Population-based reference values for tongue pressure in Japanese older adults: A pooled analysis of over 5,000 participants

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1. Introduction

Tongue pressure (TP), a quantitative evaluation of tongue function[1], is an objective indicator of oral function. Low TP was associated with low swallowing function[2], which can decrease food consumption and lead to malnutrition[3]. It has also been demonstrated that TP can predict adverse health outcomes, such as physical frailty and sarcopenia, among community-dwelling older adults[4]. This evidence highlights the importance of maintaining adequate TP for longevity.

TP has also been used to define oral frailty[4] and oral hypofunction[5]. Oral frailty presents as a series of phenomena and processes characterized by gradual loss of oral function accompanied by a de-
creased interest in oral health and physical and mental reserve capacity, leading to deterioration in eating function and physical and mental disorders[6]. In the research setting, oral frailty is defined operationally by accumulated deficits in oral health and function[4]. On the other hand, oral hypofunction is a 7-component phenotype based on the clinical features of oral health that was introduced by the Japanese Society of Gerodontology[5]. In Japan, the examination and management of oral hypofunction is covered by the National Health Insurance program.

A reference value for TP can be used to determine cutoff values indicating its relationship with adverse health outcomes, as described above. Furthermore, based on the age- and sex-specific population reference values of TP, the cutoff value of oral hypofunction diagnosis will be subject to further deliberation. Additionally, information on the reference value for TP may be valuable to clinicians for monitoring oral function and evaluating the effectiveness of management and interventions for oral function. Utanohara et al.[7] reported the standard value of TP in a Japanese population. However, their study only included approximately 200 individuals aged ≥60 years with occlusal contacts of the posterior natural teeth and without poor swallowing function[7]. Recently, a systematic review and meta-analysis was performed for TP[8]. However, no age-specific values for the older population were provided. Information on TP among older Japanese adults that is more detailed and generalizable is required. In addition, age-related changes in TP were not fully investigated. Whether these changes differed according to sex was not fully investigated. Such information will be important for further understanding oral function.

In this study, we aimed to determine age- and sex-specific population reference values for TP in community-dwelling Japanese older adults using a pooled dataset from four large-scale cohort studies with over 5,000 participants. The results will be useful in the clinical evaluation of oral function and future international comparison studies. Our secondary aim was to investigate cross-sectional, age-related changes in TP according to sex.

2. Materials and Methods

2.1. Study design and data sources

For this pooled analysis, we included data collected from four population-based cohort studies: the Otassha Study, the Kusatsu Longitudinal Study, the Kashiwa Study, and the Takashimadaira Study. The designs and protocols of each study have been described in detail elsewhere[9–12]. TP was assessed in 2018–2020 for the Otassha Study. In 2017–18 for the Kusatsu Longitudinal Study, in 2012 for the Kashiwa Study, and in 2016 for the Takashimadaira Study. The data collected at the time points described above were integrated and used for the present study. When a study measured TP more than once in participants with continuous participation in the cohort study, we discarded the measurement at first participation.

Data sources were included in the pooled analysis if they met the following criteria:

- study participants were community-dwelling adults aged ≥65 years of age[9–12]; and
- TP data were collected using standardized methods of measurement.

We excluded data from individuals who did not complete the examinations or had incomplete data.

The Otassha Study[9] targeted adults aged ≥65 years who were listed in the basic resident register of areas surrounding the Tokyo Metropolitan Institute of Gerontology in Itabashi ward, northwest Tokyo, Japan. The Kusatsu Longitudinal Study[10] targeted the residents of Kusatsu town, a rural community in northwest Gunma Prefecture, Japan, who were National Health Insurance subscribers aged 65–74 years and individuals 75 years or older in the Medical Insurance System for the Elderly Aged 75 or Over. The Kashiwa Study[11] targeted individuals aged ≥65 years who were randomly selected from the resident registry of Kashiwa, a city where Japanese urban and rural communities intermingle. The Takashimadaira Study[12] targeted adults aged ≥70 years who were listed in the basic resident register of the Takashimadaira area, Itabashi ward, Tokyo, Japan. Institutionalized individuals were excluded at recruitment in the above four studies.

All studies included in the pooled analysis were conducted in full accordance with the ethical principles of the Declaration of Helsinki and were approved by the Ethics Committee of the Tokyo Metropolitan Institute of Gerontology for the Otassha Study, the Kusatsu Longitudinal Study, and the Takashimadaira Study or Graduate School of Medicine, The University of Tokyo, for the Kashiwa Study. All participants provided written informed consent prior to participating. No separate ethics approval was required for this secondary analysis.

