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# Reduced number of teeth with and without dental prostheses and low frequency of laughter in older adults: Mediation by poor oral function

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## Abstract

**Purpose:** Laughter is expected to have health-protective effects, but the potential link between tooth loss and laughter remains unclear. Therefore, this study aimed to examine the association between tooth loss and a low frequency of laughter among older adults in Japan, to elucidate whether this association could be mitigated by dental prostheses, and to evaluate the magnitude of the association mediated by poor oral function.

**Methods:** We used cross-sectional data from 157,708 functionally independent participants aged ≥65 years (46.3% male) from the Japan Gerontological Evaluation Study. A modified Poisson regression model was applied to examine the association between the number of remaining teeth (≥20/10–19/0–9), dental prostheses use, and infrequent laughter (i.e., laughing never or almost never). Causal mediation analysis was performed to assess whether the association was mediated by difficulties in eating hard foods, choking, or dry mouth.

**Results:** Among the participants, 9,129 reported infrequent laughter. Participants with ≤9 and 10–19 teeth who did not use dental prostheses had a 1.29 and 1.14 times higher likelihood of infrequent laughter than those with ≥20 teeth, respectively. Furthermore, difficulty eating hard foods, choking, and dry mouth mediated 22.8%, 0.4%, and 4.3% of the association between fewer remaining teeth and infrequent laughter, respectively. Meanwhile, we did not find evidence for the differences in infrequent laughter between participants with ≤19 teeth using dental prostheses and those with ≥20 teeth.

**Conclusions:** Tooth loss among individuals without dental prostheses was associated with infrequent laughter, and this association was mediated by poor oral function.

**Keywords:** Laughter, Denture, Oral status, Mediation, Japan

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## 1. Introduction

Laughter is believed to confer health benefits. Previous studies have shown that laughter strengthens the immune system[1], improves cardiovascular function[2], and buffers stress[3]. According to recent large-scale studies, people with a lower daily frequency of laughter have a higher risk of developing functional disabilities[4] or mortality[5], highlighting the importance of preventing a decrease in laughter frequency. People who laugh less frequently are more prevalent in older than in younger populations[6]. Therefore, it is important to identify an effective approach to prevent the decrease in laughter frequency from the perspective of health maintenance in the current aging society.

In daily settings, laughter is more likely to be evoked in conversations than in other situations (e.g., watching television or videos) [7]. According to the previous literature[8], people who lose their teeth are more likely to have difficulties speaking, an essential component of conversations, partially because tooth loss leads to functional restrictions. Hirosaki *et al.* reported that older adults with fewer remaining teeth tended to laugh less frequently[9]. Although tooth loss is irreversible, using dental prostheses, such as dentures, can compensate for oral function after tooth loss and has potential

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preventive effects on health and psychosocial deterioration due to tooth loss[10–14]. However, it is unclear whether dental prosthesis use has similar preventive effects on changes in the frequency of laughter due to tooth loss.

The daily frequency of laughter is influenced by functional factors such as the ability of facial muscles. The neck and head organs, including facial muscles, used in laughter are partially similar to those used in mastication or swallowing[15]; therefore, masticatory and swallowing dysfunction may subsequently make laughing frequently functionally difficult. Considering that a variety of programs have been implemented to improve older adults' oral function[16], if it could be shown that poor oral function is associated with infrequent laughter, it would provide insights into the motivation to promote oral function intervention programs. However, there is a paucity of evidence regarding whether oral function is associated with tooth loss and frequency of laughter.

Our group previously reported that the number of remaining teeth was associated with positive and negative emotions[14,17]. Abbas *et al.* showed that a higher number of teeth is associated with a higher likelihood of happiness[14]. Kusama *et al.* showed that fewer teeth were associated with a higher risk of depression[17]. However, laughter is not only a positive emotional expression, but also has social meaning[18], such as improving social relationships by facilitating communication with others, and the absence of laughter is not a simple reflection of negative emotions. Despite its potential uniqueness, only one study has examined the association between tooth loss and laughter[9], but it did not investigate the effects of dental prosthesis use on the association. Thus, we hypothesized that tooth loss would be associated with an increased likelihood of infrequent laughter and that such a negative association would be mitigated by dental prostheses. This study aimed to investigate the association between the number of remaining teeth and the use of dental prostheses, and the frequency of laughter among older adults in Japan and to evaluate whether this association is mediated by poor oral function.

