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# Descriptive epidemiology of oral function in middle-aged and older Japanese individuals

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35    **Abstract**

36    **Objective:** To describe age-group differences in oral function in middle-aged and older Japanese adults.

37    **Background:** To facilitate oral function management, it is essential research spanning a wider age range.

38    **Materials and methods:** We conducted a secondary analysis of data in 2023 from two distinct populations. The  
39    Otassha Study included community-dwelling adults aged  $\geq 65$  years in Tokyo. The second sample consisted of  
40    middle-aged workers aged  $\geq 40$  years employed at municipal offices in Fukuoka. Survey items included  
41    tongue coating index, mucosal wetness, occlusal force, oral diadochokinesis, tongue pressure, masticatory  
42    function, swallowing function, and the prevalence of oral hypofunction. Trend tests and binary logistic  
43    regression analysis were conducted. The dependent variable was the presence of oral hypofunction, and the  
44    independent variable was the age group.

45    **Results:** Our analysis included 645 participants (275 men and 370 women, aged 40–89 years). The prevalence  
46    of oral hypofunction and low oral function in six elements, except mucosal wetness, showed a significant  
47    linear association by age group. The prevalence of oral hypofunction was higher in the 80s (adjusted odds  
48    ratio: 2.4, 95% confidence interval: 1.3–4.6) than in the reference category (60s).

49    **Conclusion:** Expanding middle-aged participant data and conducting longitudinal studies are essential for  
50    understanding age-related changes in oral function. These efforts will help inform effective strategies to  
51    address oral functional decline.

52

53    **Keywords**

54    Oral hypofunction, tongue pressure, masticatory function, swallowing function.

55

## 56 **Introduction**

57 Older adults with low oral function have been shown to exhibit higher prevalences of frailty<sup>1</sup> and sarcopenia.<sup>2</sup>  
58 A longitudinal study demonstrated that low oral function was associated with an increased incidence of  
59 disability and mortality among older adults in Japan.<sup>3</sup> Based on these findings, the maintenance and  
60 management of oral function in older adults has received increasing attention, leading to the inclusion of “oral  
61 hypofunction” as an officially recognized diagnosis under Japan’s national health insurance system. In Japan,  
62 the management of oral hypofunction is now regarded as an essential component of dental care for older  
63 adults. Oral hypofunction differs from classical structural disorders, such as dental caries and tooth loss, as it  
64 involves various oral functions that are interrelated and affect each other. Therefore, to assess multiple oral  
65 functions, the following seven elements were selected, with reference to studies that suggested an association  
66 with general health status: poor oral hygiene, oral dryness, reduced occlusal force, decreased tongue-lip motor  
67 function, reduced tongue pressure, diminished masticatory function, and impaired swallowing function.<sup>4</sup> A  
68 diagnosis of oral hypofunction is made when at least three of these seven elements are found to be  
69 deteriorating. These criteria were established by the Japanese Society of Gerodontology based on clinical  
70 relevance and feasibility of assessment in community and clinical settings.<sup>5</sup> Similar criteria are used for  
71 insurance coverage, making them a standardized and practical diagnostic framework for oral hypofunction in  
72 Japan. The incorporation of oral hypofunction into the national health insurance system has facilitated  
73 standardized evaluation across the country, enhancing data collection and preventive healthcare efforts.  
74 Furthermore, in 2020, insurance coverage for oral hypofunction management, which was previously limited to  
75 individuals aged 65 and over, was expanded to include individuals aged 50 and over, enabling earlier  
76 intervention before reaching older age. This expansion reflects the growing recognition of the need for  
77 comprehensive oral function management across age groups. With this change, oral function management,  
78 previously focused primarily on older adults, is now being emphasized as a preventive measure starting in  
79 middle age. To support effective oral function management across diverse age groups, including middle-aged  
80 adults, it is essential to gather comprehensive and descriptive data on oral function across varying age

81 demographics.

82

83 Several studies have explored the relationship between age and oral hypofunction. Research on older adults  
84 has shown that advancing age is associated with lower occlusal force, lingual-lip motor function,<sup>1</sup> tongue  
85 pressure,<sup>6</sup> and masticatory function.<sup>7</sup> A longitudinal study following participants aged 74 years and older over  
86 approximately three years also documented a decrease in tongue pressure.<sup>8</sup> Additionally, comparisons with  
87 younger age groups underscore the pronounced nature of oral hypofunction in older adults. Iyota et al.  
88 evaluated oral hypofunction using seven tests on college students in the 20s and dental patients aged 40 years  
89 and older.<sup>9</sup> By comparing these tests with those of the 20s group as the reference, they identified significant  
90 correlations between age and both tongue-lip motor function and tongue pressure. Similarly, Hatanaka et al.  
91 examined patients aged 32 years and older at a dental hospital, using individuals aged 32 to 64 years as the  
92 reference group for age-related comparisons.<sup>10</sup> The results showed that the prevalence of oral hypofunction  
93 was higher in older age groups. Ohta et al. surveyed dental hospital patients aged 22 to 40 years and compared  
94 the corresponding rates with those from previous studies.<sup>11</sup> The percentage of younger adults who fell below  
95 the criteria on all seven tests for oral hypofunction was lower, indicating that oral hypofunction is more  
96 pronounced in older adults than in younger adults. These studies collectively indicate that several aspects of  
97 oral function, such as occlusal force, tongue-lip motor function, tongue pressure, and masticatory function,  
98 tend to be lower in older adults. However, these reports are limited in the following aspects: the target  
99 population is restricted to dental clinic patients, the number of participants is small, and no study has  
100 systematically assessed oral function by age-groups. Therefore, there is a need for systematic comparisons of  
101 oral function across different age groups in the general population. Understanding age-related differences in  
102 oral function is critical for informing preventive strategies. We believed it was important to consider a wide  
103 range of age groups, including middle-aged and older adults.

