

Maximum bite force at age 70 years predicts all-cause mortality during the following 13 years in Japanese men

M. IWASAKI^{*†}, A. YOSHIHARA[‡], N. SATO[§], M. SATO^{*}, G. W. TAYLOR[¶], T. ANSAI[†], T. ONO[§] & H. MIYAZAKI^{*}
**Division of Preventive Dentistry, Department of Oral Health Science, Niigata University Graduate School of Medical and Dental Sciences, Niigata, †Division of Community Oral Health Development, Kyushu Dental University, Kitakyushu, ‡Division of Oral Science for Health Promotion, Department of Oral Health and Welfare, Niigata University Graduate School of Medical and Dental Sciences, Niigata, §Division of Comprehensive Prosthodontics, Niigata University Graduate School of Medical and Dental Sciences, Niigata, Japan and ¶Department of Preventive and Restorative Dental Sciences, University of California San Francisco, San Francisco, CA, USA*

SUMMARY There is limited information on the impact of oral function on mortality among older adults. The aim of this prospective cohort study was to examine whether an objective measure of oral function, maximum bite force (MBF), is associated with mortality in older adults during a 13-year follow-up period. Five hundred and fifty-nine community-dwelling Japanese (282 men and 277 women) aged 70 years at baseline were included in the study. Medical and dental examinations and a questionnaire survey were conducted at baseline. Maximum bite force was measured using an electronic recording device (Occlusal Force-Meter GM10). Follow-up investigation to ascertain vital status was conducted 13 years after baseline examinations. Survival rates among MBF tertiles were compared using Cox proportional hazards regression models stratified by sex. There were a total of 111 deaths (82 events for men and 29 for women). Univariable

analysis revealed that male participants in the lower MBF tertile had increased risk of all-cause mortality [hazard ratio (HR) = 1.94, 95% confidence interval (CI) = 1.13–3.34] compared with those in the upper MBF tertile. This association remained significant after adjustment for confounders (adjusted HR = 1.84, 95% CI = 1.07–3.19). Conversely, no association between MBF and all-cause mortality was observed in female participants. Maximum bite force was independently associated with all-cause mortality in older Japanese male adults. These data provide additional evidence for the association between oral function and geriatric health.

KEYWORDS: mortality, epidemiology, cohort studies, elderly, muscle strength, oral health

Accepted for publication 19 March 2016

Introduction

Maximum bite force (MBF), which is defined as a functional force occurring during maximal clenching, reflects the biomechanical properties of the masticatory system (1). Maximum bite force is an objective measure of oral function and is demonstrated to be a key determinant of masticatory performance along with the number of occluding pairs of teeth (2, 3).

Recent studies have suggested that poor oral health and function are associated with morbidity and mortality among older adults (4, 5). Nutrition has been suspected as one possible pathway linking oral health and systemic health (6). Individuals with poor oral health have lower intake of energy, protein, vitamins, minerals and dietary fibre (7). Deficiencies of these important nutrients are associated with adverse outcomes such as increased susceptibility to a variety of

pathogens, risks of vascular disease, cancer and frailty (8, 9). These consequences may ultimately lead to increased mortality. The above potential mechanism is supported by previous observational studies showing that self-reported poor masticatory ability was associated with mortality (10, 11). However, it should be noted that masticatory ability based on survey forms or interviews lacks objectivity and reliability (12).

Another epidemiological study demonstrated that MBF was associated with physical performance including handgrip and lower limb force, mobility, and functional balance in older adults (13). Low physical performance can lead to disability and death (14).

Overall, MBF reflects individuals' masticatory performance and physical function to a certain extent. Low MBF may be a sign of frailty. However, the impact of MBF on mortality among older adults has not yet been fully investigated. This prospective cohort study was therefore planned with the purpose of evaluating the potential association of MBF with mortality in older adults. We hypothesised that persons with low MBF would be associated with risk of mortality.

Methods

Study population and ascertainment of vital status

The current analyses are based on Niigata Study participants. The Niigata Study is a community-based study initiated in 1998 to evaluate relationships between systemic health and oral health. In April 1998, all 4542 citizens of Niigata, Japan (2099 men and 2443 women), who were born in 1927 (70 years old) were sent a written request to participate in the survey. Consequently, 81.4% ($n = 3695$) responded positively to participate in the survey. Considering the availability of resources, 600 residents from the 3695 responders were selected by random sampling, after stratification for sex. In June 1998, these individuals underwent dental and medical examinations and completed survey forms. All study participants gave informed consent to being included in the study.

In June 2011, follow-up investigations to ascertain vital status of all Niigata Study participants were conducted. Vital status was determined using forms completed by each participant. In cases of non-response,

confirmation of life or death was obtained by home visits or telephone interviews. Information on the death date was abstracted from death certificates.

