**Association between number of pairs of opposing posterior teeth, metabolic syndrome, and obesity**

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**Abstract**

We investigated the relationship between the number of pairs of posterior teeth and metabolic syndrome (MetS), abdominal obesity (AO), and obesity, among Japanese adults. In 2005, 2,807 Japanese adults aged 25–74 years participated in the Survey of Dental Diseases and the National Health and Nutrition Survey. Based on the survey data, BMI, AO (JAS) determined by the Japan Atherosclerosis Society, AO (IDF) by the International Diabetes Federation, and MetS were assessed. Total functional tooth units (t-FTUs) were scored with pairs of opposing posterior teeth, including artificial teeth. Subjects were divided into three categories of chewing ability based on the score of t-FTUs: Poor (if score ≤9), Good (if score =10-11), and Complete (if score =12). The relationships between chewing ability and BMI ≥25, BMI ≥30, AO (JAS), AO (IDF), and MetS were tested using univariate and multivariate logistic regression analysis. The chewing ability was significantly associated with MetS, AO, and obesity in the univariate and multivariate logistic regression analysis. Adjusted OR of "Poor" compared to "Complete" were 1.51 (95% confidence interval (CI), 1.24–1.84) for BMI ≥25, 2.10 (95% CI, 1.40–3.14) for BMI ≥30, 1.31 (95% CI, 1.07–1.61) for AO (JAS), 1.40 (95% CI, 1.15–1.70) for AO (IDF), and 1.34 (95% CI, 1.04–1.72) for MetS. All were statistically significant. Preventing tooth loss and maintaining pairs of good chewing ability may be important factors in preventing MetS, AO, and obesity.

## Introduction

Obesity is a significant risk factor for type 2 diabetes mellitus, hypertension, cardiovascular disease (CVD), and coronary heart disease (CHD) [1, 2]. Mortality due to heart disease, stroke, diabetes, cirrhosis, and all causes is increasing among people with BMI ≥25 [3]. In 2014, the percentage of adults with BMI ≥25 was 39% worldwide [4], and the prevalence of metabolic syndrome (MetS) worldwide was estimated at 25%[5]. MetS is composed of three or more of the following symptoms: abdominal obesity (AO), hypertension, impaired fasting glucose, and dyslipidemia (low HDL-cholesterol or high triglyceride) [6, 7]. MetS is a known significant risk factor for cerebrovascular disease and CVD[8]. People with MetS are at twice the risk for developing CVD and at five times the risk for developing type 2 diabetes mellitus compared to people without MetS [5, 6]. In addition, mortality from CHD, CVD, and all causes is higher among people with MetS [9, 10].

In 2007, the National Health and Nutrition Examination Survey in Japan reported that 30.4% of Japanese male and 20.2% of Japanese female aged 20 years or more had BMI ≥25 [11], and an estimated 26.9% of male and 9.9% of female had MetS. According to recent reports, the percentage of middle-aged people with obesity has increased year after year in Japan [11, 12]. In addition, Japanese people with BMI ≥25 have higher medical expenditures compared to those with BMI <25 [13, 14].

Therefore, a national program for preventing MetS and obesity is considered very important in light of the critical national health situation and the expected rise of national medical expenditures in the future.

Recently, several studies [15-17] have focused on the prevention of MetS, AO, and obesity from the viewpoint of oral health status. According to previous studies [18-21], occlusal force and masticatory performance are related to MetS, AO, and obesity. In addition, weak occlusal force and weak masticatory performance are associated with the prevalence of MetS and obesity. Although the posterior teeth play an important role in occlusal force and masticatory performance, few studies have focused on these teeth. In this study, we investigated the relationship between the number of pairs of posterior teeth, i.e., “total functional tooth units,” and MetS, AO, and obesity.