2.2. Measurement of TP

TP was measured using a JMS tongue pressure measuring de-
vice (TPM-01, JMS Co., Ltd., Hiroshima, Japan[1]). This device consists of a probe, connecting tube, and main body (Fig. 1). The probe has a 25-mm long and 15-mm wide balloon. The part of the probe that the subjects grip has a plastic cylinder that allows them to hold the probe in the correct position. For the TP measurement, participants were asked to sit in a relaxed position, place the balloon in their mouth and hold the plastic cylinder at the midpoint of the central incisors with their lips closed. The examiners also held the probe to keep it in the correct position. Participants were then asked to raise their tongue and compress the balloon against the hard palate for 7 seconds at maximum voluntary effort[13]. The maximum pressure value was recorded in kPa. Dentures, when used, were allowed during the measurement. Measurements were carried out three times at 1-minute intervals, and the average value of the three measurements was used for the analysis. TP measurements were performed by qualified examiners who received 2 hours of instruction and training from the authors (H.H., M.S., and Y.O.) according appropriate methods of data collection for TP measurements.

### 2.3. Assessment of oral health status

Determination of the number of natural teeth and functional teeth and denture use was carried out by qualified dentists and dental hygienists. The number of natural teeth was defined as the number of remaining teeth, excluding residual roots. The number of functional teeth was defined as the number of natural teeth, artificial teeth in dentures, pontics on bridges, and implants[14].

Anthropometric measures included weight and height. Body mass index (BMI) was calculated by dividing weight in kilograms by height squared in meters.

Comorbidities, including hypertension, stroke, heart disease, diabetes mellitus, dyslipidemia, osteoporosis, and cancer were identified through medical interviews.

### 2.4. Data collection for other variables

Data on the participants’ age, sex, education status (years of education), smoking status (never smoked, previously smoked, and currently smoking), and alcohol consumption status (never drunk, previously drank, and currently drinking alcohol) were obtained through a self-administered questionnaire.

### 2.5. Statistical analyses

We employed skewness and kurtosis tests to check the normality of the data. We then employed t tests, Mann-Whitney U-tests, or chi-squared tests, as appropriate, to compare the characteristics of the male and female study populations. If the overall test was significant for variables that had ≥3 categories (i.e., smoking status, alcohol consumption status, and cohort study membership), post hoc comparisons were performed.

We tabulated the mean and standard deviation (SD) TP per 5-year age group (65–69, 70–74, 75–79, 80–84, and ≥85 years) for each sex. We performed the Jonckheere-Terpstra trend test to evaluate linear trends in the mean TPs across age groups for each sex. We also tested sex differences in TP according to the 5-year age group using t tests. We further calculated the deciles (10th – 90th percentiles) of TP per 5 years for each sex. Quartiles (25th, 50th, and 75th percentile) of TP per 5 years for each sex were also calculated. In addition, deciles of TP were calculated among those without a history of stroke.

Linear regression analysis was performed to examine the associations among TP, age, and sex. We tested the polynomial term of age in a regression model to explore the nonlinear association of age with TP. We also tested whether sex differences in TP changed with age by adding the interaction of age and sex in the regression model.

Finally, we performed random-effects meta-analyses to examine between-study heterogeneity by age group and sex with Cochran’s Q and I².

Analyses were performed with the statistical software package STATA, version 17.0 (StataCorp, College Station, USA). Other than for the multiple tests for sex differences in TP according to 5-year age groups, the level of significance (two-tailed test) was set to 0.05. The level of significance was adjusted by the Bonferroni method to avoid a type I error when conducting multiple tests for sex differences in TP by age group.

### 3. Results

#### 3.1. Study population characteristics

In total, 5,390 community-dwelling older adults aged ≥65 years (1,191 from the Otassha Study, 907 from the Kusatsu Longitudinal Study, 2,044 from the Kashiwa Study, and 1,248 from the Takashimadaira Study) were identified. We excluded 307 of these individuals (88 from the Otassha Study, 121 from the Kusatsu Longitudinal Study, 11 from the Kashiwa Study, and 87 from the Takashimadaira Study) due to missing data. The remaining 5,083 individuals (2,150 men and 2,933 women, with a mean [SD] age of 75.2 [6.5] years) were included in the present analysis.

