OUKA
The University of Osaka
Institutional Knowledge Archive

Title	Regular Smoking Accelerates the Decline in Masticatory Performance in Japanese Men: The Suita Study
Author(s)	Kosaka, Takayuki; Ono, Takahiro; Fushida, Shuri et al.
Citation	Journal of Oral Rehabilitation. 2025
Version Type	VoR
URL	https://hdl.handle.net/11094/100549
rights	This article is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License.
Note	

The University of Osaka Institutional Knowledge Archive : OUKA

https://ir.library.osaka-u.ac.jp/

The University of Osaka

Check for updates

Journal of Oral Rehabilitation

WILEY

JOURNAL OF ORAL REHABILITATION

ORIGINAL ARTICLE OPEN ACCESS

Regular Smoking Accelerates the Decline in Masticatory Performance in Japanese Men: The Suita Study

Takayuki Kosaka[1] | Takahiro Ono[2] | Shuri Fushida[1] | Momoyo Kida[1] | Takashi Nokubi[3] | Yoshihiro Kokubo[4] | Makoto Watanabe[4] | Yoshihiro Miyamoto[5] | Kazunori Ikebe[1]

[1]Department of Removable Prosthodontics and Gerodontology, Osaka University Graduate School of Dentistry, Suita, Japan | [2]Department of Geriatric Dentistry, Osaka Dental University, Osaka, Japan | [3]Osaka University, Suita, Japan | [4]Department of Preventive Cardiology, National Cerebral and Cardiovascular Center, Suita, Japan | [5]Open Innovation Center, National Cerebral and Cardiovascular Center, Suita, Japan

Correspondence: Takayuki Kosaka (kosaka.takayuki.dent@osaka-u.ac.jp)

Received: 12 December 2023 | **Revised:** 17 December 2024 | **Accepted:** 7 January 2025

Funding: This study was supported by grants-in-aid from the Ministry of Education, Science, and Culture of Japan (grant nos. 20390489, 23390441, 26293411, 20H03877, 22K10054, and 23H03091) and the Intramural Research Fund of the National Cerebral and Cardiovascular Centre (grant nos. 22-4-5, 27-4-3, 23-B-9).

Keywords: geriatric dentistry | longitudinal study | mastication | masticatory performance | maximum bite force | smoking habit

ABSTRACT

Background: Smoking is presumed to cause a decline in masticatory performance by worsening the intraoral environment in various ways. However, no longitudinal study has examined the relationship between smoking and masticatory performance.

Objectives: To clarify how smoking affects future decline in masticatory performance through a 5-year follow-up study of a general urban population.

Methods: The study participants were 494 men (mean age at baseline: 65.8 years) who participated in baseline and follow-up dental examinations in the Suita Study. The masticatory performance of the participants was evaluated using a test gummy jelly. The rate of change in masticatory performance during the follow-up period was calculated by subtracting the masticatory performance at baseline from the masticatory performance at follow-up and dividing this by the masticatory performance at baseline. Logistic regression analysis was performed, with the presence or absence of a decline in masticatory performance as the objective variable and age at baseline, number of functional teeth, periodontal status, salivary flow rate, maximum bite force, smoking status, utilisation of dental services, and follow-up years as the explanatory variables.

Results: The rate of change in masticatory performance during the follow-up period was significantly higher in smokers than in non-smokers. Logistic regression analysis showed that age, maximum bite force, and smoking were significant explanatory variables for a decline in masticatory performance.

Conclusion: A 5-year follow-up study showed that smoking causes a decline in masticatory performance in men, even after adjusting for confounding factors.

1 | Introduction

A decline in masticatory performance in old age negatively affects nutritional intake [1] and causes deterioration of general health [2]. The decline in masticatory performance is reported ultimately to significantly worsen quality of life [3, 4] and activities of daily living [4]. Maintaining masticatory performance is therefore an important issue for protecting overall health. To prevent a decline in masticatory performance, the factors related to masticatory performance must be clarified. To date, various factors related to masticatory performance, including the number of teeth [5, 6], occlusal support [6, 7], bite

This is an open access article under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs License, which permits use and distribution in any medium, provided the original work is properly cited, the use is non-commercial and no modifications or adaptations are made.

© 2025 The Author(s). *Journal of Oral Rehabilitation* published by John Wiley & Sons Ltd.

force [6], periodontal status [8, 9], and salivary flow rate [6], have been reported; any decrease or worsening in them causes a decline in masticatory performance. However, mastication is a complex function that involves the coordination of perioral tissues, including the tongue and cheeks, in addition to the teeth. Therefore, the mechanisms underlying the decline in masticatory performance vary greatly. Many factors related to masticatory performance remain to be elucidated, and evidence is lacking.

