*Journal of Oral Rehabilitation*

WILEY

JOURNAL OF ORAL REHABILITATION

ORIGINAL ARTICLE OPEN ACCESS

# Relationships of Oral Function Tests With Sarcopenia and Frailty in Dental Outpatients

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**Received:** 12 September 2025 | **Revised:** 9 December 2025 | **Accepted:** 13 December 2025

**Keywords:** frailty | oral function | oral hypofunction | sarcopenia

## ABSTRACT

**Background:** The relationships between various oral function tests and sarcopenia or frailty remain unclear, particularly in dental outpatients.

**Objective:** The present study investigated the interrelationships among various oral function tests and the relationships of each oral function with sarcopenia and frailty in dental outpatients.

**Materials and Methods:** Patients aged 50 years or older in the Department of Prosthodontics of a university hospital were analysed. Oral function was evaluated using 11 tests and their test criteria, which included seven main tests and four alternative tests defined by the Japanese Society of Gerodontology. Sarcopenia and frailty were defined based on the Asian Sarcopenia Working Group consensus and the Japanese version of the Cardiovascular Health Study, respectively. The interrelationships among oral function tests and the relationship of each oral function with sarcopenia/frailty were evaluated, and a receiver operating characteristic (ROC) analysis was performed.

**Results:** A total of 329 participants were analysed, and a correlation was observed between occlusal force and masticatory function. A multivariate analysis showed that tongue pressure correlated with sarcopenia/frailty in dental outpatients. In the ROC analysis, cut-off values were determined for sarcopenia and frailty using tongue pressure alone (28.5 and 26.9 kPa, respectively).

**Conclusion:** Further studies are needed on testing methods for oral hypofunction. Among the various oral function tests performed herein, tongue pressure demonstrated the strongest association with sarcopenia and frailty in dental outpatients, for which cut-off values were calculated.

## 1 | Introduction

Population aging is progressing worldwide, and is particularly prevalent in Japan. By 2050, individuals aged ≥ 65 years are expected to account for 37.1% of the total population [1]. If a significant percentage of this demographic is in poor health, it may result in substantial economic, medical and social burdens, thereby increasing the pressure on younger generations. Therefore, the simultaneous extension of healthy life expectancy and promotion of population-wide health are public health priorities [2].

The relationship between oral function and systemic health is attracting increasing attention. Handgrip strength, a representative indicator of physical performance, is associated with tongue pressure and jumping ability [3, 4], and may be related to other oral functions, including occlusal force and masticatory ability [5–8]. A large-scale cohort study on community-dwelling older adults that comprehensively examined oral function in 2018 reported that oral function declines were associated with frailty, the need for nursing care, and shortened lifespan, highlighting the impact of oral function on systemic health outcomes [9]. The concept of 'oral hypofunction' was proposed in Japan at that time. In dental practice, this condition is diagnosed by assessing seven domains of oral function: poor oral hygiene, oral dryness, decreases in occlusal force, tongue-lip motor function, tongue pressure and masticatory function and the deterioration of swallowing function. Appropriate management to maintain or improve oral function is regarded as an essential component of care [10]. With growing attention to nutritional outcomes, research has increasingly examined the relationship between oral hypofunction and the risk of malnutrition. Cross-sectional [11, 12] and longitudinal studies [13] on community-dwelling older adults demonstrated that oral hypofunction correlated with malnutrition. Regarding nutrition and oral function, many studies have investigated the relationship between oral function and sarcopenia [6, 14–16], as well as that between oral function and frailty [17–20]. Systematic reviews on the relationship between oral function and general health concluded that although oral function is associated with systemic health, the nature of this relationship has not been established [21–27]. Therefore, further longitudinal studies are needed.

The relationship between oral hypofunction and physical frailty remains unclear, particularly regarding which aspects of oral function and through what mechanisms they are linked to frailty. Furthermore, many studies included in systematic reviews were designed to investigate community-dwelling older adults, not patients who visit dental clinics where oral hypofunction is diagnosed and managed. Therefore, information is needed not only from community-dwelling older adults, but also dental outpatients who undergo assessments for oral hypofunction. To conduct longitudinal studies efficiently, the interrelationships among various oral function tests and the extent to which each oral function is associated with physical frailty need to be clarified. However, some test items overlap conceptually and fundamentally, affecting the validity of the proposed diagnostic approach for oral hypofunction [10]. Decreases in tongue-lip motor function, tongue pressure and masticatory function overlap both conceptually and in principle, highlighting the need for further research into diagnostic methods and criteria.

Therefore, the present study investigated the interrelationships among various oral function tests and the relationships between oral function measures and physical frailty, specifically sarcopenia and frailty, in dental outpatients.

## 2 | Materials and Methods

### 2.1 | Study Design and Participants

We conducted a cross-sectional analysis of dental outpatients by simultaneously performing oral function tests listed for the diagnosis of oral hypofunction, along with assessments of sarcopenia and frailty, to examine the interrelationships among these factors. Participants in the present study were patients aged ≥ 50 years who visited the Department of Prosthodontics at Kagoshima University Hospital between February 2020 and July 2024, agreed to undergo tests for oral hypofunction, and provided consent to participate in this study. The present study was approved by the Epidemiological and Related Research Ethics Committee of Kagoshima University (Approval No. 250134eki) prior to its commencement. Written informed consent was obtained from all participants before their enrolment.

The inclusion criteria for participants were set as follows to ensure the reliability of oral function and physical assessments: (1) patients aged ≥ 50 years, (2) patients visiting and receiving outpatient care at the Department of Prosthodontics of our hospital and (3) patients who consented to undergo an examination for oral hypofunction under health insurance coverage. Exclusion criteria were as follows: (1) individuals with maxillofacial defects or a history of maxillofacial cancer, (2) individuals with a systemic medical history, such as cerebrovascular disease or neuromuscular disease, which was expected to make it difficult to carry out the examination, (3) individuals judged to have difficulty undergoing the examination due to dementia (including mild cognitive impairment), psychiatric illness, or psychiatric symptoms, (4) individuals unable to stand on the measuring equipment and (5) individuals deemed otherwise unsuitable for measurements, such as pain caused by teeth or dentures. In addition to the age, sex, height and weight of participants in the present study, comorbidities were recorded through medical records and interviews.

### 2.2 | Oral Function Measurements

Oral function measurements were conducted by three skilled dental hygienists, with assistance from dentists in the same manner as tests for oral hypofunction, which are covered by the national health insurance system of Japan and are based on the diagnostic criteria published by the Japanese Society of Gerodontology (JSG) [10]. These tests consisted of seven items: (a) oral hygiene, (b) oral dryness, (c) occlusal force, (d) tongue-lip motor function, (e) tongue pressure, (f) masticatory function and (g) swallowing function. Each item had primary and alternative tests, and all items, except for oral hygiene, tongue-lip motor function and tongue pressure, included an alternative test. Oral hypofunction was diagnosed when at least three of the seven items listed above were below the reference value. These tests were conducted on all participants in accordance with the methods of the JGS, and details on each test are as follows.

#### 2.2.1 | Oral Hygiene

The degree of bacteria in the oral cavity was evaluated by a visual assessment of the tongue coating index (TCI) [28]. Oral hygiene was judged to be poor at TCI ≥ 50% [10].