Table 1 presents the characteristics of the participants according to sex. Overall, the male participants had larger TP values than the female participants. In addition, males had a greater number of natural teeth and functional teeth; were younger; had more years of education; and had larger height, weight, and BMI values than females. The proportions of current smokers, previous smokers, and current drinkers were higher, and the proportions of participants with no drinking history and underweight were lower among males than females. Regarding comorbidities, hypertension, stroke, heart disease, and cancer were observed more frequently among males, while dyslipidemia and osteoporosis were observed more frequently among females.

In male participants, the mean (SD) TPs for ages 65–69, 70–74, 75–79, 80–84, and ≥85 years were 34.0 (8.4), 32.2 (8.1), 30.8 (8.3), 28.4 (8.9), and 24.4 (8.2) kPa, respectively. In female participants, the corresponding values were 31.5 (7.1), 30.5 (7.5), 29.6 (8.3), 28.4 (8.0), and 26.4 (7.6) kPa, respectively (Table 2). For both sexes, there were significant declining trends in TP with increasing age. Between-sex differences were observed at 65–69, 70–74, and 75–79 years but not at 80–84 or ≥85 years.

Table 3 presents deciles of TP according to age group and sex, with apparent declining trends with advancing age among both sexes. When excluding those with a history of stroke, TP values became slightly larger regardless of age category or sex (Supplementary
Table 1. Study population characteristics by sex

| | Total | Women | Men | p-value |
|---|---|---|---|---|
| Tongue pressure (kPa)* | 30.3 (8.2) | 29.6 (7.6) | 31.2 (8.7) | <0.001 |
| n of natural teeth† | 23 (13–27) | 22 (13–27) | 23 (14–27) | 0.011 |
| n of functional teeth‡ | 28 (27–28) | 28 (27–28) | 28 (27–28) | <0.001 |
| Denture use§ | 3,105 (61.1%) | 1,766 (60.2%) | 1,339 (62.3%) | 0.140 |
| Age* | 75.2 (6.5) | 75.7 (6.7) | 74.5 (6.1) | <0.001 |
| Years of education† | 12 (11–14) | 12 (10–13) | 13 (12–16) | <0.001 |
| Smoking status‡ | 3,192 (62.8%) | 2,565 (87.5%) | 627 (29.2%) | <0.001 |
| Alcohol consumption status‡ | 2,362 (45.8%) | 1,850 (63.1%) | 476 (22.1%) | <0.001 |
| Height (cm)* | 156.1 (8.9) | 150.3 (5.8) | 163.9 (6.0) | <0.001 |
| Body weight (kg)* | 55.9 (10.5) | 50.8 (8.3) | 62.9 (9.1) | <0.001 |
| BMI (kg/m²)* | 22.9 (3.2) | 22.5 (3.4) | 23.4 (2.9) | <0.001 |
| Comorbidities‡ | 2,317 (45.6%) | 1,283 (43.7%) | 1,034 (48.1%) | <0.001 |
| Hypertension | 342 (6.7%) | 149 (5.1%) | 193 (9.0%) | <0.001 |
| Stroke | 917 (18.0%) | 457 (15.6%) | 460 (21.4%) | <0.001 |
| Heart disease | 660 (13.0%) | 294 (10.0%) | 366 (17.0%) | <0.001 |
| Diabetes mellitus | 1,935 (38.1%) | 1,284 (43.8%) | 651 (30.3%) | <0.001 |
| Dyslipidemia | 803 (15.8%) | 709 (24.2%) | 94 (4.4%) | <0.001 |
| Osteoporosis | 782 (15.4%) | 393 (13.4%) | 389 (18.1%) | <0.001 |
| Cancer | 2,033 (40.0%) | 1,024 (34.9%) | 1,009 (46.9%) | <0.001 |
| Cohort study membership‡ | 1,161 (22.8%) | 694 (23.7%) | 467 (21.7%) | <0.001 |
| Takashimadaira Study | 1,103 (21.7%) | 756 (25.8%) | 347 (16.1%) | <0.001 |
| Otassha Study | 786 (15.5%) | 459 (15.6%) | 327 (15.2%) | <0.001 |
| Kashiwa Study | 2,033 (40.0%) | 1,024 (34.9%) | 1,009 (46.9%) | <0.001 |

*presented as the means (SD)
†presented as the medians (IQR)
‡presented as the n (%)
§Somers’ D (median difference between men and women) = 0.06, 95% confidence interval = 0.03–0.09 (reference group = women)
Underlined text indicates data with significant adjusted standardized residuals.