In addition to the abovementioned factors, lifestyle habits such as utilisation of dental services have also been reported to be related to a decline in masticatory performance [10]. Smoking is another likely lifestyle habit related to masticatory performance. Worsening of periodontal status [11] and reduced salivary secretion [12] have been reported as adverse effects of smoking on the oral cavity, which suggests that smoking has an effect on masticatory performance decline. Although previous studies [13] investigated the relationship between smoking and masticatory ability, they focused on subjective masticatory ability using questionnaires. To properly evaluate the functional state of mastication, it is important to objectively measure masticatory performance using samples, in addition to subjective evaluation using questionnaires. However, no studies to date have examined the relationship between masticatory ability and smoking. The glucose elution method using test gummy jelly is a method of objectively and quantitatively evaluating masticatory ability and is confirmed to be highly accurate and reproducible when the measurement method is strictly controlled [14].

In the present study, the masticatory performance of a general urban population was objectively evaluated using test gummy jelly, and a follow-up study was conducted over a 5-year period. The aim of this study was to clarify how smoking affects future decline in masticatory performance.

2 | Materials and Methods

2.1 | Study Participants

Included in the present study were 798 men (mean age at baseline: 65.8 ± 7.8 years, mean follow-up period: 5.1 ± 1.1 years) who participated in the Suita Study [15], which was a cardiovascular cohort study conducted by the National Cerebral and Cardiovascular Center. These men were residents of Suita City in Osaka Prefecture and underwent dental health check-ups at baseline between June 2008 and June 2013. Of those who participated in the survey at baseline, 304 dropped out, and thus 494 participated in the follow-up survey between June 2013 and July 2018. The inclusion criteria were as follows: (1) men (since there were very few women who smoked); and (2) residents of Suita City, Osaka Prefecture, aged 50–79 years (at baseline). The exclusion criteria were as follows: (1) no target teeth for periodontal tissue examination; (2) individuals with pain during bite and unable to undergo the masticatory performance examination; and (3) individuals with serious diseases (severe infectious diseases, terminal cancer, advanced dementia, etc.).

Prior to the study, approval for the research plan was obtained from the ethics committee of the National Cerebral and Cardiovascular Centre (M25-032-3), and only men who received full written and verbal explanations of the study purpose and methods and consented to participate were included as study participants.

2.2 | Oral Examination

The participants underwent intraoral examinations under sufficiently bright artificial lighting while lying supine on a bed. The number of functional teeth, occlusal support, and periodontal status were examined as the factors related to masticatory performance.

2.2.1 | Number of Functional Teeth

The number of functional teeth was the total number of natural and artificial teeth involved in masticatory function. Bridge pontics and implant-supported fixed prostheses were included; however, third molars with a high frequency of impaction, torsion, and inclination were excluded. Artificial teeth of removable dentures were excluded.

2.2.2 | Periodontal Tissue Examination

Periodontal tissue examinations were performed by five dentists who had performed calibrations in advance. Evaluations were based on the Community Periodontal Index (CPI) [16] using partial examinations. A total of 10 teeth were examined: the left and right first and second mandibular and maxillary molars, the maxillary right central incisor, and the mandibular left central incisor. When examination was not possible because of a missing central incisor, the same tooth on the opposite side was examined. No evaluation was performed if all target teeth were missing. Periodontal status was evaluated by examining six periodontal pockets per tooth using a CPI probe (YDM, Tokyo, Japan) according to the following criteria, and the highest code value was recorded. The CPI codes were as follows: Code 0, no evidence of gingival inflammation; Code 1, bleeding observed after probing; Code 2, tartar deposits (including detection by probing down to a subgingival depth of 4 mm); Code 3, periodontal pocket depths between 4 mm and 6 mm; and Code 4, periodontal pocket depths > 6 mm. Cohen's κ value for the concordance of the periodontal tissue examinations by the five dentists was 0.78. In the present study, the CPI code values obtained were used to categorise the participants into those without periodontal disease (a CPI code of 0 to 2) and those with periodontal disease (a CPI code of 3 or 4) [8].

2.3 | Maximum Bite Force Examination

The maximum bite force was measured by adjusting each subject's head position so that the Frankfurt plane was parallel to the floor, inserting a Dental Prescale 50H type R (GC, Tokyo, Japan) between the upper and lower dentition, asking the participants to gently occlude their teeth, and then biting down with the maximum force for 3 s. The obtained samples were analysed using a dedicated analyser, the Occluzer FPD-709 (GC) [17].

13652842, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/joor.13940 by The University Of Osaka, Wiley Online Library on [18/02/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Maximum bite force was measured twice, and the mean value was used.

2.4 | Masticatory Performance Examination

The participants were first instructed to freely chew a piece of test gummy jelly ($20 \times 20 \times 10\,mm^3$, 5.5 g, UHA Mikakuto Co. Ltd., Osaka, Japan) 30 times without swallowing the jelly. The participants were then asked to spit out all chewed fragments onto a gauze placed on top of a paper cup. Next, the gauze was washed with running water for 30 s to remove as much saliva and glucose as possible adhered to the surface of the collected chewed fragments. Then, only the chewed fragments were placed in a plastic container filled with water (35°C, 15 mL) and stirred for 10 s with a stirrer (Digital Stirrer PC-410D, Corning Incorporated, Corning, NY, USA) at 400 rpm. Immediately after stirring, a small amount of the supernatant was collected on the tip of the tweezers and transferred to the tip of a sensor mounted on an instrument for self-monitoring blood glucose (Glutest Every, Sanwa Kagaku Kenkyusho Co. Ltd., Aichi, Japan). The glucose concentration (mg/dL) displayed by this instrument was recorded after 15 s. The obtained glucose concentration (x) was used to calculate the increase in the surface area of the comminuted jelly (y, unit: mm^2) using a regression formula ($y = 15x - 250$), which was taken as the masticatory performance [18]. For denture users, masticatory performance was measured while wearing dentures.

