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Relationship between bleeding on probing and periodontal disease progression in community-dwelling older adults

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Abstract

Objective: The main objective of this study was to determine the relationship between bleeding on probing (BOP) and periodontal disease progression in community-dwelling older adults.

Methods: A 3-year longitudinal study was carried out in 229 non-smoking healthy older adults aged 70 years. Using pressure-controlled periodontal probes, BOP, pocket depth and attachment level at 13,289 sites were measured annually. Periodontal disease progression was defined as an increase in attachment loss of $\geqslant 3$ mm from the baseline to the final examination. The backward stepwise logistic regression analysis was performed to assess the relationship between the total number of sites with BOP in the four examinations and periodontal progression.

Results: Logistic regression analysis showed that the odds ratios of BOP frequency for periodontal disease progression ranged from 1.4 to 6.2 after controlling for pocket depth $\geqslant 4$ mm at baseline, number of missing teeth, jaw type and tooth site.

Conclusion: Increasing frequencies of bleeding might increase the probability of periodontal disease progression in community-dwelling older adults.

Key words: *bleeding on probing; longitudinal study; older adults; periodontal disease progression*

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Untreated periodontal disease leads to tooth loss, which is a major public health problem affecting a large number of older adults. The Japanese national oral health survey in 1999 showed that the mean number of missing teeth was 8.01, 15.56 and 20.77 for 60–64-, 70–74- and 80–84-year-olds, respectively (Ministry of Health and Welfare Japan 2003). According to a previous study, 22–65% of senior citizens (65 years and older) in Japan were edentulous (Miyazaki et al. 1995). As more teeth are lost because of periodontal reasons with increasing age (Splieth et al. 2002, Taani 2003), a strategy for periodontal disease prevention is necessary not only for younger adults but also for older adults.

Bleeding on probing (BOP) correlates with gingival inflammation (Greenstein et al. 1981, Goodson et al. 1982, Haffajee et al. 1983, Abbas et al. 1986, Grbic & Lamster 1992, Chaves et al. 1993, Newbrun 1996, de Souza et al. 2003) and is widely used in evaluating the risk of periodontal disease progression during periodontal therapy or maintenance (Badersten et al. 1985, Lang et al. 1986, 1990, Joss et al. 1994). However, it has been shown that many sites with no progression of periodontal disease exhibited bleeding and thus, BOP has been considered as a poor prognostic indicator for attachment loss in spite of its high degree of specificity (Newbrun 1996). The relationship between BOP and periodontal progression is difficult to establish, as the results may be easily confounded by other factors such as smoking. It has been observed that smokers have less gingival bleeding compared with non-smokers (Fung & Corbet 1995, Amarasena et al. 2002, 2003). Even though several studies have reported a correlation between BOP and periodontal disease progression, controlling for smoking status (Badersten et al. 1985, Lang et al. 1986, Joss et al. 1994), investigations on periodontal progression, particularly in older people, using biochemical assessment of smoking status have not been conducted over the last 2 decades. Accordingly, this study was carried out to determine the relationship between BOP and periodontal disease progression in older adults, after controlling for smoking status.

Material and Methods

Subjects

A longitudinal study was conducted in older adults who reside in Niigata City, Japan. Initially, questionnaires were sent to all 4542 residents aged 70 years (born in 1927). Out of them, 600 people were randomly selected in order to have approximately the same number from each gender for the baseline survey. The participants were asked to sign consent forms regarding the protocol, which had been approved by the Ethics Committee of Niigata University School of Dentistry.

The subjects were assessed by TMIG-Index of Competence subscale questionnaires. The TMIG-Index of Competence is used to assess functional capacity in older participants. The ability to perform a given function is indicated by "Yes" or "No". The highest score of the TMIG-Index subscales is 13 (Koyano et al. 1991). The mean score of the TMIG-Index subscales of the subjects in the present study was 11.9 ± 1.4. The results of this assessment pointed to a high level of competence among the participants of this study, which in turn proved that they were healthy.

The past medical history of the subjects and the number of diseases they have had (heart disease, blood disease, liver disease, kidney disease, diabetes mellitus, high blood pressure, rheumatism, respiratory disease, lumbago, allergies, digestive disease and cerebral apoplexy) at baseline were evaluated. The mean number of diseases experienced by the subjects was 1.9 ± 1.1. In addition, the percentage of persons who received professional care, such as removal of dental plaque and calculus more than once a year during the observation period, was 25.8%.

Subjects with serum cotinine levels less than 75 ng/ml were defined as non-smokers (Tangada et al. 1997). Cotinine was analysed with double-antibody liquid-phase radioimmunoassay using reagents from Diagnostic Products Corporation (Los Angeles, CA, USA), Initially, 25 μl of serum sample or standard, 100 μl of I-labelled cotinine and 100 μl of nicotine metabolite antiserum were introduced into polypropylene tubes; subsequently, tubes were incubated for 30 min. at room temperature. Following the addition of cold precipitating solution, tubes were centrifuged for 15 min. at $3000 \times g$. Having removed the supernatant, the precipitate was measured with a Gamma counter. Thereafter, the serum cotinine levels were calculated from the standard curve.

The periodontal examination included the assessment of probing pocket depth (PPD), clinical attachment level (CAL) (Glavind & Löe 1967) and BOP (Ainamo & Bay 1975) at six sites around each tooth. Probing was performed using a pressure constant probe (Vivacare TPS Probe®, Schaan, Liechtenstein) at a probing force of 20 g. The periodontal examination was carried out by four trained and calibrated dentists under sufficient illumination using artificial light. Calibration of the examiners was carried out in volunteer patients of the Faculty Hospital. As determined by replicate examinations in 18 patients, the percent agreement (within $\pm$ 1 mm) ranged from 85.5% to 100% for PPD and from 70.0% to 100% for CAL. The κ (within $\pm$ 1 mm) ranged from 0.77 to 1.00 for PPD and from 0.62 to 1.00 for CAL.

Data analysis

Out of 260 non-smokers, 229 subjects who had at least one tooth intact were selected. Consequently, 13,289 intact sites (5110 sites in the maxilla and 8179 sites in the mandible) in the selected subjects were included in the analysis. In our study, an additional attachment loss (AAL) of 3 mm or greater was set as a conservative estimate of actual change taking place in conformity with the definition of Brown et al. (1994).

Univariate statistical analyses were performed to describe the prevalence of BOP and PPD of $\geqslant$4 mm at baseline examination, and AAL $\geqslant$3 mm over a 3-year period. Then, BOP frequency (Bf) was calculated by the total number of sites presented with BOP(+) in the four examinations (one time at baseline and three times at annual recalls) for all sites, and divided into five categories. The proportion of sites with AAL of $\geqslant$3 mm over 3 years by different frequencies of BOP was calculated, and Chi-square analysis was used to determine the statistical significance.

To evaluate the relationship between BOP and periodontal disease, firstly, we conducted subject-based data analysis using multiple linear regression analysis. The percentage of sites exhibiting AAL $\geqslant$3 mm over the 3-year period per person was selected as a dependent variable, and the percentage of sites with BOP(+), the percentage of sites with PPD of 4 mm, the number of missing teeth at baseline and gender were selected as independent variables. Next, the backward stepwise logistic regression analysis using site-based data was performed to evaluate the relationship between Bf and periodontal disease progression. The dependent variable, periodontal disease progression, was defined as sites exhibiting AAL $\geqslant$3 mm. The independent variables used were gender, Bf, PPD at baseline, jaw type (Upper or Lower), tooth type, tooth site and the number of missing teeth. The odds ratios with 95% confidence intervals (CI) were calculated.

In the stepwise logistic regression analysis, $p<0.05$ was used as the entry criterion while $p>0.10$ was the removal criterion. The Hosmer and Lemeshow Goodness-of-Fit test statistic was fixed at $p>0.05$ (Lemeshow & Hosmer 1982). The software of Statistical Package for Social Sciences (SPSS for Window, Release 11.5) was used for all calculations and analyses.

Results

Out of the total number of subjects selected, 69.2% (females: 75%, males: 64%, $N=229$) exhibited AAL $\geqslant$3 mm at one or more sites over 3 years. The mean number of sites with AAL $\geqslant$3 mm per person was 3.48 ± 3.39 for females and 3.90 ± 5.29 for males. However, there was no statistically significant difference between the mean number of sites with AAL $\geqslant$3 mm in females and males (Student's t-test $p>0.50$). The number of missing teeth of the subjects was 7.88 ± 7.61 at baseline.