## 2. Methods

### 2.1. Study population and setting

This study used data from the Japan Gerontological Evaluation Study (JAGES), established in 2010, to investigate the social determinants of health among older adults[19,20]. This study used cross-sectional data from the 2016 wave conducted between October and December 2016. In this wave, self-reported questionnaires were sent to 279,661 older adults, ≥ 65 years old, randomly recruited or completely enumerated from 39 municipalities in Japan. The questionnaire contained questions regarding sociodemographic, physical, and psychological characteristics. Among 196,438 respondents (response rate = 71.1%), 179,991 remained eligible after excluding those who could not be successfully identified or did not provide valid information on sex or age. After restricting the participants to those whose activities of daily living were independent, 157,708 functionally independent participants (men, 72,944; women, 84,764) were included in the analysis (**Fig. 1**).

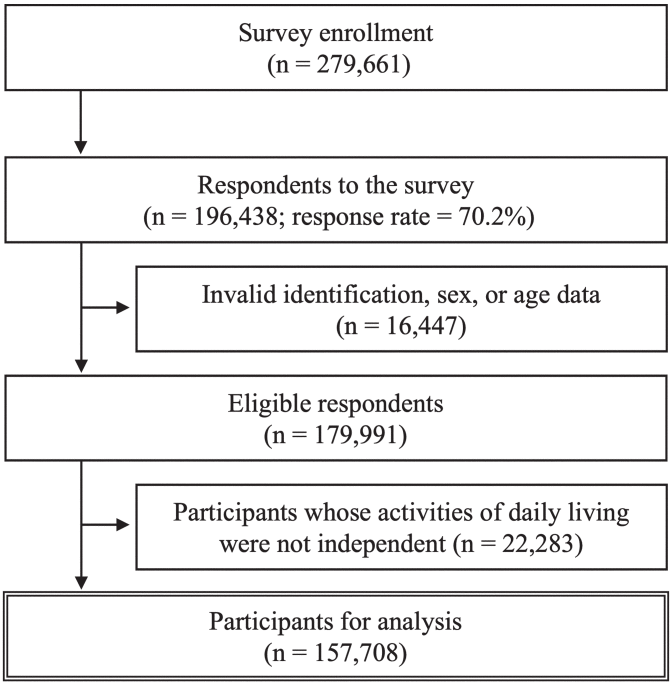


**Fig. 1.** Flow diagram of the study participant selection

### 2.2. Outcome assessment

The outcome of this study was a low frequency of laughter, which was assessed based on the response to the following single-item question: "How often do you laugh out loud?", with possible options of "almost every day," "1 to 5 days per week," "1 to 3 days per month," and "never or almost never." Considering that people who laughed never or almost never have been reported to have a high risk of cardiovascular disease[21] or functional disability[4], those who answered "never or almost never" were defined as having a low frequency of laughter.

### 2.3. Exposure assessment

The exposure in this study was a composite variable that indicated the dental status, defined by combining the following two variables: number of remaining teeth and use of dental prostheses. The number of remaining teeth was determined using the following question: 'How many natural teeth do you currently have?', with possible options of "no natural teeth," "1–4 natural teeth," "5–9 natural teeth," "10–19 natural teeth," and "≥ 20 natural teeth." According to previous validation studies[22,23], the self-reported number of teeth is broadly consistent with the clinically examined number, especially in older populations. Additionally, the use of dental prostheses was assessed using the following question: "Do you wear dentures or bridges (nonremovable dentures) or have dental implants?" with the possible options of "no," "dentures," "dental bridges," and "dental implants." Participants who selected "no" were defined as not using dental prostheses, and those who selected at least one of the other three were defined as using dental prostheses. According to the definitions used in previous studies[24,25], dental status was classified into five categories (≥ 20 teeth, 10–19 teeth using dental prostheses, 10–19 teeth without using dental prostheses, ≤ 9 teeth using dental prostheses, or ≤ 9 teeth without using dental prostheses). According to the methodology of previous mediation analysis studies[17,26,27], in addition to the result of the dental status–low frequency of laughter association analysis that showed that the participants with ≤ 19 teeth not using dental prostheses had a statistically higher