104

105 To address these challenges, the purpose of this study was to describe age-group differences in oral function in  
106 middle-aged and older Japanese adults from selected regions of Japan.

107

## 108 **Materials & Methods**

### 109 *Study Sample*

110 This study is a secondary analysis of data from two distinct samples: participants of the Otassha Study and a  
111 sample of middle-aged workers. The two samples described below, although differing in geographic location  
112 and participant characteristics, were selected because they provided access to a relatively large number of  
113 individuals from the working-age and retired populations through the framework of our ongoing studies. The  
114 Otassha Study included community-dwelling adults aged  $\geq 65$  years, registered in the basic resident database  
115 of areas surrounding the Tokyo Metropolitan Institute for Geriatrics and Gerontology, located in the Itabashi  
116 ward of northwest Tokyo, Japan. The study design and protocols of the Otassha Study have been detailed in  
117 prior publications.<sup>12,13</sup> The second sample consisted of middle-aged workers aged  $\geq 40$  years employed at  
118 municipal offices in Fukuoka, Japan. Invitations for oral function assessment were distributed to all workers  
119 aged  $\geq 40$  years at one city office. Individuals who voluntarily responded were included in the study. For the  
120 current analysis, participants aged 90 years and older in the Otassha study and participants aged 65 years and  
121 older in the sample of middle-aged workers were excluded. Participants who were certified as requiring long-  
122 term care were excluded. Participants with incomplete data were also excluded.

123

124 The study protocols for both surveys received approval from the Ethics Committee of the Tokyo Metropolitan  
125 Institute for Geriatrics and Gerontology (approval numbers: R22-034 and R23-035).

126

### 127 *Assessment of Oral Health and Function*

128 As part of the oral health assessment, a questionnaire was used to determine whether the patients receive  
129 regular dental checkups and frequency of tooth brushing. The four options for the frequency of tooth brushing  
130 were: three or more times a day, twice a day, once a day, and less than once a day. Respondents were  
131 categorized as brushing either more than or less than twice a day.<sup>14,15</sup> Assessment of oral function was  
132 conducted by trained dentists and dental hygienists. Training was verified by testing the same volunteer

133 participants prior to the survey to confirm the assessment method. The numbers of natural teeth and functional  
134 teeth were evaluated. Natural teeth were defined as teeth with remaining roots, excluding residual roots.  
135 Functional teeth encompassed both natural teeth and missing teeth replaced by prosthetics, including dental  
136 implant prosthetics, pontics in fixed dental prosthetics, and artificial teeth in removable dental prosthetics.

137

138 Seven elements indicative of oral hypofunction were assessed based on established diagnostic criteria<sup>3</sup>. If  
139 three or more of the seven elements indicated low oral function, the individual was classified as having oral  
140 hypofunction. A detailed description of the measurements for these seven elements is provided below.

141 Oral hygiene was evaluated by visual inspection using the Tongue Coating Index (TCI).<sup>16</sup> The tongue was  
142 divided into nine sections, three vertical and three horizontal. The adherence of the tongue coating on each  
143 section was evaluated on a 3-point scale (score 0–2), and the TCI was calculated. A TCI of 50% or higher was  
144 considered poor oral hygiene.

145

146 Mucosal wetness was measured three times at the center of the dorsum of the tongue using an oral moisture  
147 checker (Mucus, Life Co., Ltd.) and rated based on the median value.<sup>17</sup> A median value of less than 27  
148 indicated oral dryness.

149

150 The occlusal force was assessed using the Oramo-bf device (Sumitomo Riko Co., Ltd.).<sup>18</sup> For denture wearers;  
151 measurements were taken with their dentures in place. Each participant underwent three measurements, and  
152 the maximum value was used for analysis. Low occlusal force was defined as a maximum occlusal force of  
153 less than 375 N.

154

155 Tongue-lip motor function was evaluated through oral diadochokinesis. Participants were asked to repeat each  
156 of the syllables /pa/, /ta/, and /ka/ as many times as possible within five seconds. The number of repetitions for  
157 each syllable was measured using an automatic counter (Kenkokun Handy, Takei Scientific Instruments Co.,  
158 Ltd).<sup>19</sup> If the number of repetitions for any syllable was less than six per second, it was classified as low

159 tongue-lip motor function.

160

161 Tongue pressure was measured using a tongue pressure measuring device (JMS tongue pressure measuring  
162 instrument TPM-01, JMS Co., Ltd.)<sup>6</sup>. Measurements were performed three times, and the average value was  
163 calculated. An average tongue pressure of less than 30 kPa was classified as low tongue pressure.

164

165 Masticatory function was assessed using a gummy jelly (Test Gummy Jelly for Evaluating Masticatory  
166 Performance; UHA Mikakuto Co., Ltd.). Participants were instructed to chew the gummy jelly for 30  
167 strokes.<sup>20</sup> The degree of fragmentation of the chewed gummy jelly was evaluated by comparing it with a  
168 visual reference material, and a score ranging from 0 to 9 was assigned. A score below 2 was defined as a low  
169 masticatory function.

170

171 Swallowing function was evaluated using the Japanese version of the 10-item Eating Assessment Tool (EAT-  
172 10).<sup>21,22</sup> The EAT-10 is a self-administered questionnaire consisting of 10 items, each scored from 0 to 4,  
173 resulting in a total score ranging from 0 to 40. A total score of 3 or higher was indicative of low swallowing  
174 function.