#### 2.2.2 | Oral Dryness

The primary test for oral dryness was a measure of oral moisture using an oral moisture checker (Mucus; Life Corp., Saitama, Japan). The moisture content of the lingual mucosa on the dorsum of the tongue was measured three times, and the median was used as the measured value [29]. A value < 27.0 was considered to indicate oral dryness [10]. The alternative test was the Saxon test, which measures the amount of saliva secreted upon stimulation using a reduced amount of gauze (Sterauze; Hakujuji Co. Ltd., Tokyo, Japan). The secretion of < 2 g of saliva in 2 min indicated oral dryness [10].

#### 2.2.3 | Occlusal Force

The primary assessment of occlusal force was conducted using a system that evaluates pressure-sensitive sheets by scanning them (Dental Prescale II; GC Corp., Tokyo, Japan). The sheet was placed between the maxillary and mandibular dentition, and participants were instructed to clench with maximal force for 3 s in the intercuspal position, allowing an evaluation of the occlusal force across the entire dentition (Prescale force) [30]. Measurements for denture wearers were taken with the dentures in place. A maximal occlusal force ≤ 500 N was defined as decreased occlusal force [10]. As an alternative assessment, the total number of remaining teeth in the oral cavity was recorded, and a tooth count ≤ 20 was considered to be indicative of decreased occlusal force [10].

#### 2.2.4 | Tongue-Lip Motor Function

Motor function tests measuring lip and tongue dexterities were performed using an automatic counter (Kenko-kun Handy, Takei Scientific Instruments Co. Ltd., Niigata, Japan). Patients were instructed to repeatedly pronounce the syllables /pa/, /ta/ and /ka/ as quickly as possible for 5 s, and the number of syllables produced per second, known as oral diadochokinesis (ODK), was measured [31]. Impaired lip and tongue motor function was defined as an ODK score < 6.0 times/s for /pa/, /ta/ or /ka/ ODK measurements were based on the average value of each pronunciation [10].

#### 2.2.5 | Tongue Pressure

Tongue pressure was assessed using a tongue pressure measuring device (TPM-01, JMS Co. Ltd., Hiroshima, Japan). As previously reported [7], tongue pressure was measured three times using a disposable oral probe, and the average was used as the measurement value. The reference value for tongue pressure reduction was set at 30 kPa, as defined by the JSG [10].

#### 2.2.6 | Masticatory Function

As the first method, masticatory function was evaluated using a masticatory ability testing system (Gluco Sensor GS-II, GC Corp., Tokyo, Japan), in which glucose eluted into saliva by chewing 2 g of a gummy jelly for 20 s was measured (Gluco sensor). The reference value for this measurement was set at 100 mg/dL [10].

The second method followed a previously reported alternative test in which masticatory function is visually assessed based on the degree of comminution of a gummy jelly after chewing [10]. In this method, implemented within the aforementioned test system, a chewed and expectorated fragmented gummy jelly was visually evaluated using a 10-grade scoring chart, and a masticatory function visual score for the comminuted jelly (comminuted score) was selected [32–34]. A score ≤ 2 was considered to indicate impaired masticatory function [10].

#### 2.2.7 | Swallowing Function

Swallowing function was assessed using two self-administered questionnaires. The first was the Japanese version of the 10-item Eating Assessment Tool (EAT-10). According to the evaluation criteria for EAT-10, a total score ≥ 3 indicates a risk of dysphagia [10]. The second was the Seirei dysphagia questionnaire, a brief self-administered questionnaire (BSAQ) developed by a Japanese research group, with high sensitivity (92%) and specificity (90.1%) [35, 36]. According to its criteria, the presence of at least one severe symptom among its 15 items indicates a risk of dysphagia [10].

### 2.3 | Assessment of Sarcopenia and Frailty

An assessment of sarcopenia and frailty was conducted immediately after oral function examinations by a dentist and dental hygienist. Sarcopenia was evaluated in accordance with the 2019 consensus of the Asian Working Group for Sarcopenia (AWGS) [37]. The AWGS diagnostic criteria combine assessments of muscle mass, muscle strength and physical performance, and the present study adhered to these standards. Muscle mass was evaluated by measuring the appendicular skeletal muscle mass index (ASM) using a bioelectrical impedance analysis device (InBody470; InBody Japan Co. Ltd., Tokyo, Japan), muscle strength was assessed by handgrip strength using a grip strength dynamometer (Grip-D, Takei Scientific Instruments Co. Ltd., Niigata, Japan) and physical performance was measured by the 6-m gait speed. Grip strength was measured with both hands, and the larger value was used as the measured value. Cut-off values were as follows: ASM < 7.0 $kg/m^2$ for males and < 5.7 $kg/m^2$ for females; handgrip strength < 28 kg for males and < 18 kg for females; and gait speed < 1.0 m/s. Sarcopenia was defined as low ASM in combination with a decrease in handgrip strength or gait speed, while severe sarcopenia was defined as low AMS in combination with reductions in both handgrip strength and gait speed.

Frailty was assessed using the Japanese version of the Cardiovascular Health Study (CHS) criteria, known as the J-CHS, which consists of five components based on the phenotypic model [38, 39]: (i) unintentional weight loss, (ii) self-reported exhaustion during the past 2 weeks, (iii) low physical activity, (iv) handgrip strength and (v) gait speed. The same cut-off values for handgrip strength and gait speed as those used in the sarcopenia assessment were applied. Participants were classified as robust if none of the components were present, pre-frail if one or two components were present, and frail if three or more components were present. As discussed above, participants were divided into three subgroups each of sarcopenia and frailty. Regarding the two-group division based on whether they had been diagnosed, sarcopenia included sarcopenia corresponding to a decline in two evaluation items and severe sarcopenia, while frailty did not include pre-frailty.

### 2.4 | Statistical Analysis

Comparisons between the two groups for oral function test items and sarcopenia/frailty assessment items were performed using paired *t*-tests for parametric measurement groups, Mann–Whitney *U* tests for non-parametric measurement groups, and chi-square tests for comparisons of percentages. Correlation analyses of continuous variables among these assessment items were conducted using Spearman's rank correlation coefficient because oral function test items were non-parametric measurements. The Kruskal–Wallis and Mann–Whitney *U* tests were used to compare each oral function assessment for the two and three subgroups of sarcopenia and frailty described above. Univariate binary logistic regression analyses were performed for each oral function assessment item, with a dichotomized variable indicating the presence or absence of sarcopenia and frailty as the dependent variable. In the next step, to identify oral function items associated with sarcopenia and frailty, oral function assessment items that were selected based on the aforementioned statistical analysis were entered as independent variables in a multivariate binary logistic regression analysis using the forced entry method. Multicollinearity among the independent variables was assessed using variance inflation factor (VIF) values, with a value $<10$ indicating no multicollinearity. Furthermore, for these oral function measurements, we attempted to determine cut-off values based on the diagnostic status of sarcopenia and frailty by calculating sensitivity, specificity, receiver operating characteristic (ROC) curves and the area under the curve (AUC). Cut-off values with AUC $\geq 0.7$ were considered to be discriminative.

All statistical analyses were performed using a statistical analysis application (SPSS Statistics ver.28, IBM Japan Ltd., Tokyo, Japan). $p$ values $\leq 0.05$ were considered to be significant.

