

Association between tongue and lip functions and masticatory performance in young dentate adults

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SUMMARY Motor functions of masticatory organs such as the tongue, lips, cheeks and mandible are known to deteriorate with age, thereby influencing masticatory performance. However, there are few reports on the relationships between tongue and lip functions and masticatory performance. To investigate the relationship between tongue and lip functions and comprehensive masticatory performance, by evaluating crushing, mixing and shearing abilities in young dentate adults. Participants comprised 51 dentate adults with a mean age of 25 years. Maximum tongue pressure and oral diadochokinesis were measured to evaluate tongue and lip functions. A multiple sieving method using peanuts was performed to evaluate crushing ability. A colour-changeable chewing gum was performed to evaluate mixing ability. A test gummy jelly was performed to evaluate shearing ability. The relationship between tongue and lip functions and each masticatory performance was assessed using Pearson's correlation coefficients. In addition, stepwise

multiple regression analysis was performed to identify predictors of crushing ability. Crushing ability was significantly correlated with maximum tongue pressure and the number of repetitions of the syllables /pa/, /ta/ and /ka/. Maximum tongue pressure and number of repetitions of the syllable /pa/ were identified as significant predictors for crushing ability. Mixing ability was significantly correlated with the number of repetitions of the syllable /pa/. Shearing ability was not significantly correlated with tongue and lip functions. Masticatory performance during the chewing of brittle foods such as peanuts and solid foods such as chewing gum appears to be correlated with tongue and lip functions.

KEYWORDS: masticatory performance, tongue pressure, oral diadochokinesis, lip, mixing ability, sieving method

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Background

Various methods have been developed to evaluate masticatory performance. The crushing ability which is measured by particle size distribution in the bolus of foods such as peanuts (1, 2) and silicon rubber (3, 4), concentrations of dissolved solutions such as chewing gum (5–7) and gummy jellies (8–13) which evaluate mixing ability and shearing ability, respectively, and the mixing ability which is measured by colour mixtures and shapes of chewed wax cubes (14) have been used as methods of objective evaluations.

However, the process of mastication can only partly be evaluated by using these methods.

The factors relating to masticatory performance include mandibular movement (5), occlusal contact area (7, 13), occlusal force (8, 11, 13) and tongue movement (15, 16). In these factors, movement to be coordinated with tongue, lips, cheeks and other facial muscle is essential for smooth mastication (15). The functions of these structures limit the food between the dental arches in the oral cavity to facilitate comminution, form a food bolus by incorporating the comminuted food with saliva and transport it to

the pharynx (17). Motor functions of masticatory organs such as the tongue, lips, cheeks and mandible are known to deteriorate with age (18), thereby influencing masticatory performance (16).

However, there is a dearth of reports on the relationships between tongue and lip functions and masticatory performance (10, 15, 16). Koshino *et al.* (15) reported significant correlations between crushing ability and tongue movement in complete denture wearers, but not in dentate adults and elderly people. Kikutani *et al.* (16) reported significant correlations between mixing ability and maximum tongue pressure, as well as number of repetitions of the syllable /ta/ in elderly people who had no occlusal support. Takahashi *et al.* (10) reported significant correlations between shearing ability and tongue and cheek pressure in dentate adults. These studies assessed crushing, mixing and shearing abilities to demonstrate the relationship between tongue and lip functions and masticatory performance in each age group. However, the aforementioned studies evaluated only a part of the process of mastication and might not have evaluated comprehensive masticatory performance.

The purpose of the present study was to investigate the relationship between tongue and lip functions and comprehensive masticatory performance using three methods that evaluated each crushing, mixing and shearing ability in young dentate adults.

Methods

Participants

Fifty-one dentate adults (31 men, 20 women) with a mean age of 25.0 years were included in the study. Inclusion criteria were absence of tooth disease such as caries or periodontal disease and no missing teeth, excluding the third molars. Exclusion criteria were presence of either temporomandibular disorders or xerostomia. The type of dental occlusion in the participants was not ascertained in this study.

We evaluated the tongue and lip functions and masticatory performance for all participants as follows.