This study was conducted in accordance with the guidelines laid down in the Declaration of Helsinki and was approved by the Ethics Committee of the Faculty of Dentistry, Niigata University.

Dental examination

The dental examination included the determination of number of retained teeth and the use of dentures, and the assessment of periodontal health parameters including clinical attachment level, probing pocket depth and bleeding on probing (BOP). All erupted permanent teeth except for remaining roots were counted as retained teeth. No study participants had dental implants. Periodontal health parameters were measured at six sites on every tooth (15). These parameters were recorded by four trained dentists as reported previously (16). Periodontitis status was described according to the Centers for Disease Control and Prevention/American Academy of Periodontology definition (17).

Measurements of MBF were carried out by one trained dentist using an Occlusal Force-Meter GM10* similarly to previous studies (13, 18). Specifically, bite force during maximum voluntary clenching was measured unilaterally on the right and left sides at the first molars. Before the measurements, participants were given detailed instructions. During the measurements, participants were asked to sit in an unsupported natural position, look forward, and use dentures when present. The larger value from the left or right side was taken as the MBF value. Before the MBF measurements, intra-examiner reliability was tested by taking repeated measurements using 10 volunteers at Niigata University Hospital (intraclass correlation coefficient = 0.94).

Medical examinations and questionnaire survey

Fasting blood samples were drawn for the measurement of albumin, total cholesterol and triglyceride. Serum albumin level was measured, because it is a predictive factor for mortality in community-based

*Nagano Keiki, Inc., Tokyo, Japan.

older adults. Inflammation and malnutrition both reduce serum albumin concentration by decreasing its rate of synthesis. Compared with community-dwelling older adults with serum albumin concentrations $\geq 4 \text{ g dL}^{-1}$, the risk of mortality for those with serum albumin $< 4 \text{ g dL}^{-1}$ was reported to be significantly higher (19). Blood pressure (BP) recordings were obtained from the right arm of the participants in a sitting position after 5 min of rest. Measurements of weight and height were conducted to calculate body mass index (BMI). A standardised survey form was completed, covering socioeconomic status, health behaviour and medical history.

Masticatory ability was assessed using food intake survey form including four types of food (French bread, rice cracker, pickled vegetables and peanuts). These four foods were considered to be hard in texture and difficult to chew. Participants with ≤ 2 chewable foods were defined as having low masticatory ability (20). Furthermore, the following 'yes' or 'no' questions were used to obtain subjective oral functions: 'Do you have difficulty chewing?' and 'Do you have difficulty speaking?'

Hypoalbuminaemia was defined as albumin $< 4 \text{ g dL}^{-1}$. Lipid abnormalities were classified as follows: hypercholesterolaemia, total cholesterol $\geq 220 \text{ mg dL}^{-1}$; and hypertriglyceridaemia, triglycerides $\geq 250 \text{ mg dL}^{-1}$. Hypertension was defined as systolic/diastolic BPs of 140/90 mm Hg. Education level was classified into two categories: less than high school or not. Low income was defined as annual household income $< 2\,000\,000 \text{ JPY}$. Activities of daily living (ADL) was assessed using the Tokyo Metropolitan Institute of Gerontology (TMIG) Index of Competence, and decreased ADL was defined as a TMIG index ≤ 12 (equal or less than the median value). Participants who currently exercise ($> 30 \text{ min}$ per session and ≥ 2 times per week) were classified as those doing regular exercise. Smoking status was specified into two categories: current smoker or not. Drinking habit was specified into two categories: drinking ≥ 3 days per week or not.

Statistical analyses

Given the sex differences in MBF (1), all the analyses were stratified by sex. The principal exposure variable included MBF. Male and female participants were categorised separately by MBF tertiles.

Comparisons of baseline characteristics among the three groups were performed using analysis of variance or Kruskal–Wallis test for continuous variables, depending on distribution, and the chi-square test for categorical variables. Periodontal parameters were compared only among dentate participants.

Initial survival analysis was performed using the Kaplan–Meier survival method, and unadjusted survival curves among the three groups identified by MBF tertiles were compared using the log-rank test. Univariable and multivariable Cox proportional hazards regression models were used to identify the independent predictors of mortality. All variables significantly associated in the univariable analysis were subsequently entered into multivariable models where MBF was forced into the models. To test for trends, the tertile categories of MBF were entered into the model as an ordinal variable. Furthermore, a model including the number of teeth as a cofounder was tested. Proportional hazards assumption was verified using Schoenfeld residuals, as described by Therneau and Grambsch (21).

The level of significance was set at $\alpha = 0.05$. All calculations and statistical analyses were performed using the statistical software package STATA (version 14)[†].

Results

Among 600 original Niigata Study participants, 22 individuals with incomplete baseline (1998) information and 19 individuals with unknown vital status at June 2011 (i.e. unable to contact them or their family) were excluded. Therefore, a total of 559 Japanese (282 men and 277 women), who were born in 1927 and had complete data available for all relevant variables, were enrolled in the analyses [total completion rate: 93.2% (559/600); Fig. 1]. Nineteen individuals with unknown vital status did not differ significantly from the individuals analysed with regard to baseline characteristics.