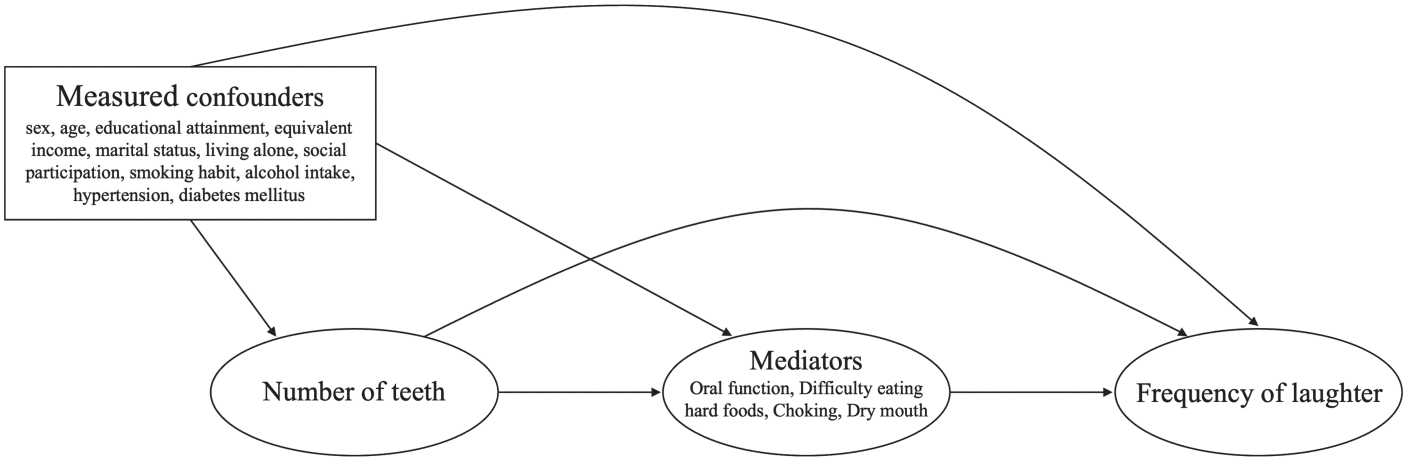


**Fig. 2.** Diagram of the analytical model

prevalence of low frequency of laughter than those with ≥ 20 teeth, a binary variable representing fewer remaining teeth (≥ 20 teeth or ≤ 19 teeth without dental prostheses) was created for causal mediation analysis.

### *2.4. Mediator assessment*

The mediator of this study was poor oral function evaluated using the Kihon Checklist proposed by the Japanese Ministry of Health, Labour, and Welfare[28,29]. Three aspects of poor oral function (difficulty eating hard food, choking, and dry mouth) were evaluated using the questionnaire. Each aspect was determined using the following question: "Do you have any difficulties eating hard foods compared to 6 months ago?"; "Have you choked on your tea or soup recently?"; and "Do you often experience a dry mouth?" Participants who answered "yes" to at least two of the three questions were defined as those with poor oral function[30]. In addition to a model that included poor oral function as a mediator, models that separately included each aspect of oral function as a mediator were constructed to investigate the differences in mediating effects in all three aspects in the analysis.