To evaluate changes in masticatory performance from baseline to follow-up, the difference between the value at follow-up and the value at baseline was taken and divided by the value at baseline to obtain the rate of masticatory performance change [10]. In the present study, the lower quartile for the rate of decline in masticatory performance was classified as the "decreased group" and the rest as the "non-decreased group."

2.5 | Salivary Flow Rate Examination

The participants assumed a sitting position and were instructed to freely chew 3.0 g of tasteless paraffin pellets (Paraffin Pellets, Ivoclar Vivadent, Schaan, Liechtenstein) for 2 min. The participants were instructed not to swallow any saliva produced while chewing, and once they had finished chewing, they were asked to spit out their oral contents into a 50-mL centrifuge tube, which was then weighed on an electric scale. The salivary flow rate during stimulation per unit of time was determined from the weight obtained by subtracting the weight of the centrifuge tube from the total weight. In the present study, the salivary flow rate during stimulation was classified into two groups with a cut-off value of 1.0 mL/min [19].

2.6 | Interview Regarding Utilisation of Dental Services

The participants were asked when they had most recently visited a dentist, and those who responded that they had visited a dentist within the past year were asked whether they regularly visited a dental clinic for periodontal disease and dental checkups. The participants who responded that they underwent regular checkups were defined as having regular checkups, and those who responded that they were not undergoing regular checkups were defined as not having regular checkups [10].

2.7 | Interview Regarding Smoking Habit

The participants were interviewed and asked whether they "smoked," "had quit smoking," or "had never smoked." In the present study, those who responded that they "smoked" were classified as smokers, and the others were classified as non-smokers [20].

All the above examinations were conducted at both baseline and follow-up.

2.8 | Statistical Analysis

Study participants who continued during the follow-up period and those who dropped out were compared using the Mann–Whitney U test and the chi-squared test. The baseline endpoints and the rate of masticatory performance change were compared by smoking status using the Mann–Whitney U test and the chi-squared test. The proportion of participants with decreased masticatory performance was compared between smokers and non-smokers using the chi-squared test. Thereafter, logistic regression analysis was performed to examine the effect of smoking on decline in masticatory performance, with the presence or absence of a decline in masticatory performance as the objective variable and age at baseline, number of functional teeth, periodontal status, salivary flow rate, maximum bite force, smoking status, utilisation of dental services, and follow-up years as explanatory variables.

To detect a minimally meaningful effect on logistic regression, a sample size of about 301 was calculated by G*power for α error of 0.05 and power = 1−β error of 0.80. The level of significance in the present study was set at 5%, and IBM SPSS Statistics 24 (SPSS Japan Inc., IBM Company, Tokyo, Japan) was used for statistical analysis.

3 | Results

Table 1 shows a comparison of basic information between the participants who continued and the participants who dropped out. The participants who dropped out had a significantly higher proportion of people in the older age groups and fewer functional teeth than the participants who continued (both $p < 0.001$). The participants who dropped out showed significantly lower masticatory performance and maximum bite force than the participants who continued (both $p < 0.001$).

Of the study participants, 87 (17.6%) were smokers, and 407 (82.4%) were non-smokers. During the follow-up period, masticatory performance declined in 356 participants (72.1%), and the median rate of masticatory performance change was −21.4%.

13652842, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/joor.13940 by The University Of Osaka, Wiley Online Library on [18/02/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 1 | Comparison of study participants who continued and those who dropped out.

Survey items	Continued	Dropped out	*p*
n	494	304	
Age			
50s	111 (22.5)	40 (13.2)	<0.001
60s	194 (39.3)	96 (31.6)	
70s	189 (38.3)	168 (55.3)	
Number of functional teeth			
20–28	426 (86.2)	221 (72.7)	<0.001
0–19	68 (13.8)	83 (27.3)	
Periodontal disease			
−	218 (44.1)	116 (38.2)	0.119
+	276 (55.9)	188 (61.8)	
Hyposalivation			
−	334 (67.6)	189 (62.2)	0.191
+	160 (32.4)	115 (37.8)	
Maximum bite force	542 (358–757)	456 (255–637)	<0.001
Masticatory performance	4381 (3483–5334)	3995 (2874–5480)	<0.001
Utilisation of dental services			
+	212 (42.9)	133 (43.8)	0.824
−	282 (57.1)	171 (56.2)	

Note: Median (first quartile—third quartile), *n* (%). Continuous variables: Mann–Whitney *U* test. Categorical variables: Chi-squared test. Periodontal disease: −, CPI 0–2; +, CPI 3–4. Hyposalivation: −, ≥1.0 mL/min; +, <1.0 mL/min.