175

#### 176 *Data Collection for Basic Information*

177 The survey items included sex, age, comorbidities (cancer, diabetes mellitus, dyslipidemia, heart disease,  
178 hypertension, osteoporosis, and stroke), and body mass index (BMI). Participants were categorized into five  
179 age-groups (40–49, 50–59, 60–69, 70–79, and 80–89 years) for the purpose of this analysis. BMI was  
180 calculated based on height and weight measured in the survey.

181

#### 182 *Statistical Analysis*

183 First, we described the prevalences of oral hypofunction and its constituent elements, as well as other  
184 demographic and health characteristics according to the five age-groups. The Shapiro–Wilk test was applied to

185 assess the normality of continuous variables. With regard to trend tests, the Cochran–Armitage test for  
186 categorical variables or Jonckheere–Terpstra test for continuous variables were performed. The same tests  
187 were also performed by sex and by sample separately.

188  
189 Second, we performed univariable and multivariable logistic regression analysis to estimate odds ratios (ORs)  
190 and 95% confidence intervals (CIs) for the prevalence of oral hypofunction according to the five age-groups.  
191 The dependent variable was the presence of oral hypofunction, and the independent variable was the age-  
192 group, with the 60s group as the reference category. Owing to the small sample size when using participants in  
193 their 40s as the reference group, the estimates were unstable. Therefore, participants in their 60s were used as  
194 the reference group instead. Covariates for the multivariable analysis were determined based on previous  
195 studies.<sup>6,7</sup> In Model 1, sex, BMI, and number of complications were included as covariates. Model 2 included  
196 number of natural teeth and regular dental checkups in addition to the variables used in Model 1. Furthermore,  
197 effect modification by sex was evaluated by adding interaction terms between sex and age-groups (i.e.,  
198 variables that multiply the two categorical variables: sex and age-groups) in the regression models.

199  
200 Finally, we performed univariable and multivariable logistic regression analysis to estimate ORs and 95% CIs  
201 for the prevalence of each element of oral hypofunction. Due to the very small number of participants with  
202 low occlusal force in the 40s (N=2, 3.9%) and 50s (N=0, 0%), these groups were combined into a single  
203 category: 40-50s. In Model 1, sex, BMI, and number of complications were included as covariates. Model 2  
204 included number of natural teeth and regular dental checkups, in addition to the variables used in Model 1.

205  
206 All statistical analyses were conducted using IBM SPSS Statistics for Windows, version 29.0 (IBM Corp.,  
207 Armonk, NY, USA). A p-value < 0.05 was considered statistically significant.

## 208 209 **Results**

210 The summary characteristics of participants by age-group are presented in Table 1. The analysis included 645  
211 participants, comprising 275 males and 370 females. Overall, 22.8% of the participants were classified as  
212 having oral hypofunction. The prevalence of oral hypofunction and low oral function in six elements, except  
213 mucosal wetness, showed a significant linear association by age group.

214

215 The characteristics of the participants by sex and age-group are shown in Table S1 and Table S2. The  
216 prevalence of oral hypofunction showed a significant linear association by age group in males and females. In  
217 males, the prevalence of low oral functions in all six elements, except mucosal wetness, showed a significant  
218 linear association by age group. In females, the prevalence of low occlusal force, low lingual-lip motor  
219 function, low tongue pressure, and low masticatory function showed a significant linear association by age  
220 group.

221

222 The characteristics of the participants by sample and age group are shown in Tables S3 and S4. The  
223 prevalence of oral hypofunction showed a significant linear association by age group in the Otassha Study,  
224 which included community-dwelling adults aged  $\geq 65$  years.

225

226 Table 2 shows the results of logistic regression analysis for oral hypofunction prevalence. When we tested the  
227 interaction between sex and age-groups, we confirmed that the interaction terms did not have a significant  
228 association with the prevalence of oral hypofunction (data not shown). Therefore, we excluded the interaction  
229 terms. Further analysis was conducted without stratification by sex. In Model 1, the prevalence of oral  
230 hypofunction was significantly higher in the 70s and 80s than in the 60s. The statistically significant  
231 association between oral hypofunction and age-group disappeared after further adjustment by number of  
232 natural teeth (Model 2).

233

234 Table 3 shows the results of logistic regression analysis for the prevalence of the seven elements of oral  
235 hypofunction. In Model 2, the percentages of poor oral hygiene, oral dryness, and low tongue pressure were

significantly lower in the younger age groups than in the 60s. Conversely the percentage of low masticatory function was significantly higher in the younger age groups than in the 60s. The percentages of low tongue-lip motor function, low tongue pressure, and low masticatory function were significantly higher in the older age groups than in the 60s.

## Discussion

The results of this study showed a pattern toward higher proportions of oral hypofunction with increasing age-group. Oral hypofunction was defined as an assessment of seven oral functions based on a previous study, with three or more of them being applicable. A similar pattern was also shown for the seven elements, except for oral dryness. In addition, comparison with those in their 60s showed a higher proportions of oral hypofunction in participants in their 80s. Interestingly, certain oral functions such as oral dryness and low tongue pressure were less prevalent in participants in the 40s, poor oral hygiene was less prevalent in the 50s, and low masticatory function was more frequent in both the 40s and 50s. Conversely, low tongue and lip motor function was more frequent in participants in the 70s and older, while low tongue pressure, low masticatory function, and low swallowing function were more frequent in the 80s. To the best of our knowledge, this is the first study to describe age-group differences in oral function in middle-aged and older Japanese adults, starting from the 40s.