### *2.5. Other covariates*

In this study, the following potential confounders were controlled: sex (men or women), age (65-69, 70-74, 75-79, 80-84, or ≥ 85 years), hypertension (diagnosed or not diagnosed), diabetes mellitus (diagnosed or not diagnosed), smoking habits (current, former, or never), alcohol intake (current, former, or never), marital status (with or without a spouse), living alone (yes or no), social participation (active or not active), depressive symptoms (depressed or not depressed), educational attainment (≤ 9 years or ≥ 10 years), and equivalent income (< 2.00, 2.00–3.99, or ≥ 4.00; 10,000$, 1 US$ = 100 JPY). Hypertension and diabetes mellitus were assessed using the following question: "Have you ever been diagnosed with hypertension or diabetes mellitus?" Participants who answered "yes" to this questions were considered to have hypertension or diabetes mellitus. Participation in eight social activities was used to define social participation (volunteer groups, sports groups or clubs, leisure activity groups, and senior citizen clubs). Participants who participated in at least one social activity more than once per week were considered socially active. Depressive symptoms were evaluated using the Japanese version of the 15-item Geriatric Depression Scale (GDS-15). Participants were divided into two groups according to their scores: not depressed (0–4 points) and depressed (≥ 5 points)[31]. Equivalent income was calculated by dividing the annual household income by the square root of the number of people living together and was categorized into three groups.

### *2.6. Statistical analysis*

For demographic characteristics, summary statistics were constructed using the frequencies for categorical variables. To calculate the adjusted prevalence ratios (PR) and their 95 percent confidence intervals (95% CI) for the prevalence of low frequency of laughter in relation to dental status, a modified Poisson regression model (i.e., a Poisson regression with sandwich standard errors) was used[32], because the prevalence of low frequency of laughter was common in some categories of dental status. According to previous methodology studies[33,34], the odds ratio (OR) may exaggerate the true risk when the outcome is common; thus, a modified Poisson regression model was used to avoid overestimation of the relative risks. Next, causal mediation analyses were used to decompose the total effect (TE) of fewer remaining teeth on the prevalence of low frequency of laughter into effects through mediators (i.e., natural indirect effect [NIE]) and without mediators (i.e., natural direct effect [NDE])[17,35,36]. A causal diagram of the analytical model is shown in **Figure 2**. Mediators (i.e., poor oral function, difficulty eating hard foods, choking, and dry mouth) were included in the models separately. Logistic regression models were applied to estimate the adjusted OR for TE, NIE, and NDE, and their 95% CI were obtained by bootstrapping with 1,000 replications. To evaluate the extent to which poor oral function mediated the association between fewer remaining teeth and the prevalence of low frequency of laughter, the proportion mediated (PM) on a risk-difference scale was estimated.

Multiple imputations using chained equations were conducted to impute missing data on all variables, and 20 imputed datasets were generated according to recommendations in a previous study[37]. The estimates across the imputed datasets were combined using Rubin's rule[38]. As an auxiliary analysis, complete case analyses were conducted to compare the estimates to those obtained from the

imputed datasets. All statistical analyses were performed using Stata (version 17.0; Stata Corp, College Station, TX, USA), and two-sided *P*-values < 0.05 were considered statistically significant in all cases. This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines.

### *2.7. Ethical considerations*

The JAGES protocol and informed consent procedure were approved by the Ethics Committees of the National Center for Geriatrics and Gerontology (No. 992) and Chiba University (No. 2493). The JAGES participants were informed that participation in the study was voluntary, and that completing and returning the questionnaire was interpreted as informed consent.

## 3. Results

**Table 1** shows the characteristics of the study population according to their dental status. Of the participants (age: 73.8 ± 6.0 years [mean ± standard deviation], 46.3% male), 55.3% had ≥ 20 teeth, 17.6% had 10–19 teeth using dental prostheses, 3.7% had 10–19 teeth without using dental prostheses, 21.7% had ≤ 9 teeth using dental prostheses, and 1.6% had ≤ 9 teeth without using dental prostheses. In addition, 11.2% of participants with ≥ 20 teeth had poor oral function. On the contrary, among participants with ≤ 19 teeth who did not use dental prostheses, 22.2% had poor oral function. The characteristics of the study population before imputation are presented in **Table S1**.