Measurement of tongue and lip functions

Maximum tongue pressure. Maximum tongue pressure was evaluated using a tongue pressure measurement

device (JMS tongue pressure device*) as described by Tsuga *et al.* (17). The balloon was positioned on the anterior part of the participant's palate, with the lips closed. The participants were instructed to raise their tongue and compress the balloon onto the palate with maximal voluntary muscular effort for approximately 7 s. The measurements were taken with intervals of more than 30 s for rest and mouth rinsing, if requested. Values were recorded three times, and the average of these values was the evaluation value as the maximum tongue pressure.

Oral diadochokinesis. Oral diadochokinesis was evaluated using an oral functions measurement device (KENKOU-KUN handy†). Participants were instructed to repeatedly pronounce a monosyllable as fast as possible for 5 s. The device recorded the number of repetitions for each syllable and calculated the number of syllables produced per second. The monosyllables /pa/ , /ta/ and /ka/ were used to evaluate the ability of the lips, the tip of the tongue and the posterior region of the tongue, respectively (19, 20).

Measurement of masticatory performance

Multiple sieving method using peanuts to evaluate crushing ability. Participants were instructed to chew 3 g of peanuts using 20 chewing cycles on the right, left or both sides of the mouth, depending on their preference (habitual chewing). This process was repeated three times (1, 2). After that, all the peanut particles were collected in a cup, rinsed with running water and dried for 6 h in a drying machine (Drying Oven DX300‡) set to 80 °C. After drying, the particles were sieved through a stack of eight sieves, with apertures (4750, 2800, 1700, 1180, 850, 600, 350 and 180 µm) using an automatic dry sonic sieving device (Robot Sifter RPS-85P§). Median particle size (X_{50}) was calculated and defined as the crushing ability of masticatory performance. The median particle size by weight (X_{50}) was defined as the aperture of a theoretical sieve through which 50% of the test food particles by weight can pass (3).

*JMS Co., Ltd., Tokyo, Japan.

†Takei Scientific Instruments Co., Ltd., Niigata, Japan.

‡Yamato Scientific Co., Ltd., Tokyo, Japan.

§Seishin Enterprise Co., Ltd., Tokyo, Japan.

Colour-changeable chewing gum to evaluate mixing ability. Mixing ability was evaluated using a colour-changeable chewing gum (Masticatory Performance Evaluating Gum Xylitol[†]), as described by Hama *et al.* (6). The participants were instructed to chew the chewing gum, using 60 chewing cycles, at a rhythm of chewing once per second. Instructions were given to chew the gum on the right, left or both sides of the mouth, depending on their preference (habitual chewing). The chewed gum was measured for colour changes and calculated ΔE values and the number of chewing cycles (N).

$$\Delta E = [(L * -72.3)^2 + (a * +14.9)^2 + (b * -33.0)^2]^{1/2}$$

The colour values of the gum can be applied as a ratio scale using non-linear regression. Thus, the number of chewing cycles (N) was calculated with the following formula and defined as the mixing ability of masticatory performance.

$$N : \Delta E = 73.2 - \frac{2.85 \times 10^7}{1 + e^{9.95 \times 10^{-3}(N + 1.35 \times 10^3)}}$$

Test gummy jelly to evaluate shearing ability. Shearing ability was evaluated using a test gummy jelly (Test gummy jelly for evaluating masticatory performance**), as described by Ikebe *et al.* (9). The participants were instructed to chew the test gummy jelly using 30 chewing cycles on the right, left or both sides of the mouth, depending on their preference (habitual chewing). A linear regression analysis showed that the concentration of glucose had a significantly high correlation to the surface area (mm²) of the comminuted jelly ($r = 0.993$, $P < 0.01$). Shearing ability was assessed by calculating the surface area of the particles (mm²) from the glucose concentration, using the following linear regression (11).

$$\begin{aligned} \text{Shearing ability (mm}^2\text{)} &= \\ 13.5 \times [\text{glucose concentration}] &- 250 \end{aligned}$$

Statistical analysis

The relationship between each evaluation value of tongue and lip functions and masticatory performance

was assessed using Pearson's correlation coefficients. Stepwise multiple regression analysis was performed to identify the predictors of crushing ability, wherein, the parameters of tongue and lip functions exhibiting significant relationships were employed as independent variables, and crushing ability was employed as the dependent variable. SPSS ver.16.0^{††}) was used for all statistical analysis. P values of ≤ 0.05 were considered statistically significant.

