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Differences in oral hypofunction prevalence and category measures across age groups and sex in Japan: a pilot study

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Abstract

Objectives The deterioration of oral function to a state of oral hypofunction (OHF) has been associated with malnutrition and frailty. This cross-sectional pilot study investigated for differences in OHF prevalence and its category measures across age groups and sex, as well as their associations with physical function.

Methods A total of 155 healthy adults (median age: 55 years, range: 22–89 years) participated in this study after providing informed consent. The cohort was age and sex matched. Seven oral function measures based on the concept of OHF were assessed: oral hygiene (Hygiene), oral dryness, maximum occlusal force (MOF), lip-tongue motor function (LTMF), maximum tongue pressure (MTP), masticatory function, and swallowing function. Hand grip strength (HGS) was also measured. The participants were divided into the young (20–39 years), middle (40–64 years), and old (≥65 years) age groups for linear regression analysis of differences in oral and physical function. Differences in OHF prevalence were tested by the chi-square test.

Results The prevalence of OHF was significantly higher in the old group than in the young and middle groups. Such OHF measures as Hygiene, MTP, LTMF, and MOF were significantly worse in the old group as well. The measures of Hygiene and LTMF showed a moderate correlation with age in the multiple regression model (standardized partial regression coefficient, $\beta = 0.24$ and -0.19, respectively). HGS was significantly associated with MTP ($\beta = 0.58$, $p < 0.001$) and LTMF ($\beta = 0.38$, $p = 0.002$) in both male and female participants.

Conclusions Our findings suggest that OHF prevalence increases with age, especially after 65 years old. However, the pathological route may vary among OHF categories.

Keywords Oral hypofunction, Physical function, Aging

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Background

Oral function significantly impacts nutrition as masticatory and swallowing functions are key elements in digestion [1–4]. A decline in oral function can cause deviations in nutritional intake, such as avoiding hard-textured foods and choosing a softer diet. This altered nutritional state can eventually lead to malnutrition, a primary cause of physical frailty [5]. Poor oral health also influences social activities, often impeding individuals from dining out with friends or family members, which can result in social frailty [6, 7]. Thus, a decline in oral function is considered the starting point of general frailty

[8]. Identifying and ameliorating oral frailty may help contribute to healthy longevity.

Mastication involves comprehensive movements of the oral apparatuses [9]. Ingested food is reduced in size by biting with the jaw and teeth, aided by tongue movements and buccal contraction. The hyoid bone moves cyclically in association with jaw movements. The crushed food is mixed with the saliva to form a bolus, which is propelled in to the oropharynx by the tongue's squeeze-back motion, and accumulates in the valleculae until swallowing is initiated. The motion of these apparatuses is temporally linked during eating and speaking [10].

The deterioration of oral function can easily be overlooked since one function often compensates for others during eating. Quantitative assessment of the decline in specific oral functions is therefore crucial for monitoring oral condition and preserving oral health. The concept of "Oral Hypofunction" was proposed by the Japanese Society of Gerodontology to describe oral function deterioration and draw attention to oral function decline in older adults [11]. Oral hypofunction (OHF) comprises seven sub-symptoms and is diagnosed if at least three symptoms meet the cut-off criteria. The prevalence of OHF in older patients has recently been reported [12], which may help with its application in the clinical setting. By examining OHF quantitatively at a dental clinic, both the examiner and patient can understand the patient's current oral status, enabling prompt intervention in the early stages of oral function deterioration.

It is widely recognized that physical strength, often represented by hand grip strength (HGS) and skeletal muscle mass, declines with age [13, 14]. As those variables tend to decrease in the older population, they are routinely used as indicators for sarcopenia. Although normative data for physical strength and body composition are abundant [13], few reports have investigated oral function across the adult lifespan. Some oral functions, such as tongue pressure across lifespan, were evaluated in several countries [15–17], but not all of the OHF categories have been examined apart from in older populations. We have hypothesized that although oral function decreases with age, the pathological pathway may vary among OHF categories. To test this notion, the present cross-sectional study investigated for differences in OHF prevalence and its category measures across age groups and sex, as well as their associations with physical function.