Significant differences in the proportions of oral hypofunction were observed between participants in the 80s and those in the 60s, even after adjusting for sex, BMI, and number of comorbidities. A previous study that compared community-dwelling older adults by 5-year age groups similarly reported an increasing pattern in the proportion of oral hypofunction with advancing age.<sup>23</sup> Another survey of adults aged 30 years and older, which grouped participants by approximate 10-year age intervals, also demonstrated that older age groups exhibited higher proportions of oral hypofunction.<sup>10</sup> Consistent with these findings, this study reinforces the association between aging and low oral function. Due to the uneven age distribution of the participants, the 60s age group was selected as the reference category. While this approach limited the ability to fully evaluate

age-related changes across all age groups, it enabled a clearer association between younger and older age groups. When further adjusted for number of natural teeth, no statistically significant associations were found. The number of natural teeth generally declines with age, but older adults with more natural teeth are reportedly less likely to experience deteriorating health.<sup>24</sup> The results of this study suggest that number of natural teeth may have a greater influence in old age. Future studies should consider incorporating longitudinal study designs and targeted data collection from younger age groups.

The following three elements were significantly less common in the younger age-groups than in the 60s: poor oral hygiene, oral dryness, and low tongue pressure. Previous studies have yielded mixed results regarding the relationship between poor oral hygiene and age. Some studies have reported significant differences in tongue coating between individuals in the 80s and those in the 20s,<sup>9</sup> while others have found no clear association with age.<sup>10</sup> It has also been reported that the degree of tongue coating correlates with low tongue motor function.<sup>25</sup> Therefore, to better understand the effects of aging, it is also necessary to examine tongue motor function and tongue-cleaning habits. In addition, previous studies comparing younger age groups, such as those in the 20s and 30s, to individuals over 40 years of age found no significant association between oral dryness and aging beyond 40 years or in older age.<sup>9,10</sup> Saliva volume at rest has been shown to decrease with age and is influenced by factors such as medication use and nutritional status in older populations.<sup>26</sup> Our study adjusted for the number of comorbidities, but it is possible that the association with diabetes could not be ruled out. Nevertheless, the findings of this study revealed that the proportion of low mucosal wetness was not significantly different between participants in the 50s and in the 60s, suggesting that signs of oral dryness may begin to manifest before the onset of old age.

Low tongue-lip motor function and tongue pressure were more common in older age groups than in the 60s. Previous studies have reported that older adults generally experience a significantly lower tongue-lip motor function than younger age groups.<sup>9,10,27</sup> Low tongue-lip motor function is primarily attributed to a reduction in the strength and functionality of the perioral muscles. This function was assessed in this study using oral

288 diadochokinesis, a well-established method for evaluating oral motor coordination. Oral diadochokinesis has  
289 been shown to be closely associated with swallowing ability and cognitive function.<sup>28,29</sup> Nonetheless,  
290 cognitive function may need to be considered in future studies to better elucidate the relationship between  
291 aging and changes in tongue-lip motor function. Furthermore, previous studies have shown that tongue  
292 pressure is significantly lower in individuals over 70 than in students in the 20s.<sup>9,30</sup> The tongue, composed of  
293 muscular tissue, is susceptible to age-related atrophy. Tongue fat is approximately twice as much in older  
294 adults as in younger individuals, potentially contributing to reduced<sup>31</sup> tongue pressure with aging.

295  
296 The following three elements were more common in individuals in their 80s than in their 60s, after adjusting  
297 for sex, BMI, and number of comorbidities: low occlusal force, low masticatory function, and low swallowing  
298 function. However, when the number of natural teeth and regular dental checkups were considered, the  
299 distribution no longer showed similar patterns. There were no significant differences in low occlusal force and  
300 low swallowing function between any age-groups. Masticatory function was higher in the 80s and younger  
301 age groups than in the 60s. It is well-established that occlusal force is closely associated with the element and  
302 number of natural teeth.<sup>32,33</sup> In contrast, masticatory function has been reported to be affected by the number  
303 of natural teeth.<sup>34</sup> The results of this study showed that the rate of low masticatory function was also higher in  
304 the younger age-groups. A previous study indicated that individuals in the 20s exhibited lower masticatory  
305 function than in those aged 40 and older.<sup>9</sup> In another study of adults with normal dentition, slight impairments  
306 in masticatory function were reported and attributed to malocclusion.<sup>35</sup> Mastication is a coordinated  
307 movement involving not only teeth but also the tongue and buccal mucosa, highlighting the multifactorial  
308 nature of masticatory function.<sup>36</sup> The present findings do not establish a clear relationship between age and  
309 masticatory function, possibly due to the small number of participants with low masticatory function, which  
310 may have influenced the results. Future studies considering both the number of natural teeth and extraction  
311 history are warranted. Low swallowing function was not associated with age, as in previous studies.<sup>9</sup>  
312 Swallowing function is generally considered to decline with age and may also be influenced by medications  
313 commonly used by older adults, which can cause loss of appetite and impaired motor coordination.<sup>37</sup> This

314 study did not examine the details of medication use among middle-aged participants and thus could not fully  
315 account for the effects of oral medications.