Table 1 shows a multivariate linear regression model for subjects who were followed up over the 3-year period. In this regression model, three variables, namely, percentage of BOP(+) sites, percentage of sites with PPD $\geqslant$4 mm and the number of missing teeth at baseline, were significantly associated with the percentage of sites with AAL $\geqslant$3 mm during the 3-year observation period.

Figure 1 shows the relationship between the proportion of sites with AAL $\geqslant$3 mm and Bf. A highly significant ($p<0.001$) relation between the increasing frequencies of BOP(+) and AAL

Table 1. Subject-based analysis with multiple linear regression and associated *p*-values

Baseline parameter	Dependent variable % of sites exhibiting additional attachment loss 3+mm during 3 years				
	Coefficient	SE	*p*-value	95% CI	
% BOP positive	0.134	0.039	0.001	0.056	0.211
% PPD 4+mm	0.112	0.038	0.003	0.038	0.186
No. of missing teeth	1.707	0.550	0.002	2.790	0.625
Gender	− 1.437	0.794	0.072	− 3.001	0.127
Constant	8.810	1.986	<0.001	4.900	12.720

Number of subjects: 260.
Prob > F: <0.001
R^2: 0.167.
BOP, bleeding on probing; PPD, probing pocket depth; CI, confidence interval; SE, standard error.

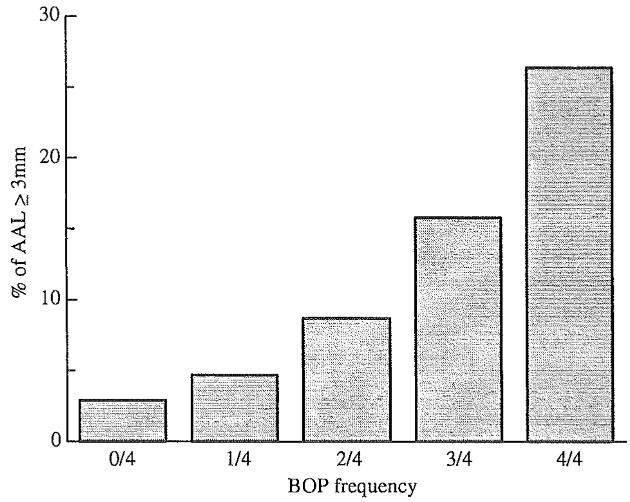

Fig. 1. Proportion of sites that had additional attachment loss (AAL) ⩾3 mm over 3 years by different frequencies of bleeding on probing (BOP). Frequency of bleeding on probing (BOP frequency) was calculated by the total number of sites that presented with BOP (+) in the four examinations (one at baseline and three times at annual recalls) for all sites and divided into five categories as follows: 0/4, BOP+ at none of four examinations; 1/4, BOP+ at one out of four examinations; 2/4, BOP+ at two out of four examinations; 3/4, BOP+ at three out of four examinations; and 4/4, BOP+ at all four examinations.

Table 2. Sensitivity, specificity and predictive values for additional attachment loss of 3+mm in relation to the frequency of bleeding on probing

Bf	Sensitivity	Specificity	PPV	NPV
0/4	67.3	19.0	3.4	93.3
1/4	18.4	85.8	5.1	96.2
2/4	8.8	96.3	9.2	96.2
3/4	4.0	99.1	15.5	96.1
4/4	1.5	99.8	26.1	96.0

Bf, frequency of bleeding on probing; PPV, positive predictive value; NPV, negative predictive value.

⩾3 mm was observed. The proportions of disease progression in the five categories were 2.9% (0/4), 4.7% (1/4), 8.7% (2/4), 15.8% (3/4) and 26.4% (4/4), respectively. Table 2 shows the sensitivity, specificity, positive and negative predictive values (PPV and NPV). It is apparent that the NPV for the absence of BOP was high, while the PPV was concomitantly increasing with rising Bf. The results of the calculation showed a good relationship between Bf and PPV.

Table 3 shows the results of the backward stepwise logistic regression analysis. Six variables (Bf, PPD ⩾4 mm, upper–lower jaws, molar, inter-proximal and number of missing teeth) remained significant in the final model. As shown in Table 3, Bf was significantly associated with periodontal disease progression after controlling for five other variables. The estimated odds ratios of Bf for periodontal progression were 1.47, 2.54, 4.39 and 6.17 for 1/4, 2/4, 3/4 and 4/4, respectively.

Discussion

Our study has addressed the same issue as reported by Lang et al. (1986) on the relationship between BOP and periodontal disease progression that was defined as an attachment loss of 2 mm or more. However, we used different methods, disease definition and subject specification (the number of subjects, distribution of age and the duration of study). Other distinctions in our study are that we included (1) only intact teeth and (2) non-smoker subjects, as determined by a serum cotinine level of less than 75 ng/ml. In addition, we believe that using multiple linear or logistic regression analysis to measure the relationship between Bf and periodontal progression would be considered a strong point in our study. The reasons for these distinctions are to avoid the confounding effects of smoking and tooth condition (decay, crown, filing and bridge-work) on periodontal disease progression.

The findings of this longitudinal study revealed a highly significant relationship between the increasing bleeding frequencies and periodontal disease progression in community-dwelling older non-smokers. In the stage of subject-based data analysis, which is shown in Table 1, BOP(+) and PPD ⩾4 mm showed significant correlations with periodontal disease progression, as well as the number of missing teeth.

Figure 1 clearly shows that the sites that have the highest score of bleeding frequency showed the greatest proportion of sites with periodontal disease progression during the period under study. Sites with a Bf of 4/4 had a 26% chance of periodontal disease progression. This proportion is slightly higher than that observed by Badersten et al. (1990), and almost equal to that reported by Lang et al. (1986). The proportions of periodontal progression in either of these two studies were not more than 30%.

We also calculated the relationship between the proportion of sites with AAL ⩾3 mm and Bf in smokers as

Table 3. Backward stepwise logistic regression analysis and associated *p*-values

Independent variables	Estimated OR	95% CI	SE	*p*-value
Bleeding frequency				
0/4 (Reference)	1.00			<0.001
1/4	1.47	1.12–1.93	0.14	0.005
2/4	2.54	1.72–3.75	0.20	<0.001
3/4	4.39	2.50–7.70	0.29	<0.001
4/4	6.17	2.21–17.25	0.52	0.001
PPD at baseline ⩾4 mm	1.48	1.05–2.09	0.17	0.024
Upper–Lower				
Lower (Reference)	1.00			<0.001
Upper	1.32	1.07–1.63	0.11	0.011
Molar	1.57	1.18–2.07	0.14	0.002
Inter-proximal	1.38	1.12–1.71	0.11	0.003
Number of missing teeth				
1–9 (Reference)	1.00			<0.001
10–19	2.00	1.58–2.54	0.12	<0.001
20+	2.51	1.72–3.65	0.19	<0.001
Constant	0.02		0.10	<0.001

$N = 13{,}289$; $\chi^2 = 24.756$, $p<0.001$; Pseudo $R^2 = 0.055$.
Hosmer & Lemeshow: $p = 0.262$.
OR, odds ratio; CI, confidence interval; SE, standard error; PPD, probing pocket depth; Bf, bleeding on probing frequency.

well. The proportions of disease progression in the five categories were 4.5% (0/4, $n = 3432$), 5.3% (1/4, $n = 815$), 5.4% (2/4, $n = 186$), 6.5% (3/4, $n = 31$) and 0% (4/4, $n = 0$). No significant relationship was observed ($p = 0.738$, chi-square test). According to these results, the relationship between Bf and AAL seems to be unclear in smokers in comparison with that observed in non-smokers.

Furthermore, the findings of the backward stepwise logistic regression analysis showed that Bf was positively associated with periodontal disease progression after adjusting for five other local factors. The odds ratios increased concomitantly with increasing Bf. The probability of having periodontal disease progression was approximately 2.5 times greater for sites, which experienced a BOP 2/4 than for sites with no BOP. Moreover, sites that presented with BOP 4/4 had a 6.2 times greater chance of periodontal progression compared with sites that showed no BOP. This finding indicates that Bf may be considered to be a strong risk factor for periodontal disease progression in older people.

On the other hand, the finding that sites with a Bf of 0/4 had only a 2.9% chance of periodontal disease progression pointed to the fact that the absence of BOP might be a criterion for periodontal stability. This is in agreement with the previous studies that BOP is a reliable indicator for periodontal stability (Lang et al. 1986, 1990).

