, clinical attachment loss, DVS, dietary variety score; IQR, interquartile range; JPY, Japanese Yen; MET, metabolic equivalent. [a]Individuals withdrew from the study or were lost to follow-up. **P* value for comparison between groups.

APPENDIX 2

Associations among four health lifestyle factors

Healthy lifestyle factors	Smoking		Physical activity		BMI		Diet	
	0	1	0	1	0	1	0	1
Smoking								
0								
1								
Physical activity								
0	28 (32.9)	57 (67.1)						
1	40 (13.8)	249 (86.2)						
	$p < 0.01$							
BMI								
0	22 (20.2)	87 (79.8)	26 (23.9)	83 (76.2)				
1	46 (17.4)	219 (82.6)	59 (22.3)	206 (77.7)				
	$p = 0.52$		$p = 0.74$					
Diet								
0	42 (20.1)	167 (79.9)	58 (27.8)	151 (72.3)	68 (32.5)	141 (67.5)		
1	26 (15.8)	139 (84.2)	27 (16.4)	138 (83.6)	41 (24.9)	124 (75.2)		
	$p = 0.28$		$p = 0.01$		$p = 0.10$			

Notes. BMI, body mass index; DVS, dietary variety score; MET, metabolic equivalents. Smoking: 0 (current smoker), 1 (non-smoker); Physical activity: 0 (<10 MET-hr/week), 1 (≥10 MET-hr/week); BMI: 0 (<18.5 or ≥25 kg/m^2), 1 (18.5–25 kg/m^2); Diet: 0 (≤6 [group DVS median]), 1 (>6 [group DVS median]).

APPENDIX 3

Risk of periodontitis incidence or progression and tooth loss by baseline healthy lifestyle score and sex

	Tooth-specific periodontitis incidence/progression (*N* = 6,443 teeth)					
	Men (*n* = 3,521 teeth)			Women (*n* = 2,922 teeth)		
	Number (%) of events	Model 1[a] OR (95% CI)	Model 2[b] OR (95% CI)	Number (%) of events	Model 1[a] OR (95% CI)	Model 2[b] OR (95% CI)
Healthy lifestyle score						
0–1	145 (27.6)	1	1	18 (28.6)	1	1
2	302 (30.6)	1.08 (0.46–2.52)	1.03 (0.43–2.48)	100 (19.8)	0.49 (0.20–1.19)	**0.32 (0.12–0.85)**
3	262 (19.8)	0.83 (0.34–1.98)	0.78 (0.32–1.90)	211 (15.1)	0.39 (0.16–0.96)	**0.28 (0.10–0.80)**
4	90 (13.1)	**0.36 (0.16–0.84)**	**0.37 (0.16–0.87)**	98 (10.3)	**0.26 (0.11–0.58)**	**0.17 (0.06–0.45)**
p_{trend*}		<0.01	<0.01		<0.01	<0.01

	Tooth-specific tooth loss (*N* = 7,157 teeth)					
	Men (*n* = 3,938 teeth)			Women (*n* = 3,219 teeth)		
	Number (%) of events	Model 1[a] OR (95% CI)	Model 2[b] OR (95% CI)	Number (%) of events	Model 1[a] OR (95% CI)	Model 2[b] OR (95% CI)
Healthy lifestyle score						
0–1	74 (12.1)	1	1	16 (18.8)	1	1
2	126 (11.2)	0.92 (0.39–2.13)	0.69 (0.34–1.43)	58 (10.1)	0.54 (0.15–1.96)	0.59 (0.18–1.9)
3	105 (7.3)	**0.40 (0.18–0.88)**	0.56 (0.28–1.12)	99 (6.5)	**0.25 (0.07–0.86)**	**0.36 (0.12–1.10)**

	Tooth-specific tooth loss (*N* = 7,157 teeth)					
	Men (*n* = 3,938 teeth)			Women (*n* = 3,219 teeth)		
	Number (%) of events	Model 1[a] OR (95% CI)	Model 2[b] OR (95% CI)	Number (%) of events	Model 1[a] OR (95% CI)	Model 2[b] OR (95% CI)
4	49 (6.5)	**0.31 (0.13–0.76)**	**0.44 (0.20–0.96)**	60 (5.8)	**0.27 (0.08–0.94)**	**0.34 (0.11–1.06)**
p_{trend*}		<0.01	0.03		0.02	0.04

Notes. CI, confidence interval; OR, odds ratio. [a]Model 1: Applying inverse probability weighting. [b]Model 2: Applying inverse probability weighting and adjusting for tooth status, tooth type, tooth location, abutment tooth, highest clinical attachment level, use of regular dental care, brushing frequency, use of devices for interdental cleaning, annual household income, years of school education, living situation, hypoalbuminemia, and high fasting blood glucose level. Bold text highlights statistically significant findings ($p < 0.05$). *p values for linear trend.