316

317 This study has several limitations. First, there were a small number of participants and large variation among  
318 age-groups, making it impossible to examine sex separately and to use the youngest group, those in their 40s,  
319 as the reference standard. Instead, we used the analysis for overall after confirming the interaction between sex  
320 and age, and also using the middle group, those in their 60s, as the reference standard. While the results were  
321 interpreted based on the direction of association, they could not be fully interpreted for the older age groups.  
322 Additionally, it was not possible to compare all groups in terms of occlusal force. Future research should include  
323 a larger number of middle-aged participants to further clarify comparisons between middle age and older age.  
324 Second, as a cross-sectional study, it was not possible to assess the effects of individual aging changes.  
325 Longitudinal research is needed to examine the impact of aging on the decline in oral function over time. Third,  
326 the study's participant characteristics may limit generalizability. The Otassha study included older adults who  
327 voluntarily participated, likely representing individuals with a high interest in their health and frequent  
328 involvement in research studies. The other survey was conducted on middle-aged workers employed at  
329 municipal offices, and this group is considered to be at the higher end of the socioeconomic status. In addition,  
330 the sample for this study consisted of older adults surveyed in Tokyo and middle-aged civil servants surveyed  
331 in Fukuoka. These two samples were selected because they provided access to a relatively large number of  
332 participants from working-age and retired populations through ongoing survey frameworks. Therefore, the age-  
333 related differences observed may partially reflect differences between these two groups rather than age effects  
334 alone. Although Japan has universal health insurance and regional differences in dental visits are expected to be  
335 small, we considered regular dental visits in our analysis. However, it is still possible that differences in health  
336 behaviors, access to medical care, and sample characteristics may have influenced these results. Future studies  
337 should consider recruiting participants from a single, more representative population to minimize potential bias  
338 and improve generalizability. Finally, this study adjusted for the number of comorbidities rather than specific  
339 disease types, which may have influenced oral function. Considering that different diseases and medications

340 may have varying impacts on oral function, future research should consider adjusting for specific conditions  
341 rather than just the total number of comorbidities.

342

343 Currently, there is a growing need for interventions to promote oral function awareness, not only in old age  
344 but also in middle age. A comprehensive assessment of oral function is crucial for planning effective  
345 interventions. This study's findings demonstrate that the differences in the distribution of each of the low oral  
346 functions. Addressing early signs of low oral function is vital when implementing strategies to preserve oral  
347 health, particularly for middle-aged and older adults.

348

### 349 **Conclusion**

350 The prevalence of oral hypofunction increased significantly among individuals in the 80s than in those in the  
351 60s. However, the seven elements of oral hypofunction did not exhibit consistent distributions with age,  
352 highlighting the complexity of age-related changes in oral function. Expanding data collection to include a  
353 larger sample of middle-aged individuals and conducting longitudinal studies are essential to better understand  
354 the progression of age-related decline in oral function over time. Such efforts would provide deeper insights  
355 into the understanding of age-related changes and inform strategies to address oral functional decline  
356 effectively.

357

### 358 **Conflict of Interest**

359 The authors declare no conflict of interest.

360

### 361 **Author Contributions**

362 M.S., M.Iwasaki, and H.Hirano conceived and designed the study. K.I., K.M., A.E., S.M., C.M., T.G., M.E.,  
363 H.K., M.Inoue, S.Y., A.I., H.Hikiji, and H.Hirano collected and analyzed the data. M.S. drafted the manuscript.  
364 T.N., H.S., K.I., Y.F., S.O., and H.Hirano supervised the study. M.Iwasaki, K.I., K.M., A.E., S.M., C.M., T.G.,  
365 M.E., H.K., M.Inoue, S.Y., A.I., H.Hikiji, T.N., H.S., K.I., Y.F., S.O., and H.Hirano critically revised the

manuscript for important intellectual content. All authors reviewed and approved the final version of the manuscript and agreed to be accountable for all aspects of the work in ensuring that any questions related to the accuracy or integrity of the work are appropriately investigated and resolved.

#### **Data Accessibility Statement**

The data are not publicly available owing to ethical and legal restrictions imposed by the Ethics Committee of the Tokyo Metropolitan Institute for Geriatrics and Gerontology (data include potentially identifying or sensitive patient information). Data may be made available from the corresponding author upon request.

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**Table 1. Characteristics of participants across the five age-groups**