We also evaluated the local factors for periodontal disease progression in this study. The prevalence of BOP, PPD ⩾4 mm and AAL ⩾3 mm tended to be higher in maxilla, molar, inter-proximal sites and the lower anterior. The high prevalence of AAL ⩾3 mm at inter-proximal sites has also been observed in other studies (Heitz-Mayfield et al. 2003, Schätzle et al. 2003). In a longitudinal study in Chinese adults, similar findings were observed (Baelum et al. 1997).

In this study, although a significant relationship between Bf and periodontal disease progression was seen in backward stepwise logistic regression analyses, the pseudo R^2 was low. This finding indicates that the variability in periodontal progression explained by the five independent variables was low (5.5%) and hence, there may be other explanatory factors that could not be accounted for in the present study. Accordingly, further longitudinal studies that incorporate such unaccounted variables and span over more than 3 years may be required to investigate the influence of BOP on periodontal disease progression in community-dwelling older adults.

Notwithstanding such limitations, the present study suggested that there was a significant relationship between Bf and periodontal disease progression and consequently, increasing frequencies of bleeding might increase the probability of having periodontal disease progression in community-dwelling older non-smokers.

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Clinical Relevance

Scientific rationale: Even though several studies have reported a correlation between bleeding on probing (BOP) and periodontal disease progression after controlling for smoking status, investigations on periodontal progression in older people using biochemical assessment of smoking status have not been conducted.

Principal findings: The subjects with serum cotinine <75 ng/ml were defined as non-smokers. The findings of this longitudinal study revealed that in community-dwelling older non-smokers, sites with BOP(+) at annual examinations had a 26% probability of periodontal disease progression over 3 years.

Practical implications: BOP may be considered as a predictor of periodontal disease progression in community-dwelling older non-smokers.

Original article

The relationship between dietary intake and the number of teeth in elderly Japanese subjects

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The relationship between dietary intake and the number of teeth in elderly Japanese subjects

Objective: This study used a precise weighing method to assess whether tooth loss was related to nutrient intake in elderly Japanese subjects.
Material and methods: Fifty-seven subjects aged 74 years were randomly selected from a longitudinal interdisciplinary study of ageing. Complete 3-day food intake data were obtained by a precise weighing method. The dietary intakes of energy and nutrients were calculated based on the Standard Tables of Food Composition in Japan (5th ed.). A clinical evaluation of the number of teeth present was carried out. Multiple regression standardised coefficients for each nutrient was estimated based on a continuous scale adjusted for gender, smoking habits, and educational level. After dividing the subjects into two groups according to the number of teeth present (0–19, 20+), the difference in the intake of nutrients and the amount of food consumed per day was evaluated.
Results: The number of teeth present had a significant relationship with the intake of several nutrients. In particular, total protein, animal protein, sodium, vitamin D, vitamin B_1, vitamin B_6, niacin, and pantothenic acid were significantly associated with the number of teeth present and with the two groups (0–19, 20+). The intake of vegetables and fish, shellfish, and their products was significantly lower among subjects with fewer teeth.
Conclusion: This study suggests that there was a significant relationship between nutrient intake, such as minerals and vitamins from food, and tooth loss.

Keywords: dietary intake, teeth present, elderly people.

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Introduction

A growing awareness of the importance of nutrition in the field of clinical dentistry, and particularly in gerodontics, has arisen in recent years. Several diet and nutrition surveys, including the National Health and Nutrition Examination Surveys (NHANES) I, II, and III in the USA, and the National Diet and Nutrition Survey (NDNS) in Britain, found inadequate intake of many nutrients in a high percentage of elderly people[1–3]. These studies reported that several factors contribute to nutritional inadequacy in older people, including physiological decline, age-related diseases, medication, insufficient food consumption, and low income.

Previous reports have suggested that chewing ability has a large influence on the nutritional status of humans, especially the elderly[4–10]. Tooth loss has been associated with nutrient deficiency and changes in food preference. Although dental prostheses can help with aesthetic issues and work to a certain degree[4], impairment of normal oral neurosensory perceptions and masticatory force is irreversible[5]. Eventually, individuals with a poor dentition prefer soft, easily chewed food that has a low nutrient density[6–10].

However, evidence that a poor diet is common in subjects with fewer teeth is sometimes inconsistent when carefully examined. Numerous methods for the quantification of diet exist, and each has strengths and weaknesses. For example, some researchers suggest that nutritional epidemiology such as the 24-hour dietary recall and food intake records may not provide a complete picture of what is being eaten on a routine basis. Other methods, such as food frequency questionnaires, are criticised because people, and particularly the elderly, may not recall exactly what they have eaten over a period of time. Among the various methods, a precise weighing method is said to measure nutrients most accurately. The NDNS in Britain studied subjects aged 65 and older using 4-day weighed records and related nutrients to the number of teeth; in addition dental status comparisons were made[8]. However, few other reports provide detailed data about the relationship between nutrient intake and the number of teeth present using a precise weighing method. In addition, many reports have included groups of subjects with a wide range of ages (more than 20 years). This means that the number of teeth present or chewing ability varied considerably among subjects.

The purpose of this study was to assess whether tooth loss is related to the intake of nutrients, as measured by a precise weighing method, in elderly Japanese subject.

Material and methods

Subjects

In 1998, a longitudinal interdisciplinary study of ageing was initiated to evaluate the relationship between general health status, including nutrient intake and anthropometry, and dental diseases. Initially, questionnaires were sent to all 4542 residents aged 70 years (born in 1927) in Niigata City, Japan. After dividing the returned questionnaires by gender, 600 people were randomly selected to have approximately the same number of each gender for the baseline survey. The participants agreed to undergo medical and dental examinations and signed informed consent forms regarding the protocol, which was approved by the Ethics Committee of Niigata University School of Dentistry. The study was carried out according to the rules of the Helsinki Declaration. Follow-up surveys have been done every year in June using the same methods as the baseline survey. A total of 436 subjects (screened population) participated in the follow-up survey conducted in June 2001.

There are eight administration areas in Niigata City, Japan, and subjects were randomly selected from each area. Sixty-two volunteers took part in this detailed nutrient survey after receiving a full explanation of the purpose of the study. Complete 3-day food intake data were obtained from 57 of the subjects (31 men and 26 women). Five volunteers did not submit complete data. At the time of this survey, all subjects were 74 years old. For the screened population, body height, weight, smoking habits, educational level, and the number of teeth present were measured, and body mass index (BMI) was calculated to evaluate the difference between the screened population and the 57 subjects.

All subjects were Japanese, in good general health, and did not require special care for their daily activities.

Dietary intake

This nutritional survey was conducted from November 5 to December 5, 2001 to avoid seasonal changes in food intake between the present study and Japan's National Nutrition Survey, which is conducted in November[11]. Trained dietitians visited the subjects the day before the survey started. The subjects were fully instructed on how to record all consumed food, including the use of nutritional supplements. Each type of food consumed by the subjects was weighed on three consecutive days using the same model of scale (TANITA, Tokyo, Japan). The dietitians checked the records of dietary intake weighed by the subjects twice, on the second of the three consecutive days and after three consecutive days. Food consumption data were obtained at the homes of the subjects by 12 trained dietitians. Finally, two dietitians checked all the food intake data. After that, nutrient intakes, excluding nutritional supplements, were calculated based on the Standard Tables of Food Composition in Japan (5th ed.)[12]. Items that were unregistered in the food tables were substituted by using the mean of existing items in the same food groups. Special care was paid to the cooking condition of food for calculation according to the Standard Tables of Food Composition[12]. In the case in which 'the composition value of cooked food' was listed in the Standard Tables, these values were used for calculation. Alcohol-derived energy was included in the total energy intake. Finally, energy, the dietary intakes of protein, lipid, carbohydrate, minerals (sodium, potassium, calcium, magnesium, phosphorus, iron, zinc, copper, and manganese), vitamins (A, D, E, K, B_1, vitamin B_2, niacin, vitamin B_6, vitamin B_{12}, folic acid, pantothenic acid, and vitamin C), fatty acids (saturated, monounsaturated, polyunsaturated fatty acids), cholesterol, and dietary fibre (total dietary fibre, water-soluble dietary fibre, and water-insoluble dietary fibre) were calculated based on the Japanese Standard Food Tables[12].

Teeth present, smoking habits and education level

Four dentists performed their clinical evaluations on the number of teeth present, the status of the teeth and the use of removable dentures. In addition, personal interviews were conducted to obtain information regarding smoking habits and educational level.