Methods

Participants

This study's protocol was approved by the Institutional Review Board of Tokyo Medical and Dental University (Approval ID: D2022-053–01). We recruited healthy asymptomatic adults in 10-year age segments from the 20's to the 80's for both male and female participants, respectively, from the community using advertising flyers distributed in public spaces. The flyers were placed in local buses, a local community center near the institute, and a dental university hospital. An advertisement was run in a local community newspaper as well. Additional participants were recruited by contacting acquaintances and friends outside of the dental field. The majority of potential participants were instructed to visit the measurement site on one of two designated days. Although the number of potential participants was controlled by the research administrative office, cancellations often occurred before or on the day of measurement. If the number of participants was insufficient in a segment, additional recruitment was conducted at the dental university hospital. The inclusion criteria were healthy individuals over 20 years of age who could take part in the trial and had no pain or complaints regarding oral health at the time of participation. The exclusion criteria were neurological disorders, cognitive decline, and severe dysphagia. All participants provided written informed consent prior to enrollment in this investigation.

Based on previous reports [15, 16], we hypothesized a decline in OHF category measures in the elderly across age groups and sex. Assuming a mean difference of five among the groups and a standard deviation of 10, with $\alpha = 0.05$ and $\beta = 0.80$, the required sample size was calculated to be 128. Therefore, we recruited a cohort of 140. The target size was 10 participants in each 10-year age segment for both male and female participants.

Measures

Oral function

OHF was proposed by the Japanese Society of Gerodontology in 2016 as the integrated deterioration of several oral functions. The measurement details and OHF cut-off thresholds are described in a previous report [11] and summarized below and in Table 1. OHF was diagnosed as meeting at least 3 of the 7 oral sub-symptom criteria.

(1) Oral hygiene (Hygiene): A sterilized swab was swiped 3 times in a 10 mm swath on the middle of the dorsal tongue surface and then placed in distilled water into a bacteria detection apparatus (Bacteria counter; Panasonic Healthcare, Tokyo, Japan) [18, 19]. Bacteria number was counted 3 times, and the calculated means were log transformed.
(2) Oral dryness (Dryness): The wetness of the buccal mucosal surface was measured by an oral moisture checker (Mucus; Life Co., Ltd., Saitama, Japan) [20, 21]. The sensor of the instrument was attached to the right-side buccal surface of the participant for

Table 1 Seven oral sub-symptoms of oral hypofunction and their cut-off criteria

Oral sub-symptom	Cut-off criterion
Oral hygiene (Hygiene)	Total number of bacteria > $10^{6.5}$ CFU/mL
Oral dryness (Dryness)	Measured value with a moisture checker < 27.0
Maximum occlusal force (MOF)	Occlusal force < 200 N
Lip-tongue motor function (LTMF)	Utterance count of /pa/, /ta/, or /ka/ < 6/s
Maximum tongue pressure (MTP)	Maximum tongue pressure < 30 kPa
Masticatory function (Mast-F)	Glucose concentration in chewing test < 100 mg/dL
Swallowing function (Swal-F)	Total Eating Assessment Tool (EAT-10) score ≥ 3

2 s, and the degree of oral wetness was measured in triplicate at the same site for calculation of mean values.

