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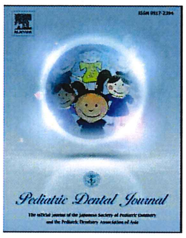

Original Article

Association of tongue pressure with masticatory performance and dental conditions in Japanese children

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ABSTRACT

The aim of this study is to evaluate the association between maximum tongue pressure, masticatory performance, and oral conditions in children aged 6–12 years. The decayed, missing, and filled teeth (DMFT) index of 70 Japanese school children (35 boys, 35 girls) was measured, as well as their height, body weight, maximum tongue pressure, and masticatory performance. Furthermore, their subjective masticatory ability was scored using a newly developed questionnaire related to the preference and hardness of 25 foodstuffs. To investigate masticatory performance, the total number and maximum projected area of chewed particles of jelly-based Kamuzokun were measured. The reliability of the questionnaire was assessed based on its internal consistency and on confirmatory factor analysis. Pearson's correlation analysis showed that maximum tongue pressure was significantly correlated with age, height, body weight, DMFT index, masticatory performance, and subjective masticatory ability score. Multiple regression analysis showed that maximum tongue pressure was associated with age, DMFT index, and the total number of chewed particles. The total number of chewed particles was the most important variable associated with maximum tongue pressure. The questionnaire exhibited good internal consistency, and satisfactory goodness-of-fit indices were obtained in the confirmatory factor analysis. These results suggest that tongue pressure is associated with healthy physical and mental development, as well as with masticatory performance and dental caries.

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1. Introduction

Developmental disabilities in tongue function and tongue habits are of interest to many pediatric and orthodontic dentists as potential etiologic factors in malocclusion [1,2].

During the neonatal period, the tongue is located in the forward suckling position for nursing, and the swallowing pattern is infantile. Over a period of 12–18 months, proprioception causes postural and functional changes in the tongue, and a transitional period ensues. Between 2 and 4 years, functionally balanced mature swallowing prevails; however, the tongue thrust that is part of the infantile swallowing pattern may be found in children older than 4 years, and even sometimes in adolescent and adult patients [3].

It was recently reported that the prevalence of tongue thrusting is 4.9% in children aged 6–12 years [4]. We hypothesize that the intake of processed soft foods, as well as retaining infantile swallowing patterns, may lead to tongue thrusting by affecting the activity of the tongue.

For several decades oral myofunctional therapy has been used to treat and prevent poor oral habits [5]. Various exercises are used to encourage mature swallowing in children, such as pushing the tip of the tongue against the hard palate [6,7]. Therefore, we hypothesized that the development of tongue pressure is related to an increase in masticatory performance and physical development in children. Evidence of tongue pressure and other factors related to tongue pressure in pediatric patients is necessary to diagnose tongue habits accurately and to use myofunctional therapy effectively. Unfortunately, however, there have been few studies investigating tongue pressure in children.

In this work, we examined tongue pressure among children aged 6–12 years, as well as the relationships between tongue pressure and various factors, including anthropometric measurements, dental status, masticatory performance, and a measure of the subjective mastication ability (SMA) score using a self-administered questionnaire associated with the preference for hard foodstuffs. Furthermore, we verified the reliability of this newly developed questionnaire.

2. Materials and methods

2.1. *Participants*

The participants were 70 healthy school children (35 boys and 35 girls) aged 6–12 years ($n = 10$ for each year-age group, where the male/female ratio was constant in each group). The participants were selected following an initial examination at the Department of Pediatric Dentistry, Kyushu Dental University Hospital, Kitakyushu, Japan. The exclusion criteria were systemic disturbances, ingestion of medicines that could interfere directly or indirectly with muscular activity, and uncooperative behavior. In addition, children with alterations in the form, structure, or number of teeth or oral tissues were excluded, as were those with a history of orthodontic treatment or temporomandibular dysfunction [8]. This study was approved by the Human Investigations Committee of Kyushu Dental University (14-7) and all participants provided written informed consent prior to participation.