**Table 2** presents the results of the modified Poisson regression analysis of the association between dental status and the prevalence of low frequency of laughter. Among the participants, 9,129 (5.8%) reported low frequency of laughter. Participants with 10–19 or ≤ 9 teeth without dental prostheses had 1.14 (95% CI, 1.04–1.26) or 1.29 (95% CI, 1.16–1.42) times higher prevalence of low frequency of laughter than those with ≥ 20 teeth, respectively. In contrast, no significant differences were observed in the prevalence of low frequency of laughter between participants with ≤ 19 teeth using dental prostheses and those with ≥ 20 teeth. In addition, among the participants with 10–19 teeth, those using dental prostheses had 1.17 (95% CI, 1.06–1.29) times higher prevalence of low frequency of laughter than those not using dental prostheses. Similar results were obtained in the complete case analysis (**Table S2**).

**Table 3** shows the results of the causal mediation analyses among participants with ≤ 19 teeth without using dental prostheses and those with ≥ 20 teeth. Although the effect size was modest, the estimated TE of fewer remaining teeth in the prevalence of low frequency of laughter was significantly mediated by poor oral function (TE: OR, 1.22 [95% CI, 1.11–1.33]; NIE: OR, 1.02 [95% CI, 1.01–1.04]; PM, 11.8%). In addition, all three aspects of oral function (difficulty in eating hard foods, choking, or dry mouth) showed statistically significant mediating effects; however, while the effect size of having difficulty eating hard foods was moderate, those with experiences of choking or dry mouth were modest. Specifically, difficulties in eating hard foods mediated 22.8% of the association between fewer remaining teeth and a low frequency of laughter. On the other hand, having experienced choking and dry mouth mediated 0.4% and 4.3% of the association, respectively. Similar results were observed in the complete case analysis (**Table S3**).

## 4. Discussion

In the present study of functionally independent Japanese older adults, we found that participants with ≤ 19 teeth and who did not use dental prostheses were associated with a higher likelihood of low frequency of laughter compared to those with ≥ 20 teeth, suggesting the possibility that prosthodontic treatments can prevent a decrease in laughing frequency after tooth loss. Poor oral function also mediated this association. Difficulties in eating hard foods mediated 22.8% of this association. On the other hand, we did not find evidence of differences in the prevalence of low frequency of laughter between participants with ≤ 19 teeth using dental prostheses and those with ≥ 20 teeth.

The findings of this study are broadly in line with those of the existing literature. According to a previous study[9], there is a clear inverse association between the number of remaining teeth and prevalence of low frequency of laughter. In this study, despite the potential preventive effects of using dental prostheses against a decrease in laughter frequency, their use was not considered in the analyses. Although dental prosthesis nonusers with ≤ 19 teeth had a significantly higher prevalence of low frequency of laughter than those with ≥ 20 teeth, the frequency of laughter among dental prosthesis users with ≤ 19 teeth was slightly different from those with ≥ 20 teeth. In addition, this is the first study to elucidate the mediating effects of poor oral function on the association between a low number of teeth and high prevalence of low frequency of laughing. In this context, we believe that the findings of this study will enhance our understanding of the association between oral status and frequency of laughter in daily life.

Our study observed that a lower number of teeth was associated with a higher likelihood of low frequency of laughter, and this association was predominantly mediated by difficulty in eating hard foods. Given that decreased occlusal forces indicate the presence of masticatory dysfunction[39], the masticatory muscles could have declined in participants with difficulty eating hard foods; therefore, it could be functionally difficult for them to laugh because the masticatory muscles play critical roles in facial expressions[40,41]. On the contrary, in our study, there was no evidence of differences in the prevalence of low laughing frequency between participants with ≥ 20 teeth and those with ≤ 19 teeth. As is known, the main objective of prosthetic treatment is to restore occlusal function after tooth loss[42], which was empirically supported by our results that, especially among participants with ≤ 9 teeth, dental prostheses users had a 20% lower prevalence of difficulty eating hard foods than nonusers (see **Table 1**). Taken together, the use of dental prostheses prevented the decline in occlusal and masticatory functions after tooth loss; and consequently, the frequency of laughter was maintained.