Mean MBF was 261 Newton (N) [standard deviation (s.d.) = 209] in men and 173 N (s.d. = 149) in women. Men had significantly greater MBF than women ($P < 0.001$, Student's *t*-test).

[†]StataCorp., College Station, TX, USA.

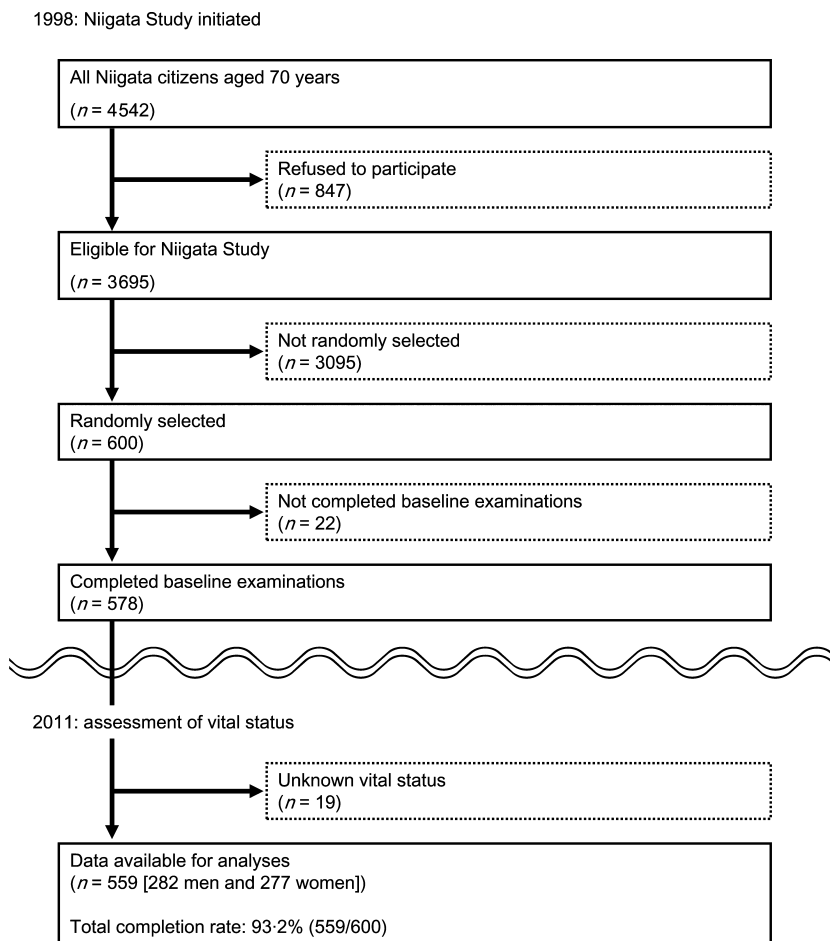


Fig. 1. Study enrolment.

The baseline characteristics of the study population stratified by sex and the lower, middle and upper tertiles of MBF are presented in Tables 1 and 2. Mild periodontitis was rare ($n < 10$) and, therefore, was combined with no periodontitis. For male participants (Table 1), decreased MBF was seen in association with lower number of teeth present, higher percentage of edentulousness and denture use, poorer periodontal health parameters and worse periodontitis severity. In addition, poor masticatory ability based on the number of chewable foods and self-reported difficulty in chewing and speaking were also associated with decreased MBF. For female participants (Table 2), decreased MBF was seen in association with lower number of teeth present, higher percentage of edentulousness and denture use, poorer periodontal health parameters, poor masticatory ability, and self-reported difficulty in chewing and speaking.

During the 13-year follow-up period from June 1998 to June 2011, there were a total of 111 deaths

(19.9%), of which 82 (73.9%) were men and 29 (26.1%) were women.

Figure 2 shows the Kaplan–Meier curves of overall survival rates by MBF tertile categories. For male participants, all-cause mortality was affected by MBF categories ($P = 0.040$).