## Materials and Methods

### *Study population*

The subjects were 2,807 Japanese adults aged 25–74 years who participated in the national Survey of Dental Diseases and the National Health and Nutrition Survey in 2005. These two surveys were carried out in 300 survey units districts selected by stratified random sampling from whole of Japan [22]. These surveys were carried out by the Ministry of Health, Labour, and Welfare of Japan, and the data were merged with their permission. Subjects were excluded if their age and sex did not match between the two surveys. Pregnant female were also excluded from the analyses because their waist circumferences (WCs) could not be measured accurately.

*Body mass index*

BMI was calculated from weight in kilograms divided by square of height in meters. The criterion for obesity set by the Examination Committee of Criteria for "Obesity Disease" in Japan and Japan Society for the Study of Obesity (2002) is BMI ≥25 [23]. In addition to this, BMI ≥30 defined by the World Health Organization [4] was used in this study because it is used widely over the world. The data for height and weight were collected during the National Health and Nutrition Survey in 2005.

*Abdominal obesity*

Abdominal obesity was defined using WCs measured at the height of the navel. The criterion for abdominal obesity of the Japan Atherosclerosis Society (JAS) is WCs ≥85 cm for male and WCs ≥90 cm for female [23, 24] . In this study, people who exceeded the JAS criterion were classified under AO (JAS). The criterion for abdominal obesity defined by the International Diabetes Federation (IDF) is WCs ≥90 cm for male and WCs ≥80 cm for female [24]. In this study, people who exceeded the criterion for IDF were classified under AO (IDF). These WCs data were also collected during the National Health and Nutrition Survey in 2005.

*Metabolic syndrome*

The criteria for MetS in this study were adopted from the National Health and Nutrition Survey in Japan [11], as follows: AO (JAS) and two or more of the following three symptoms: dyslipidemia, hypertension, and hyperglycemia. Dyslipidemia was defined as HDL-cholesterol <40 mg/dL or taking anti-cholesterol agents. Hypertension was defined as systolic blood pressure ≥130 mmHg and/or diastolic blood pressure ≥85 mmHg, or taking a hypotensive agent. Hyperglycemia was defined as hemoglobin A1c ≥5.5 or taking a hypoglycemic agent or using insulin injection. The data for WCs and blood tests were collected during the National Health and Nutrition Survey in 2005.

*Total functional tooth units*

Total functional tooth units (t-FTUs) were scored with pairs of opposing posterior teeth. And, these posterior teeth were consisted of natural teeth (i.e., sound teeth, restored teeth, and untreated teeth with caries; excluding extensive coronal destruction and wisdom teeth), artificial implant-supported teeth, prosthetic restorations (e.g., bridge), and removable prostheses. Based on previous studies [25-28], a t-FTUs score was derived, giving double weight to molars than premolars: 2 points per each pair of opposing molars and 1 point per each pair of opposing premolars. The t-FTUs score ranged from 0 to 6 in each side of the mouth. The total t-FTU score ranged from 0 to 12: a person with complete dentition, excluding wisdom teeth, would score 12 points [25-28]. Previous studies [26-28] using a questionnaire on the foods, e.g. peanuts, hard rice cracker, pickled radish and so on revealed that people with the t-FTUs score over 10 could had good chewing ability. Therefore, subjects were divided into three categories of chewing ability based on the t-FTUs: Poor (if score ≤9); Good (if score =10 or 11) and Complete (if score =12). These oral status data were collected on the Survey of Dental Diseases in 2005.

*Statistical analyses*

The relationship between three categories of chewing abilityand gender, age groups, drinking, smoking, exercise habits, and daily energy intake were evaluated using Pearson's chi-square test.

The relationships between chewing ability and BMI ≥25, BMI ≥30, AO (JAS), AO (IDF), and MetS were evaluated using univariate logistic regression analyses and multivariate logistic regression analyses in stepwise manner. The multivariate logistic regression analyses in stepwise manner were done with adjustment factors that gender, smoking, age group, drinking, exercise habits, and daily energy intake [15, 29]. In addition, we set the elimination criteria of covariate with multivariate logistic regression analysis in stepwise manner was $p > 0.25$.