2.2. *Anthropometry and dental examination*

Measurements of height and body weight were made in the consulting room of the hospital. Height was measured to an accuracy of ±0.1 cm using a portable digital stadiometer (AD-6531, A&D Co., Tokyo, Japan) with the head in the Frankfort plane, and body weight to within 0.1 kg [9]. Using these data, percentage overweight (POW) scores were calculated using the method described in the School Health Statistics Research, Ministry of Education, Culture, Sports, Science and Technology; i.e.,

$$\text{POW}\ (\%) = [\text{actual weight (kg)} - X\ (\text{kg})]/X\ (\text{kg}) \times 100 \qquad (1)$$

where X is the age- and sex-specific standard weight for a given height.

Children with POW $\geq +20\%$ were classified as overweight and those with POW $\leq -20\%$ were classified as underweight. Children with POW between these cutoffs were classified as normal weight [10].

During the intraoral examination, the sum of decayed, missing, and filled teeth (DMFT) was calculated, using criteria recommended by the World Health Organization [11].

All measurements were duplicated, with intervals of >30 s for rest, and the mean values were used in the analysis. All examinations were carried out by the same highly trained examiner.

2.3. *Maximum tongue pressure*

Maximum tongue pressure was measured using a JMS tongue pressure manometer (JMS Co. Ltd, Hiroshima, Japan; Fig. 1A). Participants were asked to assume a relaxed sitting position, in which the Frankfort plane was maintained horizontal. Additionally, participants were asked to place a balloon on the anterior part of the palate, and were asked to close their lips, with a hard ring bit with upper and lower incisors. The participants were then asked to press their tongue against the roof of their mouth as hard as possible (Fig. 1B). The pressure was measured (in units of kilopascals) using a digital voltmeter attached to the tongue pressure manometer [12,13]. Measurements were duplicated, with intervals of >30 s for rest, and the mean values were used in the analysis.

2.4. *Masticatory performance*

Masticatory performance was evaluated by determining the individual's ability to comminute a jelly-based chewable material (Kamuzokun, Mamarisshimo Ltd, Tokyo, Japan; Fig. 2A). These chewable samples had dimensions of 15 mm × 15 mm × 15 mm, and consisted of maltitol, gelatin, powdery wafer, sweetener (xylitol), and thickener (Arabian gum). Prior to experiments, the children were shown how to perform the masticatory movements, as well as the mouth-rinsing procedure to ensure that they would not swallow.

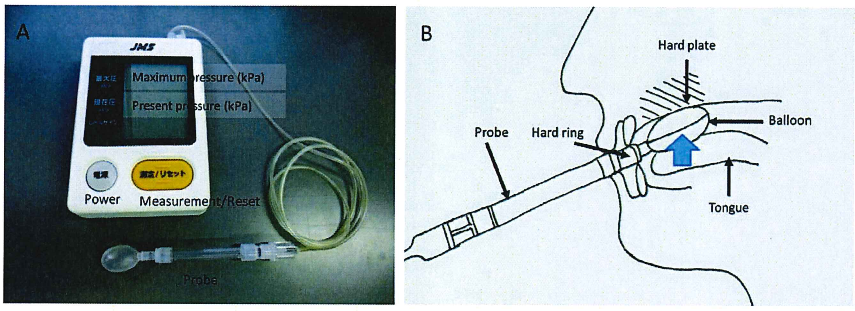

Fig. 1 – The tongue pressure test. (A) An image of the measurement device. and (B) intra-oral positioning of the balloon.