The mean number of functional teeth decreased from 24.7 to 23.8, and the proportion with 20 or more teeth decreased from 86.2% to 82.1%.

Table 2 shows the baseline background characteristics of the study participants. Smokers had a higher proportion in the younger age groups than non-smokers, and the distribution of age groups was significantly different ($p = 0.013$). No difference in the number of functional teeth was found between smokers and non-smokers ($p = 0.877$). Smokers showed lower median maximum bite force and masticatory performance at baseline than non-smokers, but the differences were not significant ($p = 0.438$, $p = 0.641$). Smokers were more likely to have periodontal disease, lower salivary flow rate, and no utilisation of dental services at baseline, but the differences were not significant ($p = 0.296$, $p = 0.142$, and $p = 0.131$, respectively). The rate of change in masticatory performance during the follow-up period was significantly greater in smokers than in non-smokers (smokers: −31.8%, non-smokers: −19.5%, $p = 0.006$).

Table 3 shows the association between smoking status and masticatory performance. The percentage of smokers with decreased masticatory performance was significantly higher than that of non-smokers (smokers: 36.8%, non-smokers: 22.6%, $p = 0.006$).

On logistic regression analysis, age (70s with 50s as the reference, $p = 0.019$, odds ratio [OR] = 2.13, 95% confidence interval [CI] = 1.13–3.99), maximum bite force ($p = 0.002$, OR = 0.87, 95% CI = 0.79–0.95), and smoking ($p = 0.006$, OR = 2.11, 95% CI = 1.24–3.59) were significant explanatory variables for decreased masticatory performance (Table 4).

4 | Discussion

The present study is the first to demonstrate an association between masticatory performance and smoking by following a general urban population and evaluating longitudinal trends in masticatory performance. Smoking was found to have an effect on the decline in masticatory performance even after adjusting for factors that may be related to masticatory performance, such as the number of functional teeth, maximum bite force, and periodontal disease.

The progression of periodontal disease has been the focus of investigations into the effects of smoking on oral health. In a national survey of adults in Australia, Do et al. reported that smokers had a higher incidence of periodontal disease than non-smokers and that periodontal disease was more likely to progress over time [11]. Furthermore, Ramseier et al. examined the risk factors for the onset and progression of periodontitis in a longitudinal study over 40 years and reported that smoking was associated with the development of periodontitis [21]. Many clinicians and researchers now believe it to be an indisputable fact that the progression of periodontal disease leads to tooth loss and decreased masticatory performance. Therefore, it is easy to imagine the mechanism by which the progression of periodontal disease under the influence of smoking leads to tooth loss and, consequently, decreased masticatory performance. In fact, of the participants in the present study, a larger proportion of smokers had periodontal disease than non-smokers, as well as a higher mean number of functional teeth lost during the follow-up period (non-smokers: 0.79 ± 1.72, smokers: 1.53 ± 2.68, $p < 0.001$, Student's *t*-test).

Although the above-mentioned mechanisms of smoking leading to decreased masticatory performance can be inferred, the present study found a significant association between smoking and decreased masticatory performance, even after adjusting for the effects of periodontal disease. These results suggest that factors other than periodontal disease may affect the progression from smoking to decreased masticatory performance. Possible factors other than the progression of periodontal disease that may be effects of smoking on the oral cavity include reduced sensory function in the oral cavity and changes in the properties of saliva. Ikebe et al. conducted a survey of older adults with complete dentures and reported that reduced oral sensory function was related to masticatory performance [22]. Rosa et al. reported that sensory functions such as touch and taste in the lower lip are reduced in smokers [23]. Furthermore, Petrusic et al. investigated differences in salivary properties according to smoking status and reported

13652842, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/joor.13940 by The University Of Osaka, Wiley Online Library on [18/02/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 2 | Characteristics of study participants at baseline by smoking status.

Survey items	All	Smoking status		*p*
		Smokers	Non-smokers	
n	494	87	407	
Age				
50s	111 (22.5)	27 (31.0)	84 (20.6)	0.013
60s	194 (39.3)	38 (43.7)	156 (38.3)	
70s	189 (38.3)	22 (25.3)	167 (41.0)	
Number of functional teeth				
20–28	426 (86.2)	72 (82.8)	354 (87.0)	0.877
0–19	68 (13.8)	15 (17.2)	53 (13.0)	
Periodontal disease				
−	218 (44.1)	34 (39.1)	184 (45.2)	0.296
+	276 (55.9)	53 (60.9)	223 (54.8)	
Hyposalivation				
−	334 (67.6)	53 (60.9)	281 (69.0)	0.142
+	160 (32.4)	34 (39.1)	126 (31.0)	
Maximum bite force	542 (358–757)	539 (341–711)	546 (374–765)	0.438
Masticatory performance	4381 (3483–5334)	4311 (3523–5215)	4397 (3449–5354)	0.641
Utilisation of dental services				
+	212 (42.9)	31 (35.6)	181 (44.5)	0.131
−	282 (57.1)	56 (64.4)	226 (55.5)	

Note: Median (first quartile—third quartile), *n* (%). Continuous variables: Mann–Whitney *U* test. Categorical variables: Chi-squared test. Periodontal disease: −, CPI 0–2; +, CPI 3–4. Hyposalivation: −, ≥1.0 mL/min; +, <1.0 mL/min.