Calculations and statistics

The total energy intake per body weight per day was calculated, as were the percentages of energy for protein, lipid, and carbohydrates. The percentages of energy of animal and vegetable proteins consumed were calculated separately. Minerals, vitamins, fatty acids, and dietary fibre intake were calculated per 1000 kcal energy intake per day. All data were expressed as mean ± standard deviation (SD). Multiple linear regression analysis was performed to evaluate the relationship between the number of teeth present and the intake of nutrients per day. Each nutritional variable was used as a dependent variable. Independent variables included the number of teeth present, gender, smoking habits, and educational level. In addition, after dividing the subjects into two groups according to the number of teeth present (0–19, 20+), we evaluated the difference in the intake of nutrients and the amount of food consumption per day using the Student t test. This grouping by number of teeth when reviewing chewing ability has been referred to in previous reports [13,14]. The level of significance was set at $p < 0.05$.

Results

There were 53 dentate (93.0%) and 59.6% of subjects used removable dentures. The status of the teeth was as follows: mean probing depth and attachment level per person were 2.20 ± 0.40 mm and 3.43 ± 1.02 mm, respectively; mean number of untreated teeth and treated teeth per person were 0.44 ± 0.93 mm and 12.09 ± 6.67 mm, respectively; among treated teeth, the mean number of cast crowns per person was 4.40 ± 3.96 mm.

Physiological characteristics, smoking habits, educational level, and the number of teeth present are shown in Table 1. There were no significant differences in body height, weight, BMI, smoking habits, educational level, and the number of teeth present between the screened population and the study subjects.

As shown in Table 2, after adjusting for gender, smoking habits, and educational level, the number of teeth present was significantly associated with total energy and animal protein intake ($p < 0.0001$), five minerals: sodium, potassium, phosphorus, iron and magnesium; eight vitamins: vitamin D, E, B_1, B_2, B_6, niacin, folic acid and pantothenic acid and cholesterol.

Furthermore, we found significant differences in total protein ($p < 0.01$), animal protein ($p < 0.05$), sodium ($p < 0.05$), vitamin D ($p < 0.05$), vitamin B_1 ($p < 0.001$), niacin ($p < 0.001$), vitamin B_6 ($p < 0.01$), and pantothenic acid ($p < 0.05$) between the two groups with teeth present (Table 3). The mean intake of the nutrients in the subjects who had less

Table 1 Comparison of selected characteristics between the screened population and study subjects.

	Males			*Females*		
Variables	*Screened population (n = 235)*	*Study subjects (n = 31)*	*p*	*Screened population (n = 201)*	*Study subjects (n = 26)*	*p*
Height (cm)	162.3 ± 5.5	161.9 ± 5.2	NS	149.1 ± 4.9	148.5 ± 5.1	NS
Weight (kg)	58.7 ± 8.4	56.2 ± 7.3	NS	51.0 ± 7.8	52.1 ± 7.3	NS
BMI (kg/m^2)[a]	22.3 ± 2.8	21.5 ± 2.8	NS	22.9 ± 3.3	23.6 ± 2.6	NS
Smoking (%)	45.8	46.4	NS	6.6	7.4	NS
Educational level (years)	10.6 ± 2.7	10.4 ± 2.6	NS	9.1 ± 2.1	9.8 ± 2.3	NS
Dental condition						
Number of present teeth	17.0 ± 9.7	18.9 ± 9.7	NS	16.7 ± 9.2	17.5 ± 9.1	NS

All the values are mean ± SD.
NS, not significant.
[a]BMI, body mass index.

Table 2 The relationship between nutrient intake and the number of teeth present.

	Independent variables									
	Number of teeth present		*Gender*		*Smoking*		*Educational level*			
Dependent variables (per day)	*Std. coef.*[a]	*p*	*Std. coef.*[a]	*p*	*Std. coef.*[a]	*p*	*Std. coef.*[a]	*p*	R^2 (%)	*p*
Energy (kcal/kg)	−0.07	NS	−0.49	<0.01	−0.22	NS	−0.05	NS	44.5	<0.0001
Protein										
Total (E %)	0.53	<0.0001	−0.04	NS	−0.01	NS	0.03	NS	28.6	<0.01
Animal (%)	0.47	<0.0001	−0.21	NS	0.08	NS	0.05	NS	26.7	<0.01
Vegetable (%)	0.12	NS	0.44	<0.05	−0.150	NS	−0.10	NS	13.6	NS
Lipid (E %)	−0.11	NS	0.13	NS	−0.19	NS	−0.04	NS	2.8	NS
Carbohydrates (E%)	−0.23	NS	0.41	NS	−0.13	NS	0.08	NS	16.9	NS
Minerals (mg/1000 kcal)										
Sodium	0.37	<0.01	0.30	NS	−0.24	NS	−0.14	NS	17.4	<0.05
Potassium	0.40	<0.01	0.34	NS	0.02	NS	0.03	NS	26.9	<0.01
Calcium	0.06	NS	0.27	NS	0.02	NS	0.13	NS	9.3	NS
Magnesium	0.33	<0.05	0.21	NS	0.11	NS	0.15	NS	20.3	<0.05
Phosphorus	0.40	<0.01	0.13	NS	−0.04	NS	0.09	NS	16.7	NS
Iron	0.35	<0.01	0.35	NS	0.02	NS	0.17	NS	25.9	<0.01
Zinc	0.15	NS	0.06	NS	0.11	NS	0.45	<0.001	23.6	<0.01
Copper	0.22	NS	0.03	NS	0.22	NS	0.35	<0.01	21.9	<0.05
Manganese	0.18	NS	0.16	NS	0.08	NS	−0.01	NS	8.2	NS
Vitamins										
Vitamin A (μg RE/1000 kcal)	0.17	NS	0.10	NS	−0.01	NS	0.17	NS	6.2	NS
Vitamin D μg/1000 kcal)	0.31	<0.05	−0.12	NS	0.12	NS	−0.19	NS	14.3	NS
Vitamin E (μg/1000 kcal)	0.29	<0.05	0.18	NS	−0.09	NS	0.13	NS	10.9	NS
Vitamin K (μg/1000 kcal)	0.19	NS	0.12	NS	0.14	NS	0.13	NS	10.5	NS
Vitamin B_1 (mg/1000 kcal)	0.39	<0.01	0.34	NS	−0.30	NS	−0.04	NS	17.9	<0.05
Vitamin B_2 (mg/1000 kcal)	0.34	<0.05	0.20	NS	−0.02	NS	0.04	NS	14.0	NS
Niacin (mg/1000 kcal)	0.44	<0.001	<0.01	NS	0.01	NS	0.01	NS	19.6	<0.05
Vitamin B6 (mg/1000 kcal)	0.53	<0.0001	−0.14	NS	0.19	NS	−0.14	NS	32.0	<0.001
Vitamin B_{12} (μg/1000 kcal)	0.19	NS	−0.14	NS	0.18	NS	0.35	<0.01	18.1	<0.05
Folic acid (μg/1000 kcal)	0.35	<0.01	0.23	NS	<0.01	NS	0.19	NS	19.8	<0.05
Pantothenic acid (mg/1000 kcal)	0.37	<0.01	0.25	NS	−0.02	NS	0.18	NS	21.0	<0.05
Vitamin C (mg/1000 kcal)	0.12	NS	0.19	NS	−0.11	NS	−0.09	NS	3.5	NS
Fatty acids										
Saturated (g/1000 kcal)	−0.20	NS	0.12	NS	−0.14	NS	0.06	NS	5.3	NS
Monounsaturated (g/1000 kcal)	−0.10	NS	0.03	NS	−0.16	NS	−0.10	NS	3.7	NS
Polyunsaturated (g/1000 kcal)	−0.11	NS	0.09	NS	−0.19	NS	−0.10	NS	4.0	NS
Cholesterol (mg/1000 kcal)	0.32	<0.05	0.04	NS	0.02	NS	0.17	NS	13.2	NS
Dietary Fibre (g/1000 kcal)										
Total	0.09	NS	0.62	<0.01	−0.09	NS	−0.09	NS	31.8	<0.001
Water-soluble	0.14	NS	0.69	<0.001	−0.22	NS	0.07	NS	29.3	<0.01
Water-insoluble	0.06	NS	0.57	<0.01	−0.11	NS	−0.14	NS	27.4	<0.01

NS, not significant.
[a]Standardised coefficient.

than 20 teeth was significantly lower than that of the members with 20 or more teeth.

