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Gerodontology

Original article

Prevalence of torus mandibularis among a group of elderly Japanese and its relationship with occlusal force

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Prevalence of torus mandibularis among a group of elderly Japanese and its relationship with occlusal force

Objective: To examine the prevalence of torus mandibularis (TM) and identify clinical factors associated with its presence.

Materials and methods: A total of 664 Japanese adults over age 60 were studied by means of a questionnaire and clinical examination.

Results: In all, 197 subjects (29.7%) had TM. We found a significant association between the presence of TM and torus palatinus (TP; 45.1% vs. 26.5%, $p < 0.001$). Moreover, occlusal force with TM was significantly higher than without TM ($p < 0.05$). Logistic regression adjusted for age and occlusal force revealed a significant relationship between TM and occlusal force and TP [$p = 0.005$, odds ratio (OR) = 2.44; $p < 0.001$, OR = 2.66, respectively].

Conclusion: This study suggests that there is a relationship between TM and factors related to occlusal factor.

Keywords: torus mandibularis, occlusal force, elderly, genetic factors

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Introduction

Torus mandibularis (TM) is a non-pathological bony growth on the inside (lingual) surface of the lower jawbone or mandible, above the mylohyoid line. It is located in the premolar segment and is frequently symmetrical. In edentulous patients, oral tori can make reconstruction with dentures difficult. According to some reports, TM can also interfere with denture fittings[1] as well as—infrequently—leading to obstructive sleep apnea without tongue pushed backward by large TM[2] and difficulties with endotracheal intubation[3].

Data on the prevalence of TM are inconsistent and controversial. Ihunwo and Phukubye[4] and Jainkittivong *et al.*[5] report that TM is more frequent in men, although others report a higher frequency among women[6–8]. Additional studies indicate an insignificant difference in prevalence between genders[9–11]. A wide variety of prevalence rates have been reported in different racial populations[4,5,12,13], although few studies have addressed the incidence of TM in a Japanese population[6,9].

The aetiology of TM is also controversial. Alvesalo *et al.*[14] have reported that TM is linked to the sex chromosomes. It has also been associated with parafunctional habits[15–17] and masticatory stress[8,18]. Other reports suggest that TM may be associated with more adequately developed marginal alveolar bone[19] or number of teeth at the mandibular level[20]. However, the prevalence and potential causes of TM remain unclear, especially among Japanese elders.

Development of torus palatinus (TP) may be related to genetic factors[21], although evidence suggests that the presence of TM is related to occlusal force or support[8,18,20]. The primary aim of this study was to determine the prevalence of TM in Japanese elders, and factors associated with them.

Material and methods

A total of 664 volunteers (294 men and 370 women; age range, 60–82 years) participated in the study. All lived independently in the

community and attended weekly lectures at the Senior Citizens' College in Osaka Prefecture in 2007–2008.

The questionnaire and study protocol were approved by the Institutional Review Board of Osaka University Graduate School of Dentistry (No. H14-7). The study was carried out in accordance with the Declaration of Helsinki for Human Experimentation. All volunteers provided written informed consent.

We used two questions on a self-administered questionnaire: (i) 'Have you been aware of clenching or grinding of the teeth when awake?'; and (ii) 'Have you or your cohabitant been aware of clenching or grinding of the teeth when sleeping?' to solicit information about dental clenching and grinding[16]. Participants were asked to respond with yes, no or 'don't know'.

In this study, the clinical examination assessed dental status, temporomandibular joint symptoms and occlusal force according to previous studies[22]. Oral examinations were performed by five dentists instructed on the research project and calibrated prior to the investigation. Participants were grouped according to the Eichner index[23–26] based on the number of occlusal contacts in existing natural teeth or fixed partial dentures in the premolar and molar regions of both jaws. Class A had contacts in four support areas; Class B in one to three areas or in the anterior area only. Class C, with few if any remaining teeth, had no contact in any area. The groups represented the functional value of each dentition based on the type, number and arrangement of the teeth. Occlusal support in the premolar or molar areas was examined in a similar fashion.

TP and TM were assessed as present when a painless bony swelling was seen or palpated in the middle of the hard palate or in the lingual area of the mandible[5,16] (Fig. 1). When a bony swelling was not distinguished clearly by inspection and palpation, it was recorded as absent.

Occlusal force was measured using a pressure-sensitive sheet (Dental Prescale, 50 H type R, 97 μm thick; Fuji Photo, Tokyo, Japan) and apparatus for analysis (Occluzer; Fuji Photo). With the sheet placed between the maxillary and mandibular dental arches, participants were indicated to occlude on the Dental Prescale with maximum force for 3-s to release microcapsules containing colour-forming and colour-developing materials in the pressure-sensitive sheets. Occlusal force in newtons was calculated from the depth of colour released (Fig. 2)[27–30]. The measurements of the system are all based on an elementary unit of an average bite pressure which is calculated from the degree of colouring in a square of 0.25 mm[30] The uses, limitations, validity and reliability of this method have been described[27–30].

The jaw joints were examined for temporomandibular disorders (TMDs), such as clicking, crepitus or pain on opening the mouth to 40 mm or more.

Chi-square and Mann–Whitney *U*-tests were performed to examine factors related to the presence of TM. A multiple logistic regression with forced entry determined whether an independent variable remained statistically significant after

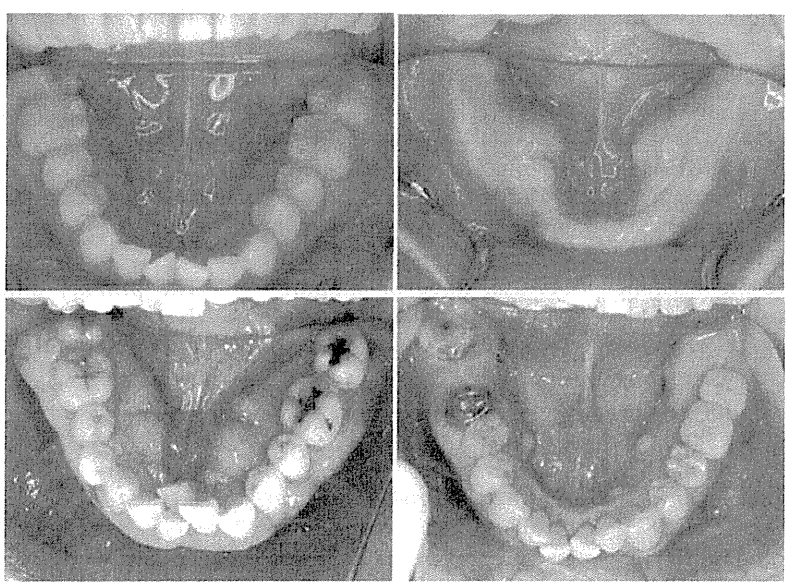

Figure 1 Torus mandibularis.