## 3 | Results

This study included 327 participants (197 men and 130 women, mean age 76.7 years), all of whom were either in pre-treatment or undergoing dental treatment or the maintenance of dentures or dental implants. Participant characteristics and the summary statistics of measurements are shown in Table 1. Mean age was 76.7 years, with 83.9% in their 70s or 80s, 14.3% in their 60s, and three participants each in their 50s and 90s. No significant sex differences were observed in the age distribution. The majority of participants in the present study (87.7%) had completed dental treatment, including denture or implant treatment, and were undergoing maintenance, while 7.4% were examined before dental treatment and 4.9% during dental treatment. However, the post-treatment assessment data for these participants were not included in the present study. The most common systemic diseases are listed. According to oral function assessments, differences between men and women were observed in the oral hygiene test, two oral dryness tests, two occlusal force tests and ODK /ka/, and the overall prevalence of oral hypofunction was 65.7%. Sarcopenia and frailty were identified in 16.5 and 7.6% of participants, respectively. Severe sarcopenia was observed in 16 participants (4.9%) and pre-frailty in 184 (56.3%). None of these conditions showed significant sex differences.

### 3.1 | Relationships Between Oral Function Examinations and Physical Items

Table 2 summarises the relationships between oral function tests and physical performance measures. A strong correlation was observed between the Gluco Sensor and Comminuted J score for masticatory function ($r=0.73$, $p<0.001$), while moderate correlations were found between the Prescale force and number of remaining teeth for occlusal force ($r=0.58$, $p<0.001$) and between EAT-10 and BSAQ for swallowing function ($r=0.40$, $p<0.001$). The two oral dryness measures showed no correlations. Moderate correlations ($r\approx 0.5$) were also noted between the four measures of occlusal force and masticatory function. Overall, correlations between oral function and physical performance were weak, with the highest values being observed between tongue pressure and handgrip strength and between ODK and gait speed. Among physical performance measures, AMS and handgrip strength showed a strong correlation ($r=0.73$, $p<0.001$).

### 3.2 | Comparisons of Oral Function Measurements Among Sarcopenia and Frailty Subgroups

Table 3 shows the measurement values for each oral function assessment item and the significance of differences between groups in the three categories for sarcopenia (robust, sarcopenia and severe sarcopenia groups) and frailty (robust, pre-frailty and frailty groups). Significant differences were only observed in four items among the three sarcopenia subgroups: occlusal force (Prescale), tongue pressure, EAT-10 and BSAQ. In addition to these items, the number of remaining teeth, three ODK items and two masticatory function items showed significant differences among the frailty subgroups.

Regarding multiple comparisons between subgroups, tongue pressure showed significant differences between the healthy and sarcopenia groups and between the healthy and severe sarcopenia groups while significant differences were found among all three frailty subgroups.

Table 3 shows a comparison of the presence or absence of sarcopenia and frailty, i.e., the two-group division of the non-affected healthy group and the affected group. Five items were observed in sarcopenia: occlusal force (Prescale), ODK/ta/, tongue pressure, EAT-10 and BSAQ. Three items were noted in frailty: tongue pressure, EAT-10 and BSAQ.

### 3.3 | Univariate and Multivariate Binary Logistic Analyses of Oral Function Affecting Sarcopenia and Frailty

Table 4 shows the results of univariate and multivariate binary logistic regression analyses conducted to identify the

**TABLE 1** | Participant characteristics, summary of evaluation results.

| | Overall | Men | Women | | Number below the reference threshold | |
|---|---|---|---|---|---|---|
| | | | | | Men | Women |
| | | | | | ($n = 198$) | ($n = 131$) |
| | ($n = 327$) | ($n = 197$) | ($n = 130$) | $p$ | ($n$, %) | ($n$, %) |
| Age (years) | 76.7 ± 6.8 | 76.8 ± 7.1 | 76.6 ± 6.5 | 0.798 | | |
| Weight (kg) | 57.1 ± 11.1 | 61.7 ± 10.4 | 50.1 ± 8.1 | < 0.001** | | |
| BMI (kg/m²) | 22.6 ± 3.4 | 22.9 ± 3.5 | 22.0 ± 3.2 | 0.014* | | |
| After dental treatment ($n$, %) | 287 (87.7) | 173 (87.8) | 114 (87.7) | 0.967 | | |
| Systemic disease ($n$, %) | | | | | | |
| Hypertension ($n$, %) | 185 (56.6) | 122 (61.9) | 63 (48.5) | 0.016 | | |
| Diabetes mellitus ($n$, %) | 85 (26.0) | 75 (38.1) | 10 (7.7) | < 0.001** | | |
| Hyperlipidemia ($n$, %) | 33 (10.1) | 16 (8.1) | 17 (13.1) | 0.145 | | |
| Cardiovascular disease ($n$, %) | 50 (15.3) | 39 (19.8) | 11 (8.5) | 0.005** | | |
| Cancer ($n$, %) | 50 (15.3) | 31 (15.7) | 19 (14.6) | 0.783 | | |
| Cerebrovascular disease ($n$, %) | 42 (12.8) | 37 (18.8) | 5 (3.8) | < 0.001** | | |
| Oral function | | | | | | |
| Oral hygiene (%) | 22.20 (11.1–39.0) | 27.80 (16.60–44.40) | 16.70 (5.60–33.3) | < 0.001** | 40 (20.3)†† | 12 (9.2)†† |
| Oral dryness | | | | | | |
| Oral moisture | 26.80 (24.2–28.6) | 27.20 (24.5–28.9) | 26.35 (23.9–27.9) | 0.029 | 94 (47.7) | 73 (56.2) |
| Saxon test (g) | 3.2 (2.2–4.4) | 3.30 (2.3–5.1) | 3.0 (1.9–4.1) | 0.012* | 34 (17.3) | 34 (26.2) |
| Occlusal force | | | | | | |
| Prescale force (N) | 417.40 (273.5–653.2) | 449.90 (305.5–678.8) | 383.75 (223.7–597.5) | 0.022* | 111 (56.3) | 87 (66.9) |
| Remaining teeth ($n$) | 8.0 (1.0–19.0) | 6.0 (0.5–16.5) | 13.0 (4.0–20.0) | 0.005** | 163 (82.7) | 96 (73.8) |
| ODK/pa/(/sec) | 6.00 (5.20–6.40) | 6.00 (5.20–6.40) | 6.00 (5.35–6.40) | 0.642 | 93 (47.2) | 56 (43.1) |
| ODK/ta/(/sec) | 5.80 (5.00–6.40) | 5.80 (5.00–6.20) | 6.00 (5.00–6.45) | 0.149 | 117 (59.4) | 63 (48.5) |
| ODK/ka/(/sec) | 5.40 (4.80–6.00) | 5.40 (4.60–5.80) | 5.60 (4.95–6.20) | 0.003* | 154 (78.2)†† | 80 (61.5)†† |
| Tongue pressure (kPa) | 28.80 (22.9–33.6) | 28.20 (22.2–32.95) | 29.95 (23.2–34.03) | 0.195 | 111 (56.3) | 65 (50.0) |
| Masticatory function | | | | | | |
| Gluco sensor (mg/dL) | 192.0 (152.0–238.0) | 198.0 (162.0–242.5) | 183.0 (137.3–233.8) | 0.094 | 13 (6.6) | 15 (11.5) |
| Comminuted score | 6.0 (5.0–7.3) | 6.0 (5.0–7.5) | 6.0 (4.0–7.0) | 0.372 | 21 (10.7) | 20 (15.4) |
| Swallowing function | | | | | | |
| EAT-10 | 0.0 (0.0–1.0) | 0.0 (0.0–2.0) | 0.0 (0.0–1.0) | 0.944 | 32 (16.2) | 21 (16.2) |
| BSAQ | 0.0 (0.0–0.0) | 0.0 (0.0–0.0) | 0.0 (0.0–0.0) | 0.922 | 39 (19.8) | 27 (20.8) |
| Oral hypofunction ($n$, %) | 215 (65.7) | 130 (66.0) | 85 (65.4) | 0.835 | | |
| Physical function | | | | | | |
| AMS (kg/m²) | 6.6 ± 1.0 | 7.2 ± 0.8 | 5.7 ± 0.7 | < 0.001** | 62 (31.5)† | 57 (43.8)† |