|                                           | Overall<br>(n=645) | 40s<br>(n=51)    | 50s<br>(n=66)    | 60s<br>(n=166)   | 70s<br>(n=260)   | Age-groups<br>80s<br>(n=102) | p for<br>linear trend |
|-------------------------------------------|--------------------|------------------|------------------|------------------|------------------|------------------------------|-----------------------|
| Oral hypofunction                         | 147 (22.8)         | 3 (5.9)          | 4 (6.1)          | 27 (16.3)        | 67 (25.8)        | 46 (45.1)                    | <0.01                 |
| Seven elements                            |                    |                  |                  |                  |                  |                              |                       |
| Poor oral hygiene                         | 116 (18.0)         | 3 (5.9)          | 5 (7.6)          | 32 (19.3)        | 58 (22.3)        | 18 (17.6)                    | <0.01                 |
| Oral dryness                              | 217 (33.6)         | 10 (19.6)        | 18 (27.3)        | 63 (38.0)        | 94 (36.2)        | 32 (31.4)                    | 0.13                  |
| Low occlusal force                        | 75 (11.6)          | 2 (3.9)          | 0 (0.0)          | 12 (7.2)         | 31 (11.9)        | 30 (29.4)                    | <0.01                 |
| Low tongue-lip<br>motor function          | 251 (38.9)         | 14 (27.5)        | 19 (28.8)        | 49 (29.5)        | 112 (43.1)       | 57 (55.9)                    | <0.01                 |
| Low tongue pressure                       | 178 (27.6)         | 2 (3.9)          | 8 (12.1)         | 40 (24.1)        | 79 (30.4)        | 49 (48.0)                    | <0.01                 |
| Low masticatory<br>function               | 54 (8.4)           | 3 (5.9)          | 3 (4.5)          | 5 (3.0)          | 18 (6.9)         | 25 (24.5)                    | <0.01                 |
| Low swallowing<br>function                | 209 (32.4)         | 12 (23.5)        | 21 (31.8)        | 48 (28.9)        | 81 (31.2)        | 47 (46.1)                    | 0.01                  |
| Oral Measurements                         |                    |                  |                  |                  |                  |                              |                       |
| No. of natural teeth                      | 27 (23–28)         | 28 (28–29)       | 28 (28–29)       | 27 (25–28)       | 26 (21–28)       | 23 (14–27)                   | <0.01                 |
| No. of functional teeth                   | 28 (27–28)         | 28 (28–29)       | 28 (28–30)       | 28 (27–28)       | 28 (27–28)       | 28 (27–28)                   | <0.01                 |
| Oral hygiene, %                           | 22.2 (11.1–38.9)   | 5.6 (0.0–22.2)   | 16.7 (0.0–23.6)  | 27.8 (11.1–44.4) | 22.2 (11.1–44.4) | 22.2 (11.1–40.3)             | <0.01                 |
| Mucosal wetness                           | 27.8 (26.2–29.4)   | 28.4 (27.1–29.7) | 28.3 (26.6–29.6) | 27.6 (25.6–29.2) | 27.6 (26.1–29.1) | 28.2 (26.1–29.8)             | 0.36                  |
| Occlusal force, N                         | 782 (528–1052)     | 930 (716–1260)   | 1046 (743–1312)  | 829 (607–1005)   | 768 (522–1013)   | 559 (327–838)                | <0.01                 |
| Tongue-lip motor<br>function              |                    |                  |                  |                  |                  |                              |                       |
| /pa/, times/second                        | 6.6 (6.2–7.2)      | 6.8 (6.4–7.2)    | 6.8 (6.4–7.2)    | 6.8 (6.4–7.2)    | 6.6 (6.2–7.0)    | 6.6 (6.0–7.0)                | <0.01                 |
| /ta/, times/second                        | 6.6 (6.2–7.0)      | 7.2 (6.6–7.4)    | 7.0 (6.4–7.6)    | 6.8 (6.4–7.2)    | 6.6 (6.1–7.0)    | 6.3 (5.8–6.8)                | <0.01                 |
| /ka/, times/second                        | 6.2 (5.6–6.6)      | 6.6 (6.0–7.0)    | 6.4 (5.8–7.0)    | 6.2 (5.8–6.6)    | 6.0 (5.6–6.6)    | 5.8 (5.4–6.2)                | <0.01                 |
| Tongue pressure, kPa                      | 34.3 (29.4–40.3)   | 41.0 (35.7–46.0) | 40.8 (32.9–46.1) | 35.0 (30.1–40.8) | 33.7 (28.8–39.0) | 30.8 (26.7–35.3)             | <0.01                 |
| Masticatory function,<br>score            | 6 (5–7)            | 6 (5–7)          | 6 (5–7)          | 6 (5–7)          | 6 (5–7)          | 5 (3–6)                      | <0.01                 |
| Swallowing function,<br>points            | 1 (0–3)            | 1 (0–2)          | 1 (0–4)          | 1 (0–3)          | 1 (0–3)          | 2 (0–5)                      | <0.01                 |
| Regular dental<br>checkups, no            | 269 (41.7)         | 32 (62.7)        | 34 (51.5)        | 57 (34.3)        | 94 (36.2)        | 52 (51.0)                    | 0.09                  |
| Tooth brushings,<br>less than twice a day | 100 (15.6)         | 5 (9.8)          | 8 (12.3)         | 25 (15.1)        | 49 (18.9)        | 13 (12.7)                    | 0.29                  |
| Other characteristics                     |                    |                  |                  |                  |                  |                              |                       |
| Sex, female                               | 370 (57.4)         | 21 (41.2)        | 24 (36.4)        | 108 (65.1)       | 151 (58.1)       | 66 (64.7)                    | <0.01                 |
| Age, years                                | 71 (65–76)         | 46 (43–48)       | 53 (51–56)       | 66 (65–68)       | 73 (72–75)       | 82 (81–85)                   | <0.01                 |

|                        |                        |                        |                        |                        |                        |                        |       |
|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|------------------------|-------|
| Height, cm             | 158.8<br>(152.5–166.2) | 165.1<br>(158.3–170.8) | 165.1<br>(158.8–170.3) | 159.1<br>(154.9–166.0) | 157.7<br>(152.3–165.4) | 151.4<br>(147.6–161.1) | <0.01 |
| Weight, kg             | 57.5 (50.1–66.5)       | 63.1 (53.0–73.3)       | 66.8 (58.3–75.7)       | 58.1 (50.5–65.8)       | 56.3 (49.9–64.4)       | 51.3 (45.8–58.5)       | <0.01 |
| BMI, kg/m <sup>2</sup> | 22.7 (20.7–24.9)       | 22.8 (20.7–25.0)       | 23.8 (22.1–28.1)       | 22.7 (20.5–24.8)       | 22.7 (20.4–24.7)       | 22.2 (20.7–23.9)       | <0.01 |
| Comorbidities          |                        |                        |                        |                        |                        |                        |       |
| Hypertension           | 238 (36.9)             | 0 (0.0)                | 16 (24.2)              | 60 (36.1)              | 115 (44.2)             | 47 (46.1)              | <0.01 |
| Stroke                 | 33 (5.1)               | 0 (0.0)                | 0 (0.0)                | 3 (1.8)                | 22 (8.5)               | 8 (7.8)                | <0.01 |
| Heart disease          | 90 (14.0)              | 0 (0.0)                | 0 (0.0)                | 18 (10.8)              | 50 (19.2)              | 22 (21.6)              | <0.01 |
| Diabetes mellitus      | 70 (10.9)              | 0 (0.0)                | 4 (6.1)                | 21 (12.7)              | 37 (14.2)              | 8 (7.8)                | 0.06  |
| Dyslipidemia           | 233 (36.1)             | 2 (3.9)                | 8 (12.1)               | 60 (36.1)              | 111 (42.7)             | 52 (51.0)              | <0.01 |
| Osteoporosis           | 64 (9.9)               | 0 (0.0)                | 0 (0.0)                | 17 (10.2)              | 28 (10.8)              | 19 (18.6)              | <0.01 |
| Cancer                 | 81 (12.6)              | 0 (0.0)                | 0 (0.0)                | 17 (10.2)              | 48 (18.5)              | 16 (15.7)              | <0.01 |

Data are presented as *n* (%) or median (IQR).