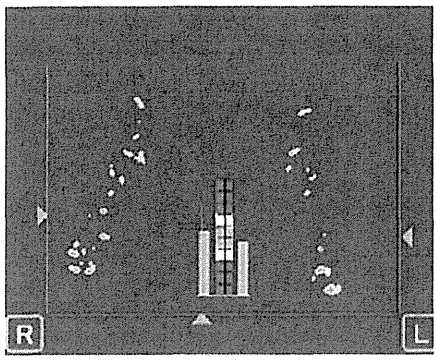

Figure 2 A measurement of occlusal force with Occluzer (Fuji Photo) in a typical case.

controlling for other confounding variables. All of the statistical significance was identified at $p < 0.05$.

Results

The mean age of participants was 66.5 ± 4.2 years (range, 60–82 years). The mean ages for men and women were 63.1 ± 4.2 years and 68.1 ± 3.3 years, respectively. In all, 197 (29.7%) participants had TM (Table 1). There was a significant difference between men and women with TM but not with TP (Table 2). A significant difference was evident between men and women having TP with TM and men and women having TP without TM (Table 2).

The presence of torus mandibularis was associated significantly with torus palatinus, the Eichner index (Class A vs. Class B and Class A vs. Class C), occlusal supports and self-reported nocturnal bruxism (Table 1). The occlusal force in subjects with TM was significantly higher than without TM (743.1 ± 335.1 N vs. 616.2 ± 325.9 N, $p < 0.05$) (Fig. 3). Logistic regression analysis adjusted for age, and occlusal force showed a significant relationship between TM and occlusal force and TP (Table 3).

Table 1 Associations between the presence of torus mandibularis (TM), and various age, gender and occlusal variables.

Variables	*n*	*TM Prevalence%*	*Difference p-value**
Overall	664	29.7	
Gender			
Men	294	32.0	0.142
Women	370	27.8	
Age			
60–69	527	31.1	0.082
70+	137	24.1	
Self-reported Diurnal bruxism			
Absent	590	30.3	0.086
Present	42	33.3	
Questionable	32	12.5	
Self-reported Nocturnal bruxism			
Absent	497	29.0	0.024
Present	102	39.2	
Questionable	65	20.0	
Eichner index			
Class A	417	34.5	0.001
Class B	215	22.3	
Class C	32	15.6	
Occlusal support on premolars			
Absent	120	14.2	<0.001
Present	544	33.1	
Occlusal support on molars			
Absent	242	20.7	<0.001
Present	422	34.8	
Torus Palatinus			
Absent	551	26.5	<0.001
Present	113	45.1	
Temporomandibular disorders			
Absent	507	29.0	0.278
Present	157	31.8	

*A chi-squared test was used.

Discussion

This report examined the prevalence of TM and TP among Japanese elders, and some of the factors associated with TM. Previous studies described the prevalence of TM, but few have assessed it in Japanese populations[6,9] or investigated factors associated with its occurrence[5,14–17,19,20,31]. The present study demonstrates that approximately one-third of the people we examined have tori and that factors related to oromaxillofacial function might have a role in creating them. The prevalence of tori varies among different populations[4,5,12,13]. In Asian populations like ours, the prevalence seems to fall somewhere around one-third[5,9,10,13], which is consistent with our findings. We also noted approximated prevalence in men and women (32.7% vs. 27.8%)—an outcome that is similar to Ohno's report[9] (29.4% vs. 28.1%) but differs from Suzuki's report[32] (38.4% vs. 51.9%). Although the reasons for the difference have yet to be determined, gender[14,32] as well as other factors[15–17,20] have been implicated in TM. These include parafunctional habits[16] and the number of present teeth[20].

Data from previous studies indicate that TM might predict the risk of TMD[15–17]. The present study found no relationship between TM and

Table 2 The prevalence of torus mandibularis and torus palatinus in 664 subjects.

Presence (+) or absence (−) of tours mandibularis (TM) & torus palatinus (TP)	*Men (n = 294) n (%)*	*Women (n = 370) n (%)*	*Total (n = 664) n (%)*	*p-value**
TP(+)TM(+)	11 (3.7)	40 (10.8)	51 (7.7)	<0.001
TP(+)TM(−)	11 (3.7)	51 (13.8)	62 (9.3)	<0.001
TP(−)TM(+)	94 (32.0)	52 (14.1)	146 (22.0)	<0.001
TP(−)TM(−)	178 (60.5)	227 (61.4)	405 (61.0)	0.447

*A chi-squared test was used.

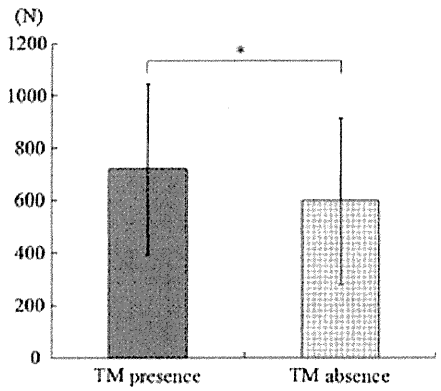

Figure 3 Associations between occlusal force and the presence of torus mandibularis. A Mann–Whitney *U*-test was used. *p <0.05.

self-reported diurnal bruxism or temporomandibular disorders. However, in our study, there was no significant association between TM and them. Rather, it was suggested that there were significant associations between TM and self-reported nocturnal bruxism, Eichner index, occlusal support at the premolar and molar areas, occlusal force, and the presence of TP. Eggen *et al.*[20] suggested that TM may be associated with number of teeth at the mandibular level; however, we found that TM was associated with mechanical stimulation from occlusal contacts. Alvesalo[31] suggested that different effects of the X and Y chromosomes on growth explain the expression of TM, but our result indicate that the participants with TP tend to increase bone mass.

Wolff's law[33,34] supports that a loading force on bone prompts remodelling over time, thereby strengthening the bone. Perhaps, therefore, occlusal load via the periodontal ligament increases the bone mass and density and causes bony ridges on the lingual surface of the mandibular corpus. Schepdael *et al.*[35] described how bone formation took place in a tension zone, whereas Christen *et al.*[36] used a murine model and suggested that the history of bone loading can be estimated from

Table 3 Contributions from multiple regression analyses of significant variables to the presence of torus mandibularis.