Table 2. Means and standard deviations of tongue pressure by age group and sex

| Age group (years) | 65-69 | 70-74 | 75-79 | 80-84 | ≥85 | p for trend |
|---|---|---|---|---|---|---|
| Men | | | | | | |
| N | 518 | 633 | 532 | 322 | 145 | |
| Tongue pressure (kPa)* | 34.0 (8.4) | 32.2 (8.1) | 30.8 (8.3) | 28.4 (8.9) | 24.4 (8.2) | <0.001 |
| Women | | | | | | |
| N | 606 | 749 | 741 | 451 | 386 | |
| Tongue pressure (kPa)* | 31.5 (7.1) | 30.5 (7.5) | 29.6 (7.3) | 28.4 (8.0) | 26.4 (7.6) | <0.001 |
| p for sex comparison† | <0.001 | <0.001 | 0.006 | 0.970 | 0.012 | |

SD = standard deviation
*presented as the means (SD)
†the level of significance (two-tailed test) was set to 0.01

Table 1. Supplementary Table 2 presents quartiles of TP according to age group and sex.

Table 4 presents the results of the regression analyses for the association among TP, age, and sex. The polynomial term for age was not significant. Moreover, adding a polynomial term for age did not improve the model fit; therefore, we selected a linear function for age. The interaction term for age and sex was significant; therefore,
Table 3. Deciles of tongue pressure by age group and sex

| Decile | Men | 65-69 | 70-74 | 75-79 | 80-84 | ≥85 |
|--------|-----|-------|-------|-------|-------|-----|
| 90th   | 42.0| 44.4 | 42.1 | 41.5 | 39.0 | 34.3 |
| 80th   | 38.3| 40.5 | 38.8 | 36.9 | 35.0 | 30.7 |
| 70th   | 35.3| 37.9 | 36.7 | 34.2 | 32.5 | 28.9 |
| 60th   | 33.3| 35.6 | 34.4 | 32.6 | 30.0 | 26.9 |
| 50th (Median) | 31.4| 34.1 | 32.3 | 31.2 | 28.6 | 25.3 |
| 40th   | 29.3| 32.0 | 30.6 | 29.2 | 26.2 | 22.6 |
| 30th   | 27.0| 30.0 | 28.4 | 26.6 | 24.2 | 20.4 |
| 20th   | 24.3| 27.2 | 25.8 | 24.3 | 22.1 | 18.9 |
| 10th   | 20.5| 23.4 | 21.9 | 20.9 | 16.7 | 15.1 |

| Decile | Women | 65-69 | 70-74 | 75-79 | 80-84 | ≥85 |
|--------|-------|-------|-------|-------|-------|-----|
| 90th   | 39.1| 40.8 | 39.8 | 38.7 | 38.5 | 35.1 |
| 80th   | 35.7| 37.1 | 36.7 | 35.7 | 35.0 | 32.5 |
| 70th   | 33.5| 35.0 | 34.1 | 33.4 | 32.7 | 30.3 |
| 60th   | 31.6| 33.1 | 32.2 | 31.6 | 30.4 | 28.5 |
| 50th (Median) | 29.7| 31.5 | 30.2 | 29.8 | 28.7 | 26.4 |
| 40th   | 27.9| 29.8 | 28.5 | 27.9 | 26.5 | 24.6 |
| 30th   | 25.9| 27.9 | 26.6 | 26.0 | 24.7 | 22.5 |
| 20th   | 23.7| 25.8 | 24.4 | 24.0 | 22.2 | 19.7 |
| 10th   | 20.2| 22.9 | 21.4 | 20.8 | 18.5 | 16.4 |

Table 4. Linear regression analysis of tongue pressure, age, and sex in community-dwelling Japanese older adults (n = 5,083)

| Exposure variables | Outcome variable = tongue pressure |
|--------------------|-----------------------------------|
|                    | Model 1 |                      | Model 2 |                      |
|                    | b       | 95% CI               | p       | b                   | 95% CI               | p       |
| Age (per one-year increase) | -0.24 (-0.28 to -0.20) | <0.001 | -0.20 (-0.25 to -0.16) | <0.001 |
| Sex (reference group = Women) | 14.53 (9.36 to 19.69) | <0.001 | 12.95 (7.83 to 18.08) | <0.001 |
| Age × Sex | -0.18 (-0.25 to -0.11) | <0.001 | -0.17 (-0.24 to -0.10) | <0.001 |
| n of natural teeth (per five increase) | -0.003 (-0.13 to 0.12) | 0.969 | -0.16 (-0.53 to 0.20) | 0.389 |
| n of functional teeth (per five increase) | -0.16 (-0.53 to 0.20) | 0.389 | -0.16 (-0.53 to 0.20) | 0.389 |
| Years of education | 0.18 (0.10 to 0.26) | <0.001 | 0.18 (0.10 to 0.26) | <0.001 |