Table 3 shows crude Cox regression models. Male participants in the lower MBF tertile had a significantly higher risk of all-cause mortality [hazard ratio (HR) = 1.94, 95% confidence interval (CI) = 1.13–3.34] compared with that of male participants in the upper MBF tertile (Table 3). Table 4 shows adjusted Cox regression models. Variables significantly associated in the univariable analysis, including hypoalbuminaemia, diabetes, coronary heart disease and smoking, were included as confounders in the multivariable model (Model 1). The association between MBF and mortality remained significant after adjustment for these confounders (adjusted HR = 1.85, 95% CI = 1.07–3.19). In addi-

Table 1. Baseline characteristics by maximum bite force (MBF) tertiles for 70-year-old men ($n = 282$)

	Total	Lower tertile (MBF ≤ 137 N)	Middle tertile (137 N < MBF ≤ 284 N)	Upper tertile (284 N < MBF)	<i>P</i> *
Number of participants	282	101	88	93	
Number of deaths during 13-year follow-up	82	37	25	20	
Oral health status					
<i>n</i> of teeth, median (IQR)	21 (10–26)	12 (4–18)	19 (10–24)	27 (24–28)	<0.001
Edentulous, <i>n</i> (%)	23 (8.2)	18 (17.8)	4 (4.6)	1 (1.1)	<0.001
Denture use, <i>n</i> (%)	166 (58.9)	86 (85.2)	58 (65.9)	22 (23.7)	<0.001
Average CAL,* median (IQR)	3.2 (2.6–4.1)	3.8 (3.0–4.8)	3.4 (3.0–4.1)	2.6 (2.2–3.2)	<0.001
Average PPD,* median (IQR)	2.0 (1.7–2.4)	2.2 (1.8–2.6)	2.0 (1.7–2.3)	1.9 (1.7–2.2)	<0.001
Percentage of sites having BOP,* median (IQR)	4.0 (1.4–9.3)	4.2 (1.4–10.3)	4.7 (2.0–11.1)	3.0 (1.1–7.1)	0.061
Periodontitis severity,* <i>n</i> (%)					
No/Mild	6 (2.3)	3 (3.7)	0 (0)	3 (3.2)	<0.001
Moderate	133 (51.4)	28 (34.1)	44 (52.4)	61 (65.6)	
Severe	120 (46.3)	51 (62.2)	40 (47.6)	29 (31.2)	
Self-reported oral function, <i>n</i> (%)					
Low masticatory ability	43 (15.3)	28 (27.7)	12 (13.6)	3 (3.2)	<0.001
Difficulty chewing	70 (24.8)	45 (44.6)	19 (21.6)	6 (6.5)	<0.001
Difficulty speaking	40 (14.2)	24 (23.8)	11 (12.5)	5 (5.4)	0.001
Annual household income <2 000 000 JPY, <i>n</i> (%)	27 (9.6)	11 (10.9)	8 (9.1)	8 (8.6)	0.849
Education less than high school, <i>n</i> (%)	113 (40.1)	40 (39.6)	32 (36.4)	41 (44.1)	0.566
Living alone, <i>n</i> (%)	3 (1.1)	2 (2.0)	1 (1.1)	0 (0)	0.404
BMI (kg m ⁻²), mean (s.d.)	22.1 (2.8)	21.8 (2.9)	22.6 (2.8)	22.0 (2.6)	0.082
Hypoalbuminaemia, <i>n</i> (%)	23 (8.2)	9 (8.9)	7 (8.0)	7 (7.5)	0.937
Hypertension, <i>n</i> (%)	125 (44.3)	39 (38.6)	43 (48.9)	43 (46.2)	0.332
Hypercholesterolaemia, <i>n</i> (%)	44 (15.6)	17 (16.8)	14 (15.9)	13 (14.0)	0.857
Hypertriglyceridaemia, <i>n</i> (%)	24 (8.9)	9 (8.9)	7 (8.0)	8 (8.6)	0.972
Self-reported diabetes, <i>n</i> (%)	17 (6.0)	7 (6.9)	5 (5.7)	5 (5.4)	0.890
History of CHD, <i>n</i> (%)	33 (11.7)	9 (8.9)	9 (10.2)	15 (16.1)	0.258
History of stroke, <i>n</i> (%)	14 (5.0)	9 (8.9)	2 (2.3)	3 (3.2)	0.071
Decreased ADL, <i>n</i> (%)	168 (59.6)	59 (58.4)	58 (65.9)	51 (54.8)	0.303
Current smoker, <i>n</i> (%)	94 (33.3)	39 (38.6)	29 (33.0)	26 (28.0)	0.289
Drinking ≥ 3 days per week, <i>n</i> (%)	139 (49.3)	46 (45.5)	45 (51.1)	48 (51.6)	0.601
Doing regular exercise, <i>n</i> (%)	158 (56.3)	52 (51.5)	50 (56.8)	56 (60.2)	0.465

ADL, activities of daily living; BMI, body mass index; BOP, bleeding on probing; CAL, clinical attachment level; CHD, coronary heart disease; IQR, interquartile range; JPY, Japanese yen; *n*, number; *P*, *P* value for the comparison among the three groups; PPD, probing pocket depth.