	Contributions		
Variables	*Significance (p-value)*	*Odds- ratio*	*95% confidence interval*
Significant explanatory variables			
Occlusal Force (×1000N)	0.005	2.44	1.32–4.52
The presence of TP	<0.001	2.66	1.65–4.30
Insignificant explanatory variables			
Age	0.067	0.63	0.39–1.03
Gender (men)	0.083	1.42	0.95–2.13
Diurnal bruxism	0.857	1.08	0.49–2.38
Nocturnal bruxism	0.278	0.76	0.46–1.25
Eicher index	0.598	1.23	0.56–2.70
TMD symptom	0.859	0.96	0.62–1.50
Occlusal support at premolar area	0.079	1.36	0.92–3.97
Occlusal support at molar area	0.474	1.04	0.57–3.22

its morphology. Long-term stress from nocturnal bruxism increases the load on the premolar or molar areas, increasing the bone mass and strengthening the occlusal force. It also gives TM an unusual character in the incisal areas[5], which supports our finding that occlusal force is stronger in the presence of TM than in its absence. However, further studies are needed to confirm the significance of this observation.

Overall, our results suggested that the prevalence of TM in Japanese elders is associated with oromaxillofacial functions rather than genetic factors.

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Association of periodontal status with occlusal force and food acceptability in 70-year-old adults: from SONIC Study

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SUMMARY **This cross-sectional study aimed to investigate the association of periodontal status with occlusal force and food acceptability. We hypothesised that mastication deteriorated with reduced periodontal support, even when posterior occlusal contacts with natural teeth were maintained and the patients remained clinically asymptomatic. Participants were 482 independently living 69-71-year-olds, classified as Eichner's group A, having no mobile teeth and no periodontal symptoms. The periodontal probing depth (PPD) and restoration status of each tooth were examined. Occlusal force in the intercuspal position was measured with pressure-sensitive films. Food acceptability was evaluated from the difficulty experienced in chewing apples, grilled beef, and hard rice crackers. Multivariate regression analysis was performed to investigate the association of periodontal status with occlusal force and food acceptability. A *P*-value of <0·05 was considered statistically significant. Multiple linear regression analysis showed that occlusal force had significant negative associations with maximal PPD (standardised partial regression coefficient (β) = −0·121) after controlling for gender, handgrip strength, number of teeth, and percentage of restored teeth. Approximately 15% of participants were included in the compromised food acceptability group. Logistic regression analyses showed that compromised food acceptability was significantly associated with PPD, after controlling for gender, number of teeth, and percentage of restored teeth. Periodontal probing depth (PPD) was significantly correlated with occlusal force and self-rated food acceptability after controlling for the possible confounding factors in septuagenarians, even those with complete posterior occlusal contacts and no tooth mobility.**

KEYWORDS: **geriatric dentistry, periodontics, occlusal force, food acceptability, epidemiology, multiple regression analysis**

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Introduction

One of the primary reasons for undergoing dental treatment is to maintain natural teeth and to preserve oral function, especially mastication. The number of remaining teeth and pairs of functional occlusal contacts are important factors in mastication. Despite increasing life expectancy and tooth retention into old age, the periodontal status of older adults is often compromised. The deleterious effects of the progression of periodontal disease on oral function have not been well discussed.

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The ability to generate occlusal force is positively linked with masticatory performance and dietary selection (1–6). Therefore, occlusal force measurements have often been used as a proxy for objective evaluation of masticatory function. Occlusal force can be reduced by the collapse of the posterior bite as a result of losing posterior tooth contacts. Atrophy of masticatory muscles such as the masseter, temporalis and medial pterygoid also diminishes occlusal force. As we reported previously, occlusal support of residual teeth was the most important variable for determining bilateral occlusal force (5, 6). We determined that the occlusal forces of Eichner's class B and C groups were 81% and 50% of the class A group, respectively (6).

It is intuitive that high occlusal forces demand that teeth are firmly supported by healthy periodontal tissue. However, there is some controversy regarding whether reduced periodontal support without mobility affects occlusal force and/or masticatory ability. One study reported that clinical attachment level showed a significantly negative correlation with occlusal force by bivariate analysis. However, a subsequent multiple regression analysis identified the number of teeth, gender, and age, but not periodontal indices, as significant factors affecting occlusal force in 142 Chinese adults (7). A Turkish study showed that tooth mobility, even in the absence of inflammation, negatively affected occlusal force (8). However, that study population included only 20 treated and 20 compromised patients and data were not adjusted for other predictable factors of occlusal force (8). Multiple stepwise regression analysis showed that occlusal force was positively associated with the number of teeth present and negatively associated with female gender and mean probing pocket depth (PPD) among 198 Japanese patients (9).

Skeletal muscle atrophy, declining strength and physical frailty are archetypal concomitants of ageing. Nevertheless, the severity of these conditions differs substantially between individuals with advancing age, therefore, general muscle strength must be adjusted before making any comparison of occlusal force in older adults. There has been no large population study associating periodontal status with masticatory ability after controlling for possible confounding variables (e.g. age, gender, number of teeth, and general muscle strength).

The purpose of this cross-sectional study was to investigate the association of PPD with bilateral maximal occlusal force and food acceptability in independently living older adults maintaining posterior tooth contacts without tooth mobility. We hypothesised that masticatory ability deteriorates with reduced periodontal support, even if posterior occlusal contacts between natural teeth are maintained.

Methods

Study population and procedure

This research was a cross-sectional analysis of a prospective cohort study of health and longevity called the 'SONIC' (Septuagenarians, Octogenarians, Nonagenarians Investigation with Centenarians). Participants were volunteers aged 69–71 years from four areas of western and eastern Japan comprising both urban and rural parts and incorporating Itami City, Hyogo (western-urban); Asago City, Hyogo (western-rural); Itabashi ward, Tokyo (eastern-urban) and Nishitama County, Tokyo (eastern-rural). An invitation letter was sent to all community-dwelling septuagenarians living in the vicinity of the research venue.

Community-dwelling septuagenarians in each area (2071 male and 2196 female; age: 69–71 years) were identified from the local residential register and contacted by mail. Of those, 1000 (477 male and 523 female) took part in the SONIC Study, although 90 participants who could not complete any research item were excluded. This left a total of 910 participants for analysis (427 male and 483 female). Data collection was conducted during the 2010–2011 period at each local hall.

This study was undertaken with the understanding and written informed consent of each participant. The protocol was independently reviewed and approved by the Institutional Review Board of Osaka University Graduate School of Dentistry (approval number H22-E9).