Smoking status

| Status      | Ref. | 95% CI               | p       |
|-------------|------|----------------------|---------|
| Never smoked | 0.41 (-0.18 to 0.99) | 0.173   |
| Currently smoke | 0.64 (-0.27 to 1.55) | 0.165   |

Alcohol consumption status

| Status         | Ref. | 95% CI               | p       |
|----------------|------|----------------------|---------|
| Never drunk alcohol | -0.21 (-1.06 to 0.64) | 0.625   |
| Currently drink alcohol | -0.04 (-0.53 to 0.45) | 0.866   |

BMI (per one increase)

| BMI          | 0.47 (0.40 to 0.54) | <0.001 |

Comorbidities

| Condition      | 95% CI               | p       |
|----------------|----------------------|---------|
| Hypertension | -0.14 (-0.59 to 0.31) | 0.545   |
| Stroke        | -0.90 (-1.76 to -0.04) | 0.041   |
| Heart disease | -0.59 (-1.15 to -0.02) | 0.042   |
| Diabetes mellitus | 0.49 (-0.16 to 1.13) | 0.141   |
| Dyslipidemia  | 0.17 (-0.28 to 0.63) | 0.449   |
| Osteoporosis  | -0.94 (-1.56 to -0.32) | 0.003   |
| Cancer        | 0.24 (-0.35 to 0.83) | 0.426   |

b = coefficient, BMI = body mass index, CI = confidence interval
Model 1 includes age, sex and interaction term for age and sex.
Model 2 added the number of natural teeth and functional teeth, years of education, smoking status, alcohol consumption status, body mass index, and comorbidities.
In this study, we reported age- and sex-specific reference values for TP based on a large-scale, pooled dataset of community-dwelling Japanese older adults. Examining the association of TP with other oral functions, with factors other than age and sex, and with any specific adverse health outcome was beyond the scope of our study. Epidemiological studies have demonstrated that TP is associated with increased risks of unfavorable outcomes, such as physical frailty and sarcopenia, in community-dwelling older adults[4]. Therefore, the reference values of TP obtained from this study could be used for risk assessments regarding such events and to determine cutoff ranges. In addition, we classified our data according to different age strata so that the researchers can take reference to these cutoff values flexibly to define weak TP. Moreover, the reference values can be utilized to assess the effectiveness of management and interventions for individuals with poor oral function, oral frailty, or oral hypofunction. Finally, the reference values presented in this study are useful information for international comparison studies.

To derive population-based reference values of TP, we used pooled datasets from four large-scale community-based cohort studies. The study population of four cohort studies was set as representative of the general population at the target area by using systematic sampling strategies[9–12]. We performed a random-effects meta-analysis and did not find heterogeneity among the studies included in our analysis. These results indicate that our study sample well represents community-dwelling Japanese adults aged ≥65 years old.

Our recent national survey, the National Health and Nutrition Survey 2019[15], obtained data on several important clinical characteristics, such as height and weight, and reported the mean BMI of adults aged ≥70 years old (23.4 kg/m² for men and 22.9 kg/m² for women). These values were very similar to those of the subgroup of our study participants (i.e., individuals aged ≥70 years old; 23.3 kg/m² for men and 22.5 kg/m² for women), which supports our study as being representative of the typical older Japanese population. Nonetheless, the absence of national TP data did not allow us to further assess the generalizability of the TP data obtained in this study. We recognize that it is challenging to acquire representative data on TP among Japanese older adults. However, we believe that our results are at present the best TP reference values obtained in community-dwelling Japanese older adults. Obtaining reference values of TP in frail geriatric populations, such as institutionalized or hospitalized persons, is an important next step. Previous studies reported that low TP was associated with dysphagia, malnutrition, and sarcopenia in such populations[16,17].

There are various reports on reference or normative data on the parameters in other parts of the body, such as handgrip strength[18], gait speed[19], and body composition[20]. In these reports[18–20], exclusion criteria based on systemic diseases, such as stroke and neuromuscular diseases, were not set. The ‘generalized’ population consists of individuals with various health characteristics. Excluding those with specific diseases may limit generalizability. Nonetheless, there might be a need for the determination of TP among those without stroke. Therefore, we performed additional descriptive statistics to report these data. Because information on neuromuscular diseases was not consistently obtained throughout the four cohorts, we could not report TP values among those without neuromuscular diseases.