Results

Table 1 illustrates the relationship between tongue and lip functions and masticatory performance amongst the participants in the present study. Significant correlations were observed between crushing ability and maximum tongue pressure ($r = -0.42$, $[-0.62, -0.16]$), as well as the number of repetitions of the syllables /pa/ ($r = -0.38$, $[-0.59, -0.11]$), /ta/ ($r = -0.36$, $[-0.58, -0.09]$) and /ka/ ($r = -0.36$, $[-0.58, -0.09]$) (Fig. 1a–d). A significant correlation was observed between mixing ability and the number of repetitions of the syllable /pa/ ($r = 0.32$, $[0.04, 0.54]$) (Fig. 2). In addition, a tendency for positive correlation between mixing ability and the number of repetitions of the syllable /ta/ ($r = 0.27$, $[-0.01, 0.51]$) was observed. No significant correlation was observed between shearing ability and tongue and lip functions. Correlation coefficients ranged from -0.42 to 0.32 ; tongue and lip functions were observed between 10% and 17% of the variance in masticatory performance.

Stepwise multiple regression analysis identified maximum tongue pressure ($r = -0.46$) and the number of repetitions of the syllable /pa/ ($r = -0.43$) as significant predictors for crushing ability, which accounted for 30.0% of the variance in crushing ability. Beta values were -0.43 for maximum tongue pressure and -0.39 for the number of repetitions of the syllable /pa/ (Table 2). The regression analysis did not demonstrate any relationships between the number of repetitions of the syllables /ta/ and /ka/ and crushing ability.

Discussion

In the present study, we investigated the relationship between tongue and lip functions and masticatory

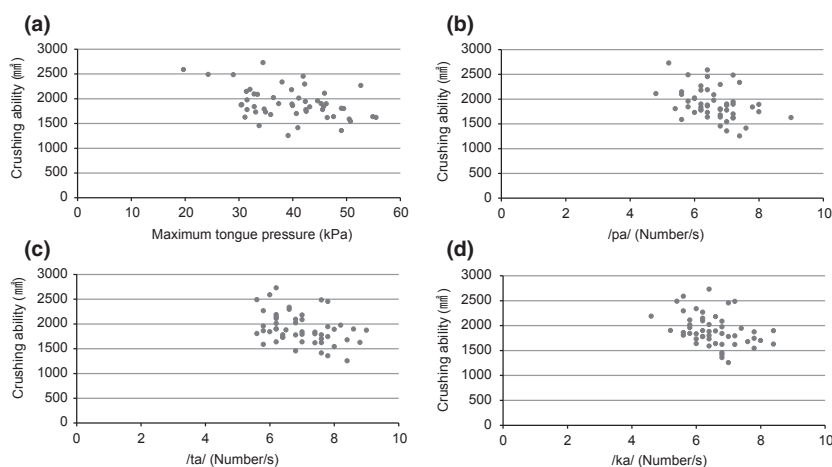
[†]Lotte Co., Ltd., Tokyo, Japan.

^{**}UHA Mikakuto Co., Ltd., Osaka, Japan.

^{††}SPSS Japan Inc., Tokyo, Japan.

Table 1. Correlation coefficients (*r*), with confidence intervals (CI) and *P* values between tongue and lip functions (maximum tongue pressure and oral diadochokinesis) and masticatory performance (crushing, mixing and shearing abilities) following Pearson's correlation coefficients in 51 young dentate adults

| Masticatory performance | Statistical value | Maximum tongue pressure | Oral diadochokinesis | | |
|-------------------------|-------------------|-------------------------|----------------------|----------------|----------------|
| | | | /pa/ | /ta/ | /ka/ |
| Crushing ability | <i>r</i> | −0.42 | −0.38 | −0.36 | −0.36 |
| | 95% CI | [−0.62, −0.16] | [−0.59, −0.11] | [−0.58, −0.09] | [−0.58, −0.09] |
| | <i>P</i> | < 0.01* | 0.01* | 0.01* | 0.01* |
| Mixing ability | <i>r</i> | −0.08 | 0.32 | 0.27 | 0.19 |
| | 95% CI | [−0.35, 0.20] | [0.04, 0.54] | [−0.01, 0.51] | [−0.09, 0.44] |
| | <i>P</i> | 0.57 | 0.02* | 0.06 | 0.18 |
| Shearing ability | <i>r</i> | 0.07 | −0.17 | −0.01 | 0.13 |
| | 95% CI | [−0.21, 0.34] | [−0.43, 0.11] | [−0.29, 0.26] | [−0.15, 0.39] |
| | <i>P</i> | 0.61 | 0.24 | 0.93 | 0.38 |