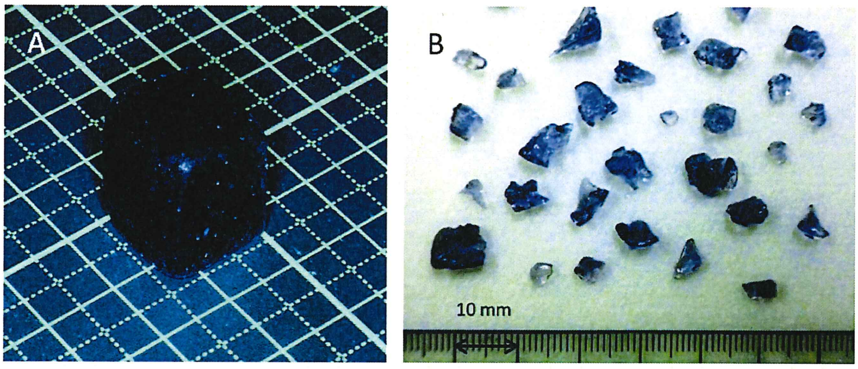

Fig. 2 – The chewable Kamuzokun test samples. (A) The shape of the jelly-based samples and (B) a magnified image of chewed particles.

In line with the manufactures' instructions, after chewing the jelly-based samples for 60 s, the participants were instructed to stop chewing, expectorate the sample into a plastic filter, and rinse with water until all particles were removed from the mouth. The chewed particles were then washed with water and dried at room temperature on a paper filter (Super Absorption Paper, Mamarisshimo Ltd, Tokyo, Japan) for 10 min. The samples were positioned on white filter papers, and a digital camera (D750, Nikon Co, Tokyo, Japan) was used to photograph the samples from above under standard lighting. A plastic calibration ruler was used as an index of length (Fig. 2B). The ImageJ software (National Institutes of Health, Bethesda, MD, USA) was used to measure the total number and maximum projected area (in units of mm^2) of the particles [14,15]. The procedures were repeated in duplicate at random with intervals of >30 s for rest. Data were measured twice with an interval of 2 weeks, and the mean was used in the analysis.

2.5. SMA scoring

SMA was scored using a modified version of the method used by Koshino et al. [16]. A questionnaire was prepared using 25 foodstuffs to quantify the subjective evaluation of food hardness, based on food lists reported previously [16,17] (Table 1). The examiner described the foods, and all the participants were asked to assign each food item to one of five categories (i.e., dislike or have never eaten, hard, slightly hard, slightly soft, and soft). To calculate the SMA score, mastication ability was characterized using a 4-point Likert scale as follows: soft (4 points), slightly soft (3 points), slightly hard (2 points), hard (1 points), and dislike or have never eaten (0 points). Additionally, the 25 food items were classified into five grades (with 5 foods in each) depending on difficulty of mastication, and the average food intake rate (%) in each grade was calculated from the average values of the ratings of the children who marked 1, 2, 3, or 4 for each food (Table 2). To determine the difficulty ratio, the average food intake rate for Grade I was defined as a reference (i.e., 1.000), and the average food intake rate for Grade I was normalized to food intake rate for each grade. The resulting data were defined as the difficulty ratios for Grades II, III, IV, and V as 1.0002, 1.0030, 1.0059, and 1.0122, respectively. The average point for each grade was calculated from the average of five foods, except for the foods that were marked "0". Using these data, SMA scores for each child were calculated as follows:

$$\text{SMA score (\%)} = (A + 1.0002B + 1.0030C + 1.0059D + 1.0122E)/20.0852 \times 100, \tag{2}$$

where A is the average for Grade I, B is the average for Grade II, C is the average for Grade III, D is the average for Grade IV, and E is the average for Grade V.

Table 1 – Questionnaire on subjective masticatory function. Please mark the number as follows: 0 = dislike or have never eaten, 1 = hard, 2 = slightly hard, 3 = slightly soft, and 4 = soft.

Foodstuffs	Score					Foodstuffs	Score					Foodstuffs	Score				
Tofu[a]	0	1	2	3	4	Jelly	0	1	2	3	4	Steamed potato	0	1	2	3	4
Boiled egg (yolk)	0	1	2	3	4	Steamed eggplant	0	1	2	3	4	Banana	0	1	2	3	4
Fried egg	0	1	2	3	4	Spaghetti	0	1	2	3	4	Bread	0	1	2	3	4
Sponge cake	0	1	2	3	4	Boiled scallop	0	1	2	3	4	Sausage	0	1	2	3	4
Boiled green soybean	0	1	2	3	4	Mochi[b]	0	1	2	3	4	Konnyaku[c]	0	1	2	3	4
Boiled mushroom	0	1	2	3	4	Boiled squid	0	1	2	3	4	Pear	0	1	2	3	4
Raw asparagus	0	1	2	3	4	Grilled pork rib	0	1	2	3	4	Grilled chicken	0	1	2	3	4
Apple	0	1	2	3	4	Hard rice cracker	0	1	2	3	4	Raw radish	0	1	2	3	4
Almond	0	1	2	3	4												

[a] Soybean curd.