(3) Maximum occlusal force (MOF): Occlusal force was measured by 3 s of clenching using pressure-indicating film (Dental Prescale II; GC Corp., Tokyo, Japan) [22]. The area of changed color on the sheet caused by clenching was measured by analysis software, calculated as occlusal force, and log transformed for analysis.
(4) Lip-tongue motor function (LTMF): Participants were instructed to say the syllables /pa/, /ta/, or /ka/ as many times as possible within 5 s. The number of utterances was counted by a digital counter (Kenkokun Handy; Takei Scientific Instruments Co., Ltd., Niigata, Japan) [23]. The minimum number per second for /pa/, /ta/, and /ka/ utterances was calculated and used for analysis.
(5) Maximum tongue pressure (MTP): A tongue pressure sensor balloon probe connected to a digital tongue pressure meter (JMS tongue pressure measuring instrument TPM-01; JMS Co. Ltd., Hiroshima, Japan) was placed on the dorsal tongue surface [15]. Participants were asked to press up against the probe with the tongue towards the hard palate at maximum strength for 3 s. After several practice movements, tongue pressure was assessed 3 times for calculation of mean values.
(6) Masticatory function (Mast-F): Masticatory function was measured using a gummy jelly. Participants were instructed to chew 2 g of gummy jelly without swallowing the bolus or saliva for 20 s. They were then asked to hold 10 mL of distilled water in their mouth and spit out the jelly and water into a cup fitted with a funneled mesh. The amount of eluted glucose was measured with a masticatory ability testing system (Gluco Sensor GS-II; GC Corp. Tokyo, Japan) [24].
(7) Swallowing function (Swal-F): Swallowing function was assessed by a self-administered questionnaire for swallowing (10-item Eating Assessment Tool; EAT-10) and expressed as a numerical score from 0 to 40 [25].

Physical properties and activities

(1) Body composition: Body mass index was calculated from measured height and weight for analysis. Body composition was measured by bioelectrical impedance analysis using an In Body 470 device (In Body Japan Inc., Tokyo, Japan). Participants stood on the apparatus during measurements. Appendicular muscle mass was divided by the square of the subject's height and used for calculation of skeletal muscle mass index (SMI). Body fat percentage was determined as well.
(2) HGS: Measurements were carried out in triplicate for each hand with a digital hand dynamometer (Grip-D; Takei Instruments, Niigata, Japan). The maximum HGS in the trials for both hands were used for analysis.

Data analysis

Associations between oral function and physical function

To examine the association between oral function and physical function, simple correlation coefficients were calculated for bivariate analysis. Given the high collinearity between HGS and SMI, HGS was selected for multivariate analysis, for which multiple linear regression was employed. In the regression model, oral function was designated as the dependent variable, while age, sex, number of teeth, and HGS were set as independent variables. The age groups were established as the young group (20 to 39 years), middle group (40 to 64 years), and old group (65 years and older) for statistical analysis.

Differences in oral function were scrutinized using one-way ANOVA segmented by age group and sex. If the main effect was significant, Tukey's test was utilized for multiple comparisons. The proportions of participants who met the criteria for each OHF sub-symptom and overall OHF were calculated. Differences in the proportion of OHF among age groups and sex were evaluated using the chi-square test.

The critical value for rejecting the null hypothesis was $P < 0.05$. Statistical analyses were performed using IBM SPSS Statistics 28.0 software (IBM, Armonk, NY, USA).

Results

A total of 155 participants (median age: 55 years, range: 22 to 89 years) completed the measurements (Table 2). In the multiple linear regression analysis (Table 3), all dependent variables were significantly associated with Hygiene and LTMF. For MTP, only HGS showed a strong correlation. Regarding MOF and Mast-F, the number of teeth was moderately correlated, with no significant correlations for the other factors. For Dryness and Swal-F, no significant contributors were identified by the regression model.

In the analysis of differences among age groups with ANOVA, the categories of LTMF, MTP, and MOF were significantly lower in the old group than in the other two groups, and were also lower in women except for LTMF (Table 4). Hygiene also increased with age, with significant differences between the young and old groups. No significant differences were observed for the mean values of Dryness, Mast-F, or Swal-F among the three age groups or by sex.

The proportion of participants who met the criteria for each and overall OHF symptoms is shown in Table 5. For MTP and LTMF, the prevalence of test-positive was significantly higher in the older group for both male and female participants. For Hygiene, the prevalence of test-positive was remarkably high across all three groups. The prevalence of OHF was over 50% for both sexes in the old group, which was significantly higher than in the other groups.