Other explanations for a lower number of teeth that directly leads to a higher likelihood of a low frequency of laughter may be possible. First, people who lose their teeth, especially when they do not use dental prostheses, may hesitate to laugh in front of others for aesthetic reasons[43], probably resulting in a low frequency of laughter. On the flip side, it is possible that dental prostheses restored smile aesthetics after tooth loss and reduced hesitation, so the prevalence of low frequency of laughter was slightly different between participants with ≤ 19 teeth using dental prostheses and those with ≥ 20 teeth. Second, tooth loss leads to difficulty in eating food, which, in turn, may reduce opportunities to eat together[25]. In this context, people who lost their teeth missed the opportunity to

**Table 1.** Baseline characteristics of the study population according to the dental status (n = 157,708)

| | Total (n = 157,708) | | Dental Status | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | ≥ 20 teeth (n = 87,233) | | 10–19 teeth using dental prostheses (n = 27,831) | | 10–19 teeth without using dental prostheses (n = 5,859) | | ≤ 9 teeth using dental prostheses (n = 34,273) | | ≤ 9 teeth without using dental prostheses (n = 2,512) | |
| | n | % | n | % | n | % | n | % | n | % | n | % |
| Sex | | | | | | | | | | | | |
| Women | 84,764 | 53.7 | 48,847 | 56.0 | 15,329 | 55.1 | 2,602 | 44.4 | 17,145 | 50.0 | 841 | 33.5 |
| Age, years | | | | | | | | | | | | |
| 65–69 | 49,428 | 31.3 | 32,572 | 37.3 | 7,630 | 27.4 | 2,285 | 39.0 | 6,087 | 17.8 | 854 | 34.0 |
| 70–74 | 43,331 | 27.5 | 25,316 | 29.0 | 7,799 | 28.0 | 1,655 | 28.3 | 7,887 | 23.0 | 674 | 26.8 |
| 75–79 | 35,807 | 22.7 | 18,450 | 21.2 | 6,869 | 24.7 | 1,108 | 18.9 | 8,895 | 26.0 | 484 | 19.3 |
| 80–84 | 20,329 | 12.9 | 8,465 | 9.7 | 3,948 | 14.2 | 564 | 9.6 | 7,042 | 20.5 | 311 | 12.4 |
| ≥ 85 | 8,813 | 5.6 | 2,430 | 2.8 | 1,585 | 5.7 | 248 | 4.2 | 4,362 | 12.7 | 188 | 7.5 |
| Hypertension | | | | | | | | | | | | |
| Diagnosed | 69,046 | 43.8 | 36,623 | 42.0 | 12,750 | 45.8 | 2,741 | 46.8 | 15,903 | 46.4 | 1,029 | 41.0 |
| Diabetes mellitus | | | | | | | | | | | | |
| Diagnosed | 20,537 | 13.0 | 10,010 | 11.5 | 3,828 | 13.8 | 959 | 16.4 | 5,336 | 15.6 | 404 | 16.1 |
| Smoking habits | | | | | | | | | | | | |
| Current | 16,964 | 10.8 | 6,958 | 8.0 | 3,195 | 11.5 | 1,024 | 17.5 | 5,071 | 14.8 | 717 | 28.5 |
| Former | 45,562 | 28.9 | 23,728 | 27.2 | 8,305 | 29.8 | 1,708 | 29.1 | 11,070 | 32.3 | 751 | 29.9 |
| Never | 95,182 | 60.4 | 56,547 | 64.8 | 16,332 | 58.7 | 3,127 | 53.4 | 18,132 | 52.9 | 1,044 | 41.6 |
| Alcohol intake | | | | | | | | | | | | |
| Current | 61,316 | 38.9 | 35,640 | 40.9 | 10,766 | 38.7 | 2,442 | 41.7 | 11,551 | 33.7 | 918 | 36.5 |
| Former | 16,346 | 10.4 | 7,890 | 9.0 | 2,924 | 10.5 | 698 | 11.9 | 4,421 | 12.9 | 413 | 16.4 |
| Never | 80,046 | 50.8 | 43,703 | 50.1 | 14,140 | 50.8 | 2,720 | 46.4 | 18,302 | 53.4 | 1,181 | 47.0 |
| Marital status | | | | | | | | | | | | |
| With a spouse | 115,076 | 73.0 | 66,422 | 76.1 | 20,045 | 72.0 | 4,276 | 73.0 | 22,769 | 66.4 | 1,564 | 62.3 |
| Living alone | | | | | | | | | | | | |
| Yes | 20,757 | 13.2 | 10,740 | 12.3 | 3,789 | 13.6 | 809 | 13.8 | 4,945 | 14.4 | 473 | 18.8 |
| Social participation | | | | | | | | | | | | |
| Active | 52,795 | 33.5 | 33,239 | 38.1 | 8,923 | 32.1 | 1,407 | 24.0 | 8,801 | 25.7 | 425 | 16.9 |
| Depressive symptoms | | | | | | | | | | | | |
| Depressed | 32,696 | 20.7 | 15,382 | 17.6 | 6,082 | 21.9 | 1,593 | 27.2 | 8,665 | 25.3 | 974 | 38.8 |
| Educational attainment | | | | | | | | | | | | |
| ≥ 10 years | 107,809 | 68.4 | 65,168 | 74.7 | 18,495 | 66.5 | 3,802 | 64.9 | 19,058 | 55.6 | 1,286 | 51.2 |
| Equivalent income (10,000$; 1$ = 100JPY) | | | | | | | | | | | | |
| < 2.00 | 78,216 | 49.6 | 38,539 | 44.2 | 14,509 | 52.1 | 3,381 | 57.7 | 20,055 | 58.5 | 1,732 | 69.0 |
| 2.00–3.99 | 62,121 | 39.4 | 37,625 | 43.1 | 10,595 | 38.1 | 1,999 | 34.1 | 11,291 | 32.9 | 611 | 24.3 |
| ≥ 4.00 | 17,371 | 11.0 | 11,069 | 12.7 | 2,727 | 9.8 | 480 | 8.2 | 2,926 | 8.5 | 168 | 6.7 |
| Oral function | | | | | | | | | | | | |
| Poor | 24,854 | 15.8 | 9,755 | 11.2 | 5,692 | 20.5 | 1,100 | 18.8 | 7,553 | 22.0 | 755 | 30.1 |
| Difficulty in eating hard foods | | | | | | | | | | | | |
| Yes | 42,439 | 26.9 | 13,322 | 15.3 | 10,915 | 39.2 | 2,130 | 36.4 | 14,543 | 42.4 | 1,529 | 60.9 |
| Choking | | | | | | | | | | | | |
| Yes | 27,840 | 17.7 | 14,219 | 16.3 | 5,256 | 18.9 | 983 | 16.8 | 6,856 | 20.0 | 527 | 21.0 |
| Dry mouth | | | | | | | | | | | | |
| Yes | 31,448 | 19.9 | 15,951 | 18.3 | 6,143 | 22.1 | 1,271 | 21.7 | 7,403 | 21.6 | 680 | 27.1 |

