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Original Article

A Study on Developmental Changes of Masticatory Function in Children

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The purposes of this study were to examine the differences in masticatory function of children with different dental stages when they chew pieces of chewing gum with various volume and hardness, and to examine the relationships of the number of chewing strokes to masticatory efficiency as well as maximum bite force. Forty-six children (7.9±2.4 years old) and eleven adults (28.5±7.1 years old) participated in this study. The subjects chewed three pieces of color-changeable chewing gum with different volumes and one piece of hard gum and the number of chewing strokes per minute, masticatory efficiency, and maximum bite force were determined. It was concluded that the 'adaptability' of masticatory function of children to the different volume and hardness increased with the development. Significant correlation was found between the ratio of the number of chewing strokes in hard gum chewing to that in soft gum chewing and the maximum bite force of children with deciduous dentition.

Key words: Children, Masticatory performance, Chewing gum

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Introduction

It is clinically important to evaluate the developmental changes of masticatory function in children for the screening of the child patients with masticatory dysfunction. There have been many studies on the masticatory function of children in comparison to that of adults, using electromyography of masticatory muscles[1-3], recording of mandibular movements[4-6], evaluation of masticatory efficiency[7-12], and counting of the number of chewing strokes before swallowing[13-17]. However, there have been few studies on the developmental changes of masticatory function in children with different dental stages.

The selection of testing materials is very important in the study of masticatory function. Many previous studies used natural foods, such as almonds[11] and peanuts[3,7-9], as test foods to analyze masticatory function. However, these natural foods are not consistent in their hardness and water contents, leading to difficulties in reproducibility of the results. To resolve this problem, artificial test materials such as chewing gum[2,5,6,18], gummy jelly[4], ATP particles[10] and silicone tablets[12] have been used for the analysis of masticatory function. The physical properties of these materials in terms of hardness and stickiness could be controlled easily in the fabrication process. Hayakawa *et al.*[19] and Hirano *et al.*[20] developed color-changeable chewing gum (Lotte Co. Ltd., Saitama, Japan) for the evaluation of the masticatory efficiency in denture wearers. This color-changeable chewing gum had the advantages of reduced measurement time and ease of evaluation.

It was reported that the track of mandibular movement in the frontal view became wider and the cycle duration was prolonged with increasing volume and hardness of the food[4,21-23]. Shiga *et al.* recorded mandibular movement during gum chewing, and found that the cycle duration became longer and the width of the track of mandibular movement became wider in the frontal view, as the volume of food increased[21]. Bhatka *et al*. found no difference in cycle duration of stroke among chewing of 1.0g, 2.0g and 4.0g pieces of gum. However, they found that the cycle duration was prolonged in chewing 8.0g piece of gum[24]. The cycle duration remained unchanged when the gum volumes were kept within a certain range and was prolonged when the volume became to be oversized in adults[21,24]. On the contrary, there have been no previous reports to describe the effect of volume changes on the cycle duration of chewing strokes in children.

Plesh *et al*. reported that cycle duration in adults during chewing of hard gum was longer than that during chewing of soft gum[23]. In children, it was reported that cycle duration was prolonged in chewing of harder jelly[4]. Takada *et al*. reported that the cycle duration in the hard jelly chewing was longer than that in the soft jelly chewing. They also found that the track of the mandibular movement became wider horizontally and vertically in frontal view in the hard jelly chewing[4]. Anderson *et al*. reported the similar findings in the gum chewing in adults that the recorded tracks of mandibular movements became wider in the hard gum chewing[22]. There have been no previous reports on the developmental changes of masticatory function relating with the hardness of food when it was changed.

The purposes of this study were to examine whether there is any difference in the number of chewing strokes of children with different dental stages when they chew pieces of chewing gum with various volume and hardness, and to examine the relationships of the number of chewing strokes to masticatory efficiency as well as maximum bite force in children with different dental stages.

Materials and Methods

Subjects

Forty-six children (average age 7.9±2.4 yrs), who attended the Pediatric Dental Clinic of Tokyo Medical and Dental University Dental Hospital, and eleven adults (average age 28.5±7.1 yrs), all of whom were staff and students of Tokyo Medical and Dental University, were selected as test subjects. Child subjects were divided into three groups according to Hellman's dental developmental stages[25] (Table 1). None of the subjects had dental caries with clinical history of spontaneous pain or crown defect causing collapse of occlusion. They had neither history of orofacial dysfunction and temporo-mandibular joint disturbances nor orthodontic treatment. All of the subjects and the parents have given consents to the experiments after they were informed thoroughly about the purposes and the methods of the study which were approved by the Declaration of Helsinki.