TABLE 3 | Association between smoking status and masticatory performance.

	Smoking status		*p*
	Smokers	Non-smokers	
Masticatory performance			
Decreased	32 (36.8)	92 (22.6)	0.006
Non-decreased	55 (63.2)	315 (77.4)	

Note: n (%), Chi-squared test.

that smokers had thicker saliva, whereas non-smokers mainly had serous saliva [24]. The sensory function of the oral mucosa and salivary properties play an important role in smooth masticatory movements. Previous studies have reported that the sensory functions of the oral cavity affect masticatory performance [25]. Although no previous studies have reported the relationship between salivary properties and masticatory performance, it is easy to imagine that serous saliva is more advantageous than mucous saliva for smooth food bolus formation. These results suggest a mechanism by which smoking alters oral sensory and salivary functions, leading to a decline in masticatory performance.

To date, one epidemiological study has investigated the association between smoking and masticatory ability. Feizi et al. evaluated masticatory ability using a questionnaire and reported that a smaller proportion of non-smokers had decreased masticatory ability than heavy smokers [26]. However, the evaluation of masticatory ability by a questionnaire may be affected by the preferences and personalities of the participants. Therefore, objective and quantitative evaluation is important to properly evaluate masticatory ability. In addition, because the Feizi et al. study was a cross-sectional study, it was not possible to address the causal relationship between smoking and decreased masticatory ability. In the present study, it was possible to show that smoking habits have an effect on future decline in masticatory performance. These aspects suggest that the present study has novelty and academic significance in clarifying the relationship between smoking and masticatory ability, which has not yet been done.

Logistic regression analysis showed that, in addition to smoking, age and maximum bite force were significant explanatory variables for decreased masticatory performance. Changes in oral function associated with ageing include a decline in perioral motor function, such as a decline in the functions of the tongue and lips [27] and reduced strength of the masticatory muscles [28]. These factors, which could not be evaluated in

13652842, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/joor.13940 by The University Of Osaka, Wiley Online Library on [18/02/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

TABLE 4 | Logistic regression analysis for decline in masticatory performance.

Explanatory variables	*n*	OR	95% CI	*p*
Age				
50s	111	Ref		
60s	194	1.04	0.56–1.96	0.892
70s	189	2.13	1.13–3.99	0.019
Number of functional teeth				
20–28	426	Ref		
0–19	68	1.50	0.80–2.82	0.202
Periodontal disease				
−	218	Ref		
+	276	1.08	0.69–1.69	0.740
Hyposalivation				
−	334	Ref		
+	160	1.24	0.78–1.96	0.370
Maximum bite force		0.87	0.79–0.95	0.002
Smoking habits				
−	407	Ref		
+	87	2.11	1.24–3.59	0.006
Utilisation dental services				
+	212	Ref		
−	282	1.25	0.79–1.96	0.341
Follow-up years		0.85	0.70–1.04	0.112

Note: $n = 494$. The objective variable was the lower quartile of the rate of decline in masticatory performance. The explanatory variables were the survey items at baseline. Periodontal disease: −, CPI 0–2; +, CPI 3–4. Hyposalivation: −, ≥ 1.0 mL/min; +, < 1.0 mL/min. The maximum bite force was defined as one unit per 100N.
Abbreviations: OR, odds ratio; CI, confidence interval.

the present study, may have affected the decline in masticatory performance over time. Various studies to date have reported that the maximum bite force is a factor strongly related to masticatory performance [6, 29, 30]. The results of the present study support these previous findings.

Regarding the statistical model, the present study adopted an analytical design in which changes in masticatory performance at follow-up were predicted by survey items at baseline. Therefore, individual changes during the follow-up period, such as dental status, utilisation of dental services, and smoking habits, were not incorporated into the analysis. Although not shown in the results, 160 (32.4%) participants had changes in utilisation of dental services, and 37 (7.5%) participants had changes in smoking habits between baseline and follow-up. In this study, only information at baseline was used to keep the predictors and outcomes consistent; however, changes in these factors during the follow-up period may have affected the change in masticatory performance. Research that takes these aspects into account is considered an important step toward clarifying more complex and detailed causal relationships in future analyses. In addition, from a previous report, factors affecting future masticatory performance can be inferred to differ depending on the remaining teeth and the occlusal support area [30]. To analyse these factors in detail, there is a need to conduct stratified analyses separately for those with low and high numbers of teeth. In the future, it will also be necessary to construct a statistical model that includes consideration of the behavioural changes and environmental factors mentioned above.