Number of remaining teeth, and restorative and periodontal status

Oral examinations were conducted by registered dentists who recorded the number of remaining and restored teeth. Participants were subsequently divided according to Eichner's classification (10), which is based on existing natural tooth contacts between the maxilla and mandible in the bilateral premolar and

molar regions. Group A has occlusal contacts in four posterior support zones, that is, the premolar and molar zones on each side. Groups B1, B2, and B3 have three, two, and one such contact, respectively, while B4 has occlusal contacts only in the anterior region. Group C has no occlusal contact in any part of the dentition (10). To examine the association of periodontal status with masticatory ability, we analysed only participants classified as Group A, that is those with complete posterior occlusal support. None of the participants wore a removable partial denture.

The PPD, mobility and restoration status (±restoration) of each tooth were examined. Tooth mobility was evaluated using Miller's classification (11). The PPD was measured with a colour-coded probe (CP-12*). Periodontal probing depth was assessed at six sites (mesio-buccal, mid-buccal, disto-buccal, mesio-lingual, mid-lingual, and disto-lingual) for all teeth present. Mean PPD, maximum PPD, the percentage of teeth with ≥4 mm PPD, and the percentage of mobile teeth (Grade I or more) were used as indicators of periodontal status (9).

Maximal occlusal force and food acceptability

The occlusal force was measured with pressure-sensitive films (Dental Prescale 50H R type†), the thickness of which was 97 μm (9, 12). The participants performed maximal clenching in the intercuspal position with the pressure-sensitive film placed between the maxillary and mandibular dental arches. The pressure-sensitive sheet used here measures total biting ability for the whole dentition (8). The uses, limitations, validity, and reliability of this method have been discussed elsewhere (9, 12, 13). Gender and hand-grip strength were used as indicators of general muscle strength (14).

Food acceptability was evaluated from responses to the questions 'Can you chew apples/grilled beef/hard rice crackers without difficulty?' (15). The participants were asked to answer 'yes' or 'no' to these questions. These foods are eaten in different ways: for example, apples must be bitten with the anterior teeth, hard rice crackers must be crunched and beef must be ground. The 'healthy control' group was defined as participants that were able to eat all three foods without difficulty. Any participants experiencing difficulty with any of the three foods were placed in the 'compromised group'.

Statistical analysis

In this study, dental, medical, and psychological professionals undertook a comprehensive evaluation of health and longevity in the same cohort of individuals. The numerous measurements and statistical methods used necessitated a large sample size to produce adequate statistical power. Using G* power, we estimated that a total sample size of at least 395 was required when the defined effect size was small, α error was 0·05, Power = 1-β error was 0·80, and number of predictors was five in a multiple linear regression. Therefore, our sample of 482 subjects was deemed more than sufficient for our study.

The data analyses were performed using SPSS Version 20‡ . A two-sided *P*-value of <0·05 was considered statistically significant.

Initial analyses focused on descriptive statistics and bivariate associations between the dependent variables. First, each parameter was compared by gender using the Mann–Whitney *U*-test. Second, Spearman correlation coefficients were used to evaluate the relationship between occlusal force and other parameters. Because tooth mobility is so important in reducing the occlusal force (11), we conducted further analyses on participants with no tooth mobility. Third, to investigate the independent effect of periodontal status on occlusal force, multiple linear regression analysis was performed after controlling for the possible confounding factors, because the occlusal force was normally distributed. There were strong correlations (rs > 0·7) between the mean PPD, maximal PPD and percentage of teeth with PPD ≥4 mm. Therefore, these periodontal parameters were included in the separate models.

For food acceptability as the outcome variable, participants were dichotomized into two groups depending on whether the participants had any difficulty eating certain foods (compromised group) or not (healthy control group). To investigate the independent effect of periodontal status on food acceptability,

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Table 1. Comparison of measured variables between groups by Eichner's classification

Variables	Class A (n = 482)		Class B (n = 315)		Class C (n = 113)		P-value
	Mean	CI	Mean	CI	Mean	CI	
Number of teeth	26·5	26·2–26·7	18·9	18·3–19·4	7·1	6·4–7·7	<0·001*
Occlusal force (N)	714	684–743	419	389–448	250	213–287	<0·001*
Food acceptability compromised group	21·6%		53·7%		85·7%		<0·001†

Food acceptability was self-evaluated by participants rating their ability to eat apple, beef and rice crackers. Those able to eat all three foods without difficulty were classified as the 'healthy control' group. Those experiencing difficulty in eating any of the three foods were classified in the 'compromised' group.
CI: 95% confidence interval; PPD: Probing pocket depth; * and † denote statistically significant results as determined by the Kruskal–Wallis test and the Chi-square test, respectively.

a multiple logistic regression analysis was carried out after controlling for gender, number of teeth, and percentage of restored teeth. The three significantly associated periodontal parameters were entered into the separate models.

Results

Of the 910 participants, 482 (53%), 315 (35%) and 113 (12%) were classified into Eichner's groups A, B and C, respectively. Participants classified into Eichner's group A had not only more teeth but also higher occlusal force and better food acceptability than groups B and C (Table 1). The number of teeth, a critical variable for oral function, was limited within a very small range (95% confidence interval: 26.2–26.7 teeth) in Eichner's group A participants, so these were selected for further analyses. Tooth number was more variable in groups B and C. These groups were thus deemed more suitable for the study of the effects of removable dentures on oral function and were not studied further here.

Hand-grip strength and occlusal force were significantly larger in male than female participants (Table 2). The mean number of teeth in male participants (26·9) was significantly larger than in female participants (26·1). In contrast, the periodontal parameters of mean PPD, maximal PPD and percentage of PPD ≥4 mm were significantly worse in male participants. The percentage of restored teeth was significantly higher in female participants. The overall percentage of teeth with PPD ≥4 mm was <20% and that of mobile teeth was <2%.

In both the total participant group and the subgroup of participants with no mobile teeth, hand-grip strength and total tooth numbers had significant positive correlations to occlusal force (Table 3). In contrast, the percentage of teeth with mobility had a significant negative correlation to occlusal force in the total participant group. Furthermore, maximal PPD, the percentage of teeth with PPD ≥4 mm, and the percentage of restored teeth all had significant negative correlation to occlusal force in both the total participant group and the subgroup of participants with no mobile teeth.

Among the participants with no mobile teeth, multiple linear regression analysis showed that occlusal

Table 2. Comparison of measured variables between males and females

Variables	Male (n = 224)		Female (n = 258)		P-value*
	Mean	CI	Mean	CI	
Hand-grip strength (kgf)	32·3	31·4–33·2	19·3	18·7–19·9	<0·001
Number of teeth	26·9	26·6–27·2	26·1	25·8–26·4	0·006
Restored teeth (%)	42·2	39·4–45·0	53·9	51·3–56·5	<0·001
Mean PPD (mm)	3·06	2·98–3·14	2·87	2·79–2·95	<0·001
Maximal PPD (mm)	5·02	4·77–5·27	4·57	4·36–4·78	0·008
Teeth with PPD ≥4 mm (%)	20·0	17·1–22·9	15·7	13·1–18·2	0·011
Mobile teeth (%)	1·97	1·26–2·68	1·97	1·36–2·59	0·723
Occlusal force (N)	782	737–827	654	616–693	<0·001

CI, 95% confidence interval; PPD, Probing pocket depth.
*Mann–Whitney U-test.