Table 4 shows the mean intake of food per day compared with the number of teeth present. Results indicated that the intake of total vegetables, other vegetables, fish, and shellfish and their products was significantly lower among the subjects with 0–19 teeth. The daily consumption of total vegetables and other vegetables was 350 ± 103 g and 230 ± 85 g for the 0–19 group, and 438 ± 157 g and 314 ± 123 g for the 20+ group, respectively ($p < 0.05$ for total vegetables,

Table 3 Relationship between nutrient specimens and the number of teeth present by group.

	Number of teeth present				
	0–19 (n = 24)		*20+ (n = 33)*		
Variables (per day)	*Mean*	*SD*	*Mean*	*SD*	*p*
Energy (kcal/kg)	43.7	9.2	40.3	7.9	NS
Protein					
Total (E %)	15.1	2.1	17.1	2.4	<0.01
Animal (%)	51.4	11.0	56.9	8.7	<0.05
Vegetable (%)	46.3	13.8	43.2	8.6	NS
Lipid (E%)	22.5	4.5	22.0	4.6	NS
Carbohydrates (E%)	61.3	6.8	58.2	6.5	NS
Minerals (mg/1000 kcal)					
Sodium	2148	387	2552	755	<0.05
Potassium	1652	291	1774	249	NS
Calcium	351	80	337	89	NS
Magnesium	163	33	174	29	NS
Phosphorus	601	91	645	85	NS
Iron	4.7	1.2	5.2	1.1	NS
Zinc	5.3	3.4	5.6	2.9	NS
Copper	0.8	0.2	0.8	0.2	NS
Manganese	2.4	0.6	2.5	0.8	NS
Vitamins					
Vitamin A (μg RE/1000 kcal)	585	237	625	361	NS
Vitamin D (μg/1000 kcal)	6.0	2.8	9.5	6.7	<0.05
Vitamin E (μg/1000 kcal)	4.9	1.3	5.5	1.1	NS
Vitamin K (μg/1000 kcal)	157.6	82.0	180.2	93.2	NS
Vitamin B_1 (mg/1000 kcal)	0.5	0.1	0.6	0.1	<0.001
Vitamin B_2 (mg/1000 kcal)	0.7	0.2	0.8	0.1	NS
Niacin (mg/1000 kcal)	8.0	2.0	9.8	2.2	<0.001
Vitamin B_6 (mg/1000 kcal)	0.7	0.1	0.9	0.2	<0.01
Vitamin B_{12} (μg/1000 kcal)	7.7	8.2	9.6	8.1	NS
Folic acid (μg/1000 kcal)	215.0	54.0	242.1	75.1	NS
Pantothenic acid (mg/1000 kcal)	3.4	0.5	3.8	0.7	<0.05
Vitamin C (mg/1000 kcal)	97	39	99	30	NS
Fatty acids					
Saturated (g/1000 kcal)	7.0	1.8	6.3	1.7	NS
Monounsaturated (g/1000 kcal)	8.0	2.2	8.0	2.2	NS
Polyunsaturated (g/1000 kcal)	6.0	1.4	5.9	1.7	NS
Cholesterol (mg/1000 kcal)	171	62	190	74	NS
Dietary fibre (g/1000 kcal)					
Total	11.22	2.87	11.08	2.45	NS
Water-soluble	2.34	0.64	2.48	0.68	NS
Water-insoluble	8.35	2.20	8.14	1.79	NS

NS, not significant.

$p < 0.01$ for other vegetables). The daily consumption of fish, shellfish, and their products was 124 ± 67 g for the 0–19 group and 191 ± 127 g for the 20+ group ($p < 0.05$).

Discussion

As diet and tooth loss are both governed by health behaviour, socio-behavioural factors may confound the results. An attempt was made to control for such factors by using surrogate variables such as gender, smoking habits, and educational level. In addition, a homogenous group restricted to the age of 74 years was selected to exclude the influence of race and age variation in the results. In addition, there were no significant differences in general health and dental conditions between the screened population and the subjects in the study. Therefore,

Table 4 The relationship between the number of teeth present and food group.

	Number of teeth present				
	0–19 (n = 24)		*20+ (n = 33)*		
Food groups (g/day)	*Mean*	*SD*	*Mean*	*SD*	*p*
Cereals	433	150	421	122	NS
Nuts and seeds	4.0	6.2	5.2	9.9	NS
Potatoes and starches	74	52	82	46	NS
Sugars and sweeteners	14.8	10.0	10.6	6.7	NS
Confectionaries	46	42	29	38	NS
Fats and oils	13.5	7.7	11.8	7.6	NS
Bean (pulses) and their products	67	37	70	42	NS
Fruits	382	262	342	174	NS
Vegetables					
Total vegetables	350	103	438	157	<0.05
Dark green and yellow vegetables	120	74	124	74	NS
Other vegetables	230	85	314	123	<0.01
Fungi	17	15	23	18	NS
Seaweed	8.3	15.1	12.5	14.6	NS
Fish, shellfish, and their products	124	67	191	127	<0.05
Meat and its products	33	27	43	27	NS
Egg and its products	39	26	37	33	NS
Milk and its products	213	128	148	119	NS

NS, not significant.

it was believed that the subjects in this study represented a valid sample group.

In this study, the number of teeth present had a significant relationship with the intake of several key nutrients. In particular, total protein, animal protein, sodium, vitamin B_1, vitamin D, niacin, vitamin B_6, and pantothenic acid were significantly associated with both the number of teeth present and the two 0–19 and 20+ groups. In addition, subjects with fewer teeth consumed fewer vegetables and fish, shellfish, and their products than subjects with more teeth.

As masticatory efficiency declines, people report increasing difficulty chewing and choose not to eat foods that are difficult. The most pronounced difference in intake involves hard-to-chew foods such as vegetables and some fruits, which are likely to be most affected by tooth loss[15–17].

Daily intake of fresh fruit and vegetables in adequate amounts (400–500 g/day) is recommended to reduce the risk of heart disease, stroke, and high blood pressure[18]. Previous reports show that difficulties in chewing fruit and raw vegetables could be a cause for a low intake of vitamins derived from these foods[17,19]. Adequate intake of these vitamins is thought to prevent cardiovascular disease, gastrointestinal disease, and other health problems[20–24]. It is also possible that an inability to chew might be a risk factor for these diseases.

In addition, the difference in the intake of protein, especially animal protein, between the 0–19 and 20+ groups was significant due to the intake of fish, shellfish, and their products, which contain a large amount of animal protein. According to one report, the amount of animal protein intake was related to the intake of some vitamins and minerals[25]. Fish and shellfish contain more vitamin D, magnesium, and calcium than meat[12], and a significant relationship between the intake of vitamins or minerals and periodontal disease has been shown in other studies[26,27].

Because fish and shellfish are generally easier to chew, the associations found in this study, in part, may reflect a reverse causation; that is, the results may reflect the effect of diet on periodontal disease and consequently on tooth loss, rather than the effect of tooth loss on diet.

Many previous studies were on Western populations. However, even if the nature of the Japanese diet and methods of cooking and eating are different from those of Western populations, it is possible to compare nutrient intakes because these intakes were based on the Standard Tables of Food Composition in Japan (5th ed.)[12].

From previous studies, there was a significant relationship between the number of teeth present and intake of vegetables and fruits, as well as intake of vitamins, minerals, and fibres. Subjects with dentures consumed fewer of these nutritious foods[10,15,19]. However, no significant differences between the number of teeth present and the intake of vitamin C or fibre could be found in this study.

There are various types of foods in the Japanese diet, from rigid items, such as soya beans, to soft items, such as tofu. In addition, there are various ways of cooking these foods, including as boiling, baking, frying, and eating them raw. Furthermore, the small sample size of this study may not have allowed potential weak associations to be detected. A larger sample could be subdivided further according to the number of teeth present for a more detailed evaluation. This may explain why no differences in the number of teeth present and the intake in vitamin C and fibre were seen in our study.

In the present study, 41.4% of subjects took vitamin or mineral supplements (data not shown in results). However, it was impossible to evaluate the nutritional intake including supplements because of lack of detailed information about the supplements the subjects took. Further studies should be undertaken to confirm the observations in this study.

In conclusion, this study suggests that there was a significant relationship between nutrient intake such as minerals and vitamins from food and tooth loss.