P* ≤ 0.05.Fig. 1.** Correlation between tongue and lip functions and crushing ability. (a) Tongue pressure. (b) The number of repetitions of the syllable /pa/. (c) The number of repetitions of the syllable /ta/. (d) The number of repetitions of the syllable /ka/.

performance in 51 young dentate adults. Our results showed that significant correlations and its variance were observed between tongue and lip functions and masticatory performance. Thus, our data indicated that tongue and lip functions are factors related to masticatory performance.

Stepwise multiple regression analysis showed that maximum tongue pressure and the number of repetitions of the syllable /pa/ significantly impacted crushing ability in the present study. Brittle foods such as peanuts are ground to fine particles during the chewing process. Therefore, a considerable amount of fine peanut particles would have to be placed on to the occlusal surfaces, using the tongue, to chew them effectively. In addition, the orbicularis oris muscle is connected to the buccinator muscle and prevents the

spilling of food from the occlusal surface during mastication. This is in accordance with another recent study, where the number of repetitions of the syllable /pa/ has been reported to be significantly correlated with lip pressure (17). These factors may be associated with the significant predictors for masticatory performance in the case of brittle foods such as peanuts. The findings from the present study contradict the results of the study by Koshino *et al.*, where significant correlations were found between crushing ability and tongue functions in complete denture wearers, but not in dentate adults and elderly people. This contradiction may be attributed to the different methods used in the two studies (15). In the present study, maximum tongue pressure and oral diadochokinesis were measured to evaluate tongue and lip functions.

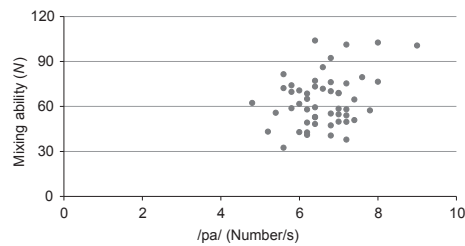


Fig. 2. Correlation between the number of repetitions of the syllable /pa/ and mixing ability.

Furthermore, the multiple sieving method using peanuts was used to evaluate crushing ability. Participants chewed peanuts as their habitual chewing, and the estimated median particle size (X_{50}) was used to define crushing ability. In contrast, Koshino *et al.* measured tongue movements in motion-modulation with sound signals using an ultrasound system to evaluate tongue functions. The multiple sieving method using peanuts was used to evaluate crushing ability; however, the participants in their study were instructed to chew on their preferred chewing side (left or right). Crushing ability was evaluated by dividing the volume of peanuts passed through the 5-mesh sieve by the total volume of peanuts remaining on the sieves, and this fraction was expressed as a per cent. Due to the different methods used to evaluate tongue functions and crushing ability, both studies obtained different results with regard to the relationship between tongue functions and crushing ability in dentate adults.

Significant correlations were observed between mixing ability and the number of repetitions of the syllable /pa/ in the present study. In addition, a tendency for positive correlation was also observed between mixing ability and the number of repetitions of the syllable /ta/. The colour-changeable chewing gum is a solid food, which requires mixing and kneading. The bolus is placed on the occlusal surface using the tongue. Similar to the correlation between the crushing ability and tongue and lip functions, the orbicularis oris and buccinator muscles act by holding the food within the dental arches during mastication. This may account for the significant association observed between masticatory performance in the case of solid foods such as chewing gum and the functions of the tip of the tongue and lips in the present study. Kikutani *et al.* demonstrated significant correlations between tongue and lip functions and mixing ability in elderly people with no occlusal support (16).