[b] Rice cake.

[c] Jelly made from devil's-tongue starch.

The denominator here is given by:

$$(1 + 1.0002 + 1.0030 + 1.0059 + 1.0122) \times \text{maximum point } (4) = 20.0852. \quad (3)$$

2.6. *Validity and reliability of the questionnaire*

To assess the validity and reliability of the questionnaire, factor analyses were performed. The Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy [18,19] and Bartlett's test of sphericity [20] were used to characterize the appropriateness of the factor analysis. In general, where the value of the KMO exceeds 0.8, the sampling adequacy of factor analysis may be considered valid, and the Bartlett's test of sphericity should be significant ($p < 0.05$).

For the exploratory factor analysis, principal factor analysis with Varimax rotation was performed. Kaiser's criterion (i.e., eigenvalues >1.0) together with a visual examination of scree plots were used to determine the number of components to retain.

Following exploratory factor analysis, confirmatory factor analysis was carried out to explore the valid factor structure. The goodness-of-fit index (GFI), adjusted GFI (AGFI), comparative fit index (CFI), and root-mean-square error of approximation (RMSEA) were used as indices of conformity. In general, with GFI, AGFI, and CFI values of ≥ 0.90 indicate good fits [21,22]. In addition, the RMSEA was interpreted as follows: ≤ 0.05 as good, and ≤ 0.08 as acceptable [23].

Furthermore, as an index of internal consistency of the questionnaire, Cronbach α coefficient was used, with values of $\alpha \geq 0.7$ accepted as evidence of good internal consistency [24].

To assess time stability, the test–retest reliability of all participants was investigated, with an interval of 2 weeks. The results of the test–retest reliability were expressed in terms of the intraclass correlation coefficient (ICC) as follows: $0.700 \leq \text{ICC} \leq 0.899$ corresponded to good, and $0.900 \leq \text{ICC} \leq 1.000$ corresponded to excellent [25].

2.7. *Reliability of measurements*

Data pertaining to height, body weight, DMFT index, maximum tongue pressure, and masticatory performance were analyzed for reliability. Systematic error was investigated using Bland–Altman analysis, and the random error was characterized based on the intrarater reliability quantified using the ICC.

Table 2 – Food intake rate and difficulty ratio for each grade.[a,b]

Grade[c]	Average food intake rate (%)	Difficulty ratio	Average point	Rate of the children who marked 1, 2, 3, or 4 (%) N = 70
I	99.16	1.000 (reference)	A	Tofu; soy bean curd (98.6), jelly (100.0), steamed potato (100.0), boiled egg (yolk) (98.6), steamed eggplant (98.6)
II	99.14	1.0002	B	Banana (97.1), fried egg (100.0), spaghetti (98.6), bread (100.0), sponge cake (100.0)
III	98.86	1.0030	C	Boiled scallop (100.0), sausage (98.6), boiled green soybean (98.6), mochi; rice cake (97.1), Konnyaku; jelly made from devil's-tongue starch (100.0)
IV	98.58	1.0059	D	Boiled mushroom (98.6), boiled squid (98.6), pear (98.6), raw asparagus (97.1), grilled pork rib (100.0)
V	98.00	1.0122	E	Grilled chicken (98.6), apple (98.6), hard rice cracker (98.6), raw radish (97.1), almond (97.1)

[a] Subjective mastication ability score (%) = $(A + 1.0002B + 1.0030C + 1.0059D + 1.0122E)/20.0852 \times 100$.