Abbreviations: No., number; BMI, body mass index; IQR, interquartile range.

**Table 2. Logistic regression results for oral hypofunction prevalence**

|                       |            |             | Outcome variable<br>Oral hypofunction (0: No, 1: Yes) |           |                 |
|-----------------------|------------|-------------|-------------------------------------------------------|-----------|-----------------|
| Exposure variable     |            |             | OR                                                    | 95% CI    | <i>p</i> -value |
| Univariable model     | Age-groups | 40s         | 0.32                                                  | 0.09–1.11 | 0.07            |
|                       |            | 50s         | 0.33                                                  | 0.11–0.99 | <0.05           |
|                       |            | 60s (ref.)  |                                                       |           |                 |
|                       |            | 70s         | 1.79                                                  | 1.09–2.94 | 0.02            |
|                       |            | 80s         | 4.23                                                  | 2.40–7.46 | <0.01           |
| Exposure variable     |            |             | ad OR                                                 | 95% CI    | <i>p</i> -value |
| Multivariable model 1 | Age-groups | 40s         | 0.47                                                  | 0.12–1.83 | 0.27            |
|                       |            | 50s         | 0.31                                                  | 0.08–1.17 | 0.08            |
|                       |            | 60s (ref.)  |                                                       |           |                 |
|                       |            | 70s         | 1.38                                                  | 0.66–2.88 | 0.40            |
|                       |            | 80s         | 3.42                                                  | 1.41–8.27 | 0.01            |
| Multivariable model 2 | Sex        | Male (ref.) |                                                       |           |                 |
|                       |            | Female      | 0.48                                                  | 0.21–1.12 | 0.09            |
|                       | Age-groups | 40s         | 0.85                                                  | 0.21–3.48 | 0.82            |
|                       |            | 50s         | 0.51                                                  | 0.13–2.02 | 0.34            |
|                       |            | 60s (ref.)  |                                                       |           |                 |
|                       |            | 70s         | 1.37                                                  | 0.62–3.01 | 0.43            |
|                       | Sex        | 80s         | 2.17                                                  | 0.82–5.72 | 0.12            |
|                       |            | Male (ref.) |                                                       |           |                 |
|                       |            | Female      | 0.55                                                  | 0.23–1.34 | 0.19            |

Model 1 was adjusted for body mass index and number of comorbidities.

Model 2 was adjusted for the number of natural teeth and regular dental checkups in addition to the adjustment variables of Model 1.

Abbreviations: OR, odds ratio; CI, confidence interval; ref., reference; ad OR, adjusted odds ratio.