Note: Each value is mean of 20 imputed datasets.

laugh with others, and this may have decreased their daily frequency of laughter.

The strengths of this study include its relatively large sample size and adjustment for various key sociodemographic factors and underlying health conditions, which were expected to address potential confounding biases. However, this study had several limitations. First, the possibility of reverse causality owing to the cross-sectional

**Table 2.** Association between the dental status and the prevalence of low frequency of laughter (n = 157,708)

| | n | Low frequency of laughter, n (%) | Crude PR (95% CI) | Adjusted PR (95% CI)* | Adjusted PR (95% CI)* |
|---|---|---|---|---|---|
| Dental status | | | | | |
| ≤ 9 teeth without using dental prostheses | 2,512 | 354 (14.1) | 2.97 (2.68–3.29) | 1.29 (1.16–1.42) | 1.31 (1.18–1.46) |
| ≤ 9 teeth using dental prostheses | 34,273 | 2,590 (7.6) | 1.59 (1.52–1.67) | 1.05 (0.99–1.10) | 1.07 (1.003–1.13) |
| 10–19 teeth without using dental prostheses | 5,859 | 481 (8.2) | 1.73 (1.58–1.90) | 1.14 (1.04–1.26) | 1.17 (1.06–1.29) |
| 10–19 teeth using dental prostheses | 27,831 | 1,566 (5.6) | 1.19 (1.12–1.26) | 0.98 (0.93–1.04) | 1.00 (reference) |
| ≥ 20 teeth | 87,233 | 4,138 (4.7) | 1.00 (reference) | 1.00 (reference) | 1.02 (0.96–1.08) |