Table 2. Partial regression coefficients (B), standardised partial regression coefficients (β) and P values between tongue and lip functions [maximum tongue pressure and oral diadochokinesis (/pa/)] and crushing ability following stepwise multiple regression analysis in 51 young dentate adults

| Dependent variable | Independent variables | Statistical value | | |
|--------------------|-----------------------------|-------------------|---------|-------|
| | | B | β | P |
| Crushing ability | Intercept | 3631.87 | – | <0.01 |
| | Maximum tongue pressure | –17.23 | –0.43 | <0.01 |
| | Oral diadochokinesis (/pa/) | –157.86 | –0.39 | <0.01 |

$R^2 = 0.33$, adjusted $R^2 = 0.30$, F value = 11.61 ($P < 0.01$).

They reported that mixing ability was significantly correlated with maximum tongue pressure and the number of repetitions of the syllable /ta/. In contrast, we did not find any significant correlations between mixing ability and maximum tongue pressure in the present study. This is possibly due to the differences in participants' age and number of teeth between the two studies. The present study comprised young dentate adults, while the study by Kikutani *et al.* involved elderly people with no occlusal support. It is known that motor functions of masticatory organs such as the tongue, lips, cheeks and mandible deteriorate with age (18) and influences masticatory performance (16). This may explain why tongue pressure was associated with mixing ability in elderly people in the aforementioned study.

Shearing ability was not significantly correlated with tongue and lip functions in the present study. Due to the hard and elastic nature of the test gummy jelly, it requires additional occlusal forces and time to be comminuted into a fine bolus. In previous studies, the test gummy jelly was significantly correlated with occlusal force (8, 11, 13) and occlusal contact area (13). Thus, it was suggested that shearing ability is more easily influenced by factors relating to the teeth or masticatory muscles than by tongue and lip functions. The shearing ability on the preferred chewing side (left or right) has been reported to be significantly correlated to maximum tongue pressure and cheek pressure in healthy dentate adults (10). This is not in accordance with the findings from the present study and can be attributed to the difference in hardness of the gummy jellies used in the two studies. The gummy jelly that Takahashi *et al.* used was softer than

that used in our study (8, 12) and make it easier to comminute. Therefore, the gummy jelly that they used was correlated with perioral muscles function.

In the present study, simple regression analysis and multiple regression analysis were used to assess the relationship between tongue and lip functions and masticatory performance. Our results showed that the variance in masticatory performance was between 10% and 17% by simple regression analysis and variance in crushing ability was 30.0% by multiple regression analysis; therefore, tongue and lip functions did not show a high coefficient of determination. This may be because of many factors such as mandibular movement (5), occlusal contact area (7, 13) and occlusal force (8, 11, 13) that are related to masticatory performance in addition to tongue and lip functions, which may explain the variance in masticatory performance observed in the present study. Significant correlations were observed between crushing ability and the number of repetitions of the syllables /ta/ and /ka/ by simple regression analysis; however, multiple regression analysis did not reveal any direct associations between the variables. This may be attributed to the fact that the syllables /ta/ and /ka/ evaluate the ability of the tongue and could be supplemented by tongue pressure.

Young dentate adults were chosen as participants in the present study; however, evaluation of the effect of dental treatment may require assessment of masticatory performance in patients with missing teeth and those belonging to a wide range of age groups. Hence, further studies investigating the relationship between tongue and lip functions and masticatory performance in elderly dentate people or in edentulous patients are warranted.

Conclusion

We investigated the relationship between tongue and lip functions and comprehensive masticatory performance by evaluating crushing, mixing and shearing abilities in young dentate adults. The following results were observed:

- 1 The masticatory performance while chewing brittle foods such as peanuts was significantly correlated with maximum tongue pressure and lip functions.
- 2 The masticatory performance while chewing solid foods such as chewing gum was significantly corre-

lated with lip function and demonstrated a tendency for correlation with the functions of the tip of the tongue.

- 3 The masticatory performance while chewing hard and elastic foods such as the test gummy jelly was not significantly correlated with tongue and lip functions.

The findings from the present study provide further insight into the effect of the functions of the tongue and lips on masticatory performance.

Disclosure

The study protocols were approved by the Ethics Committee at Faculty of Dentistry, Tokyo Medical and Dental University (#844), which conformed to the principles described in the World Medical Association Declaration of Helsinki (2002), and all participants provided written and informed consent before enrolment in the study. This research was carried out without funding. No conflict of interests are declared.

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