**n* analysed = 259 (excluding men with no teeth).

tion, lower MBF group showed a trend towards increased mortality (*P* for trend = 0.027). Other significant predictors of all-cause mortality were hypoalbuminaemia (adjusted HR = 2.13, 95% CI = 1.14–3.97) and smoking (adjusted HR = 1.64, 95% CI = 1.05–2.55). Furthermore, MBF remained significantly associated with mortality even after adjusting for the number of teeth (adjusted HR for

lower tertile of MBF = 1.99, 95% CI = 1.05–3.77; Table 4, Model 2). When the analysis was restricted to dentate men ($n = 259$) and severe periodontitis was forced into the model, the association between MBF and all-cause mortality remained significant (Table S1).

Conversely, no association between MBF and all-cause mortality was observed in female participants.

Table 2. Baseline characteristics by maximum bite force (MBF) tertiles for 70-year-old women ($n = 277$)

	Total	Lower tertile (MBF ≤ 78 N)	Middle tertile (78 N < MBF ≤ 196 N)	Upper tertile (196 N < MBF)	
Number of participants	277	97	90	90	
Number of deaths during 13-year follow-up	29	12	10	7	<i>P</i> *
<hr/>					
Oral health status					
<i>n</i> of teeth, median (IQR)	19 (10–25)	10 (4–18)	18 (12–25)	25 (22–28)	<0.001
Edentulous, <i>n</i> (%)	19 (6.9)	12 (12.4)	5 (5.6)	2 (2.2)	0.019
Denture use, <i>n</i> (%)	169 (61.0)	87 (89.7)	56 (62.2)	26 (28.9)	<0.001
Average CAL,* median (IQR)	2.6 (2.1–3.2)	2.9 (2.5–3.3)	2.7 (2.1–3.2)	2.3 (2.0–2.7)	<0.001
Average PPD,* median (IQR)	1.9 (1.5–2.2)	1.9 (1.6–2.3)	1.9 (1.7–2.3)	1.7 (1.5–2.0)	0.016
Percentage of sites having BOP,* median (IQR)	5.3 (1.5–11.1)	7.4 (1.4–12.8)	6.0 (2.3–11.9)	4.0 (1.3–8.4)	0.079
Periodontitis severity,* <i>n</i> (%)					
No/Mild	32 (12.4)	11 (12.9)	7 (8.2)	14 (15.9)	0.228
Moderate	163 (63.2)	54 (63.5)	51 (60.0)	58 (65.9)	
Severe	63 (24.4)	20 (23.5)	27 (31.8)	16 (18.2)	
Self-reported oral function, <i>n</i> (%)					
Low masticatory ability	64 (23.1)	39 (40.2)	20 (22.2)	5 (5.6)	<0.001
Difficulty chewing	83 (30.0)	46 (47.4)	23 (25.6)	14 (15.6)	<0.001
Difficulty speaking	36 (13.0)	20 (20.6)	15 (16.7)	1 (1.1)	<0.001
Annual household income <2 000 000 JPY, <i>n</i> (%)	54 (19.5)	25 (25.8)	14 (15.6)	15 (16.7)	0.151
Education less than high school, <i>n</i> (%)	137 (49.5)	53 (54.6)	46 (51.1)	38 (42.2)	0.220
Living alone, <i>n</i> (%)	47 (17.0)	21 (21.7)	15 (16.7)	11 (12.2)	0.228
BMI (kg m ^{−2}), mean (s.d.)	22.6 (3.1)	22.4 (3.0)	22.8 (3.3)	22.6 (3.0)	0.610
Hypoalbuminaemia, <i>n</i> (%)	17 (6.1)	9 (9.3)	4 (4.4)	4 (4.4)	0.278
Hypertension, <i>n</i> (%)	91 (32.9)	26 (26.8)	30 (33.3)	35 (38.9)	0.212
Hypercholesterolaemia, <i>n</i> (%)	133 (48.0)	43 (44.3)	50 (55.6)	40 (44.4)	0.219
Hypertriglyceridaemia, <i>n</i> (%)	20 (7.2)	8 (8.3)	8 (8.9)	4 (4.4)	0.458
Self-reported diabetes, <i>n</i> (%)	11 (4.0)	5 (5.2)	3 (3.3)	3 (3.3)	0.760
History of CHD, <i>n</i> (%)	11 (4.0)	5 (5.2)	3 (3.3)	3 (3.3)	0.760
History of stroke, <i>n</i> (%)	8 (2.9)	2 (2.1)	3 (3.3)	3 (3.3)	0.834
Decreased ADL, <i>n</i> (%)	157 (56.7)	56 (57.7)	59 (65.6)	42 (46.7)	0.058
Current smoker, <i>n</i> (%)	10 (3.6)	3 (3.1)	5 (5.6)	2 (2.2)	0.460
Drinking ≥3 days per week, <i>n</i> (%)	15 (5.4)	4 (4.1)	6 (6.7)	5 (5.6)	0.743
Doing regular exercise, <i>n</i> (%)	151 (54.5)	58 (59.8)	42 (46.7)	51 (56.7)	0.174

ADL, activities of daily living; BMI, body mass index; BOP, bleeding on probing; CAL, clinical attachment level; CHD, coronary heart disease; IQR, interquartile range; JPY, Japanese yen; *n*, number; *P*, *P* value for the comparison among the three groups; PPD, probing pocket depth.