(Continues)

**TABLE 1** | (Continued)

| | Overall | Men | Women | | Number below the reference threshold | |
|---|---|---|---|---|---|---|
| | | | | | Men | Women |
| | | | | | ($n = 198$) | ($n = 131$) |
| | ($n = 327$) | ($n = 197$) | ($n = 130$) | $p$ | ($n$, %) | ($n$, %) |
| Hand grip strength (kg) | 26.5 ± 7.7 | 30.8 ± 6.4 | 19.9 ± 3.9 | < 0.001** | 53 (26.9) | 38 (29.2) |
| Gait speed (s/m) | 1.2 ± 1.8 | 1.3 ± 2.3 | 1.1 ± 0.2 | 0.141 | 61 (31.0) | 32 (24.6) |
| Weight loss ($n$, %) | 38 (11.6) | 23 (11.7) | 15 (11.5) | 0.970 | | |
| Exhaustion ($n$, %) | 59 (18.0) | 34 (17.3) | 25 (19.2) | 0.650 | | |
| Physical inactivity ($n$, %) | 58 (17.8) | 36 (18.3) | 22 (17.2) | 0.803 | | |
| Sarcopenia ($n$, %) | 54 (16.5) | 31 (15.7) | 23 (17.7) | 0.641 | | |
| Severe sarcopenia ($n$, %) | 16 (4.9) | 10 (5.1) | 6 (4.6) | 0.793 | | |
| Frailty ($n$, %) | 25 (7.6) | 15 (7.6) | 10 (7.7) | 0.979 | | |
| Pre-frailty ($n$, %) | 184 (56.3) | 116 (58.9) | 68 (52.3) | 0.468 | | |

*Note:* Parametric variables are expressed as the mean ± standard deviation, and non-parametric variables are expressed as medians and interquartile ranges (IQR). Nominal variables are indicated by the $n$ value. IQR, interquartile range (25th–75th percentile). $p$-values were calculated using the Student's $t$-test, Mann–Whitney $U$ test, and chi-square test. *$p < 0.05$, **$p < 0.01$. Significant differences between the number of men and women who fell below the reference threshold are indicated by crosses: $^{\dagger}p < 0.05$, $^{\dagger\dagger}p < 0.01$; chi-square test.
Abbreviations: AMS, appendicular skeletal muscle mass index; BMI, body mass index; BSAQ, brief self-administered questionnaire (Seirei dysphagia questionnaire); Comminuted score, masticatory function test by the visual score of a comminuted gummy jelly; EAT-10, 10-item Eating Assessment Tool; Gluco sensor, masticatory function test by the Gluco sensor; Prescale force, occlusal force by the Dental Prescale, ODK, oral diadochokinesis.

oral function test items most closely associated with sarcopenia and frailty. The univariate analysis revealed correlations with six oral function test items for sarcopenia (Prescale force, tongue pressure, two masticatory function tests and two swallowing function tests) and four tests for frailty (tongue pressure, comminuted score and two swallowing function tests). Based on these results and the results of the subgroup analysis described above (Table 3), we performed a multivariate logistic regression analysis using oral function test items that were significant in both analyses as independent variables. This multivariate analysis shows the results of Model 1, which adjusted for age, sex, the timing of the examination during treatment (3 time points: before, during and after treatment), cancer, and cerebrovascular disease as covariates, and the results of Model 2, which added BMI as a covariate to Model 1. In addition, for covariates of systemic diseases, such as cancer and cerebrovascular disease, diseases that affect the presence or absence of sarcopenia and frailty were selected using a binary logistic analysis (Table S1) and were entered into the above analysis. Among the oral function items tested, only tongue pressure in model 1, which did not adjust for BMI, correlated with the presence or absence of sarcopenia. However, tongue pressure and EAT-10 in model 2, which adjusted for BMI, correlated with the presence or absence of sarcopenia. Furthermore, only tongue pressure in model 1, which did not adjust for BMI, correlated with the presence or absence of frailty. However, no significant independent variables were found in model 2, which adjusted for BMI. Although not shown in the table, the results of the analysis without any covariates included showed that only tongue pressure was significant for both sarcopenia and frailty, similar to the results of model 1. Multicollinearity in the multivariate analysis was assessed, and VIF values for all independent variables were ≤ 2.8, while tolerance levels were ≥ 0.44, indicating no significant multicollinearity.

In subgroup and univariate logistic regression analyses, the oral function test items that were significant for both sarcopenia and frailty were tongue pressure and the two swallowing function tests.

Since some of the oral function items (such as occlusal force) in Table 1 showed sex differences, they were analysed separately for men and women (Table S2). In the multivariate analysis, tongue pressure affected the presence or absence of sarcopenia in both men and women, while no oral function items were significantly affected by the presence or absence of frailty in either sex.

### 3.4 | ROC Analysis of Oral Function Affecting Sarcopenia and Frailty

A ROC analysis was performed to evaluate the discriminatory accuracy of not only tongue pressure related to sarcopenia and frailty, but also other oral function test items. The AUC is shown in Table 5 and the ROC curve for tongue pressure in Figure 1. Only the AUC for tongue pressure showed good results, and the detection power was moderate. The Youden Index was used to determine cut-off values for sarcopenia and frailty. Tongue pressure cut-off values for sarcopenia and