**Table 3. Logistic regression results for the prevalence of the seven elements of oral hypofunction**

|                          |               | Poor oral hygiene<br>(0: No, 1: Yes) |                     | Oral dryness<br>(0: No, 1: Yes) |                     | Low occlusal force<br>(0: No, 1: Yes) |                     | Outcome variables<br>Low tongue-lip motor<br>function<br>(0: No, 1: Yes) |                     | Low tongue pressure<br>(0: No, 1: Yes) |                     | Low masticatory function<br>(0: No, 1: Yes) |                     | Low swallowing<br>function<br>(0: No, 1: Yes) |                     |
|--------------------------|---------------|--------------------------------------|---------------------|---------------------------------|---------------------|---------------------------------------|---------------------|--------------------------------------------------------------------------|---------------------|----------------------------------------|---------------------|---------------------------------------------|---------------------|-----------------------------------------------|---------------------|
| Exposure variable        |               | OR<br>(95% CI)                       | <i>p</i> -<br>value | OR<br>(95% CI)                  | <i>p</i> -<br>value | OR<br>(95% CI)                        | <i>p</i> -<br>value | OR<br>(95% CI)                                                           | <i>p</i> -<br>value | OR<br>(95% CI)                         | <i>p</i> -<br>value | OR<br>(95% CI)                              | <i>p</i> -<br>value | OR<br>(95% CI)                                | <i>p</i> -<br>value |
| Univariable<br>model     | 40s           | 0.26<br>(0.08–0.89)                  | 0.03                | 0.40<br>(0.19–0.85)             | 0.02                | 0.22<br>(0.05–1.02)                   | 0.05                | 0.90<br>(0.45–1.82)                                                      | 0.78                | 0.13<br>(0.03–0.55)                    | <0.01               | 2.01<br>(0.46–8.73)                         | 0.35                | 0.76<br>(0.37–1.57)                           | 0.45                |
|                          | 50s           | 0.34<br>(0.13–0.92)                  | 0.03                | 0.61<br>(0.33–1.15)             | 0.13                |                                       |                     | 0.97<br>(0.51–1.81)                                                      | 0.91                | 0.43<br>(0.19–0.99)                    | <0.05               | 1.53<br>(0.36–6.61)                         | 0.57                | 1.15<br>(0.62–2.13)                           | 0.66                |
|                          | 60s<br>(ref.) |                                      |                     |                                 |                     |                                       |                     |                                                                          |                     |                                        |                     |                                             |                     |                                               |                     |
|                          | 70s           | 1.20<br>(0.74–1.95)                  | 0.46                | 0.93<br>(0.62–1.39)             | 0.71                | 1.74<br>(0.87–3.49)                   | 0.12                | 1.81<br>(1.19–2.73)                                                      | <0.01               | 1.38<br>(0.88–2.14)                    | 0.16                | 2.40<br>(0.87–6.58)                         | 0.09                | 1.11<br>(0.73–1.70)                           | 0.62                |
|                          | 80s           | 0.90<br>(0.47–1.70)                  | 0.74                | 0.75<br>(0.44–1.26)             | 0.28                | 5.35<br>(2.59–11.05)                  | <0.01               | 3.02<br>(1.81–5.06)                                                      | <0.01               | 2.91<br>(1.72–4.93)                    | <0.01               | 10.46<br>(3.85–28.36)                       | <0.01               | 2.10<br>(1.26–3.51)                           | <0.01               |
| Exposure variable        |               | ad OR<br>(95% CI)                    | <i>p</i> -<br>value | ad OR<br>(95% CI)               | <i>p</i> -<br>value | ad OR<br>(95% CI)                     | <i>p</i> -<br>value | ad OR<br>(95% CI)                                                        | <i>p</i> -<br>value | ad OR<br>(95% CI)                      | <i>p</i> -<br>value | ad OR<br>(95% CI)                           | <i>p</i> -<br>value | ad OR<br>(95% CI)                             | <i>p</i> -<br>value |
| Multivariable<br>model 1 | 40s           | 0.30<br>(0.09–1.06)                  | 0.06                | 0.45<br>(0.21–0.99)             | <0.05               | 0.25<br>(0.05–1.16)                   | 0.08                | 0.81<br>(0.39–1.68)                                                      | 0.57                | 0.13<br>(0.03–0.57)                    | <0.01               | 2.71<br>(0.60–12.29)                        | 0.20                | 0.81<br>(0.38–1.72)                           | 0.58                |
|                          | 50s           | 0.31<br>(0.11–0.87)                  | 0.03                | 0.66<br>(0.35–1.27)             | 0.21                |                                       |                     | 0.79<br>(0.41–1.53)                                                      | 0.49                | 0.55<br>(0.24–1.30)                    | 0.17                | 2.16<br>(0.48–9.68)                         | 0.32                | 1.32<br>(0.69–2.52)                           | 0.41                |
|                          | 60s<br>(ref.) |                                      |                     |                                 |                     |                                       |                     |                                                                          |                     |                                        |                     |                                             |                     |                                               |                     |
|                          | 70s           | 1.11<br>(0.68–1.84)                  | 0.67                | 0.88<br>(0.58–1.32)             | 0.54                | 1.64<br>(0.81–3.32)                   | 0.17                | 1.79<br>(1.17–2.73)                                                      | <0.01               | 1.33<br>(0.84–2.11)                    | 0.22                | 2.28<br>(0.82–6.33)                         | 0.11                | 1.02<br>(0.66–1.58)                           | 0.92                |
|                          | 80s           | 0.84<br>(0.44–1.63)                  | 0.61                | 0.70<br>(0.41–1.20)             | 0.19                | 4.98<br>(2.39–10.40)                  | <0.01               | 3.16<br>(1.86–5.34)                                                      | <0.01               | 2.79<br>(1.61–4.81)                    | <0.01               | 9.59<br>(3.50–26.29)                        | <0.01               | 1.91<br>(1.13–3.23)                           | 0.02                |
| Multivariable<br>model 2 | 40s           | 0.34<br>(0.10–1.22)                  | 0.10                | 0.45<br>(0.20–0.99)             | <0.05               | 0.60<br>(0.12–3.06)                   | 0.54                | 0.82<br>(0.39–1.73)                                                      | 0.61                | 0.14<br>(0.03–0.60)                    | <0.01               | 10.91<br>(1.94–61.17)                       | <0.01               | 0.83<br>(0.38–1.80)                           | 0.64                |
|                          | 50s           | 0.35<br>(0.12–0.98)                  | <0.05               | 0.66<br>(0.34–1.27)             | 0.21                |                                       |                     | 0.84<br>(0.43–1.64)                                                      | 0.60                | 0.58<br>(0.25–1.38)                    | 0.22                | 10.15<br>(1.85–55.78)                       | <0.01               | 1.37<br>(0.71–2.65)                           | 0.34                |
|                          | 60s<br>(ref.) |                                      |                     |                                 |                     |                                       |                     |                                                                          |                     |                                        |                     |                                             |                     |                                               |                     |
|                          | 70s           | 1.08<br>(0.65–1.79)                  | 0.76                | 0.88<br>(0.58–1.33)             | 0.55                | 1.27<br>(0.56–2.87)                   | 0.57                | 1.70<br>(1.11–2.60)                                                      | 0.02                | 1.30<br>(0.82–2.07)                    | 0.27                | 1.75<br>(0.55–5.63)                         | 0.35                | 1.00<br>(0.64–1.55)                           | 0.99                |
|                          | 80s           | 0.74<br>(0.37–1.49)                  | 0.41                | 0.71<br>(0.41–1.24)             | 0.22                | 1.70<br>(0.68–4.23)                   | 0.26                | 2.54<br>(1.47–4.41)                                                      | <0.01               | 2.57<br>(1.45–4.56)                    | <0.01               | 3.61<br>(1.11–11.76)                        | 0.03                | 1.72<br>(1.00–3.00)                           | 0.05                |

Model 1 was adjusted for sex, body mass index, and number of comorbidities, respectively.

Model 2 was adjusted for the number of natural teeth and regular dental checkups in addition to the adjustment variables of Model 1, respectively.

Abbreviation: OR, odds ratio; CI, confidence interval; ref., reference; ad OR, adjusted odds ratio.