Based on the 2005 National Health and Nutrition Survey, the scores for the factors: Drinking, Smoking and Exercising were dichotomized according to whether or not the subjects were, respectively, habitual drinkers (drinking at least once a month), smokers (including former smokers) or habitual exercisers (exercising 2 days a week continuously for at least 1 year), by research guidelines. Daily energy intake was categorized into three levels (from 219.40 to 1698.95 kcal; from 1699.04 to 2134.97 kcal; and from 2135.01 to 5738.14 kcal) by tertiles.

The statistical analyses were performed using IBM SPSS 23 software (IBM Inc., Tokyo, Japan). The level of significance was set at $p$ <0.05.

*Ethical approval*

Because this study was conducted based on the information obtained from national surveys, according to the Japanese Ethical Guidelines for Medical and Health Research Involving Human Subjects [30], the permission of an ethics committee was unnecessary.

## Results

The results of univariate logistic regression analysis and multivariate logistic regression analysis were shown in Table 2-4.

Univariate odds ratios (OR) for BMI ≥25, BMI ≥30, AO (JAS), AO (IDF), and MetS increased with decreasing t-FTU scores. All univariate OR in the group with "Poor" chewing ability were significantly higher than those of the group with "Complete" chewing ability.

Adjusted OR for BMI ≥25, BMI ≥30, AO (JAS), AO (IDF), and MetS increased with decreasing t-FTUs scores. Adjusted OR of "Poor" compared to "Complete" were 1.51 (95% confidence interval (CI), 1.24–1.84) for BMI ≥25, 2.10 (95% CI, 1.40–3.14) for BMI ≥30, 1.31 (95% CI, 1.07–1.61) for AO (JAS), 1.40 (95% CI, 1.15–1.70) for AO (IDF), and 1.34 (95% CI, 1.04–1.72) for MetS. All were statistically significant.

Univariate and adjusted OR for BMI ≥25, AO (JAS), AO (IDF), and MetS increased with increasing age. The values were significantly lower in female with BMI ≥25, BMI ≥30, AO (JAS), and MetS than in male, but showed different trends with regard to age groups for BMI ≥30 and in female for AO (IDF) compared to other categories.

## Discussion

This study showed that chewing ability as measured by t-FTUs are significantly associated with MetS, obesity, and AO among Japanese adults. The findings suggest the possibility of lowering the prevalence of MetS, AO, and obesity by maintaining chewing ability.

This is the first study to show that chewing ability as measured by t-FTUs are associated with the prevalence of MetS, AO, and obesity among Japanese adults. Previous studies have reported that the percentages of people with MetS, AO, and obesity increase with decreasing numbers of teeth and weakening occlusal force and masticatory performance [18-21, 31-33]. People with fewer teeth or weakened masticatory performance have a significant tendency to eat more sweet snacks/fats/carbohydrate and less vegetables/fruits/fiber/vitamins/minerals [31, 32, 34-37]. This is quite similar to the dietary pattern of people with MetS, AO, and obesity [29, 38, 39]. This kind of unhealthy dietary pattern would lead to a decreased number of teeth and also a decreased quality of nutrition, as well as an increased likelihood of periodontal disease [40]. Although t-FTUs did not explain masticatory performance completely, they had significant relationships with MetS, AO, and obesity.

Previous animal experiments have shown that hypothalamic neuronal histamine controls meal volume. Furthermore, stimulation through periodontal ligaments and masseter muscle spindles during mastication activates neuronal histamine [41]. One animal study reported that soft foods increase meal volume significantly compared to hard foods [42]. Another study reported that chewing calorie-free gum for 10 min before a meal decreases meal volume in people [41]. Together, these studies suggest that stimulation of the oral cavity by mastication involving the posterior teeth might enhance calorie-independent satiety and limit meal volume. For this reason, people with good chewing ability (i.e. high t-FTUs scores) and good masticatory function might not become obese.