[b] The denominator here is given by $(1 + 1.0002 + 1.0030 + 1.0059 + 1.0122) \times$ maximum point (4) = 20.0852.

[c] 1 = hard, 2 = slightly hard, 3 = slightly soft, and 4 = soft.

2.8. *Data analysis*

Data pertaining to the anthropometric measurements, DMFT index, maximum tongue pressure, masticatory performance, and SMA scores in each age group are presented in the form of mean ± standard deviation. Statistical comparisons between boys and girls were made using two-tailed t tests for unpaired samples. Multiple comparisons among age groups were made using one-way analysis of variance with Tukey's honest significant difference test. Pearson's correlation coefficients were used to determine the association between each variable. Stepwise multiple linear regression analysis was used to investigate the relationships between maximum tongue pressure as the dependent variable and the parameters that showed significant associations according to the Pearson correlations as the independent variables, where $p < 0.05$ was considered to be statistically significant. Confirmatory factor analysis was implemented using Amos Version 23.0 for Windows (IBM Japan, Inc., Tokyo, Japan), and the other analyses using SPSS Version 23.0 for Windows (IBM Japan Inc., Tokyo, Japan).

3. Results

3.1. *Factor extraction, validity, and reliability of the questionnaire*

The KMO measure was 0.879, and the result of Bartlett's test of sphericity was $\chi^2 = 1118.7$ (where $p < 0.001$), indicating that the factor analysis was appropriate.

Table 3 lists the results of the principal factor analysis. From Kaiser's criterion, three factors had eigenvalues of >1, which together accounted for 54.1% of the variance in the total scores. Furthermore, the scree plot clearly indicated that the first three factors were acceptable. Factor 1 is termed "dryness," Factor 2 "springiness," and Factor 3 "chewiness."

The results of the confirmatory factor analysis show that the goodness-of-fit of the three-factor structure models was as follows: GFI = 0.920, AGFI = 0.904, CFI = 0.931, and RMSEA = 0.061.

In the questionnaire, the three factors describing the 25 food items yielded a reliability coefficient (i.e., Cronbach α coefficient) of $\alpha = 0.930$. The scores for individual factors were $\alpha = 0.914$ for dryness, $\alpha = 0.899$ for springiness, and $\alpha = 0.754$ for chewiness. The test–retest reliability was characterized by an ICC of 0.80.

3.2. *Distribution and correlation of the measurements*

The ICCs for height, body weight, DMFT index, maximum tongue pressure, total number of chewed particles, and maximum projected area of the particles were all ≥0.97. These data were not observed for the fixed bias and proportional bias results of the Bland–Altman analysis.

In the anthropometry of children, the prevalence of overweight (i.e., POW ≥ +20%) was four (5.7%), with the remaining 66 (94.3%) children belonging to the normal weight group.

For each age, statistically significant differences were not found in any parameters between the sexes (data not shown).

Table 3 – Results of rotated principal factor analysis.

Food item	Factor loading component[a]		
	1	2	3
Jelly	0.116	**0.913**	0.331
Tofu	0.165	**0.806**	0.286
Steamed potato	0.221	**0.800**	0.304
Boiled egg (yolk)	0.217	**0.608**	0.234
Steamed eggplant	0.102	**0.402**	0.182
Sponge cake	**0.772**	0.317	0.206
Bread	**0.755**	0.311	0.261
Fried egg	**0.739**	0.237	0.253
Banana	**0.719**	0.147	0.149
Spaghetti	**0.625**	0.377	0.238
Boiled scallop	0.137	**0.685**	0.155
Sausage	0.209	**0.628**	0.114
Konnyaku	**0.409**	**0.595**	−0.097
Boiled green soybean	0.186	**0.574**	0.187
Mochi	0.353	**0.497**	−0.092
Raw asparagus	0.114	0.195	**0.765**
Grilled pork rib	0.258	0.250	**0.632**
Boiled squid	0.270	**0.463**	**0.507**
Pear	−0.004	0.105	**0.451**
Boiled mushroom	0.283	0.181	**0.409**
Apple	**0.758**	0.093	0.179
Almond	**0.732**	0.102	0.143
Hard rice cracker	**0.702**	0.389	−0.081
Raw radish	**0.685**	0.199	0.197
Grilled chicken	**0.424**	0.164	−0.113
Eigenvalue	10.218	2.779	1.824
% Variance	22.607	21.742	9.752
Cronbach α	0.914	0.899	0.754

[a] Factor loading over 0.400 are shown in bold.