In the present study, the analysis was limited to men only because the proportion of smokers among women was very small and a sufficient sample size was not available, making statistical analysis difficult. Some previous studies have concluded that there are no relevant sex differences in masticatory performance [29]. However, in a previous longitudinal study of the Suita Study participants, sex was a significant explanatory variable as a factor related to masticatory performance [30]. Sex differences in masticatory performance are assumed to occur due to differences in lifestyle, habits, and other factors between men and women. It is therefore conceivable that, if a sufficient sample size were obtained and the analysis were limited to women, results different from those in the present study could be obtained. In that case, it would be possible to examine the mechanisms mediating the relationship between smoking and decreased masticatory performance in greater detail.

The significance of the present study is that smoking, a lifestyle-related factor, affects masticatory performance in addition to factors directly related to masticatory performance, such as the number of teeth and occlusal support. As for the effect of smoking on the decline in masticatory performance, it is thought that the act of smoking does not directly reduce masticatory performance, but it ultimately leads to reduced masticatory performance through the various effects on the oral cavity that have been described so far. It is very significant that the present study showed that dental treatment and maintenance can not only maintain the number of teeth and occlusal support, but that improving lifestyle can also prevent the decline in masticatory performance.

The present study had several limitations. First, the smoking questionnaire did not evaluate the amount and duration of smoking. It is possible that the effects on the oral cavity may differ between heavy and light smokers [31], but this could not be considered in the present study. The second limitation is that there are confounding factors that were not investigated in the present study. Factors that may affect smoking and masticatory performance, such as level of education [32, 33] and economic status [34, 35], were not investigated in the present study. In addition, utilisation of dental services and smoking habits prior to baseline or during the follow-up period may also have affected changes in masticatory performance. One cannot rule out the possibility that these factors, which were not investigated in the present study, may have had little effect on the results. Third, there were differences in the characteristics of participants who continued in the study and those who dropped out. Those who dropped out were older, had fewer teeth, and had poorer masticatory function than those who continued. It is possible that

13652842, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/joor.13940 by The University Of Osaka, Wiley Online Library on [18/02/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

participants with more severe masticatory dysfunction were excluded from follow-up, and the results of this study can only be generalised with caution.

5 | Conclusions

A 5-year follow-up study showed that smoking had an effect on the decline in masticatory performance in men, even after adjusting for various confounding factors. The findings of the present study may serve as useful basic data for introducing new measures to prevent the decline in masticatory performance in old age.

Author Contributions

Takayuki Kosaka, Takahiro Ono, and Takashi Nokubi contributed to conception and design. Takayuki Kosaka, Shuri Fushida, Momoyo Kida, Yoshihiro Kokubo, Makoto Watanabe, and Yoshihiro Miyamoto contributed to the acquisition of data. Takayuki Kosaka and Shuri Fushida contributed to the analysis. Takayuki Kosaka, Takahiro Ono, Takashi Nokubi, and Kazunori Ikebe contributed to the interpretation of data. Takayuki Kosaka contributed to draughting the manuscript. Takayuki Kosaka, Takahiro Ono, Yoshihiro Kokubo, Makoto Watanabe, Yoshihiro Miyamoto, and Kazunoti Ikebe contributed to revising the manuscript critically. All the authors gave their final approval and agreed to be accountable for all aspects of the work.

Acknowledgements

The authors would like to thank the Suita Medical Association, the Suita City Health Centre, the Preventive Cardiology and Preventive Healthcare Departments, and all cohort members.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

If there is a request for data disclosure, the authors will leave it to the judgement of the Facility Ethics Committee.

Peer Review

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/joor.13940.

References

1. K. Motokawa, Y. Mikami, M. Shirobe, et al., "Relationship Between Chewing Ability and Nutritional Status in Japanese Older Adults: A Cross-Sectional Study," *International Journal of Environmental Research and Public Health* 18, no. 3 (2021): 1216, https://doi.org/10.3390/ijerph18031216.

2. R. E. Nowjack-Raymer and A. Sheiham, "Association of Edentulism and Diet and Nutrition in US Adults," *Journal of Dental Research* 82 (2003): 123–126, https://doi.org/10.1177/154405910308200209.

3. Y. Takata, T. Ansai, S. Awano, et al., "Chewing Ability and Quality of Life in an 80-Year-Old Population," *Journal of Oral Rehabilitation* 33 (2006): 330–334, https://doi.org/10.1111/j.1365-2842.2005.01567x.

4. Y. Nomura, E. Kakuta, A. Okada, et al., "Impact of the Serum Level of Albumin and Self-Assessed Chewing Ability on Mortality, QOL, and ADLs for Community-Dwelling Older Adults at the Age of 85: A 15 Year Follow Up Study," *Nutrients* 12, no. 11 (2020): 3315, https://doi.org/10.3390/nu12113315.