Materials

A newly developed color-changeable chewing gum and ordinary chewing gum having higher hardness were used in this experiment. Hirano *et al*.[20] used one whole piece of color-changeable chewing gum for the evaluation of masticatory efficiency in adult subjects. This color-changeable chewing gum contains xylitol, coloring agents for red, yellow and blue, fragrance, citric acid and gum base. The initial color of the gum is light green because the red color is inhibited to show by citric acid. The color of the gum changes to red when the citric acid is eluted from the gum base by chewing, resulting in turning pH of the gum base from acidic to alkaline.

This color-changeable chewing gum (3.36 g, $1.52 \times 10^3 mm^3$: **Type A**), used in Hirano *et al*.'s study[20], was also used in the present study. And 2/3-size color-changeable chewing gum (2.21g, $1.01 \times 10^3 mm^3$: **Type B**) and half size gum (1.61g, $7.62 \times 10^2 mm^3$: **Type C**) were prepared. These three sizes of the color-changeable chewing gum were used to determine the effects of the food volume on the number of chewing strokes of the subjects.

A hard gum (1.61g, $7.92 \times 10^2 mm^3$, Gum's, Lotte Co. Ltd., Saitama, Japan) with the viscosity of 5.1×10^4 poise was also used to determine the effect on the number of chewing strokes by food hardness. The hard gum was approximately 2.5-fold more viscous than the color-changeable chewing gum (2.0×10^4 poise). Type C gum (1.61g) was used as a sample for soft food in the experiment of hard gum chewing.

Table 1. Number of subjects and the average age of each group (SD: standard deviation)

Group	Number	Mean± SD (yrs)
IIA	14	4.7 ± 1.0
IIIA	20	7.6 ± 1.5
IIIB	12	10.0 ± 1.2
Adult	11	28.5 ± 8.1

Methods

All of the experiments were performed in a quiet room under the supervision of a single examiner. The subjects were instructed to chew type C gum for practice for one minute. After this practice session, the subjects were instructed to have a rest for one minute before the experiment. In the experiments, the subjects were instructed to chew three pieces of chewing gum of type C, type B and type A, and hard chewing gum in this order for one minute respectively. This order of gum chewing was followed throughout all the experiments to obtain compliances especially from young children. The resting periods of two minutes were inserted in between each chewing to keep, as minimum as possible, the influences of both fatigue and adaptation to repeated chewing. The subjects were also instructed to chew freely.

Masticatory efficiency was evaluated by measuring the number of strokes per unit of time in stead of evaluating the efficiency per chewing stroke which had been used in many previous studies[8,9,20]. This would better reflect masticatory function of children in transitional dentition where significant morphological and functional changes occur.

The type A color-changeable chewing gum was used for the evaluation of masticatory efficiency according to Hirano *et al.*[20]. After each trial of type A gum chewing, the chewed gum bolus was placed on the glass plate and pressed with other glass plate to make a sheet with the thickness of 2 mm. Color measurement using a spectrophotometer “Color Reader CR-13” (Konica Minolta, Tokyo, Japan) was performed through the glass plate at five random sites of the flattened sheet. The color was evaluated using the L*a*b* color space, which was developed by the Commission Internationale de l’Eclairage (CIE)[26]. ‘L’ indicates lightness and ‘a*’ and ‘b*’ are the chromaticity coordinates. The coordinate a*, representing the degree of red, was measured. The mean values of a*, measured at five sites on the gum, represented the color come out in each trial.

All the experiments were recorded on videotape, which were replayed for examination of the number of chewing strokes by the same single examiner. According to Schwartz’s method, a chewing cycle was defined as an upward and downward movement of the chin[13-17]. The video review session was repeated three times. The average number of chewing strokes per minute was recorded as the measured value. The ratios of the numbers of chewing strokes in the experiments with piece of type A and type B gum to that with piece of type C gum were calculated to determine the effects on the number of chewing strokes by the food volume.