Table 3. Spearman correlation coefficients between occlusal force and other parameters

	Total subjects (n = 482)		No tooth mobility (n = 383)	
Variables	rs	P-value	rs	P-value
Hand-grip strength (kgf)	0·226	<0·001	0·200	<0·001
Number of teeth	0·213	<0·001	0·181	<0·001
Restored teeth (%)	−0·174	<0·001	−0·208	<0·001
Mean PPD (mm)	−0·089	0·051	−0·054	0·292
Maximal PPD (mm)	−0·144	0·002	−0·102	0·046
Teeth with PPD ≥4 mm (%)	−0·136	0·003	−0·105	0·039
Mobile teeth (%)	−0·158	0·002	–	–

PPD, Probing pocket depth; rs, Spearman correlation coefficient.

force had significant negative association with maximal PPD (standardised partial regression coefficient: $\beta = -0{\cdot}121$, $P = 0{\cdot}016$) after controlling for gender, hand-grip strength, number of teeth, and percentage of restored teeth (Table 4). However, there was no significant relationship between occlusal force and mean PPD or percentage of teeth with PPD ≥4 mm.

Regarding food acceptability in participants with no tooth mobility, 15% of participants had difficulty chewing at least one food ('compromised group'; Table 5) and this percentage was not significantly affected by gender. The 'compromised group' had significantly fewer teeth, a higher percentage of restored teeth and worse periodontal status than the 'healthy control' group according to all three PPD parameters (Table 5).

Multiple logistic regression analyses showed that compromised food acceptability was associated with mean PPD (odds ratio = 2·30), maximal PPD (odds ratio = 1·35), and the percentage of teeth with PPD ≥4 mm (odds ratio = 1·32 by 10%) after controlling for gender, number of teeth and percentage of restored teeth (Table 6).

Discussion

This cross-sectional research evaluated a population sample of 69- to 71-year-old adults in urban and rural areas of western and eastern Japan. We have shown previously that a decline in the degree of occlusal contact between remaining teeth contributes to a reduction in occlusal force and creates difficulty for older adults in eating certain foods (6, 15, 16). We added periodontal status as a critical variable in the present study. Multiple regression analyses demonstrated that the PPD was significantly correlated with occlusal force and self-rated food acceptability after controlling for several confounding factors in our cohort of aged adults exhibiting complete posterior occlusal contacts with no tooth mobility. These findings suggest that reduced periodontal support is a predictive parameter that influences food selection and nutrient intake.

Most previous studies in older adult populations have examined a wider age range of patients from clinics in a dental school, hospital, or nursing home. However, this wide age range produces a generation gap among participants. Attitudes regarding oral health and levels of dental treatment strongly reflect the era in which the individuals grew up. For example, whereas 24·1% of 80-year-old Japanese people had 20 or more teeth in 2005, 38·3% of the same age group did only 6 years later in 2011. Neither the attitudes nor the oral health awareness level can be

Table 4. Multiple linear regression analysis for occlusal force among participants with no clinical tooth mobility (n = 383)

	Model 1		Model 2		Model 3	
Variables	β	P-value	β	P-value	β	P-value
Gender (female)	−0·050	0·518	−0·062	0·418	−0·053	0·495
Handgrip strength (kgf)	0·103	0·172	0·095	0·203	0·096	0·199
Number of teeth	0·100	0·076	0·102	0·068	0·101	0·070
Restored teeth (%)	−0·116	0·046	−0·108	0·063	−0·110	0·059
Mean PPD (mm)	−0·067	0·182	–	–	–	–
Maximal PPD (mm)	–	–	−0·121	0·016	–	–
Teeth with PPD ≥4 mm (%)	–	–	–	–	−0·081	0·110

Models 1, 2 and 3 included Mean PPD, Maximal PPD and Percentage of 'PPD ≥4 mm' teeth, respectively, as independent variables. PPD, Probing pocket depth; β, standardized partial regression coefficient.

Table 5. Periodontal status by food acceptability among participants with no clinical tooth mobility (n = 383)

Variables	Compromised group (n = 58)		Healthy control group (n = 325)		
	Mean	CI	Mean	CI	P-value*
Number of teeth	25·3	24·6–26·1	26·7	26·5–27·0	<0·001
Restored teeth (%)	54·3	48·2–60·3	46·9	44·5–49·4	0·027
Mean PPD (mm)	3·04	2·89–3·20	2·80	2·75–2·86	0·002
Maximal PPD (mm)	4·97	4·57–5·37	4·29	4·14–4·44	0·001
Teeth with PPD ≥4 mm (%)	22·5	16·4–28·6	12·0	10·2–13·7	<0·001

Food acceptability was self-evaluated by participants rating their ability to eat apple, beef and rice crackers. Those able to eat all three foods without difficulty were classified as the 'healthy control' group. Those experiencing difficulty in eating any of the three foods were classified in the 'compromised' group. CI, 95% confidence interval; PPD, Probing pocket depth. * Denotes a statistically significant result as determined by the Mann–Whitney U-test.

Table 6. Multiple logistic regression analyses for food acceptability among participants with no mobile teeth (n = 383)

Variables	Odds ratio	CI	P-value
Mean PPD			
Gender (female)	1·32	0·71–2·47	0·379
Number of teeth	0·85	0·76–0·95	0·006
Percentage of restored teeth	1·00	0·99–1·02	0·840
Mean PPD (mm)	2·30	1·36–3·87	0·002
Maximal PPD (mm)			
Gender (female)	1·33	0·71–2·49	0·367
Number of teeth	0·85	0·76–0·95	0·004
Percentage of restored teeth	1·00	0·99–1·02	0·865
Maximal PPD (mm)	1·35	1·12–1·62	0·001
Percentage of teeth with PPD ≥4 mm			
Gender (female)	1·33	0·71–2·49	0·376
Number of teeth	0·85	0·75–0·95	0·003
Percentage of restored teeth	1·00	0·99–1·02	0·980
Teeth with PPD ≥4 mm (%)*	1·32	1·15–1·51	<0·001

*Unit = 10%; CI, 95% confidence interval; PPD, Pocket probing depth.

adjusted by statistical procedures. The homogeneous age range was advantageous in that it eliminated the generation gap.