Table 4 lists the means and standard deviations of the anthropometric measurements, DMFT index, maximum tongue pressure, masticatory performance, and SMA scores. Both height and body weight increased with age. The maximum tongue pressure in 9-, 11-, and 12-year-old children was significantly higher than that in 6-year-old children ($p < 0.05$). The total number of particles chewed was significantly higher among 12-year-old children than that it was among 6-year-old children ($p < 0.05$).

Table 5 lists the results of the Pearson's correlation analysis. Maximum tongue pressure was significantly positively correlated with age, height, body weight, total number of particles, and SMA score ($r = 0.46$, $r = 0.32$, $r = 0.38$, $r = 0.73$, and $r = 0.44$, respectively, all with $p < 0.01$). In addition, maximum tongue pressure was significantly negatively correlated with the DMFT index and maximum projected area of the particles ($r = -0.63$ and $r = -0.69$, respectively, both with $p < 0.01$).

The total number of particles was strongly correlated with the maximum projected area of particles and the SMA score ($r = -0.76$ and $r = 0.77$, respectively, $p < 0.01$ for both).

Table 6 lists the results of multiple linear regression analysis. Finally, age, DMFT, and the total number of particles were selected as the independent variables. The other parameters that exhibited significant associations according to the Pearson correlations were removed to avoid multicollinearity. Maximum tongue pressure was significantly associated with age (with a standardized partial regression

Table 4 – Parameters of anthropometry, decayed, missing, and filled teeth index, maximum tongue pressure, masticatory performance, and subjective masticatory ability score in 6–12-year-old children.

Age (y)	Height (cm)	Body weight (kg)	Percentage of overweight (%)	DMFT index	Maximum tongue pressure (kPa)	Total number of particles (N)	Maximum projected area of the particles (mm^2)	SMA score
6	121.80 ± 8.01	23.70 ± 4.69	−0.63 ± 6.52	2.50 ± 2.07	27.15 ± 4.80	27.30 ± 12.23	93.68 ± 37.96	60.57 ± 8.57
7	124.60 ± 3.86	24.75 ± 2.44	−0.19 ± 6.03	2.00 ± 2.06	32.46 ± 4.09	47.20 ± 23.21	62.53 ± 14.47	63.09 ± 8.34
8	129.50 ± 2.68*	29.15 ± 5.36	4.35 ± 14.38	3.50 ± 3.44	32.10 ± 7.57	44.00 ± 25.23	66.15 ± 21.98	59.38 ± 10.66
9	134.33 ± 4.79*,**	32.65 ± 6.08*	6.21 ± 19.46	1.60 ± 2.95	35.33 ± 7.24*	51.40 ± 30.38	82.06 ± 49.45	62.95 ± 9.29
10	141.52 ± 5.8*,**,***	35.10 ± 4.93*,**	−1.15 ± 7.03	3.00 ± 1.94	32.82 ± 6.77	42.20 ± 20.91	78.10 ± 27.15	61.10 ± 10.70
11	146.99 ± 3.41*,**,***,****	39.16 ± 4.47*,**,***	−0.63 ± 8.57	1.80 ± 1.69	37.52 ± 3.33*	55.10 ± 16.51	62.23 ± 10.86	58.47 ± 6.61
12	158.40 ± 4.03*,**,***,****,*****,******	50.00 ± 6.82*,**,***,****,*****,******	2.29 ± 10.42	1.80 ± 2.49	37.48 ± 5.97*	59.50 ± 23.73*	60.65 ± 13.36	60.80 ± 8.72

Data are presented as mean ± standard deviation.

*$p < 0.05$ versus 6-year-old children.