5. K. Ikebe, K. Matsuda, R. Kagawa, et al., "Association of Masticatory Performance With Age, Gender, Number of Teeth, Occlusal Force and Salivary Flow in Japanese Older Adults: Is Ageing a Risk Factor for Masticatory Dysfunction?," *Archives of Oral Biology* 56, no. 10 (2011): 991–996, https://doi.org/10.1016/j.archoralbio.2011.03.019.

6. T. Kosaka, T. Ono, M. Kida, et al., "A Multifactorial Model of Masticatory Performance: The Suita Study," *Journal of Oral Rehabilitation* 43, no. 5 (2016): 340–347, https://doi.org/10.1111/joor.12371.

7. K. Morita, H. Tsuka, K. Kato, et al., "Factors Related to Masticatory Performance in Healthy Elderly Individuals," *Journal of Prosthodontic Research* 62, no. 4 (2018): 432–435, https://doi.org/10.1016/j.jpor.2018.03.007.

8. T. Kosaka, T. Ono, Y. Yoshimuta, et al., "The Effect of Periodontal Status and Occlusal Support on Masticatory Performance: The Suita Study," *Journal of Clinical Periodontology* 41, no. 5 (2014): 497–503, https://doi.org/10.1111/jcpe.12241.

9. T. Kosaka, T. Ono, M. Kida, et al., "Deterioration of Periodontal Status Affects Declines in Masticatory Performance: The Suita Study," *Journal of Clinical Periodontology* 48, no. 9 (2021): 1208–1215, https://doi.org/10.1111/jcpe.13515.

10. K. Fujii, T. Kosaka, Y. Hasegawa, et al., "Periodical Utilization of Dental Services Is an Effective Breakthrough for Declining Masticatory Performance: The Suita Study," *Odontology* 108, no. 4 (2020): 715–722, https://doi.org/10.1007/s10266-020-00501-3.

11. L. G. Do, G. D. Slade, K. F. Roberts-Thomson, and A. E. Sanders, "Smoking-Attributable Periodontal Disease in the Australian Adult Population," *Journal of Clinical Periodontology* 35, no. 5 (2008): 398–404, https://doi.org/10.1111/j.1600-051X.2008.01223.x.

12. M. Rad, S. Kakoie, F. Niliye Brojeni, and N. Pourdamghan, "Effect of Long-Term Smoking on Whole-Mouth Salivary Flow Rate and Oral Health," *Journal of Dental Research, Dental Clinics, Dental Prospects* 4, no. 4 (2010): 110–114, https://doi.org/10.5681/joddd.2010.028.

13. M. Yoshioka, D. Hinode, M. Yokoyama, A. Fujiwara, Y. Sakaida, and K. Toyoshima, "Relationship Between Subjective Oral Health Status and Lifestyle in Elderly People: A Cross-Sectional Study in Japan," *ISRN Dentistry* 2013 (2013): 687139, https://doi.org/10.1155/2013/687139.

14. K. Ikebe, K. Morii, K. Matsuda, T. Hazeyama, and T. Nokubi, "Reproducibility and Accuracy in Measuring Masticatory Performance Using Test Gummy Jelly," *Prosthodontic Research & Practice* 4, no. 1 (2005): 9–15, https://doi.org/10.2186/prp.4.9.

15. Y. Kokubo, T. Okumura, Y. Yoshimasa, et al., "Impact of Metabolic Syndrome Components on the Incidence of Cardiovascular Disease in a General Urban Japanese Population: The Suita Study," *Hypertension Research* 31, no. 11 (2008): 2027–2035, https://doi.org/10.1291/hypres.31.2027.

16. J. Ainamo, D. Barmes, G. Beagrie, T. Cutress, J. Martin, and J. Sardo-Infirri, "Development of the World Health Organization (WHO) Community Periodontal Index of Treatment Needs (CPITN)," *International Dental Journal* 32, no. 3 (1982): 281–291.

17. O. Hidaoka, M. Iwasaki, M. Saito, and T. Morimoto, "Influence of Clenching Intensity on Bite Force Balance, Occlusal Contact Area, and Average Bite Pressure," *Journal of Dental Research* 78, no. 7 (1999): 1336–1344, https://doi.org/10.1177/00220345990780070801.

18. T. Nokubi, F. Nokubi, Y. Yoshimuta, K. Ikebe, T. Ono, and M. Maeda, "Measuring Masticatory Performance Using a New Device and β-Carotene in Test Gummy Jelly," *Journal of Oral Rehabilitation* 37, no. 11 (2010): 820–826, https://doi.org/10.1111/j.1365-2842.2010.02112.x.

13652842, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/joor.13940 by The University Of Osaka, Wiley Online Library on [18/02/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

19. S. Fushida, T. Kosaka, M. Kida, et al., "A Decrease in the Posterior Occlusal Support Area Accelerated Tooth Loss in the Suita Study," *Journal of Prosthodontic Research* 65, no. 3 (2021): 321–326, https://doi.org/10.2186/jpr.JPR_D_20_00005.