To examine any association between periodontal status and masticatory ability, we analysed only participants classified as Eichner's group A and without tooth mobility. Posterior occlusal contact is a critical determinant of masticatory ability (5, 6). It should therefore be broadly equivalent within the study sample to allow a fair evaluation of the relationship between periodontal status and masticatory function.

Miyaura *et al.* (17) reported that the presence of mobile teeth does not always reduce biting ability after controlling for gender and age. However, in this study, the percentage of mobile teeth had a significant negative correlation with occlusal force, so we excluded participants with mobile teeth from our subsequent multivariate analyses.

It is well known that hand-grip strength is a good predictor of general muscle strength in geriatric persons. Hand-grip strength was significantly associated with occlusal force in a bivariate analysis. The direction of cause and effect was not clarified by this analysis, but this finding suggests that elderly people with reduced hand-grip strength experienced a greater impact on their oral function. However, this association disappeared in the multivariate analysis when adjusted for gender and other variables.

Miyaura *et al.* (17) also demonstrated that occlusal forces in participants with full-cast crowns and fixed partial dentures were lower than in those with a natural dentition. We showed here that not only the total number of teeth but also the percentage of restored teeth had significant associations with occlusal force in our bivariate analysis. This association diminished (P = 0·068–0·076 for the total number of teeth; P = 0·046–0·063 for the percentage of restored teeth) in a multivariate analysis. However, maximal PPD was still significantly associated with occlusal force in this multivariate analysis, and associations between PPD and food acceptability were more consistent. All of these periodontal status parameters were significantly related to food acceptability in our multivariate analyses.

Further studies are needed to clarify why reduced periodontal support affects occlusal force and food acceptability. Reduced periodontal support might decrease the threshold level of mechanoreceptor

function because the loading forces produced by the masticatory muscles are controlled by mechanoreceptors in the periodontal ligament (18). Although the participants were symptom free and without clinically evident tooth mobility, subtle movements of each tooth may occur during clenching, which would reduce the maximal occlusal force.

Several aspects in our study design limit our conclusions. This population was drawn from non-institutionalized, 69- to 71-year-old community-dwelling Japanese people, most of whom were physically and cognitively healthy despite the sample being drawn from a complete enumeration of the resident record. Consequently, our results cannot be extrapolated to younger, older or less healthy people. However, compared with national data (19), the average number of remaining teeth in our participants was similar to that determined for the same generation in the whole Japanese population. Another limitation is that, along with most other studies in this area, our study was cross-sectional rather than longitudinal in nature, rendering it difficult to identify any causal relationship.

On the contrary, the strength of this study was that it was a multi-disciplinary effort involving prosthodontists, periodontists, psychologists and nutritionists from a range of geographical areas with different characteristics. The data collection strategy thus enhanced the external validity of our findings and enabled us to reveal the most important confounding factors.

Conclusions

We studied a population of older adults with complete posterior occlusal contacts and no tooth mobility. When controlled for possible confounding factors, multiple regression analysis of this population revealed that the probing pocket depth was significantly correlated with occlusal force and self-rated food acceptability. This study showed that a loss of periodontal tissue support negatively affected masticatory ability. However, further longitudinal studies with a larger study population should be done to identify any causal associations.

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Influence of genetic and environmental factors on oral diseases and function in aged twins

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SUMMARY **This study was conducted to quantify the genetic and environmental contributions to oral disease and function in twins. Participants were middle-aged and old twins, 116 monozygotic and 16 dizygotic pairs whose mean age was 66·1 ± 10·3 (SD) years. Number of teeth, percentage of decayed, filled and missing teeth and periodontal status were recorded as indicators of oral disease. The widths of upper and lower dental arch served as indicators of morphological figures. Furthermore, stimulated salivary flow rate, occlusal force and masticatory performance were measured as indicators of oral function. Univariate genetic analysis with monozygotic and dizygotic twin pairs was conducted to detect the fittest structural equation model of each outcome. Both number of teeth and periodontal status fitted the model composed of common environmental factor and unique environmental factor. Decayed, filled and missing teeth, morphological figures and measurements of oral function fitted the model composed of additive genetic factor and unique environmental factor. The model fitting of each measurement suggested that periodontal disease was mainly affected by environmental factors, while morphological figures and oral functions were influenced by both genetic and environmental factors.**

KEYWORDS: **geriatric dentistry, genetics, oral function, periodontal disease(s)/periodontitis, caries, twins**

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Introduction

Twin studies comparing monozygotic (MZ) and dizygotic (DZ) twins are considerably valuable in genetic research. MZ twins share 100% of their genes, while DZ twins share only half of their segregating genes on average. The findings of heritability would help to predict and prevent oral conditions and also to recognise therapeutic limits.

Past twin studies that identified genetic components of caries, tooth size and morphology (1, 2) reported a strong genetic component behind the number of filled teeth and a weaker genetic component affecting gingival bleeding. It was concluded that genetic factors contribute to interindividual differences in oral health among young adults. Periodontal disease was previously assessed in US twins and approximately half of all variances were found to have a genetic component (3, 4). In a large twin cohort in Sweden (10 000 pairs), genetic factors were shown to contribute to 14% of variation in tooth loss among women and 39% among men, while heritability estimates of periodontal disease were 39% and 33% for women and men, respectively (5). Overall, the results suggest a more substantial role for genetics.

The majority of these past studies in the field of dentistry involved young and not older twins. Oral problems such as tooth loss, decreased masticatory

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function are highly prevalent among middle-aged people. Therefore, it would be useful to detect the heritability of middle-aged or older people.

Most previous twin studies involved self-reported questionnaires or telephone interviews, which are notoriously limited and unreliable because they only rely on self-judgment and memories (3). Such self-assessment would underestimate rather than overestimate the present oral condition; possible underestimation of the genetic component as a measurement error is subsumed in the environmental component of factors not correlated between twins. Some data, such as morphology of teeth and dental arches, radiographic findings, oral functions and periodontal pocket depth, cannot be accurately collected by self-reports.

Moreover, not only oral disease but also oral function is important in evaluating oral health comprehensively. Occlusal force, masticatory performance and stimulated salivary flow rate (SSFR) are important objective variances of oral function because these variables are directly connected to mastication. In twin studies, the heritability of oral function has never been discussed, although some researchers have reported a genetic predisposition in patterns or levels of physical function (6).

The aim of the study, therefore, was to determine the relative contributions of genetic and environmental factors to oral structures, diseases and functions in middle-aged and old twins.