Table 2 Distribution of participants in the age categories

	Age group (years)	Male	Female	Total
Young	20	11	10	21
	30	12	10	22
	40	11	10	21
Middle	50	11	14	25
	60	10	14	24
Old	70	10	13	23
	80	9	10	19
Total		74	81	155

Discussion

The current study examined the age-related differences in OHF and its category measures across age groups and sex in accordance with the criteria for OHF, in addition to their association with physical function. We observed that oral function was significantly influenced by both age and sex, although the effects varied among the measured factors. Our findings suggest that tongue strength and motor function are more closely associated with physical strength as represented by HGS, while the number of teeth may exert a greater influence on occlusal force and masticatory function. In terms of gender differences, tongue pressure and occlusal force were higher in men, while pronunciation performance was superior in women. Our results also indicate that the decline in oral function does not progress linearly with age; rather, it is generally preserved until middle age and then diminishes remarkably over the age of 65 years. The associations with HGS and the number of teeth were also different among the measured oral functions. MTP and LTMF showed moderate correlations with HGS, a representative of physical strength. Physical decline may influence oral muscle strength and motor function [2]. On the

Table 3 Multiple linear regression analysis of oral functions

	Hygiene		Dryness		MTP		LTMF		MOF		Mast-F		Swal-F	
R^2	**0.111**		**0.009**		**0.309**		**0.271**		**0.292**		**0.081**		**0.037**	
	Std.β	***P* value**	**Std.β**	***P* value**	**Std.β**	***P* value**	**Std.β**	***P* value**	**Std.β**	***P* value**	**Std.β**	***P* value**	**Std.β**	***P* value**
Sex	-0.312	***0.014***	0.141	0.286	0.135	0.223	0.422	***< 0.001***	-0.082	0.461	0.038	0.763	0.089	0.496
Age	0.240	***0.012***	0.046	0.642	-0.042	0.614	-0.185	***0.032***	-0.094	0.263	0.039	0.682	0.156	0.115
No. of teeth	0.230	***0.011***	0.024	0.799	0.127	0.107	0.225	***0.006***	0.379	***< 0.001***	0.278	***0.002***	0.088	0.345
HGS	-0.270	***0.045***	0.090	0.525	0.578	***< 0.001***	0.378	***0.002***	0.166	0.165	0.087	0.525	-0.040	0.776

MTP Maximum tongue pressure, *LTMF* Lip-tongue motor function, *MOF* Maximum occlusal force, *Mast-F* Masticatory function, *Swal-F* Swallowing function, *HGS* Hand grip strength, Bold indicates significant correlation ($P < 0.05$)

Table 4 Mean (standard deviation [SD]) values for oral function by age and sex

	Young		Middle		Old		*P* value		
	Mean	SD	Mean	SD	Mean	SD	Age	Sex	Age x Sex
Hygiene	6.90	(0.54)	7.10	(0.48)	7.20	(0.34)	***0.006***[a]	0.091	0.390
	6.85	(0.49)	6.91	(0.51)	7.06	(0.60)			
Dryness	28.4	(5.7)	27.9	(2.3)	28.7	(2.2)	0.986	0.354	0.770
	28.7	(3.0)	29.2	(2.0)	28.6	(3.2)			
MTP	41.8	(6.9)	39.4	(8.1)	33.2	(9.3)	***< 0.001***[a,b]	***< 0.001***	0.911
	34.5	(9.5)	35.9	(9.9)	26.5	(8.3)			
LTMF	32.2	(3.9)	29.7	(4.5)	28.0	(2.7)	***< 0.001***[a,b]	0.146	0.096
	32.7	(3.3)	31.6	(2.7)	28.7	(3.7)			
MOF	2.99	(0.23)	2.85	(0.33)	2.68	(0.32)	***< 0.001***[a,b]	***0.003***	0.738
	2.80	(0.22)	2.78	(0.24)	2.58	(0.28)			
Mast-F	196.7	(62.2)	176.7	(67.5)	170.9	(81.7)	0.182	0.482	0.340
	188.3	(50.8)	183.9	(45.4)	160.1	(69.8)			
Swal-F	0.2	(0.7)	0.2	(0.6)	0.4	(0.8)	0.061	0.152	0.204
	0.3	(1.1)	0.6	(1.8)	2.0	(5.8)			
HGS	42.4	(7.0)	37.6	(3.8)	31.6	(6.4)	***< 0.001***[a,b]	***< 0.001***	0.083
	25.8	(4.5)	24.7	(3.5)	20.7	(4.3)			