20. S. Fushida, T. Kosaka, M. Nakai, et al., "Lower Masticatory Performance Is a Risk for the Development of the Metabolic Syndrome: The Suita Study," *Frontiers in Cardiovascular Medicine* 8 (2021): 752667, https://doi.org/10.3389/fcvm.2021.752667.

21. C. A. Ramseier, A. Anerud, M. Dulac, et al., "Natural History of Periodontitis: Disease Progression and Tooth Loss Over 40 Years," *Journal of Clinical Periodontology* 44, no. 12 (2017): 1182–1192, https://doi.org/10.1111/jcpe.12782.

22. K. Ikebe, M. Amemiya, K. Morii, et al., "Association Between Oral Sensory Stereognostic Ability and Masticatory Performance in Aged Complete Denture Wearers," *International Journal of Prosthodontics* 20, no. 3 (2007): 245–250.

23. M. B. Rosa, M. D. S. Fernandes, L. R. Bonjardim, M. B. D. Gavião, L. A. Calixto, and P. M. Castelo, "Evaluation of Oral Mechanical and Gustatory Sensitivities and Salivary Cotinine Levels in Adult Smokers," *Acta Odontologica Scandinavica* 78, no. 4 (2020): 256–264, https://doi.org/10.1080/00016357.2019.1694978.

24. N. Petrušić, M. Posavac, I. Sabol, and M. Mravak-Stipetić, "The Effect of Tobacco Smoking on Salivation," *Acta Stomatologica Croatica* 49, no. 4 (2015): 309–315, https://doi.org/10.15644/asc49/4/6.

25. K. Hirano, S. Hirano, and I. Hayakawa, "The Role of Oral Sensorimotor Function in Masticatory Ability," *Journal of Oral Rehabilitation* 31, no. 3 (2004): 199–205, https://doi.org/10.1111/j.1365-2842.2004.01175.x.

26. A. Feizi, A. H. Keshteli, S. Khazaei, and P. Adibi, "A New Insight Into Masticatory Function and Its Determinants: A Latent Class Analysis," *Community Dentistry and Oral Epidemiology* 44, no. 1 (2016): 46–52, https://doi.org/10.1111/cdoe.12189.

27. A. Yamada, M. Kanazawa, Y. Komagamine, and S. Minakuchi, "Association Between Tongue and Lip Functions and Masticatory Performance in Young Dentate Adults," *Journal of Oral Rehabilitation* 42, no. 11 (2015): 833–839, https://doi.org/10.1111/joor.12319.

28. J. P. Newton, R. Yemm, R. W. Abel, and S. Menhinick, "Changes in Human Jaw Muscles With Age and Dental State," *Gerodontology* 10, no. 1 (1993): 16–22, https://doi.org/10.1111/j.1741-2358.1993.tb00074.x.

29. K. Ikebe, K. Matsuda, R. Kagawa, et al., "Masticatory Performance in Older Subjects With Varying Degrees of Tooth Loss," *Journal of Dentistry* 40, no. 1 (2012): 71–76, https://doi.org/10.1016/j.jdent.2011.10.007.

30. T. Kosaka, M. Kida, M. Kikui, et al., "Factors Influencing the Changes in Masticatory Performance: The Suita Study," *JDR Clinical and Translational Research* 3, no. 4 (2018): 405–412, https://doi.org/10.1177/2380084418785863.

31. C. Susin, A. N. Haas, P. M. Valle, R. V. Oppermann, and J. M. Albandar, "Prevalence and Risk Indicators for Chronic Periodontitis in Adolescents and Young Adults in South Brazil," *Journal of Clinical Periodontology* 38, no. 4 (2011): 326–333, https://doi.org/10.1111/j.1600-051X.2011.01699.x.

32. T. Tabuchi and N. Kondo, "Educational Inequalities in Smoking Among Japanese Adults Aged 25-94 Years: Nationally Representative Sex- and Age-Specific Statistics," *Journal of Epidemiology* 27, no. 4 (2017): 186–192, https://doi.org/10.1016/j.je.2016.05.007.

33. T. Ohi, T. Komiyama, Y. Miyoshi, et al., "Maximum Occlusal Force and Incident Functional Disability in Older Adults: The Tsurugaya Project," *JDR Clinical and Translational Research* 3, no. 2 (2018): 195–202, https://doi.org/10.1177/23800844187613.

34. H. Tanaka, J. P. Mackenbach, and Y. Kobayashi, "Widening Socioeconomic Inequalities in Smoking in Japan, 2001–2016," *Journal of Epidemiology* 31, no. 6 (2021): 369–377, https://doi.org/10.2188/jea.JE20200025.

35. N. Nakahori, M. Sekine, M. Yamada, T. Tatsuse, H. Kido, and M. Suzuki, "Socioeconomic Status and Remaining Teeth in Japan: Results From the Toyama Dementia Survey," *BMC Public Health* 19, no. 1 (2019): 691, https://doi.org/10.1186/s12889-019-7068-7.

13652842, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/joor.13940 by The University Of Osaka, Wiley Online Library on [18/02/2025]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License