**$p < 0.05$ versus 7-year-old children.

***$p < 0.05$ versus 8-year-old children.

****$p < 0.05$ versus 9-year-old children.

*****$p < 0.05$ versus 10-year-old children.

******$p < 0.05$ versus 11-year-old children.

DMFT = decayed, missing, and filled teeth; SMA = subjective masticatory ability.

coefficient of $\beta = 0.296$, with $p = 0.001$), DMFT index ($\beta = -0.298$, with $p = 0.017$), and the total number of particles ($\beta = 0.404$, with $p = 0.003$).

4. Discussion

We used a tongue pressure measurement device, which is a simple chair-side method for children aged 6–12 years (Fig. 1). Many studies using such a device have been reported for adults and the elderly [12,26,27]; however, our results differed significantly. The mean maximum pressure of children aged 6 years was similar to that of adults aged >70 years [12,26]. By contrast, the mean maximum tongue pressure for 12-year-olds was less than that for adults aged 20–30 years [12,27]. In our data, the maximum tongue pressure increased with age (although there were some vertical variations). This suggests that tongue pressure increases during the growth period, peaks during early adulthood, and decreases in old age.

Multiple linear regression showed that maximum tongue pressure was associated with masticatory performance, age, and DMFT index among children aged 6–12 years. The total number of particles was the most important variable associated with maximum tongue pressure.

The Kamuzokun chewable samples used to test masticatory performance were both hard and elastic in nature, which makes them suitable for investigating shearing and comminution ability. Recently, several types of test materials have been reported to characterize masticatory performance in adults, including a method using an automatic measuring device where the β-carotene concentration dissolved in an aqueous solution from the surface of the test substance [28], as well as a method of calculating the surface area of the particles from the concentration of dissolved glucose [27,29]. We used Kamuzokun chewable test samples because it allows visual observation of the chewed particles, making evaluation simple. A strong correlation was found between the total number of particles and the maximum projected area of the particles. In addition, systematic error was absent from the measured data, and the intrarater reliability was high. These results suggest that our method for measuring masticatory performance was reproducible and quantitatively useful.

The mean total number of particles and mean maximum projected area of the particles were not stable among children aged 6–11 years. Toro et al. [30] showed that age and body weight are the most import sources of variation in masticatory performance among growing individuals. Pearson's correlation analysis showed that measurements of masticatory performance were more significantly correlated with body weight and POW than age, suggesting that an increase in body weight led to an increase the strength of the masticatory muscles.

With respect to maximum tongue pressure, multiple linear regression analysis showed that age was the most significant parameter. This suggests that the development of tongue function may be related not only to body weight but also total development.

It has been reported that tongue pressure and masticatory performance are positively correlated (also using jelly-based test samples) [27], which is consistent with our data. Therefore, we believe that the development of shearing and

Table 5 – Correlation coefficients amongst parameters of anthropometry, decayed, missing, and filled teeth index, maximum tongue pressure, masticatory performance, and subjective masticatory ability score in children aged 6–12 years.

	Age	Height	Body weight	% of overweight	DMFT index	Maximum tongue pressure	Total no. of particles	Maximum projected area of the particles
Age								
Height	0.92^{**}							
Body weight	0.83^{**}	0.92^{**}						
% of overweight	−0.08	−0.06	0.28^{*}					
DMFT index	−0.09	−0.09	−0.17	−0.22				
Maximum tongue pressure	0.46^{**}	0.32^{**}	0.38^{**}	0.19	-0.63^{**}			
Total no. of particles	0.34^{**}	0.29^{*}	0.41^{**}	0.34^{**}	-0.76^{**}	0.73^{**}		
Maximum projected area of the particles	−0.21	−0.18	-0.26^{**}	-0.24^{*}	0.69^{**}	-0.69^{**}	-0.76^{**}	
SMA score	−0.06	−0.03	0.09	0.30^{*}	-0.79^{**}	0.44^{**}	0.77^{**}	-0.58^{**}

$^{*}p < 0.05$.
$^{**}p < 0.01$.
DMFT = decayed, missing, and filled teeth; SMA = subjective masticatory ability.