The adjusted OR for BMI ≥30 wasn't consistent trend in age groups. The results of other categories show different patterns. In Japan, only 2.2% of male and 3.5% of female have a BMI ≥30, the highest being for male in their thirties and for female in their sixties [43]. For this reason, we considered that the tendency of people with BMI ≥30 might not be stable compared to other categories. In addition, more female than male had AO (IDF), probably because the criterion of AO (IDF) was smaller than that of AO (JAS) for female. No similar trends were found for the other categories.

This study had some limitations. First, t-FTUs only count the number of pairs of posterior teeth, including artificial teeth, and we could not assess how much these teeth contributed to occlusion. For example, t-FTUs may classify a tooth recovering from severe periodontal disease as a functional tooth. Second, the data used in this study were collected by national surveys in Japan, but the survey response rates were low; for example, the response rate of the Survey of Dental Disease in 2005 was 37.3% (standard deviation: 19.9%) [22]. Therefore, these data might include sampling bias. Third, this study is cross-sectional as it was a part of two national surveys. Therefore, there might be a possibility of having reserved causal relationship. According to previous study[44], MetS was associated with increasing tooth loss in middle-aged Japanese worker. For this reason, MetS and obesity may be influence number of teeth and t-FTUs scores. In the future, it is required to test to the causal relation by cohort studies.

A public screening program called "specified health checkups" has been carried out by all local governments in Japan since 2008. Its objective is to detect signs of MetS, AO, and obesity among people aged 40–74 years [45]. Our study suggests that maintaining pairs of opposing posterior teeth, including artificial teeth, could contribute to the prevention of MetS, AO, and obesity. A new adult dental screening system for maintaining posterior occlusion should be provided to community residents together with specified health checkups.

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**Conflict of Interest**

The authors declare that they have no conflict of interest.

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Table 1. Comparison of characteristics between subjects with occlusal functional groups

| Variables | Overall N =2807 | Poor (t-FTUs ≤9) N =689 | Good (t-FTUs =10 or 11) N =519 | Complete (t-FTUs =12) N =1599 | *p* value |
|---|---|---|---|---|---|
| Gender (Male vs Female)[a] | 1154 (41%) | 310 (45%) | 223 (43%) | 621 (39%) | 0.02 |
| Smoker (Yes vs No)[b] | 1196 (43%) | 314 (46%) | 231 (45%) | 651 (41%) | 0.06 |
| Habitual Drinker (Yes vs No)[b] | 1433 (51%) | 351 (51%) | 270 (52%) | 812 (51%) | 0.88 |
| Habitual Exercising (Yes vs No)[b] | 862 (31%) | 206 (30%) | 171 (33%) | 485 (30%) | 0.46 |
| Age Group | | | | | <0.001 |
| 35-44 vs 25-34 | 384 / 319 | 51 / 20 | 74 / 33 | 259 / 266 | <0.001 |
| 45-54 vs 25-34 | 508 / 319 | 136 / 20 | 92 / 33 | 280 / 266 | <0.001 |
| 55-64 vs 25-34 | 750 / 319 | 238 / 20 | 159 / 33 | 353 / 266 | <0.001 |
| 65-74 vs 25-34 | 846 / 319 | 244 / 20 | 161 / 33 | 441 / 266 | <0.001 |
| Tertile of daily energy intake | | | | | 0.38 |
| Middle vs Lower | 936 / 936 | 212 / 242 | 175 / 162 | 549 / 532 | 0.25 |
| Upper vs Lower | 935 / 936 | 235 / 242 | 182 /162 | 518 /532 | 0.48 |

Statistical analysis carried out Pearson’s chi-square test for cross-tabulations.