**n* analysed = 258 (excluding women with no teeth).

Discussion

In the current study, lower MBF at age 70 years was found to be an independent predictor of all-cause mortality during the following 13 years among older Japanese men. This association remained significant even after adjusting for the number of teeth. These

findings indicated that low MBF is not merely the marker of tooth loss but reflects, to a certain extent, general frailty among older Japanese men.

In contrast, there was no statistically significant association between MBF and all-cause mortality among older Japanese women. Lower numbers of deaths were observed in women than in men. It is

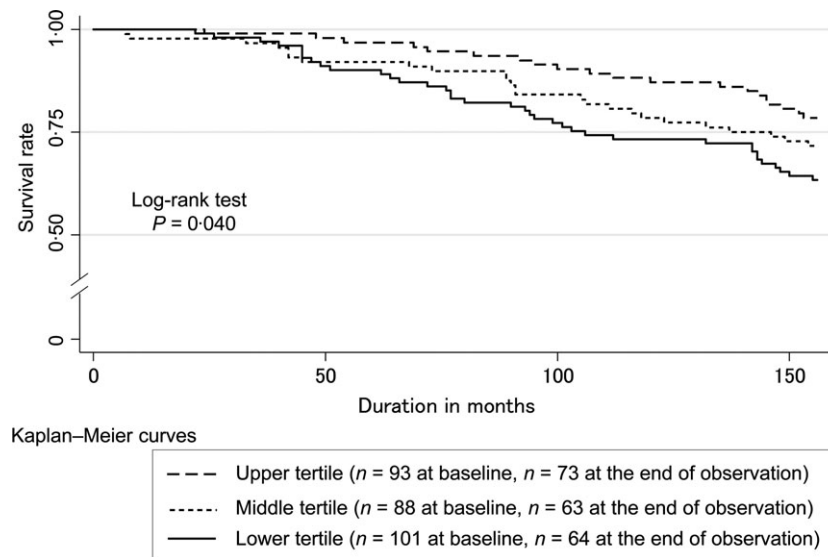


Fig. 2. Thirteen-year all-cause mortality for men by baseline maximum bite force (MBF) tertiles at age 70 years.

Table 3. Unadjusted hazard ratios for 13-year all-cause mortality in men by their baseline characteristics at age 70 years ($n = 282$ at baseline; $n = 82$ deaths during follow-up)*

Predictors	HRs (95% CIs)	<i>P</i>	
MBF			
Upper tertile	Reference	—	<i>P</i> for trend
Middle tertile	1.43 (0.79–2.57)	0.237	= 0.016
Lower tertile	1.94 (1.13–3.34)	0.017	
<i>n</i> of teeth	0.99 (0.96–1.01)	0.200	
Annual household income <2 000 000 JPY	0.88 (0.41–1.91)	0.749	
Education less than high school	0.79 (0.50–1.24)	0.296	
Living alone	1.33 (0.19–9.55)	0.777	
BMI (kg m^{-2})	0.97 (0.89–1.05)	0.424	
Hypoalbuminaemia	2.43 (1.32–4.49)	0.005	
Hypertension	1.11 (0.72–1.71)	0.637	
Hypercholesterolaemia	1.03 (0.57–1.56)	0.929	
Hypertriglyceridaemia	1.45 (0.73–2.90)	0.294	
Self-reported diabetes	2.36 (1.22–4.57)	0.011	
History of CHD	1.83 (1.03–3.25)	0.040	
History of stroke	1.23 (0.50–3.05)	0.648	
Decreased ADL	0.92 (0.59–1.43)	0.715	
Current smoker	1.64 (1.06–2.54)	0.027	
Drinking ≥ 3 days per week	0.84 (0.54–1.29)	0.425	
Doing regular exercise	0.72 (0.46–1.10)	0.129	

ADL, activities of daily living; BMI, body mass index; CHD, coronary heart disease; CI, confidence interval; HR, hazard ratio; JPY, Japanese yen; MBF, maximum bite force; *n*, number.

*Univariable Cox proportional hazards regression analyses.

conceivable that the lack of statistical association between MBF and mortality among women was not due to the fact that there was no biological association, but because the number of deaths among women ($n = 29$) was too small to assess any statistical significance in the analyses.