Bold indicates significant differences ($P < 0.05$)

MTP Maximum tongue pressure, *LTMF* Lip-tongue motor function, *MOF* Maximum occlusal force, *Mast-F* Masticatory function, *Swal-F* Swallowing function, *HGS* Hand grip strength

[a] young vs. old

[b] middle vs. old

Table 5 Proportion of participants meeting the criteria for individual and overall OHF symptoms

		Young		Middle		Old		Total		*P* value
		N	(%)	N	(%)	N	(%)	N	(%)	
Oral Hygiene	Male	20	87.0%	23	85.2%	23	95.8%	66	89.2%	0.435
	Female	12	60.0%	28	90.3%	26	86.7%	66	81.5%	***0.016***
Oral Dryness	Male	5	21.7%	6	22.2%	6	25.0%	17	23.0%	0.959
	Female	1	5.0%	7	22.6%	9	30.0%	17	21.0%	0.100
MTP	Male	2	8.7%	2	7.4%	7	29.2%	11	14.9%	0.056
	Female	6	30.0%	8	25.8%	17	56.7%	31	38.3%	***0.032***
LTMF	Male	6	26.1%	8	29.6%	16	66.7%	30	40.5%	***0.006***
	Female	6	30.0%	5	16.1%	15	50.0%	26	32.1%	***0.018***
MOF	Male	2	8.7%	3	11.1%	7	29.2%	12	16.2%	0.109
	Female	4	20.0%	2	6.5%	7	23.3%	13	16.0%	0.171
Mast-F	Male	0	0.0%	3	11.1%	4	16.7%	7	9.5%	0.139
	Female	2	10.0%	0	0.0%	5	16.7%	7	8.6%	0.066
Swal-F	Male	1	4.3%	0	0.0%	0	0.0%	1	1.4%	0.139
	Female	1	5.0%	0	0.0%	4	13.3%	5	6.2%	0.066
OHF	Male	5	21.7%	5	18.5%	13	54.2%	23	31.1%	***0.012***
	Female	4	20.0%	6	19.4%	18	60.0%	28	34.6%	***0.001***

Bold indicates significant differences ($P < 0.05$)

MTP Maximum tongue pressure, *LTMF* Lip-tongue motor function, *MOF* Maximum occlusal force, *Mast-F* Masticatory function, *Swal-F* Swallowing function, *OHF* Oral hypofunction other hand, MOF and Mast-F showed mild correlations with the number of teeth but not with HGS, which indicated that masticatory performance was more influenced by tooth loss than by physical strength, as reported previously [26, 27]. Oral dryness and Swal-F showed no significant correlations with the number of teeth or HGS. These factors may be more independent from tooth number or physical strength, instead being more influenced by systemic diseases and medications, which increase in older age. The findings from this investigation may have clinical implications for determining the optimal timing of OHF evaluation towards prompt intervention in the early stages of oral function decline.

As limitations, the present study included a small cohort but spanned a wide age range, starting from 20 years old. Moreover, physical strength and body composition can vary significantly among different countries and ethnicities [13, 28]. For instance, the diagnostic criteria for sarcopenia differ between Europe and Asia [29, 30]. Tongue pressure measurements also vary between Japan, Europe and the United States [15–17], with lower values typically observed in Japan, despite the use of different measurement devices. Consequently, while our findings provide normative data on oral function across a broad age range, their applicability may be limited to Japan or East Asia. Further studies incorporating data from other countries are warranted to better understand global variation [13]. Another potential limitation of this study was that the participants were relatively healthy as they were recruited through flyers distributed in public spaces. This recruitment method may have attracted individuals with a particular interest in oral function and possessing a higher level of oral health literacy, which possibly influenced the study results. Furthermore, the excess in participants in some segments might have affected the results of the analysis, although this influence was considered relatively minor due to their small numbers.