Notation in the table of binary items: [a]: number of Male (percentage of Male); [b]: number of Yes (percentage of Yes)

Abbreviations: t-FTUs, total functional tooth units; BMI, body mass index; AO (JAS), abdominal obesity determined by the waist circumference criteria of the Japan Atherosclerosis Society; AO (IDF), abdominal obesity determined by the criteria of the International Diabetes Federation; MetS, metabolic syndrome

Table 2. Factors associated with BMI: univariate or multivariate logistic regression analysis.

| Covariate | BMI ≥25 N =790 | | | | BMI ≥30 N =131 | | | |
|---|---|---|---|---|---|---|---|---|
| | Univariate OR (95% CI) | *p* value | Adjusted OR (95% CI) | *p* value | Univariate OR (95% CI) | *p* value | Adjusted OR (95% CI) | *p* value |
| Gender | | | | | | | | |
| Female vs Male | 0.61 (0.52-0.72) | <0.001 | 0.50 (0.40-0.63) | <0.001 | 1.40 (0.97-2.03) | 0.07 | - | - |
| Age Group | | <0.001 | | 0.10 | | 0.99 | | 0.02 |
| 35-44 vs 25-34 | 1.08 (0.75-1.54) | 0.68 | 1.15 (0.80-1.65) | 0.46 | 1.78 (0.90-3.51) | <0.01 | 1.76 (0.88-3.50) | 0.11 |
| 45-54 vs 25-34 | 1.33 (0.95-1.84) | <0.01 | 1.26 (0.90-1.78) | 0.18 | 0.72 (0.34-1.53) | 0.39 | 0.59 (0.27-1.27) | 0.18 |
| 55-64 vs 25-34 | 1.57 (1.16-2.14) | <0.01 | 1.41 (1.02-1.94) | 0.04 | 1.08 (0.56-2.09) | 0.81 | 0.88 (0.45-1.74) | 0.72 |
| 65-74 vs 25-34 | 1.70 (1.25-2.30) | <0.01 | 1.47 (1.08-2.01) | 0.02 | 1.26 (0.67-2.38) | 0.47 | 1.04 (0.53-2.01) | 0.92 |
| t-FTUs | | <0.001 | | <0.001 | | <0.01 | | <0.001 |
| 10-11 vs 12 | 1.07 (0.85-1.34) | 0.57 | 1.01 (0.80-1.27) | 0.93 | 0.94 (0.56-1.59) | 0.82 | 0.99 (0.58-1.68) | 0.97 |
| 0-9 vs 12 | 1.65 (1.36-2.00) | <0.001 | 1.51 (1.24-1.84) | <0.001 | 1.94 (1.32-2.85) | <0.01 | 2.10 (1.40-3.14) | <0.001 |

Statistical analysis for the Univariate OR carried out univariate logistic regression analysis.

Statistical analysis for the Adjusted OR carried out multivariate logistic regression analysis in stepwise manner that adjusted by gender, age groups, t-FTUs, smoking, drinking, exercise habits, and daily energy intake in a day.

Abbreviations: BMI, body mass index; OR, odds ratio; CI, confidence interval; t-FTUs, total functional tooth units

Table 3. Factors associated with AO: univariate or multivariate logistic regression analysis.