Several possible explanations exist, for the current association between low MBF and mortality. Firstly, as mentioned above, one postulated pathway involves adverse effects of poor oral function on nutrition that, in turn, impacts systemic health (6). Bite force is demonstrated to be a key determinant of masticatory

Table 4. Adjusted hazard ratios for 13-year all-cause mortality in men by their baseline characteristics at age 70 years ($n = 282$ at baseline; $n = 82$ deaths during follow-up)*

Predictors	Model 1 (controlling for significant variables in univariable analysis)			Model 2 (Model 1 + n of teeth)		
	HRs (95% CIs)	<i>P</i>		HRs (95% CIs)	<i>P</i>	
MBF						
Upper tertile	Reference		<i>P</i> for trend =0.027	Reference		<i>P</i> for trend =0.034
Middle tertile	1.44 (0.80–2.60)	0.228		1.50 (0.81–2.79)	0.199	
Lower tertile	1.85 (1.07–3.19)	0.028		1.99 (1.05–3.77)	0.034	
n of teeth				1.00 (0.98–1.03)	0.655	
Hypoalbuminaemia	2.13 (1.14–3.97)	0.017		2.11 (1.13–3.94)	0.018	
Self-reported diabetes	1.98 (0.98–3.97)	0.055		2.05 (1.00–4.19)	0.049	
History of CHD	1.78 (0.98–3.22)	0.058		1.77 (0.97–3.21)	0.061	
Current smoker	1.64 (1.05–2.55)	0.029		1.66 (1.06–2.58)	0.026	

CHD, coronary heart disease; CI, confidence interval; HR, hazard ratio; MBF, maximum bite force; n , number.

*Multivariable Cox proportional hazards regression analyses.

performance (2). In fact, current study participants with lower MBF were observed to have poor masticatory performance based on the survey responses. Additionally, lower MBF was associated with self-reported difficulty in chewing.

Although nutrition was suspected as one possible pathway, we did not find a significant association between MBF tertiles and hypoalbuminaemia at baseline examinations. The association might become non-significant because of the decreased statistical power as a result of the lower prevalence of hypoalbuminaemia (<10%).

Another explanation can be proposed for the association between MBF and all-cause mortality. It was indicated that decline in masticatory muscles and systemic musculoskeletal function shares common factors (13, 22). Older adults with low MBF were reported to have poor physical performance (13). Recent systematic review has shown that low levels of objectively measured physical function can predict mortality in community-dwelling populations (14). Collectively, decreased MBF correlates with deterioration in systemic musculoskeletal function to some degree, and these unfavourable changes in oral and systemic function may ultimately lead to disability and mortality. Unfortunately, lack of information on systemic musculoskeletal function in the current study did not allow us to perform further investigations. Furthermore, information on the cause of death was not obtained. Future studies investigating associations between MBF and cause-specific mortality and

other health outcomes may help to elucidate the biological mechanism underlying the current study findings.

There are several other limitations to the present study. First, the sample size was not enough to allow us to perform stratified analyses by denture use. A further study with a larger sample size would be necessary to elucidate our findings. Second, our study participants were restricted to Japanese older adults aged 70 years at enrolment. Compared with other industrialised countries such as United States (23), the prevalence of edentulousness was very low. In addition, the percentage of sites having BOP was lower than that of the previous epidemiological study. Therefore, extension of interpreting the findings to other age groups or populations is limited. Third, because other information previously recognised as relevant to mortality, such as oral hygiene (24) and depression (25), was not collected, a number of other potentially important confounders could not be included in the analyses. Residual confounding remains a risk. Fourth, diabetes was self-reported, which may have led to potential misclassification of the participants. Additionally, glycaemic control status, which is associated with adverse outcomes including mortality, was unknown. Finally, data on eating habits were not obtained, and such data could improve the validity of the current findings and should be examined in any future study.

In summary, MBF, an objective measure of oral function, was independently associated with all-cause

mortality in older community-dwelling Japanese men. These data provide additional evidence for the association between oral function and geriatric health.

Acknowledgments

The authors thank all the Niigata Study participants for their time and generosity. This work was supported by Grant-in-Aid from the Ministry of Health, Labour and Welfare of Japan (H10-Iryo-001, H13-Iryo-001 and H16-Iryo-020) and Japan Society for the Promotion of Science (JSPS) KAKENHI (26861827).

Conflict of interest

The authors have stated explicitly that there are no conflict of interests in connection with this article.