Unweighted simple mean TPs measured using a TPM-01 were 30.3 kPa in the current study participants, which was identical to that of a recent meta-analysis (30.3 kPa in individuals aged ≥60 years)[8]. The mean (SD) TP assessed using the prototype TPM-01 (PS-03, ALNIC, Higashi-Hiroshima, Japan) was 31.9 (8.9) kPa in 70–79-year-old individuals in the study of Utanohara et al.[7] This value was higher...
than that in our study (30.7 [7.8] kPa in 70–79-year-old individuals). Differences in study design could explain this discrepancy. The study by Utanohara et al.[7] restricted the study population to those with occlusal contacts of the posterior natural teeth and without poor swallowing function. In contrast, we did not set exclusion criteria based on dentition status or swallowing function. Although occlusal status was not associated with TP in a previous study[21], swallowing difficulties were suggested to be associated with low TP[22]. Therefore, excluding those with poor swallowing function might have led to an increase in TP in Utanohara et al.[7].

In the current definition of oral hypofunction, TP of <30 kPa was defined as low[5]. The reference TP value is essential for considering how to define a low or abnormal TP value. Regarding other parts of the body, the reference value of handgrip strength based on a pooled dataset was used to define the cutoff value to diagnose sarcopenia. In the current diagnostic algorithm of sarcopenia among Asian populations, the sex-specific lowest quintile handgrip strength value was used[23]. We determined that the lowest quintile TP values were 24.3 kPa for men and 23.7 kPa for women. With this population-based reference value from our study, the cutoff values of TP for oral hypofunction could be revisited.

We used TP data measured using a JMS tongue pressure measuring device. This device is widely used in Japan[8]. Another type of device, the Iowa Oral Performance Instrument (IOPI Medical LLC, Washington, USA), is commonly used in other countries. TP values are affected by the device used[8,24]; therefore, caution should be paid when conducting international comparison studies in the future, as the absolute values obtained from different devices are not directly comparable.

We observed that TP declined with advancing age in both men and women, which was consistent with previous findings[7,8]. Regression analyses revealed that there was a linear trend of decreasing TP with increasing age. Similar to other parts of the body[19,20,25,26], oral function may be significantly affected by aging. Age-related loss of tongue muscle mass as well as reduction in muscle tone accompanied by the accumulation of nonmuscular tissue were suggested to be causes of age-related decreases in TP[27].

In the overall study population, we observed that men had higher TP values than women. However, we also observed an age*-sex interaction effect on TP, which has interesting implications and is consistent with the findings of a previous study[7]. TP decreases at a faster pace in men than in women, which leads to a decrease in sex differences in TP with increasing age. Sex differences in TP were diminished in those aged 80–85. However, beyond the age of 85, women were observed to have larger TP than men. The exact reason for this interaction is unclear. Future studies to obtain additional data, such as muscle quality, maxillofacial morphology, and hormone levels, are necessary to investigate the sex differences in age-related declines in TP.

The present study has the following strengths. First, our study had a large sample size, which enabled us to provide robust descriptive statistics related to TP. Second, trained examiners carried out the TP measurements using a unified protocol, increasing the validity of the study outcome. On the other hand, the present study had some limitations that must also be considered. First, the current study population consisted of those living in the eastern part of Japan. To investigate potential regional differences, data from broader geographic areas are necessary. Sociocultural and economic diversity throughout Japan might affect the TP values, which should be investigated in the future. Second, selection bias might have occurred, as participation was voluntary. Individuals with poor physical or mental function tend to avoid participating in community-based surveys[28]. Therefore, our study findings could not be applied to the more frail population.

In conclusion, this study determined age- and sex-specific reference values for TP in community-dwelling Japanese older adults aged ≥65 years old. These reference values will be useful for clinicians and researchers in geriatric oral function assessments.

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Conflicts of interest

The authors have no conflict of interest to declare.