Table 6 – Stepwise multiple linear regression analysis for maximum tongue pressure.

Dependent variable	Independent variables	B^{a}	SE^{a}	β^{a}	p^{a}
Maximum tongue pressure	Age	0.963	0.273	0.296	0.001
	DMFT index	−0.804	0.330	−0.298	0.017
	Total no. of particles	0.113	0.036	0.404	0.003

B = an unstandardized partial regression coefficient; β = a standardized partial regression coefficient, which indicates the relative importance of each variable; DMFT = decayed, missing, and filled teeth; SE = standard error.
[a] $R = 0.787$, $R^2 = 0.620$, adjusted $R^2 = 0.602$, $p < 0.001$.

comminution ability is closely associated with an increase of tongue pressure in children.

The SMA score was significantly correlated with objective measurements of masticatory performance, although it was not directly associated with tongue pressure.

It has been shown that an increase in tongue pressure is associated with hard foodstuffs being crushed by pressing the tip of the tongue against the anterior hard palate [31]. Mastication of hard foodstuffs induces cartilaginous ossification in the midpalatal suture of the palatal plate; by contrast, in rats, an excessive intake of soft foodstuffs inhibits this chondrocytic development, and hence the maturity of the midpalatal cartilage [32]. These results suggest that a hard diet has a positive effect on the process associated with tongue pressure on the palate.

Therefore, how frequency and how easily individuals are able to chew hard foodstuffs may be indirectly attributed to strength of tongue pressure.

The DMFT index was also directly correlated with maximum tongue pressure. Several studies have reported that a larger number of missing teeth are correlated with inferior masticatory performance in children [33,34]. However, to our knowledge, there have been no reports that tongue pressure is directly correlated with the DMFT index. A recent report has suggested that crushing performance with hard foodstuffs is determined by unified movements of the teeth and tongue [31]. Therefore, we believe that poor dental status affects the development of tongue pressure in children.

Another aim of this study was to verify the reliability and validity of the questionnaire relating to the preference and hardness of 25 foods. Cronbach α reliability coefficient was $\alpha = 0.930$, which indicates that the questionnaire exhibited acceptable internal consistency. Furthermore, the time stability was acceptable, as shown by test–retest reliability.

Exploratory factor analysis suggested that the three subjective measures of "dryness," "springiness", and "chewiness" were significant. Furthermore, confirmatory factor analysis suggested that these three factors exhibited satisfactory conformity.

The 25 foodstuffs were classified into five grades depending on the difficulty of mastication, which allowed us to calculate SMA scores. The results of factor analysis showed that the 10 food items included in Grades II and V corresponded to foods in Factor 1, and that these foods had commonalities in that the moisture content was low and the mouthfeel was dry, although there were differences in hardness. An additional 10 food items were included in Grades I and III, which corresponded to the foods in Factor 2, and these foods had commonalities in terms of high glossiness and springiness, but were different in terms of brittleness. Foods belonging in Factors 1 and 2 (i.e., those exhibiting dryness and springiness) corresponded with the established classification of food textures reported by Yanagisawa et al. [17]. The remaining five food items included in Grade IV corresponded to foods in Factor 3, with commonalities in hardness, springiness, and cohesiveness. Szczesniak [35] indicated that chewiness may be defined as a product of hardness, springiness, and cohesiveness; therefore Factor 3 was termed chewiness.

The reliability and the validity of the questionnaire were thus established. Furthermore, the SMA score was shown to be useful for characterizing masticatory function in children.

5. Conclusion

In summary, we have demonstrated that an increase in masticatory performance, good dental status, physical health, and intellectual development are associated with tongue pressure in children. Furthermore, we believe that the frequency and ease of chewing hard foodstuffs can be (indirectly) attributed to tongue pressure.

Furthermore, we have developed a measure of masticatory ability using a self-administered questionnaire regarding preferences for hard foodstuffs, and have demonstrated its reliability and validity.

Conflicts of interest

The authors declare no conflicts of interest.

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