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PAPER

Long-period accelerometer monitoring shows the role of physical activity in overweight and obesity

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CONTEXT: Physical activity (PA) plays an important role in obesity. A new accelerometer has been developed to assess total energy expenditure as well as PA.
OBJECTIVE: To investigate the association of PA with overweight and obesity in Japanese men and women, a large cross-sectional study was performed using a single-axis accelerometer.
DESIGN, SETTING AND PARTICIPANTS: Population-based cross-sectional study of Japanese 18–84 y of age. Height, body weight and PA were measured in 400 male and 388 female Japanese volunteers from 1999 to 2000. The outcome measurements were overweight and obesity, which are defined as a body mass index $\geq$25 kg/m^2. PA was measured for 1 to 4 weeks and was then categorized into three activity levels, which were defined as light, moderate and vigorous PA.
RESULTS: Prevalence of overweight and obesity was 22.3%. Number of steps and time spent in moderate and vigorous PA per day were lower in overweight and obese individuals. No difference was found in time spent in light PA. Individuals who are in the 4th and 5th quintile of moderate and vigorous PA showed a significantly lower body mass index. When odd ratios (ORs) of overweight and obesity estimated by logistic regression were used as effect measures, overweight and obesity were negatively associated with vigorous PA (ORs = 0.91).
CONCLUSION: These results indicate that overweight and obese individuals have a lower step rate and are spending less time for moderate to vigorous PA. Participation in vigorous PA is an important predictor of overweight and obesity.
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Keywords: accelerometer; overweight; Japanese and physical activity

Introduction

Obesity is one of the major concerns for public health according to recent increasing trends in obesity-related diseases such as Type 2 diabetes[1] and hyperlipidemia,[2] which are more prevalent in Japanese adults with body mass index (BMI) values $\geq$25 kg/m^2.[3] In the adult population of industrialized countries, it has been reported that obesity and higher body weight are strongly associated with a sedentary lifestyle and lack of physical activity (PA) at leisure time as well as at work.[4,5] A longitudinal epidemiological study has also revealed that regular PA prevents body mass gain and low PA is a risk factor for body mass gain and obesity.[6] Moreover, a participation in vigorous PA is related with a lower adiposity.[7,8] Therefore, the amount as well as the intensity of PA might be important potential determinants of overweight and obesity in Japanese population.

Several devices have been developed to assess the amount and intensity of PA in free-living conditions; the validation of these methods has been discussed.[9–12] Westerterp[13] has suggested that accelerometers are an objective tool for the assessment of PA in large populations over periods long enough to be representative of normal daily life. Since an increase in PA is an effective therapeutic intervention for the prevention and treatment of obesity and its related diseases, a single-axis accelerometer has been developed in Japan for assessing daily PA over long periods (6 weeks). The device has been used in a clinical setting to monitor daily PA and

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to prescribe appropriate levels of PA in order to reach their therapeutic goals. Although questionnaires have a disadvantage that subjects can easily overestimate or underestimate PA,[13] most population studies[4–6] have used a questionnaire to assess a daily PA because of its convenience. In some epidemiological studies, PA records were also used to estimate the amount and intensity of PA.[7,8] However, these procedures are very demanding for subjects. In contrast, the accelerometer is small, light, and easy to use. It also provides a digital data log that can be downloaded directly to a personal computer for further analysis. These properties make the accelerometer a useful tool to assess the amount and intensity of PA in a population study. Therefore, we have performed a cross-sectional study in a Japanese population using the accelerometer to investigate the relationship between amount and intensity of PA and prevalence of obesity.

Subjects and methods

Subjects

The subjects were 847 Japanese volunteers who underwent a regional medical examination in Fukuoka, Saga and Niigata regions of Japan and from university students in Fukuoka region. In all, 43 subjects (5.1%) refused to participate to the study and 16 accelerometer measurements (1.9%) had technical failures. Thus, 400 males and 388 females aged from 18 to 84 y were participated in this study from 1999 to 2000.

Measurements

Body mass index (BMI). For each participant, weight and height were directly measured and the BMI as the weight in kilograms divided by the squared height in meters (kg/m^2) was calculated. In USA, obesity is defined as BMI > 30 kg/m^2, whereas $30 \geq$ BMI ≥ 25 kg/m^2 is overweight. However, obesity for Japanese is defined as BMI ≥ 25 kg/m^2, according to the criteria established by the Japan Society for the Study of Obesity (JASSO).[14] Thus, we analyzed data using BMI ≥ 25 kg/m^2 and used terms 'overweight and obesity' for BMI ≥ 25 kg/m^2.

Physical activity. PA levels were measured by a single-axis accelerometer (Lifecorder, Suzuken Co. Ltd, Nagoya, Japan). The accelerometer ($625 \times 465 \times 260$ mm^3, 40 g) was firmly attached to a belt or a waistband of the subject's clothing during all waking hours over 1 to 4 weeks period. The accelerometer is designed to detect acceleration along the vertical axis at the waist during body movements, and automatically calculate total energy expenditure (TEE) from the product of the step rate, acceleration and basal metabolic rate (BMR). The subject's data (age, gender, height and body weight (W)) are entered into the accelerometer for the estimation of BMR. The validity of this device for assessing PA correlates well with other methods of energy expenditure (EE) measurement such as doubly labeled water (DLW),[15] metabolic chamber[16] and indirect calorimeter.[16,17]

The device samples the acceleration at 32 Hz and assesses that ranging from 0.06 to 1.94 G (one G is equal to earth gravity acceleration). The acceleration signal is filtered by an analog bandpass filter and digitized. The device requires three criteria to detect the steps. The sampled acceleration was classified into four categories (The target threshold 1 and the target threshold 4 are corresponded to 0.06 and 1.94 G, respectively. The thresholds 2 and 3 were determined by the manufacturer.) A first criterion is that the peak magnitude of the acceleration was categorized to the target threshold 2 or higher. A second criterion is that the acceleration was kept continuously above 0.06 G for 0.19 to 1.56 s. A third criterion is that the interval of the acceleration wave is less than 1.56 s. When these three criteria were satisfied, the number of step was integrated. These second and third criteria have been established in order to cancel noise and/or artifacts.

The accuracy of the step counts detected by this device has been calibrated during the manufacturing process according to the Japanese Industrial Standards (JIS). Briefly, in the JIS, the error of step counts must be bellow $\pm 3\%$ per artificial 1000 vibrations corresponding to 0.24 G (2.4 m/s^2) or 0.5 G (4.9 m/s^2). It must be noted that the accuracy of step counts in the accelerometer was confirmed at 0.24 G. Therefore, this accelerometer is considered as a superior assessment of ambulatory activity among older and/or low-fit individuals compared with the previously released pedometers, according to the higher sensitivity and the unique criteria. Furthermore, the reported error of the step counts of this devise was within $\pm 1\%$ during treadmill walking.

By measuring the magnitude and frequency of accelerations, the device determines the level of movement intensity every 4 s. If the device detects three or more step counts during a 4-s period, a value of 1–9, based on the intensity of the PA (1 = minimal intensity of PA, 9 = maximal intensity of PA) is given for that time period. In contrast, if the device detects two or less steps during a 4-s period, a zero value is given to that time period, indicating there was no movement. The PA is subsequently converted to energy expenditure (EE_{PA}):

$$EE_{PA}(\text{kcal}) = Ka \times W(kg)$$

where 'Ka' is a constant with nine values experimentally determined by the manufacturer to reflect acceleration under various conditions and is considered to be confidential by the manufacturer.

If an acceleration pulse due to PA is not immediately succeeded by another acceleration pulse, then it is not counted as zero. However, a level of 0.5 is arbitrarily ascribed for 3 min. It is assumed that the subject is standing up and maintaining that state (or sitting down). The latter posture involves a higher EE than resting supine position. These minor activities will show isolated spurts of acceleration, since walking and moving around are typically rhythmic activities. EE due to minor activities ($EE_{minorAct}$, that is, posture changes, light desk work, etc) is calculated by using BMR and a constant Kx:

$$EE_{minorAct}(\text{kcal}) = Kx \times \text{BMR}\,(\text{kcal/min})$$

The value of the constant '*Kx*' is not given here, since it is considered to be confidential by the manufacturer.