**TABLE 2** | Correlation between each oral function examination and physical function item.

| | Oral hygiene | Oral moisture | Saxon test | Prescale force | Remaining teeth | ODK /pa/ | ODK /ta/ | ODK /ka/ | Tongue pressure | Gluco sensor | Comminuted score | EAT-10 | BSAQ | AMS | Hand grip | Gait speed |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oral hygiene | 1.000 | −0.016 | −0.040 | −0.033 | −0.096 | 0.023 | −0.070 | −0.089 | −0.130* | −0.040 | −0.072 | 0.003 | −0.013 | 0.240** | 0.180** | −0.120* |
| Oral moisture | | 1.000 | 0.082 | 0.066 | 0.012 | 0.036 | 0.031 | 0.027 | 0.075 | 0.110* | 0.150** | −0.073 | −0.059 | 0.140* | 0.18** | −0.059 |
| Saxon test | | | 1.000 | 0.185** | 0.116* | 0.127** | 0.146** | 0.228** | 0.188** | 0.151** | 0.179** | −0.172** | −0.084 | 0.032 | 0.119* | 0.217** |
| Prescale force | | | | 1.000 | 0.576** | 0.128* | 0.157** | 0.175** | 0.219** | 0.450** | 0.542** | −0.278** | −0.286** | 0.109* | 0.177** | 0.165** |
| Remaining teeth | | | | | 1.000 | 0.188** | 0.306** | 0.287** | 0.217** | 0.394** | 0.525** | −0.148** | −0.094 | −0.058 | 0.023 | 0.207** |
| ODK /pa/ | | | | | | 1.000 | 0.766** | 0.656** | 0.258** | 0.223** | 0.191** | −0.143** | −0.068 | 0.034 | 0.100 | 0.223** |
| ODK /ta/ | | | | | | | 1.000 | 0.816** | 0.283** | 0.254** | 0.239** | −0.164** | −0.041 | −0.003 | 0.101 | 0.242** |
| ODK /ka/ | | | | | | | | 1.000 | 0.335** | 0.248** | 0.260** | −0.175** | −0.038 | −0.095 | 0.022 | 0.266** |
| Tongue pressure | | | | | | | | | 1.000 | 0.262** | 0.249** | −0.244** | −0.191** | 0.156** | 0.197** | 0.098 |
| Gluco sensor | | | | | | | | | | 1.000 | 0.729** | −0.258** | −0.294** | 0.134* | 0.165** | 0.172** |
| Comminuted score | | | | | | | | | | | 1.000 | −0.292** | −0.296** | 0.061 | 0.144** | 0.224** |
| EAT-10 | | | | | | | | | | | | 1.000 | 0.400** | −0.015 | −0.151** | −0.143** |
| BSAQ | | | | | | | | | | | | | 1.000 | −0.073 | −0.097 | −0.010 |
| AMS | | | | | | | | | | | | | | 1.000 | 0.730** | −0.146** |
| Hand grip | | | | | | | | | | | | | | | 1.000 | 0.045 |
| Gait speed | | | | | | | | | | | | | | | | 1.000 |

*Note: p*-values were calculated using Spearman's correlation test, $*p < 0.05$, $**p < 0.01$.
Abbreviations: AMS, appendicular skeletal muscle mass index; BSAQ, brief self-administered questionnaire (Seirei dysphagia questionnaire); Comminuted score, masticatory function test by the visual score of a comminuted gummy jelly; EAT-10, 10-item Eating Assessment Tool; Gluco sensor, masticatory function test by the Gluco sensor; ODK, oral diadochokinesis; Prescale force, occlusal force by the Dental Prescale.

**TABLE 3** | Comparison of oral function measurements among sarcopenia and frailty subgroups.

| | Sarcopenia | | | | | | Frailty | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Robust | Sarcopenia | Severe sarcopenia | All sarcopenia | | | Robust | Pre-frailty | Frailty | No frailty | | |
| | ($n = 275$) | ($n = 38$) | ($n = 16$) | ($n = 54$) | | | ($n = 118$) | ($n = 186$) | ($n = 25$) | ($n = 304$) | | |
| | Median (IQR) | Median (IQR) | Median (IQR) | Median (IQR) | $p$ between 3 groups | $p$ between 2 groups | Median (IQR) | Median (IQR) | Median (IQR) | Median (IQR) | $p$ between 3 groups | $p$ between 2 groups |
| Oral hygiene (%) | 22.2 (11.1–39.0) | 22.2 (11.1–41.7) | 22.4 (7.0–43.0) | 22.2 (11.1–39.0) | 0.889 | 0.583 | 22.2 (9.8–38.9) | 22.2 (11.1–44.0) | 22.2 (11.1–38.9) | 22.2 (11.1–40.3) | 0.584 | 0.742 |
| Oral dryness | | | | | | | | | | | | |
| Oral moisture | 26.9 (24.4–28.5) | 25.9 (23.2–28.9) | 27.1 (24.7–28.7) | 26.6 (23.6–28.8) | 0.707 | 0.747 | 26.5 (24.7–28.2) | 27.2 (24.0–28.7) | 27.0 (24.1–28.5) | 26.8 (24.2–28.6) | 0.888 | 0.789 |
| Saxon test (g) | 3.2 (2.2–4.7) | 3.2 (2.1–3.9) | 3.4 (2.0–4.4) | 3.2 (2.1–4.2) | 0.734 | 0.552 | 3.4 (2.3–5.1) | 3.2 (2.0–4.2) | 2.8 (1.8–4.4) | 3.2 (2.2–4.4) | 0.057 | 0.693 |
| Occlusal force | | | | | | | | | | | | |
| Prescale force (N) | 431.2 (296.0–658.7) | 325.0 (190.8–566.1) | 294.7 (81.0–639.7) | 325.0 (164.4–578.6) | 0.026* | 0.006† | 470.0 (337.0–720.0)[a] | 385.7 (225.4–622.7)[b] | 382.1 (170.0–571.1)[ab] | 421.8 (274.8–657.4) | 0.005** | 0.247 |
| Remaining teeth ($n$) | 9.0 (1.5–19.0) | 7.0 (0.0–17.0) | 7.0 (1.3–16.0) | 7.0 (0.0–16.0) | 0.150 | 0.068 | 14.5 (5.0–21.0)[a] | 6.0 (0.3–16.0)[b] | 6.0 (0.5–16.0)[ab] | 8.0 (1.0–19.0) | < 0.001** | 0.395 |
| ODK (/pa/) (/sec) | 6.0 (5.4–6.4) | 5.8 (5.0–6.3) | 5.9 (4.6–6.2) | 5.8 (5.0–6.2) | 0.137 | 0.052 | 6.0 (5.8–6.6)[a] | 5.0.8 (5.2–6.4)[b] | 6.0 (5.1–6.2)[ab] | 6.0 (5.4–6.4) | 0.002** | 0.516 |
| ODK (/ta/) (/sec) | 5.8 (5.2–6.4) | 5.4 (5.0–6.4) | 5.8 (4.5–6.2) | 5.5 (4.8–6.2) | 0.084 | 0.026† | 6.0 (5.4–6.6) | 5.8 (4.8–6.2) | 5.8 (4.7–6.0) | 5.8 (5.0–6.4) | < 0.001** | 0.130 |
| ODK (/ka/) (/sec) | 5.4 (4.8–6.0) | 5.2 (4.4–5.8) | 5.5 (4.2–6.0) | 5.2 (4.4–5.9) | 0.206 | 0.081 | 5.6 (5.2–6.2) | 5.2 (4.5–5.8) | 5.4 (4.1–6.0) | 5.4 (4.8–6.0) | < 0.001** | 0.427 |
| Tongue pressure (kPa) | 30.2 (23.9–34.2) | 23.3 (15.3–28.2)[a] | 20.6 (14.1–27.7)[a] | 22.4 (15.2–28.1) | < 0.001** | < 0.001†† | 31.1 (25.7–35.6)[a] | 28.4 (21.1–33.1)[b] | 21.5 (16.2–26.5)[c] | 29.9 (23.2–33.9) | < 0.001** | < 0.001†† |
| Masticatory function | | | | | | | | | | | | |
| Gluco sensor (mg/dL) | 194.0 (154.0–239.5) | 187.0 (126.5–243.0) | 155.5 (93.5–206.8) | 185.5 (119.2–230.0) | 0.070 | 0.073 | 210.5 (176.0–255.3) | 177.0 (133.0–227.3)[a] | 162.0 (120.0–228.0)[a] | 193.0 (153.8–238.0) | < 0.001** | 0.341 |
| Comminuted score | 6.0 (5.01–7.0) | 6.0 (3.0–8.0) | 6.0 (1.31–7.0) | 6.0 (2.8–7.0) | 0.134 | 0.060 | 7.0 (6.0–8.0) | 6.0 (4.0–7.0)[a] | 5.0 (1.0–7.0)[a] | 6.0 (5.0–7.3) | < 0.001** | 0.063 |