Materials and methods

Study population

Japanese middle-aged and old twin pairs from all over Japan participated in this cross-sectional study. We carried out the study at the Osaka University Centre for Twin Research (OUCTR), which was founded in 2009 (7). Its original twin registry was launched before 1980 and has expanded to become one of the largest twin registries in Japan (8–10). Eligibility criteria were same-sex, middle-aged and old twin pairs. Written informed consent was obtained from all twins before the clinical examination for which both twins arrived together. The study was independently approved by the Osaka University ethics committee.

Zygosity of the pairs was confirmed using the 15 short tandem repeat (STR) (11) markers derived from blood, which were previously shown to be accurate and reliable (12). A twin pair completely concordant with these STRs was designated MZ. All other pairs were designated DZ.

Dental status and oral function

The dental status of each subject was examined by one of two trained and calibrated periodontists who was blinded to the twin's zygosity. Dental, periodontal and orthopantomographic examinations were conducted to evaluate the dental status. As a screening test for periodontal status, salivary occult blood tested by Perioscreen* was conducted. Probing depth was assessed in six sites (mesiobuccal, mid-buccal, distobuccal, mesiolingual, mid-lingual and distolingual), and the maximum pocket depth of all over sites and teeth was recorded. The bone resorption score was measured using the Schei's ruler technique, in which the percentage of bone loss at the deepest interproximal site of each tooth was measured on an orthopantomograph (13). The total proportion of decayed, filled and missing teeth (DMF) of all teeth (usually 28 teeth except in subjects who had extraction prior to orthodontic treatment or still had wisdom teeth) was used to assess the prevalence of dental caries.

The oral function of each subject was also examined by one of two trained and calibrated prosthodontists. Occlusal force, masticatory performance and SSFR were used to determine the oral function. Occlusal force was measured from a pressure-sensitive sheet (Dental Prescale, 50H-R†). Participants were asked to clench their teeth as hard as possible in the intercuspal position while the pressure-sensitive sheet was placed between their upper and lower dental arches (14). To evaluate masticatory performance, participants were instructed to chew a piece of gummy jelly,‡ a standardised testing food, using 30 chewing strokes on their preferred chewing side and to expectorate the comminuted particles. Masticatory performance was scored by comparing images of visual samples of these particles (15). SSFR was

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‡UHA Mikakuto Co., Osaka, Japan.

collected by the mastication method (16) in which a measured amount of paraffin wax[§] was chewed for 2 min. The distance between the left and right buccal cusps of the first pre-molars for upper and lower plaster models was measured to determine the width of the dental arch.

There were no missing data except for morphologic ones. Alveolar width could not be evaluated in the absence of first pre-molar teeth. In total, 63 individuals had missing units in the upper jaw, while 73 had missing data in the lower jaw. We used the full information maximum likelihood method to handle missing data.

Statistical analysis

In the classical twin study, it is assumed that MZ share 100% of their genes while DZ share 50% of their segregating genes. Based on this assumption, the following three analyses were conducted.

As the first necessary step, we compared means and population variances (the sum of between-pair and within-pair variances) between MZ and DZ twins for each clinical measurement (3). If these values differ between twin groups, estimates of heritability would be biased.

Next, we calculated the similarity of MZ and DZ twins. The value of the intra-class correlation (ICC) could vary from 0 (indicating that the statistical variation within twin pairs was equal to the variation between pairs) to 1 (indicating that all variation is among different twin pairs and there is no variation within pairs).

Finally, we used the quantitative genetic method based on structural equation modelling (17) to estimate genetic and environmental variances and heritability. The comparison between MZ and DZ provides information about genetic and environmental effects on each measurement. Quantitative genetic modelling with the statistical programme Mx (18) permits the estimation of variance components following a comparison of different models (2). For the formal estimation of variance components, we divided phenotypic variance into four latent components: additive genetic effects (*A*), dominant genetic factor (*D*), common environmental effects (*C*) and unique environmental effects (*E*). '*A*' represents all the polygenes whose effects are small and additive to forming a quantitative phenotype. '*D*' denotes the effects of alleles at a locus that do not simply add up to represent genotypic values. '*C*' is the element shared with family members. '*E*' is different from family members even if they live together. The relation between these latent variables and observed variables is depicted in a path diagram as the full model (Fig. 1). This analysis estimates model parameters using maximum likelihood techniques. The goal of this model is to divide the observed variance in phenotype into these four sources. The fits of reduced models were compared with the full model by inspecting changes in χ^2 values relative to differences in the degrees of freedom between models (19). Akaike information criterion [AIC = χ^2 – 2(df)] scores were calculated to provide an additional means of comparing models based on fit and simplicity. Models with the lowest AIC values are generally considered to be the most parsimonious. As the first step, the fully saturated model was compared with the full ACE and ADE model using these variables. If the means and variances are not equal within twins and also between MZ and DZ subjects, the model does not fit. The significance of the genetic variance was tested by inspecting 95% confidence intervals of the A parameter in the full ACE or ADE model, or by examining differences between the AE and E models, adjusted for age and sex using a regression technique.

Results

In this analysis, 132 twin pairs were included. Of these, 116 twin pairs were classified as MZ and 16 as

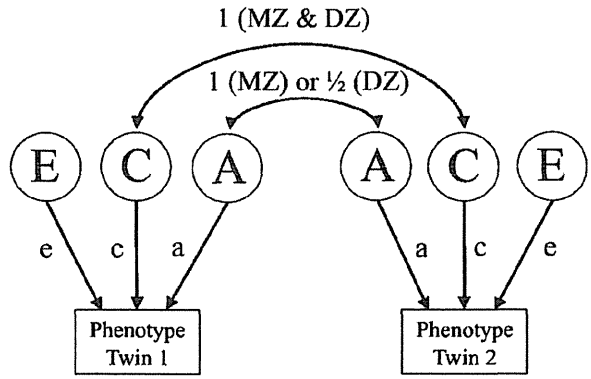

Fig. 1. The path diagram for the basic univariate twin analysis.

[§]Orion Diagnostica, Espoo, Finland.

DZ. The MZ twin pairs consisted of 43 male and 73 female twin pairs, while the DZ twin pairs consisted of eight male and eight female twin pairs. The mean age of all subjects was 66·1 ± 10·3 (SD) years. Salient characteristics of the twins are summarised in Table 1. There was no significant difference between MZ and DZ twins in any clinical parameter. The population variances also did not differ ($P > 0·2$) between the groups for any measure, validating an important assumption of the twin model.