TEE is calculated with the following equation:

$$TEE = \frac{1}{10}TEE + EE_{PA} + EE_{minorAct} + BMR$$

where $\frac{1}{10}$ TEE (kcal) is dietary-induced thermogenesis.

$$BMR\,(kcal) = Kb \times BSA \times T \times 1/10000$$

'*Kb*' is a standard value of Japanese (kcal/m^2/h),[18] BSA is body surface area (cm^2) and 'T' is time (h)

$$BSA\,(cm^2) = W^{0.444}(kg) \times HT^{0.663}(cm) \times 88.83$$

Data analysis and statistics

No correction factor was used to correct for some activities (swimming, weight lifting bicycling, etc), which can not be captured by accelerometers; therefore, TEE might be underestimated.[19,20] Since epidemiological studies investigating the effects of PA on public health are often interested in categorizing various activities into metabolic equivalent (MET) intensities,[21] PA was also categorized into three activity categories, which are defined as light PA (PA levels 1–3), moderate PA (PA levels 4–6) and vigorous PA (PA levels 7–9) by using an equation (METs $= 0.043x^2 + 0.379x + 1.361$, where x represents the PA level, $r = 0.929$).[16]

Student's *t*-test was used to determine the distinctive effects of gender and BMI. We also used the one-way ANOVA to determine the effect of age and time spent in each PA level. When the ANOVA revealed a significant effect, Tukey-Kramer *post hoc* test was applied to identify which conditions were different from each other. Since there was a significant age effect on BMI, the ANCOVA was performed to evaluate the effect of time spent in each PA level on BMI with age as a covariance. Values are expressed as mean $\pm$ s.e.m.

In order to explore the association between obesity and PA, odd ratios (ORs) were calculated by logistic regression analysis. Thus, ORs were interpreted as relative risks. Indicator (factored) variables for each category of independent variable were created by dividing into five similar-sized quintiles except for age, sex and vigorous PA. The lowest category was used as the reference category. ORs with 95% confidence intervals (95% CI) were estimated for each variable. OR of each variable was adjusted for the other variables, that is, OR_{Ad} of age is adjusted for gender and intensities of PA. Tests for trend were performed after unfactorizing and adding it to the previous model. The likelihood ratio statistic was used to evaluate the significance of linear trends. All the statistical analyses were carried out using StatView (SAS Institute, Cary, NC, USA). All the statistical significance was considered at $P < 0.05$.

Results

The overall prevalence of overweight and obesity in this population were 22.3% and that of obesity was 2.3%. Prevalence of overweight and obesity, and BMI in age categories and distinction of gender and PA are presented in Table 1. Prevalence of overweight and obesity was 8.2, 23.3, 29.6 and 23.3% for age quartiles of 18–29, 30–49, 50–69 and 70–84 y, respectively. BMI in the age group of 50–69 y was significantly higher than in groups of 18–29 and 70–84 y, whereas no difference was found between 50–69 and 30–49 y groups. According to gender, prevalence of overweight and obesity was 22.8% for men and 21.9% for women. Individuals who are in the 4th and 5th quintiles of moderate PA showed a significantly lower BMI than those in the 1st and 3rd quintile of moderate PA. Individuals who are in the 4th and 5th quintiles of vigorous PA also showed a significantly lower BMI than those in other categories. Regarding the effects of PA on BMI, the ANCOVA with adjustment for age revealed the same significant results as the ANOVA without adjustment for age.

Number of steps in the age quartiles of 18–29, 30–49, 50–69 and 70–84 y was 8910 $\pm$ 221, 9128 $\pm$ 269, 7922 $\pm$ 217 and 5512 $\pm$ 168 (mean $\pm$ s.e.m.), respectively. Subjects in the age group of 50–69 y showed significantly lower steps than those in the younger quartiles, whereas 70–84 y subjects showed the lowest value. On the other hand, there was no difference in gender (males: 7481 $\pm$ 171 and females 7587 $\pm$ 166).

Table 2 presents TEE as well as the number of steps and time spent in PA in distinction of BMI. Overweight and obese individuals showed higher TEE and BMR, whereas number of steps and time spent in moderate and vigorous PA were lower than nonobese individuals. No difference was found in EE_{PA} and time spent in light PA.

Prevalence of obesity according to age, gender and intensities of PA was estimated by logistic regression (Table 3). After adjustment for gender and intensities of PA, age was not independently related to prevalence of obesity. Moreover, after adjustment for age and PA, gender was not independently related to prevalence of obesity. However, time spent in vigorous PA was significantly negatively related with prevalence of obesity when adjusted for age, gender and light and moderate PA.

Discussion

The purpose of the present study was to investigate the role of PA in obesity by using a single-axis accelerometer in adult Japanese population. Our data revealed that overweight and obese individuals had a lower step rate and spent less time for moderate to vigorous PA. Moreover, overweight and obesity was inversely related with time spent in vigorous PA.

Prevalence of obesity in Japanese population estimated by international criteria (BMI $\geq$ 30 kg/m^2)[22,23] is quite low (2 or 3%)[24] compared to the data in Western populations (from 7 to 20%).[25–27] The overall prevalence of obesity in our data set was 2.3%, which is consistent with previous Japanese data, which includes 23 556 males and 28 751 females aged 15–84 y.[24] Prevalence of overweight and obesity in our study was 22.3%, which is also consistent with the previous study.[24] Thus, our subjects well represent Japanese population for a study of obesity.

Table 1 Estimated prevalence of overweight and obesity in Fukuoka, Saga and Niigata regions of Japan

		BMI≥ 25 kg/m²		*BMI≥ 30 kg/m²*				
	No. of subjects	*No.*	*%*	*No.*	*%*	*BMI*	*Height*	*Weight*
Age (y)								
18–29	146	12	8.2	2	1.4	21.4±0.23[a]	165.0±0.69[a]	57.8±0.89[a]
30–49	150	35	23.3	2	1.3	23.2±0.23[b,c]	163.5±0.70[a]	62.3±0.85[b]
50–69	230	68	29.6	10	4.3	23.6±0.21[b]	158.3±0.52[b]	59.3±0.64[a]
70–84	262	61	23.3	4	1.5	22.9±0.19[c]	156.1±0.52[c]	55.8±0.55[c]
Gender								
Males	400	91	22.8	9	2.3	23.0±0.15	164.9±0.40[a]	62.8±0.50[a]
Females	388	85	21.9	9	2.3	22.8±0.16	154.5±0.33[b]	54.3±0.41[b]
Light PA (min/day)								
4.3–38.1	158	44	27.8	6	3.8	23.3±0.26	157.8±0.68[a]	58.1±0.81
38.2–48.1	158	32	20.3	1	0.6	22.7±0.23	159.6±0.74[a,b]	57.9±0.72
48.2–58.8	157	36	22.9	2	1.3	22.8±0.24	160.9±0.78[b]	59.1±0.82
58.9–73.8	157	38	24.2	6	3.8	22.9±0.28	160.1±0.67[a,b]	58.9±0.86
73.9–162.3	158	26	16.5	3	1.9	22.8±0.23	160.6±0.69[a,b]	59.0±0.78
Moderate PA (min/day)								
0.0–6.7	158	48	30.4	1	0.6	23.3±0.24[a]	156.6±0.64[a]	57.3±0.73[a]
6.8–13.6	158	36	22.8	5	3.2	23.1±0.24[a,b]	158.7±0.74[a,b]	58.3±0.79[a,b]
13.7–21.9	157	43	27.4	7	4.5	23.3±0.27[a]	160.9±0.73[b]	60.6±0.89[b]
22.0–32.0	157	28	17.8	4	2.5	22.3±0.25[b]	161.1±0.66[b]	58.0±0.77[a,b]
32.1–101.4	158	21	13.3	1	0.6	22.4±0.22[b]	161.8±0.72[c]	58.8±0.79[a,b]
Vigorous PA (min/day)								
0.0	214	58	27.1	3	1.4	23.2±0.20[a]	157.3±0.58[a]	57.5±0.64[a]
0.1–0.9	236	62	26.3	6	2.5	23.2±0.31[a]	158.8±0.54[a,b]	58.5±0.61 [a,b]
1.0–1.9	107	26	24.3	7	6.5	23.2±0.27[a]	161.3±0.82[b]	61.2±0.99[b]
2.0–4.9	142	22	15.5	2	1.4	23.0±0.25[b]	162.7±0.77[c]	59.1±0.95[a,b]
5.0–34.7	89	8	9.0	0	0.0	21.8±0.22[b]	162.0±1.04[c]	57.3±1.11[a,b]

BMI = body mass index. BMI values are expressed as mean ± s.e.m. Different alphabet letters show significant differences analyzed by the ANOVA and Tukey–Kramer *post hoc* test ($P<0.05$).