We witnessed that MTP was approximately 20% lower in the old group than in the young group. MTP also showed a strong correlation with HGS. Our results align with previous studies demonstrating a significant decline in MTP in individuals over the age of 65 years [15]. Given that the tongue is a mass of muscles representing oral muscle strength, lower tongue strength has been associated with diminished eating function and dietary level in older adults at nursing care facilities [31, 32]. Tongue strength also influences swallowing, thereby implicating reduced tongue pressure as a risk factor for sarcopenic dysphagia [33]. Age-related declines in functional reserve, frailty, and sarcopenia have been linked to adverse health outcomes. We observed that oral muscle strength was somewhat correlated with physical strength across the different age categories; thus, preserving tongue strength may contribute to preventing oral frailty and promoting a healthy diet in the later stages of life.

LTMF was significantly correlated with age, sex, number of teeth, and HGS in the multiple regression analysis. Articulation involves complex movements of the lips and/or tongue along with the jaw and phonation. Although speaking and eating utilize the same oral cavity, the control mechanisms for the tongue and jaw differ significantly between those activities, where tongue motion is more independent from jaw motion in speech [10]. LTMF showed a moderate correlation with HGS as well in our study. LTMF is indicative of general oral motor function and serves as a marker for oral frailty [8]. It should be noted that the relationship between LTMF and HGS does not represent a direct pathway. However, physical and oral muscle functions may exhibit similar patterns as influenced by age and sex.

In contrast to MTP and LTMF, MOF and Mast-F scores were more closely associated with the number of teeth rather than age itself and were not significantly related to HGS. Past studies are consistent with our results on the slight effects of gender and age in relation to masticatory performance, while the number of teeth is highly associated with masticatory function and occlusal force [26, 27]. Regardless of the age, occlusal force and masticatory function may be conserved if tooth number is properly maintained.

Lastly, the prevalence of OHF and its sub-symptoms increased with age in this investigation. The cut-off values for each measure were initially established in a foundational report [11] that drew on data from earlier sources. Generally, the prevalence of OHF was lower in the young group and higher in the old group, reflecting an age-related decline in oral function. In the young group, approximately 20% met the criteria for OHF as compared with 60% in the old group, as similarly reported [34]. OHF measures such as MTP and LTMF, which represent oral muscle strength and motor function, respectively, displayed increased prevalence in the old population. The proportion of individuals meeting the OHF criteria for MOF was also higher in the old group, likely influenced by the lower number of teeth in this subgroup. Notably, most participants in this study met the OHF criteria for Hygiene. Although bacterial count tended to increase with age, it met the established cut-off even in the young group, which indicated a low specificity in for excluding a normal level of oral hygiene. It may therefore be necessary to reconsider the threshold for bacterial count to increase the specificity of the examination for deteriorated oral hygiene in the OHF criteria.

Conclusion

Our study demonstrated an age-related increase in the prevalence of OHF along with age- and sex-related differences in multiple oral function categories that varied across parameters. Whereas tongue strength and motor function correlated significantly with age, occlusal force and masticatory function were more strongly influenced by the number of teeth than by age alone. Our findings may help determine the optimal timing for OHF evaluation and enable prompt intervention in the early OHF stages.

Authors' contributions
Study design and conceptualization: KM, MK, MS, Statistical analysis: KM, Interpretation of data: KM, Drafting and revision of manuscript: RH, KM, Review of manuscript: All authors approved the final version of the manuscript.

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Data availability
The data that support the findings of this study are available from the corresponding author (KM) upon reasonable request.

Declarations

Ethics approval and consent to participate
This study's protocol was approved by the Institutional Review Board of Tokyo Medical and Dental University (Approval ID: D2022-053–01). Informed consent was obtained from all participants involved in the study.

Consent for publication
Not applicable.

Competing interests
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