(Continues)

**TABLE 3** | (Continued)

| | Sarcopenia | | | | | | Frailty | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Robust | Sarcopenia | Severe sarcopenia | All sarcopenia | | | Robust | Pre-frailty | Frailty | No frailty | | |
| | ($n$ = 275) | ($n$ = 38) | ($n$ = 16) | ($n$ = 54) | | | ($n$ = 118) | ($n$ = 186) | ($n$ = 25) | ($n$ = 304) | | |
| | Median (IQR) | Median (IQR) | Median (IQR) | Median (IQR) | $p$ between 3 groups | $p$ between 2 groups | Median (IQR) | Median (IQR) | Median (IQR) | Median (IQR) | $p$ between 3 groups | $p$ between 2 groups |
| Swallowing function | | | | | | | | | | | | |
| EAT-10 | 0.0 (0.0–1.0)$^a$ | 0.5 (0.0–2.0)$^{ab}$ | 2.0 (1.0–5.5)$^b$ | 1.0 (0.0–4.0) | < 0.001** | 0.001†† | 0.0 (0.0–1.0)$^a$ | 0.0 (0.0–2.0)$^b$ | 2.0 (0.0–6.0)$^c$ | 0.0 (0.0–1.0) | < 0.001** | < 0.001†† |
| BSAQ | 0.0 (0.0–0.0)$^a$ | 0.0 (0.0–1.0)$^{ab}$ | 0.0 (0.0–1.8)$^b$ | 0.0 (0.0–1.0) | 0.013* | 0.012† | 0.0 (0.0–0.0)$^a$ | 0.0 (0.0–0.0)$^a$ | 0.0 (0.0–2.0) | 0.0 (0.0–2.0) | < 0.001** | < 0.001†† |

*Note:* IQR: interquartile range (25th–75th percentile). $p$-Value between 3 groups: $p$-Value between Robust, sarcopenia and severe sarcopenia or between Robust, pre-frailty and frailty, $p$-Value between 2 groups: $p$-Value between Robust and all sarcopenia or between no frailty and frailty. Within group differences: *$p$ < 0.05, **$p$ < 0.01; Kruskal–Wallis test, †$p$ < 0.05, ††$p$ < 0.01; Mann–Whitney $U$ test. The letters on the right side of the measurement values indicate the results of multiple comparisons between subgroups, and there is no significant difference between letters of the same type (Dunn's multiple comparison test).

Abbreviations: BSAQ, Brief self-administered questionnaire (Seirei dysphagia questionnaire); Comminuted score, masticatory function test by the visual score of a comminuted gummy jelly; EAT-10, 10-item Eating Assessment Tool; Gluco sensor, masticatory function test by the Gluco sensor; ODK, oral diadochokinesis; Prescale force, occlusal force by the Dental Prescale.

frailty were 28.5 and 26.9 kPa, respectively, with sensitivities of 0.818 and 0.833 and specificities of 0.580 and 0.629, respectively.

## 4 | Discussion

This cross-sectional study on dental outpatients investigated the interrelationships among numerous oral function test items for oral hypofunction, how these tests relate to sarcopenia and frailty, and which oral function items need to be considered. Furthermore, the present study was planned with the aim of managing oral hypofunction in dental clinics, and oral function tests were conducted using all oral hypofunction tests issued by the JGS [10].

In the multivariate analysis, the results for both sarcopenia and frailty were affected by whether BMI was included as a covariate. Tongue pressure alone was significantly associated with sarcopenia when BMI was not adjusted for, while tongue pressure and EAT-10 both remained significant when BMI was included. Although sarcopenia has been associated with a low BMI [40], sarcopenia itself is defined as the loss of muscle mass. A lower BMI may reflect reductions in both muscle and fat mass, which may be linked to a decreased nutritional intake. Therefore, oral dysfunction (e.g., a decline in tongue pressure) may lead to sarcopenia via a reduced nutritional intake, with BMI potentially mediating this pathway. In consideration of this result and also that some studies on the relationship between sarcopenia and oral hypofunction did not adjust for BMI [41], we presented models with and without the BMI adjustment. Furthermore, the result showing that EAT-10 was only significant when BMI was included may reflect a correction for a confounding factor or an emphasis on a direct effect after the mediating effect was removed, which needs to be regarded as a limitation of this cross-sectional study.

Tongue pressure was significantly associated with frailty when BMI was not adjusted for; however, this relationship disappeared after the BMI adjustment. This may be explained by the use of the J-CHS criteria, which include weight loss as a component, and by the possible exclusion of the mediating pathway 'reduced tongue pressure → reduced nutritional intake → lower BMI → malnutrition → frailty'. A recent retrospective cohort study reported that malnutrition occurred after a decrease in tongue pressure [42]. Based on this causal perspective, BMI may function as a mediator, and analyses without the BMI adjustment may more accurately capture the overall effect of oral function on frailty. In summary, the multivariate analysis in the present study indicated that among the oral function measures of oral hypofunction, tongue pressure was associated with sarcopenia and was also likely to be associated with frailty in dental outpatients. Two large community-based studies examined the relationships between the diagnostic items for oral hypofunction defined by the JSG and sarcopenia and frailty. Nakamura et al. reported that no oral function items were significantly associated with sarcopenia after adjusting for BMI, while only EAT-10 correlated with frailty [43]. In contrast, Kugimiya et al., who did not adjust for BMI, reported significant associations between sarcopenia and occlusal force (Prescale force), tongue pressure, masticatory function (Gluco sensor), and swallowing function

**TABLE 4** | Univariate and multivariate binary logistic regression analyses using the presence or absence of sarcopenia and frailty as the dependent variable and each oral function as an independent variable.