References

[1] Tsuga K, Yoshikawa M, Oue H, Okazaki Y, Tsuchioka H, Maruyama M, et al. Maximal voluntary tongue pressure is decreased in Japanese frail elderly persons. Gerodontology. 2012;29:e1078–85. https://doi.org/10.1111/j.1741-2358.2011.00615.x; PMID:22288526
[2] Ogino Y, Suzuki H, Ayukawa Y, Jinnouchi A, Koyano K. Analyses of swallowing function and its related factors in community-dwelling elderly patients: a case-control study. J Clin Med. 2021;10:3437. https://doi.org/10.3390/jcm10153437; PMID:34362220
[3] Nishida T, Yamabe K, Honda S. The influence of dysphagia on nutritional and frailty status among community-dwelling older adults. Nutrients. 2021;13:512. https://doi.org/10.3390/nu13020512; PMID:33557341
[4] Tanaka T, Takahashi K, Hirano H, Kikutani T, Watanabe Y, Ohara Y, et al. Oral frailty as a risk factor for physical frailty and mortality in community-dwelling elderly. The Journals of Gerontology; Series A. 2018;73:1661–7. https://doi.org/10.1093/gerona/glx225; PMID:29161342
[5] Minakuchi S, Tsuga K, Kibe K, Ueda T, Tamura F, Nagao K, et al. Oral hypofunction in the older population: Position paper of the Japanese Society of Gerodontology in 2016. Gerodontology. 2018;35:317–24. https://doi.org/10.1111/ger.12347; PMID:29982364
[6] Japan Dental Association. Manual for oral frailty at dental clinics 2019, https://www.jda.or.jp/dentist/oral_frail/pdf/manual_all.pdf. [accessed 6 October 2021]
[7] Utanohara Y, Hayashi R, Yoshikawa M, Yoshida M, Tsuga K, Akagawa Y. Standard values of maximum tongue pressure taken using newly developed disposable tongue pressure measurement device. Dysphagia. 2006;23:286–90. https://doi.org/10.1007/s00455-006-9142-z; PMID:18574632
[8] Arakawa I, Igarashi K, Imamura Y, Müller F, Abou-Ayash S, Schimmel M. Variability in tongue pressure among elderly and young healthy cohorts: A systematic review and meta-analysis. J Oral Rehabil. 2021;48:430–48. https://doi.org/10.1111/joor.13076; PMID:32799377
[9] Fujiwara Y, Suzuki H, Kawai H, Hirano H, Yoshida H, Kojima M, et al. Physical and sociopsychological characteristics of older community residents with mild cognitive impairment as assessed by the Japanese version of the Montreal Cognitive Assessment. J Geriatr Psychiatry Neurol. 2013;26:209–20. https://doi.org/10.1177/0891987713497096; PMID:23920040
[10] Shinkai S, Yoshida H, Fujiwara Y, Amano H, Fukaya T, Ri S, et al. [A 10-year community intervention for disability prevention and its effect on healthy aging in Kusatsu town]. Nihon Koshu Eisei Zasshi. 2013;60:596–605. PMID:24125819
[11] Ishii S, Tanaka T, Shibusaki K, Ouchi Y, Kikutani T, Higashiyachi T, et al. Development of a single screening test for sarcopenia in older adults. Geriatr Gerontol Int. 2014;14(suppl 1):93–101. https://doi.org/10.1111/jgi.12197; PMID:24450566
The Ministry of Health, Labour, and Welfare. National Health and Nutrition Survey, 2019, https://www.mhlw.go.jp/content/000711007.pdf. [accessed 6 October 2021]

Maeda K, Akagi J. Decreased tongue pressure is associated with sarcopenia and sarcopenic dysphagia in the elderly. Dysphagia. 2015;30:80–7. https://doi.org/10.1007/s00455-014-9577-y

Maekawa K, Ikuchi T, Shinkai S, Hirano H, Ryu M, Tamaki K, et al. Kusatsu ISLE Study Working Group Collaborators. Number of functional teeth more strongly predicts all-cause mortality than number of present teeth in Japanese older adults. Geriatr Gerontol Int. 2020;20:607–14. https://doi.org/10.10111/ggi.13911, PMID:32227400

Sakai K, Nakayama E, Tohara H, Maeda T, Sugimoto M, Takehisa T, et al. Physical performance measures for community-dwelling older Japanese men and women: a pooled analysis of four cohort studies. PLoS One. 2015;10:e0131975. https://doi.org/10.1371/journal.pone.0131975, PMID:26147341