Age- and sex-adjusted ICCs are indicated in Table 2. Although the ICC of three items, occult blood testing of DZ twins and maximum probing depth of MZ and DZ twins were not significant, the remaining 17 items were significant. The ICC with six variables out of ten variables was greater for MZ twins than DZ twins. To further explore heritability, formal genetic modelling was carried out for each variable to determine the best-fitting model (Tables 3 and 4). The best-fit models for the total number of remaining teeth (*C*: 65%, *E*: 35%), occult blood test (*C*: 32%, *E*: 68%) and alveolar bone resorption (*C*: 63%, *E*: 37%) were all CE models. And maximum probing depth was E model. The best-fit model for DMF (*A*: 52%, *E*: 48%) was the AE model.

The best-fit models for occlusal force (*A*: 45%, *E*: 55%) and masticatory performance (*A*: 63%, *E*: 37%) were both AE models. These variables represented masticatory function. SSFR as the variable of oral function (*A*: 51%, *E*: 49%) also fitted in the AE model. The best-fit models for the width of upper dental arch (*A*: 28%, *E*: 72%) and lower dental arch (*A*: 29%, *E*: 71%) were both AE models.

Discussion

The present study indicated the heritability of oral health in the later stages of life. Periodontal disease and number of teeth are influenced by environmental factors. In contrast, morphological figures, dental

Table 1. Clinical and behavioural characteristics of monozygotic (MZ) and dizygotic (DZ) twins

	MZ (n = 232*)			DZ (n = 32*)			
	Mean (SD)	Minimum Maximum	Median	Mean (SD)	Minimum Maximum	Median	*P*-value
Age (years)	65·6 (10·3)	50 88	65	69·8 (14·0)	51 84	69	0·87
Total number of remaining teeth†	21·9 (8·6)	0 32	25	20·9 (9·7)	0 31	25·5	0·77
Occult blood test (0, 1, 2)	0·93 (0·92)	0 2	1	1·22 (0·87)	0 2	1·5	0·73
Maximum probing depth (mm)	5·9 (2·1)	3 12	6·0	6·2 (2·0)	3 12	6·2	0·82
Score of bone resorption	1·9 (0·94)	1 4	1·5	2·0 (1·04)	1 4	1·6	0·82
Percentage of decayed, filled and missing teeth (%)	67·1 (24·6)	3 100	70·9	72·4 (24·9)	20 100	76·8	0·98
Occlusal force (N)	466 (276)	24 1350	423	577 (301)	63 1264	473	0·84
Masticatory performance (mm^2)	3541 (950)	425 5912	3710	3253 (1310)	431 6820	3130	0·54
Stimulated salivary flow rate (ml min^{-1})	1·5 (0·9)	0·1 11·4	1·3	1·3 (0·9)	0·3 (5·3)	1·2	0·99
Width of upper dental arch (mm)	42·9 (3·7)	24 55	43	43·5 (4·1)	36 51	44	0·81
Width of lower dental arch (mm)	35·1 (4·5)	20 42	35	36·7 (2·9)	31 41	36·8	0·45

P-value was calculated by *F* test to compare MZ and DZ observed variables.
*Number of twin individuals.
†Include third molars.

Table 2. Twin intra-class correlation for age- and sex-adjusted clinical measures

	Intra-class correlation (CI)	
	Monozygotic	Dizygotic
Total number of remaining teeth	0·64 (0·52, 0·73)	0·77 (0·46, 0·91)
Occult blood test	0·31 (0·16, 0·45)	0·12 (−0·28, 0·48)
Maximum probing depth	0·10 (−0·12, 0·30)	0·11 (−0·49, 0·65)
Score of bone resorption	0·63 (0·48, 0·74)	0·68 (0·28, 0·88)
Percentage of decayed filled and missing teeth	0·52 (0·38, 0·66)	0·48 (0·34, 0·62)
Occlusal force	0·45 (0·29, 0·59)	0·23 (0·15, 0·30)
Masticatory performance	0·54 (0·38, 0·67)	0·27 (0·20, 0·34)
Stimulated salivary flow rate	0·49 (0·33, 0·62)	0·24 (0·17, 0·31)
Width of upper dental arch	0·28 (0·02, 0·50)	0·14 (0·02, 0·26)
Width of lower dental arch	0·24 (0·02, 0·44)	0·12 (0·01, 0·23)

CI, 95% Confidence Interval.

caries and oral function are affected by both genetic and environmental factors.

Contrary to previous studies (2, 3, 5), our data suggested that genetic factors did not significantly contribute to the number of teeth and periodontal status in older persons. A possible reason for this could be that our participants were relatively older than the subjects of other investigations and were more affected by environmental factors. Furthermore, previous studies primarily considered major oral diseases to be behavioural diseases (20), in which individuals are able to control the extent or onset of disease by adopting a healthy lifestyle including a good diet, oral self-care (21) and regular dental check-ups (22). Age and smoking are also established as important environmental factors affecting periodontal disease (4, 8).

By contrast, we observed that shared environmental factors, which represent familial experiences and habits common within twin pairs, played a significant role in periodontal status and the number of teeth. They accounted for around two-thirds of variability in the number of teeth in middle-aged and old persons. Future studies should identify the shared environmental factors that influence the presence of oral diseases among MZ discordant twins.

The genetic factor was shown to contribute to the presence of dental caries, morphological figures and masticatory functions. The fact that dental caries and not periodontal disease have a genetic contribution may be reflected in the earlier onset of the former. After all, dental caries may be more susceptible to the effect of inheritable immunity function from the bacteria than periodontal disease. Conversely, periodontal disease would be more affected by environmental factors such as oral hygiene practices, smoking, alcohol intake and dietary patterns than dental caries. Morphological figures, which are parts of the skeletal framework of the human body appear to be influenced by genetic factors, similar to the height and weight of an individual (23), while this is also likely for oral function. A possible reason for this is that they are influenced more by anatomical and physiological conditions than pathological changes.

The present study had the following strengths. First, the participants were middle-aged and old twins who were older than those in most twin studies that focused on a younger generation before the onset of severe periodontitis, tooth loss, dry mouth and masticatory disorders. Generally, the oral condition would have changed, and the individual difference would also have begun to widen from middle age.

Second, our data included oral functions objectively measured by highly trained dental professionals. Previous comparisons between self-perceived oral health and clinical findings have shown various degrees of usefulness in determining the number of teeth and the presence of removable prostheses; however, they are less useful in identifying dental caries and periodontal disease (24–26). Additionally, objective oral functions, dental morphology and radiographic findings cannot be measured by self-assessment. The high prevalence of caries and periodontal diseases in old persons reduces the probability of accurate self-assessment, mostly resulting in underestimation. In our study, experienced prosthodontists and periodontists examined the oral status of the participants in person, so our records were highly reliable. However, a major limitation of our study was the sample size, which may affect the generalisability of the findings.

In conclusion, structural equation modelling of middle-aged and old twin pairs suggested that genetic