| | Univariate analysis | | | | Multivariate analysis | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Sarcopenia | | | | | | Frailty | | | | | |
| | Sarcopenia | | Frailty | | Model 1[a] | | | Model 2[b] | | | Model 1[a] | | | Model 2[b] | | |
| | Odds ratio | 95% CI | Odds ratio | 95% CI | Odds ratio | 95% CI | *p* | Odds ratio | 95% CI | *p* | Odds ratio | 95% CI | *p* | Odds ratio | 95% CI | *p* |
| Oral hygiene | 1.005 | 0.991–1.019 | 1.000 | 0.980–1.020 | | | | | | | | | | | | |
| Oral dryness | | | | | | | | | | | | | | | | |
| Oral moisture | 0.994 | 0.919–1.075 | 0.984 | 0.885–1.093 | | | | | | | | | | | | |
| Saxon test | 0.919 | 0.795–1.062 | 0.914 | 0.743–1.124 | | | | | | | | | | | | |
| Occlusal force | | | | | | | | | | | | | | | | |
| Prescale force | 0.999* | 0.997–1.000 | 0.999 | 0.997–1.000 | 0.999 | 0.998–1.001 | 0.286 | 0.999 | 0.997–1.000 | 0.108 | 0.999 | 0.997–1.001 | 0.517 | 0.999 | 0.997–1.001 | 0.482 |
| Remaining teeth | 0.970 | 0.937–1.004 | 0.979 | 0.933–1.027 | | | | | | | 1.053 | 0.970–1.144 | 0.220 | 1.054 | 0.970–1.146 | 0.215 |
| ODK (/pa/) | 1.040 | 0.961–1.125 | 1.081 | 0.964–1.212 | | | | | | | 1.101 | 0.529–2.293 | 0.797 | 1.162 | 0.554–2.438 | 0.692 |
| ODK (ta/) | 0.689* | 0.505–0.941 | 0.724 | 0.472–1.110 | 0.954 | 0.668–1.363 | 0.797 | 0.878 | 0.602–1.280 | 0.499 | 0.555 | 0.227–1.358 | 0.197 | 0.546 | 0.226–1.318 | 0.178 |
| ODK (/ka/) | 0.785 | 0.583–1.056 | 0.799 | 0.529–1.206 | | | | | | | 1.855 | 0.821–4.192 | 0.138 | 1.776 | 0.778–4.055 | 0.173 |
| Tongue pressure | 0.897** | 0.862–0.933 | 0.913** | 0.869–0.959 | 0.908 | 0.867–0.952 | < 0.001** | 0.934 | 0.889–0.980 | 0.006** | 0.934 | 0.876–0.996 | 0.037* | 0.941 | 0.881–1.005 | 0.069 |
| Masticatory function | | | | | | | | | | | | | | | | |
| Gluco sensor | 0.995* | 0.990–0.999 | 0.996 | 0.990–1.003 | 0.999 | 0.993–1.006 | 0.876 | 0.999 | 0.992–1.007 | 0.859 | 1.008 | 0.998–1.018 | 0.111 | 1.008 | 0.998–1.018 | 0.110 |
| Comminuted score | 0.859** | 0.765–0.964 | 0.802** | 0.687–0.936 | 1.058 | 0.867–1.291 | 0.580 | 1.019 | 0.822–1.264 | 0.862 | 0.774 | 0.579–1.035 | 0.084 | 0.760 | 0.565–1.022 | 0.070 |
| Swallowing function | | | | | | | | | | | | | | | | |

(Continues)

**TABLE 4** | (Continued)

| | Univariate analysis | | | | Multivariate analysis | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sarcopenia | | Frailty | | Sarcopenia | | | | | | Frailty | | | | | |
| | | | | | Model 1[a] | | | Model 2[b] | | | Model 1[a] | | | Model 2[b] | | |
| | Odds ratio | 95% CI | Odds ratio | 95% CI | Odds ratio | 95% CI | *p* | Odds ratio | 95% CI | *p* | Odds ratio | 95% CI | *p* | Odds ratio | 95% CI | *p* |
| EAT-10 | 1.105** | 1.034–1.180 | 1.150** | 1.067–1.239 | 1.091 | 0.975–1.220 | 0.128 | 1.126 | 1.000–1.266 | 0.049* | 1.090 | 0.965–1.231 | 0.166 | 1.097 | 0.969–1.242 | 0.145 |
| BSAQ | 1.257* | 1.013–1.560 | 1.623** | 1.280–2.057 | 0.870 | 0.579–1.308 | 0.504 | 0.763 | 0.502–1.160 | 0.206 | 1.300 | 0.819–2.062 | 0.075 | 1.249 | 0.778–2.005 | 0.357 |

Abbreviations: BSAQ, brief self-administered questionnaire (Seirei dysphagia questionnaire); Comminuted score, masticatory function test by the visual score of a comminuted gummy jelly; EAT-10, 10-item Eating Assessment Tool; Gluco sensor, masticatory function test by the Gluco sensor; ODK, oral diadochokinesis; Prescale force, occlusal force by the Dental Prescale.
[a]Model 1: values adjusted for age, sex, timing of the test during treatment, cancer and cerebrovascular disease.
[b]Model 2: values adjusted for model 1 with BMI added.
*$p < 0.05$, **$p < 0.01$.

**TABLE 5** | Area under the curve (AUC), sensitivity, specificity and cut-off points of oral function assessment items.

| | Prescale force | Remaining teeth | ODK /pa/ | ODK /ta/ | ODK /ka/ | Tongue pressure | Gluco sensor | Comminuted score | EAT-10 | BSAQ |
|---|---|---|---|---|---|---|---|---|---|---|
| Sarcopenia | | | | | | | | | | |
| AUC (95% CI) | 0.615 (0.525–0.705) | 0.578 (0.498–0.658) | 0.592 (0.508–0.677) | 0.595 (0.512–0.679) | 0.575 (0.493–0.657) | 0.744 (0.671–0.818) | 0.573 (0.484–0.662) | 0.577 (0.487–0.667) | 0.634 (0.549–0.719) | 0.579 (0.491–0.666) |
| Cut-off value | — | — | — | — | — | 28.450 kPa | — | — | — | — |
| Frailty | | | | | | | | | | |
| AUC (95% CI) | 0.579 (0.463–0.696) | 0.551 (0.441–0.660) | 0.558 (0.449–0.667) | 0.591 (0.486–0.695) | 0.548 (0.427–0.668) | 0.728 (0.622–0.833) | 0.575 (0.448–0.702) | 0.629 (0.505–0.753) | 0.691 (0.583–0.823) | 0.647 (0.535–0.787) |
| Cut-off value | — | — | — | — | — | 26.850 kPa | — | — | — | — |

Abbreviations: BSAQ, brief self-administered questionnaire (Seirei dysphagia questionnaire); Comminuted score, masticatory function test by the visual score of a comminuted gummy jelly; EAT-10, 10-item Eating Assessment Tool; Gluco sensor, masticatory function test by the Gluco sensor; ODK, oral diadochokinesis; Prescale force, occlusal force by the Dental Prescale.

assessed by EAT-10 [41]. Differences between these studies and the present results may be partly explained by the study populations (community-dwelling individuals vs. dental outpatients). The majority of participants in the present study (87.7%) were dental outpatients receiving maintenance care after the completion of prosthetic treatment. Although their occlusal force was below the reference value, their masticatory function exceeded the reference threshold, suggesting that masticatory function had been adequately maintained. This may explain why neither masticatory function nor occlusal force had a significant effect in the present analysis. A previous study conducted on a similar population of dental outpatients receiving regular maintenance care also did not include BMI as a covariate in its multivariate analysis [44]. In that study, sarcopenia was significantly associated with tongue pressure and ODK, which was attributed to the low percentage of patients with impaired masticatory function in the maintenance group.