| Covariate | AO (JAS) N =945 | | | | AO (IDF) N =1201 | | | |
|---|---|---|---|---|---|---|---|---|
| | Univariate OR (95% CI) | *p* value | Adjusted OR (95% CI) | *p* value | Univariate OR (95% CI) | *p* value | Adjusted OR (95% CI) | *p* value |
| Gender | | | | | | | | |
| Female vs Male | 0.21 (0.18-0.25) | <0.001 | 0.22 (0.18-0.26) | <0.001 | 2.49 (2.12-2.91) | <0.001 | 2.46 (2.01-3.02) | <0.001 |
| Age Group | | <0.001 | | <0.001 | | <0.001 | | <0.001 |
| 35-44 vs 25-34 | 1.12 (0.77-1.63) | 0.56 | 1.41 (0.95-2.10) | 0.09 | 1.80 (1.28-2.54) | <0.01 | 1.60 (1.12-2.27) | 0.01 |
| 45-54 vs 25-34 | 1.69 (1.20-2.38) | 0.01 | 1.93 (1.34-2.78) | <0.001 | 2.32 (1.68-3.20) | <0.001 | 2.10 (1.50-2.92) | <0.001 |
| 55-64 vs 25-34 | 2.65 (1.93-3.63) | <0.001 | 2.98 (2.11-4.19) | <0.001 | 3.30 (2.44-4.47) | <0.001 | 3.12 (2.27-4.30) | <0.001 |
| 65-74 vs 25-34 | 3.49 (2.55-4.76) | <0.001 | 3.86 (2.76-5.39) | <0.001 | 4.34 (3.21-5.85) | <0.001 | 4.39 (3.19-6.03) | <0.001 |
| t-FTUs | | <0.001 | | 0.02 | | <0.001 | | 0.01 |
| 10-11 vs 12 | 1.13 (0.91-1.40) | 0.26 | 0.94 (0.75-1.19) | 0.63 | 1.08 (0.89-1.32) | 0.44 | 1.00 (0.81-1.24) | 1.00 |
| 0-9 vs 12 | 1.66 (1.38-2.00) | <0.001 | 1.31 (1.07-1.61) | 0.01 | 1.57 (1.31-1.88) | <0.001 | 1.40 (1.15-1.70) | 0.01 |

Statistical analysis for the Univariate OR carried out univariate logistic regression analysis.

Statistical analysis for the Adjusted OR carried out multivariate logistic regression analysis in stepwise manner that adjusted by gender, age groups, t-FTUs, smoking, drinking, exercise habits, and daily energy intake in a day.

Abbreviations: AO, abdominal obesity; AO (JAS), abdominal obesity determined by the waist circumference criteria of the Japan Atherosclerosis Society; AO (IDF), abdominal obesity determined by the criteria of the International Diabetes Federation; OR, odds ratio; CI, confidence interval; t-FTUs, total functional tooth units

Table 4. Factors associated with MetS: univariate or multivariate logistic regression analysis.

| Covariate | MetS N =424 | | | |
|---|---|---|---|---|
| | Univariate OR (95% CI) | *p* value | Adjusted OR (95% CI) | *p* value |
| Gender | | | | |
| Female vs Male | 0.33 (0.27-0.41) | <0.001 | 0.27 (0.21-0.35) | <0.001 |
| Age Groups | | <0.001 | | <0.001 |
| 35-44 vs 25-34 | 2.09 (0.95-4.61) | 0.07 | 2.54 (1.14-5.65) | 0.02 |
| 45-54 vs 25-34 | 3.43 (1.66-7.11) | 0.001 | 3.67 (1.75-7.67) | 0.01 |
| 55-64 vs 25-34 | 7.36 (3.69-14.65) | <0.001 | 7.46 (3.71-15.04) | <0.001 |
| 65-74 vs 25-34 | 11.74 (5.94-23.18) | <0.001 | 11.18 (5.61-22.29) | <0.001 |
| t-FTUs | | <0.001 | | 0.07 |
| 10-11 vs 12 | 1.26 (0.95-1.67) | 0.11 | 1.05 (0.78-1.42) | 0.73 |
| 0-9 vs 12 | 1.80 (1.42-2.27) | <0.001 | 1.34 (1.04-1.72) | 0.02 |

Statistical analysis for the Univariate OR carried out univariate logistic regression analysis.

Statistical analysis for the Adjusted OR carried out multivariate logistic regression analysis in stepwise manner that adjusted by gender, age groups, t-FTUs, smoking, drinking, exercise habits, and daily energy intake in a day.

Abbreviations: MetS, metabolic syndrome; OR, odds ratio; CI, confidence interval; t-FTUs, total functional tooth units