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### Supplementary Table 1. Deciles of tongue pressure by age group and sex (excluding study participants with a history of stroke)

| Age group (years) | Decile | Total | 65-69 | 70-74 | 75-79 | 80-84 | ≥85 |
|-------------------|--------|-------|-------|-------|-------|-------|-----|
| **Men**           | Tongue pressure (kPa) | 90th | 42.2 | 44.5 | 42.2 | 41.6 | 39.0 | 35.2 |
|                   |        | 80th | 38.4 | 40.7 | 38.9 | 36.7 | 34.6 | 30.6 |
|                   |        | 70th | 35.4 | 38.3 | 36.7 | 34.0 | 32.5 | 29.1 |
|                   |        | 60th | 33.4 | 35.8 | 34.4 | 32.6 | 30.2 | 26.8 |
|                   | 50th (Median) | 31.5 | 34.3 | 32.3 | 31.2 | 28.8 | 25.3 |
|                   | 40th   | 29.5 | 32.3 | 30.7 | 29.2 | 26.4 | 22.6 |
|                   | 30th   | 27.2 | 30.0 | 28.4 | 26.6 | 24.3 | 21.1 |
|                   | 20th   | 24.4 | 27.2 | 25.8 | 24.4 | 22.0 | 19.3 |
|                   | 10th   | 20.8 | 23.6 | 21.9 | 21.0 | 17.7 | 17.0 |
| **Women**         | Tongue pressure (kPa) | 90th | 39.1 | 40.7 | 39.8 | 38.7 | 38.5 | 35.3 |
|                   |        | 80th | 35.7 | 37.0 | 36.7 | 35.7 | 35.0 | 32.5 |
|                   |        | 70th | 33.5 | 34.8 | 34.2 | 33.4 | 32.8 | 30.3 |
|                   |        | 60th | 31.6 | 33.1 | 32.3 | 31.7 | 30.4 | 28.5 |
|                   | 50th (Median) | 29.7 | 31.5 | 30.3 | 29.7 | 28.5 | 26.4 |
|                   | 40th   | 27.9 | 29.8 | 28.5 | 27.8 | 26.5 | 24.6 |
|                   | 30th   | 25.9 | 27.9 | 26.6 | 26.0 | 24.7 | 22.6 |
|                   | 20th   | 23.7 | 25.8 | 24.3 | 24.1 | 22.3 | 19.6 |
|                   | 10th   | 20.1 | 23.0 | 21.3 | 20.8 | 18.7 | 16.4 |

### Supplementary Table 2. Quartiles of tongue pressure according to age group and sex

| Age group (years) | Quartile | Total | 65-69 | 70-74 | 75-79 | 80-84 | ≥85 |
|-------------------|----------|-------|-------|-------|-------|-------|-----|
| **Men**           | Tongue pressure (kPa) | 75th | 36.6 | 39.3 | 37.9 | 35.3 | 33.7 | 29.8 |
|                   |          | 50th (Median) | 31.4 | 34.1 | 32.3 | 31.2 | 28.6 | 25.3 |
|                   | 25th    | 25.6 | 28.8 | 27.1 | 25.6 | 23.1 | 19.6 |
| **Women**         | Tongue pressure (kPa) | 75th | 34.5 | 35.9 | 35.3 | 34.5 | 33.6 | 31.4 |
|                   |          | 50th (Median) | 29.7 | 31.5 | 30.2 | 29.8 | 28.7 | 26.4 |
|                   | 25th    | 24.9 | 26.9 | 25.5 | 25.1 | 23.9 | 21.6 |

### Supplementary Table 3. Weighted means and their 95% confidence intervals of tongue pressure obtained from a random-effects meta-analysis model by age group and sex across 4 cohort studies

| Age group (years) | Total | 65-69 | 70-74 | 75-79 | 80-84 | ≥85 |
|-------------------|-------|-------|-------|-------|-------|-----|
| **Men**           | Tongue pressure (kPa) | Weighted mean (95% CI) | 29.8 (26.16 to 33.44) | 34.11 (24.59 to 43.64) | 32.62 (24.93 to 40.3) | 31.14 (22.97 to 39.31) | 28.54 (19.92 to 37.16) | 24.68 (17.47 to 31.89) |
|                   | I² (%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                   | p for Cochran's Q | >0.999 | 0.980 | 0.984 | 0.998 | 0.997 | 0.935 |
| **Women**         | Tongue pressure (kPa) | Weighted mean (95% CI) | 29.12 (25.85 to 32.4) | 31.68 (23.62 to 39.74) | 30.63 (23.34 to 37.92) | 29.63 (22.58 to 36.68) | 28.6 (20.99 to 36.22) | 25.94 (19.16 to 32.73) |
|                   | I² (%) | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                   | p for Cochran's Q | >0.999 | 0.923 | 0.983 | 0.988 | 0.970 | >0.999 |

CI = confidence interval
Supplementary Fig. 1. Linear regression analysis for tongue pressure and age for men (n=2,150) and women (n=2,933).