Furthermore, the cut-off values of tongue pressure for sarcopenia (28.5 kPa) and frailty (26.9 kPa) identified in the present study were slightly lower, but not markedly different, from the current diagnostic threshold for oral hypofunction (30 kPa). In a systematic review and meta-analysis [45], the mean tongue pressure among healthy adults aged ≥60 years, measured with the same device used in the present study (TPM-01, JMS Co. Ltd.), was approximately 31 kPa. Similarly, using the same device, Iwasaki et al. [46] demonstrated that the values for healthy individuals aged 70–85 years ranged from approximately 32.5–28.5 kPa. These findings suggest that the cut-off values obtained in the present study for sarcopenia and frailty were reasonable. Regarding the appropriate reference values of tongue pressure for the diagnosis of oral hypofunction, Iwasaki et al. [46] proposed 24.3 kPa for men and 23.7 kPa for women based on the lowest quintile of tongue pressure values. However, since a recent longitudinal study [13], which demonstrated that a low tongue pressure increased the risk of malnutrition, adopted 30 kPa as the reference threshold, and current clinical practices generally employ stricter cut-off values for preventive purposes, maintaining 30 kPa as a health-oriented target reference may be a reasonable choice. Nevertheless, forthcoming longitudinal data will be needed to establish whether lower cut-off values are more suitable.

According to a review of studies based on the JGS criteria for oral hypofunction [22], nine of the 10 studies included were cross-sectional, with seven being conducted on community-dwelling older adults and only one on dental outpatients. The reported prevalence of oral hypofunction ranged from 42.7% to 60.0% in community samples, and was 49.1% in the single study on dental outpatients. In contrast, the prevalence of oral hypofunction in the present study was higher at 65.7%. This may be attributed to the study population primarily consisting of patients in their 70s and 80s receiving prosthodontic treatment with multiple missing teeth, and also to the setting in a university hospital dental clinic, where patients often also receive concurrent medical care and, thus, may present with higher levels of frailty. On the other hand, although not shown in the present results, the use of two tests, including alternative assessments, for each oral function domain in this study was confirmed to not have contributed to the higher prevalence observed.

Regarding redundancy among the seven oral function tests used for diagnosing oral hypofunction, correlation and multivariate analyses suggested that the integration of occlusal force and masticatory function for dental outpatients is reasonable. With respect to the validity of the main and alternative assessments, the two tests for oral dryness, the oral moisture measurement and Saxon test, may need to be reconsidered. Although oral moisture and stimulated salivary flow rates are generally recognised to show weak to moderate correlations [29], the Saxon test may be less suitable for use in older adults, as it is more affected by medication-related reductions in salivary secretion than oral moisture measurements using a moisture checker [47].

The major limitation of this study is that because of its cross-sectional design, it cannot establish causal relationships between sarcopenia or frailty and oral function measures, such as tongue pressure. Additionally, since the participants were dental outpatients at a university hospital, some degree of selection bias is likely. Furthermore, the information obtained on lifestyle factors, which are associated with sarcopenia and frailty, was insufficient, precluding the analyses that incorporated them.

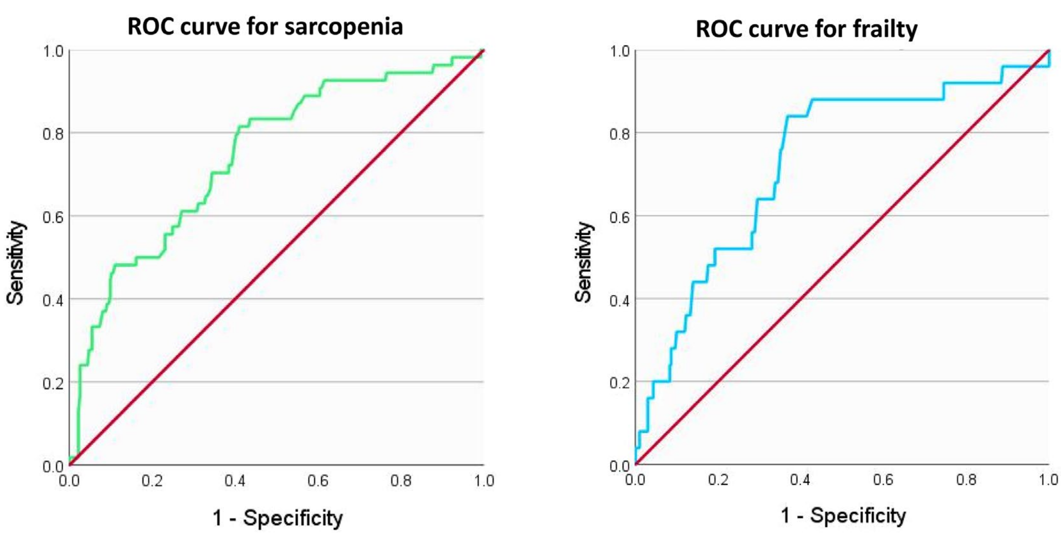


**FIGURE 1** | Receiver operating characteristic curve (ROC) analysis of sarcopenia and frailty measured by tongue pressure.

Nevertheless, in Japan, where the diagnosis of 'oral hypofunction' has been formally positioned within dental practice, the ability to evaluate oral function and simultaneously screen for sarcopenia and frailty during routine dental outpatient care has significant implications. Such an integrated strategy in dental clinics may contribute more effectively to the health management of the general population than population-based approaches. Therefore, the present study, conducted in dental outpatients, has meaningful implications within the context of the current social background and healthcare system.

## 5 | Conclusion

Among the alternative assessment methods employed for each test item, some correlated with the corresponding main test, whereas others did not. In addition, a moderate correlation was observed between occlusal force and masticatory function; therefore, further studies are needed on the testing methods for oral hypofunction. Among these oral function tests, tongue pressure showed the strongest relationship with sarcopenia and frailty in dental outpatients, and only tongue pressure enabled the derivation of cut-off values based on the presence or absence of sarcopenia and frailty.

### Author Contributions

Conceptualization, S.T. and Y.N.; methodology, Y.N.; validation, S.T. and Y.N.; formal analysis, S.T. and Y.N.; investigation, S.T., Y.N., N.I., T.S., T.N., M.H., M.K., H.M., R.H., F.S., K.H. and M.M.; resources, Y.N.; data curation, S.T. and Y.N.; writing – original draft preparation, S.T. and Y.N.; writing – review and editing, Y.N., N.I. and T.H.; visualisation, S.T. and Y.N.; supervision, Y.N. and T.H.; funding acquisition, Y.N. All authors have read and agreed to the published version of the manuscript.

### Acknowledgements

We wish to thank all the participants for their involvement in this study. This study was supported by a Grant-in-Aid for Scientific Research (C) (No. 23K09483) from the Japan Society for the Promotion of Science.

### Funding

This study was supported by JSPS KAKENHI Grant Number JP23K09483 from the Japan Society for the Promotion of Science.

### Conflicts of Interest

The authors declare no conflicts of interest.

### Data Availability Statement

Data that support the results of this study are available from the corresponding author upon reasonable request. Data are not publicly available because of ethico-legal restrictions imposed by the Epidemiological and Related Research Ethics Committee of Kagoshima University.

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## Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Table S1:** Univariate and multivariate binary logistic regression analyses using the presence or absence of sarcopenia and frailty as the dependent variable and major systemic diseases as the independent variable. **Table S2:** Univariate and multivariate binary logistic regression analyses using the presence or absence of sarcopenia and frailty as the dependent variable and each oral function as the independent variable by sex.