Table 2 EE step and time spent for PA measured by the Lifecorder according to BMI

	BMI	
	<25 kg/m²	*≥25 kg/m²*
Number of subjects	612	176
Height (cm)	160.1±0.36	158.9±0.66
Weight (kg)	55.6±0.34	68.9±0.63*
TEE (kcal/day)	1762±12	1857±24*
BMR (kcal/day)	1228±7.5	1302±15.8*
EE due to PA (kcal/day)	193±4.3	194±8.5
No. of steps (counts/day)	7756±137	6766±233*
Time spent in PA (min/day)		
Light PA	57.2±0.96	53.5±1.79
Moderate PA	21.4±0.63	17.1±1.13*
Vigorous PA	2.37±0.17	1.11±0.15*

Values are expressed as mean ± s.e.m. *Significant differences analyzed by the Student's *t*-test ($P<0.05$).

Several correlation studies on motion sensors and DLW have been published.[9–11] A tri-axial accelerometer for movement registration showed a close correlation with the DLW assessed PA level,[9,10] whereas no correlation was reported between a single-axis accelerometer, the Caltrac and DLW.[11] However, Ekelund *et al*[28] have reported that another single-axis accelerometer, the Computer Science and Application's activity monitor, showed a significant correlation with the DLW measurement. They have suggested that the discrepancy between studies may be due to different activity monitors used since they may differ in their sensitivity in measuring vertical acceleration during free-living condition.[28] In our recent study, TEE assessed by the accelerometer showed a significant correlation with TEE measured by the DLW during 2 weeks free-living condition in Japanese men ($r=0.83$, $P<0.0001$).[15] Moreover, TEE assessed by the accelerometer showed a significant correlation with TEE measured by a metabolic chamber ($r=0.928$, $P<0.001$).[16] Furthermore, PA levels of accelerometer were significantly correlated with EE ($r=0.808$, $P<0.001$).[16] In addition, Schneider *et al*[29] have compared 13 models of pedometer in a free-living condition, and have suggested that this accelerometer and three others are suitable for applied PA research. Since the device is a small and light accelerometer that can memorize data every 2 min for 6 weeks and directly transfer the data to an Excel file, it is a useful tool to assess the TEE, PA levels and step rate in a population study.

Table 3 OR_{Ad} of overweight and obesity (BMI ≥ 25 kg/m^2) according to age, gender or time spent in different intensities of PA

	No. of subjects	OR_{Ad} [a]	*95% CI*	$\chi^2_{trend\ test}$ [b]
Age (y)				
18–29	146	1.00		
30–49	150	3.39	1.60–7.17	
50–69	230	3.96	1.87–8.40	
70–84	263	2.32	1.06–5.07	
OR across category[c]		1.009	0.998–1.021	$P=0.12$
Gender				
Males	400	1.00		
Females	389	1.00	0.70–1.42	
OR across category		0.989	0.703–1.394	$P=0.95$
Light PA (min/day)				
4.3–38.1	158	1.00		
38.2–48.1	158	0.76	0.44–1.31	
48.2–58.8	157	0.89	0.51–1.55	
58.9–73.8	157	0.92	0.52–1.62	
73.9–162.3	158	0.53	0.29–1.00	
OR across category		0.998	0.990–1.006	$P=0.65$
Moderate PA (min/day)				
0.0–6.7	158	1.00		
6.8–13.6	158	0.67	0.38–1.17	
13.7–21.9	157	1.05	0.59–1.85	
22.0–32.0	157	0.63	0.33–1.22	
32.1–101.4	158	0.51	0.25–1.05	
OR across category		0.994	0.980–1.208	$P=0.38$
Vigorous PA (min/day)				
0.0	214	1.00		
0.1–0.9	236	1.07	0.66–1.73	
1.0–1.9	107	1.24	0.65–2.36	
2.0–4.9	142	0.94	0.45–1.96	
5.0–34.7	89	0.56	0.22–1.46	
OR across category		0.910	0.834–0.922	$P=0.03$

[a]OR_{Ad} of each variable is adjusted for the other variables, that is, OR_{Ad} of age is adjusted for gender and intensities of PA. [b]χ^2 trend test: chi-squared test for trend with one degree of freedom. [c]OR across categoty was estimated after adding the unfactored variable to the previous model.

In the adult population of the United States, overweight (BMI 25–29.9 kg/m^2) or obese (BMI ≥30 kg/m^2) individuals have reported less regular PA compared to individuals with BMI of less than 25 kg/m^2.[30] In the adult population of the European Union, obesity and higher body weight are strongly associated with a sedentary lifestyle (amount of time sitting down) and lack of PA.[4] Moreover, the evidence reviewed by Jebb and Moore[31] clearly showed that low levels of activity are associated with overweight and obesity. In the present study, number of steps and time spent in moderate and vigorous PA were lower in overweight and obese individuals than in normal-weight individuals. These results indicate that overweight and obese people are moving less and that they participate less in moderate to vigorous PA. The Centers for Disease Control and Prevention in the United States and the American College of Sports Medicine have recommended that every adult should perform 30 min or more of moderate-intensity PA on most, preferably all, days of the week.[21] In the present study, individuals who are participating in moderate PA more than 30 min/day showed a significantly lower BMI than the others (22.4±0.2, 184 and 23.0±0.1, 604, respectively; mean±s.e.m., *n*), supporting the recommendation from the Centers for Disease Control and Prevention in the United States and the American College of Sports Medicine.[21] Moreover, individuals who are in the 4th and 5th quintile of moderate PA and 5th quintile of vigorous PA showed a lower BMI than the others. These results also support the notion that individuals who engage in vigorous PA are leaner than individuals who never take part in such activities.[8] On the other hand, the current study shows that energy expenditure due to PA and TEE in overweight and obese are, respectively, similar and higher than normal weight. The obese individuals are often less active, but since they carry a heavier load requiring more energy, their TEE may not be lower.

When OR estimated by logistic regression was adjusted by age, gender and time spent in PA (light, moderate and vigorous PA), and was used as effect measures, overweight and obesity were associated with time spent in vigorous PA (inversely). OR across category of time spent in vigorous PA was 0.91. Thus, this result indicates that time spent in vigorous PA is significantly associated with overweight and obesity. Furthermore, subjects spent 3.93, 1.42 and 0.15% of day for light, moderate and vigorous PA, respectively. Taken together, it suggests that even for a very small part of a day, participation in vigorous PA is important for the prevention of overweight and obesity.

A few epidemiological studies have investigated the step rate and obesity levels. Recently, preliminary pedometer indices for public health have been reported to classify PA levels in healthy adults:[32] (i) <5000 steps/day may be used as a 'sedentary lifestyle index', (ii) 5000–7499 steps/day is typical of daily activity excluding sport/exercise and might be considered as 'low active', (iii) 7500–9999 steps/day likely includes some volitional activities (and/or elevated occupational activity demands) and might be considered as 'somewhat active', and (iv) ≥10 000 steps/day indicates the level that should be used to classify individuals as 'active'. When we compared BMI according to this classification by using the one-way ANOVA and also ANCOVA (adjusted by age) as well as the Tukey–Kramer *post hoc* test, 'somewhat active' individuals showed significantly lower BMI than those in 'sedentary' and 'low active' classifications ($P<0.05$). Moreover, step rate in overweight and obese individuals was lower than normal-weight individuals and there was a significant correlation between BMI and step rate ($r=-0.093$; $P=0.009$). Lower BMI in individuals whose step rates are <6000,[33] lower step rate in obese[34] and the negative correlation[33–36] were also reported in North American. Furthermore, longitudinal studies demonstrate that increasing step rate could improve body mass, blood pressure, serum lipid profiles, as well as insulin sensitivity and resistance in individuals who have history of obesity-related diseases.[37–41] These observations indicate the necessity and usefulness of step counter in the prevention and treatment of obesity and related diseases.

In conclusion, this is the first epidemiological study to demonstrate the importance of moderate to vigorous PA and step rate in the level of obesity in Japanese population. Our results support the PA recommendation from the Centers for Disease Control and Prevention in the United States and the American College of Sports Medicine[21] as well as our earlier finding in Caucasians.[8] From a clinical standpoint, vigorous PA should not be prescribed to individuals who are at risk for sudden death or to overweight and obese individuals who are not used to exercise. Under these circumstances, the most prudent approach remains a moderate PA with a progressive increase in duration, frequency and intensity. With the increasing prevalence of obesity in industrialized countries, wide use of an accelerometer that can assess PA levels and step rate for a long-enough period may provide better monitoring and managing lifestyle, which may contribute to the prevention and treatment of lifestyle-related diseases.

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