Abbreviations: PR: prevalence ratio, CI: confidence interval. * Adjusted for sex, age, hypertension, diabetes mellitus, smoking habits, alcohol intake, marital status, living alone, social participation, depressive symptoms, educational attainment, and equivalent income.

**Table 3.** Effect decomposition of total effect of fewer remaining teeth[a] on the prevalence of low frequency of laughter (n = 95,604[b])

| Mediators[c] | TE | NDE | NIE | PM[d] |
|---|---|---|---|---|
| | OR (95% CI[e]) | OR (95% CI[e]) | OR (95% CI[e]) | % |
| Oral function: poor | 1.22 (1.11–1.33) | 1.19 (1.08–1.31) | 1.02 (1.01–1.04) | 11.8 |
| Difficulty eating hard foods: yes | 1.23 (1.11–1.34) | 1.17 (1.05–1.30) | 1.04 (1.00–1.08) | 22.8 |
| Choking: yes | 1.22 (1.11–1.33) | 1.22 (1.11–1.33) | 1.00 (1.00–1.00) | 0.4 |
| Dry mouth: yes | 1.21 (1.10–1.32) | 1.20 (1.09–1.31) | 1.01 (1.00–1.01) | 4.3 |

Abbreviations: OR: odds ratio, CI: confidence interval, TE: total effect, NDE: natural direct effect, NIE: natural indirect effect, PM: proportion-mediated. All models were adjusted for sex, age, hypertension, diabetes mellitus, smoking habits, alcohol intake, marital status, living alone, social participation, depressive symptoms, educational attainment, and equivalent income. [a] Tooth loss was classified into two categories (> 20 teeth/≤ 19 teeth without using dental prostheses). [b] People who had ≤ 19 teeth using dental prostheses were excluded. [c] Each mediator was separately included. [d] Proportion mediated were calculated on a risk difference scale. [e] Estimated by bootstrap with 1000 replications.

design of this study cannot be ruled out. For instance, according to the broaden-and-build theory[44], it may be plausible that having more laughter experiences as an expression of positive emotions could improve health-seeking behaviors such as increasing the frequency of regular dental visits or tooth brushing, which may contribute to preventing tooth loss. Second, the number of teeth was assessed using a self-reported questionnaire. In previous studies[22,23], the validity of self-reported number of teeth was confirmed; however, the possibility of misclassification of the number of teeth remains. Third, although this study assessed the three aspects of oral function as mediators of the association between fewer remaining teeth and a low frequency of laughter, the effect sizes were modest to moderate, which may suggest the presence of other essential mediating factors, such as smile aesthetics. Denture loss has been reported to be associated with embarrassment to laugh in front of others[43], suggesting that smile aesthetic impairments reduce the frequency of laughter. Further studies are needed to explore the major mediating effects on the link between dental status and laughter. Fourth, the participants may not be representative of the Japanese national older adult population because of the voluntary nature of their participation. Therefore, our findings should be interpreted with caution, especially when generalizing them to other populations[45].

## 5. Conclusions

This study demonstrated that having fewer teeth and not using dental prostheses were associated with a high likelihood of low frequency of laughter among older Japanese adults. Furthermore, poor oral function, especially difficulty in eating hard foods, mediated this association. Meanwhile, the use of dental prostheses was observed to mitigate the association between a lower number of teeth and a higher likelihood of low frequency of laughter. Our results suggest that facilitating the use of dental prostheses and preventing a decline in oral function may contribute to preventing a decrease in the frequency of laughter due to tooth loss.

## Appendix

Supplementary materials can be found in the online version of the journal.

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## Conflict of interest statement

The authors declare no conflict of interest.

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