References

1. Koc D, Dogan A, Bek B. Bite force and influential factors on bite force measurements: a literature review. *Eur J Dent.* 2010;4:223–232.
2. Hatch JP, Shinkai RS, Sakai S, Rugh JD, Paunovich ED. Determinants of masticatory performance in dentate adults. *Arch Oral Biol.* 2001;46:641–648.
3. Fontijn-Tekamp FA, Slagter AP, Van Der Bilt A, Van THMA, Witter DJ, Kalk W *et al.* Biting and chewing in overdentures, full dentures, and natural dentitions. *J Dent Res.* 2000;79:1519–1524.
4. Aida J, Kondo K, Hirai H, Nakade M, Yamamoto T, Hanibuchi T *et al.* Association between dental status and incident disability in an older Japanese population. *J Am Geriatr Soc.* 2012;60:338–343.
5. Aida J, Kondo K, Yamamoto T, Hirai H, Nakade M, Osaka K *et al.* Oral health and cancer, cardiovascular, and respiratory mortality of Japanese. *J Dent Res.* 2011;90:1129–1135.
6. Ritchie CS, Joshupura K, Hung HC, Douglass CW. Nutrition as a mediator in the relation between oral and systemic disease: associations between specific measures of adult oral health and nutrition outcomes. *Crit Rev Oral Biol Med.* 2002;13:291–300.
7. Iwasaki M, Taylor GW, Manz MC, Yoshihara A, Sato M, Muramatsu K *et al.* Oral health status: relationship to nutrient and food intake among 80-year-old Japanese adults. *Community Dent Oral Epidemiol.* 2014;42:441–450.
8. Knekt P, Ritz J, Pereira MA, O'Reilly EJ, Augustsson K, Fraser GE *et al.* Antioxidant vitamins and coronary heart disease risk: a pooled analysis of 9 cohorts. *Am J Clin Nutr.* 2004;80:1508–1520.
9. Scrimshaw NS, SanGiovanni JP. Synergism of nutrition, infection, and immunity: an overview. *Am J Clin Nutr.* 1997;66:464S–477S.
10. Ansai T, Takata Y, Soh I, Akifusa S, Sogame A, Shimada N *et al.* Relationship between chewing ability and 4-year mortality in a cohort of 80-year-old Japanese people. *Oral Dis.* 2007;13:214–219.
11. Nakanishi N, Fukuda H, Takatorige T, Tatara K. Relationship between self-assessed masticatory disability and 9-year mortality in a cohort of community-residing elderly people. *J Am Geriatr Soc.* 2005;53:54–58.
12. Boretti G, Bickel M, Geering AH. A review of masticatory ability and efficiency. *J Prosthet Dent.* 1995;74:400–403.
13. Iinuma T, Arai Y, Fukumoto M, Takayama M, Abe Y, Asakura K *et al.* Maximum occlusal force and physical performance in the oldest old: the Tokyo oldest old survey on total health. *J Am Geriatr Soc.* 2012;60:68–76.
14. Cooper R, Kuh D, Hardy R. Objectively measured physical capability levels and mortality: systematic review and meta-analysis. *BMJ.* 2010;341:c4467.
15. Moss KL, Mauriello S, Ruvo AT, Offenbacher S, White RP Jr, Beck JD. Reliability of third molar probing measures and the systemic impact of third molar periodontal pathology. *J Oral Maxillofac Surg.* 2006;64:652–658.
16. Hiroto T, Yoshihara A, Yano M, Ando Y, Miyazaki H. Longitudinal study on periodontal conditions in healthy elderly people in Japan. *Community Dent Oral Epidemiol.* 2002;30:409–417.
17. Eke PI, Page RC, Wei L, Thornton-Evans G, Genco RJ. Update of the case definitions for population-based surveillance of periodontitis. *J Periodontol.* 2012;83:1449–1454.
18. Varga S, Spalj S, Lapter Varga M, Anic Milosevic S, Mestrovic S, Slaj M. Maximum voluntary molar bite force in subjects with normal occlusion. *Eur J Orthod.* 2011;33:427–433.
19. Sahyoun NR, Jacques PF, Dallal G, Russell RM. Use of albumin as a predictor of mortality in community dwelling and institutionalized elderly populations. *J Clin Epidemiol.* 1996;49:981–988.
20. Mochizuki Y, Omura K, Harada H, Marukawa E, Shimamoto H, Tomioka H. Functional outcomes and patient satisfaction after vascularized osteocutaneous scapula flap reconstruction of the mandible in patients with benign or cancerous tumours. *Int J Oral Maxillofac Surg.* 2014;43:1330–1338.
21. Therneau T, Grambsch P. Modeling survival data: extending the cox model. New York (NY): Springer; 2000.
22. Raadsheer MC, Van Eijden TM, Van Ginkel FC, Prahl-Andersen B. Human jaw muscle strength and size in relation to limb muscle strength and size. *Eur J Oral Sci.* 2004;112:398–405.
23. Eke PI, Dye BA, Wei L, Slade GD, Thornton-Evans GO, Borgnakke WS *et al.* Update on prevalence of periodontitis in adults in the United States: NHANES 2009 to 2012. *J Periodontol.* 2015;86:611–622.
24. Terpenning M. Geriatric oral health and pneumonia risk. *Clin Infect Dis.* 2005;40:1807–1810.
25. Schulz R, Drayer RA, Rollman BL. Depression as a risk factor for non-suicide mortality in the elderly. *Biol Psychiatry.* 2002;52:205–225.

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

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Adjusted hazard ratios for 13-year all-cause mortality in dentate men by their baseline characteristics at age 70 years ($n = 259$ at baseline; $n = 75$ deaths during follow-up)*.