Maximum bite force of first molar (from IIIA to adult) or second deciduous molar (IIA) was measured in the both sides of the mouth using an occlusal force meter (GM10, Nagano-Keiki, Tokyo, Japan). The average bite force was calculated from those in right and left sides of the mouth.

Statistical analysis

One-way Analysis of Variance (ANOVA) and a multiple comparison test (Tukey-Kramer test) were used to analyze differences between the groups. Pearson’s correlation coefficients were used to assess the interrelations between the measurement values. A software package of SPSS Ver.10.0J for Windows was used for the statistical analyses. The significance level was set at 0.05.

Results

The results of one-way ANOVA between the groups are shown in Table 2. The statistical significance was found for all the variables except for the ratio of the number of chewing strokes in type B gum chewing to that in type C gum chewing. Hence this variable was not used for the multiple comparison tests in the analyses of differences between the groups.

Table 3 shows the number of chewing strokes per minute for chewing of type A, type B, and type C of gum. In type A gum chewing, the number of chewing strokes increased from IIA (75.0±19.7) group to adult group (106.0±8.0). In type B gum chewing, the number of chewing strokes increased from IIA group (84.9±18.2) to adult group (105.5±8.5). In type C gum chewing, the number of chewing strokes was about the same with those in type B gum chewing through the

Table 2. Results of one-way ANOVA between the groups (** $P<0.01$)

		F value	P value
Number of chewing strokes	type A gum	4.68	0.006**
	type B gum	5.17	0.003**
	type C gum	9.62	< 0.001**
	hard gum	8.07	< 0.001**
Ratio of the number of chewing strokes	type B gum / type C gum	1.73	0.175
	type A gum / type C gum	6.59	0.001**
a* value		7.73	< 0.001**
Maximum bite force		11.4	< 0.001**

Table 3. Number of chewing strokes per minute for each volume of chewing gums (SD: standard deviation)

Gum type	Group	Mean± SD
Type A (3.36g)	IIA	75.0 ± 19.7
	IIIA	87.9 ± 11.4
	IIIB	92.4 ± 12.1
	Adult	106.0 ± 8.0
Type B (2.21g)	IIA	84.9 ± 18.2
	IIIA	92.9 ± 10.4
	IIIB	98.3 ± 12.5
	Adult	105.5 ± 8.5
Type C (1.61g)	IIA	85.5 ± 17.5
	IIIA	92.3 ± 9.6
	IIIB	96.4 ± 12.9
	Adult	105.6 ± 7.0

Table 4. Multiple comparisons of the number of chewing strokes per minute between all the groups with three volumes of chewing gum
(**P*<0.05, ***P*<0.01, ns: not significant)

Type A (3.36g)	IIIA	IIIB	Adult
IIA	*	*	**
IIIA		ns	**
IIIB			ns
Type B (2.21g)	IIIA	IIIB	Adult
IIA	ns	ns	**
IIIA		ns	*
IIIB			ns
Type C (1.61g)	IIIA	IIIB	Adult
IIA	ns	ns	**
IIIA		ns	*
IIIB			ns

developmental stages. The number of chewing strokes increased from IIA group (85.5±17.5) to adult group (105.6±7.0). The results of the multiple comparisons are shown in Table 4. In type A gum chewing, significant differences in the number of chewing strokes were found between IIA group and IIIA group (P<0.05), IIA group and IIIB group (P<0.05), IIA group and adult group (P<0.01), IIIA group and adult group (P<0.01). In type B gum chewing, significant differences in the numbers of chewing strokes were found between IIA group and adult group (P<0.01), and between IIIA group and adult group (P<0.05). In type C gum chewing, significant differences in the number of chewing strokes were found between IIA group and adult group (P<0.01), and between IIIA group and adult group (P<0.05).

The ratios of the number of chewing strokes per minute in the type A and type B gum chewing, to that of type C gum chewing are shown in Fig. 1. The ratio of the number of chewing strokes in the type A gum chewing to that in type C gum chewing was 0.86 in IIA group, and increased to 1.01 in adult group. The ratio of the number of chewing strokes in the type B gum chewing to that in type C gum chewing remained at between 0.98 and 1.02 from IIA group to adult group. There were significant differences in the ratio of the number of chewing strokes in type A gum chewing to that in type C gum chewing between IIA group and IIIA group (P<0.05), IIA group and IIIB group (P<0.05), IIA group and adult group (P<0.01), IIIA group and adult group (P<0.05) respectively.

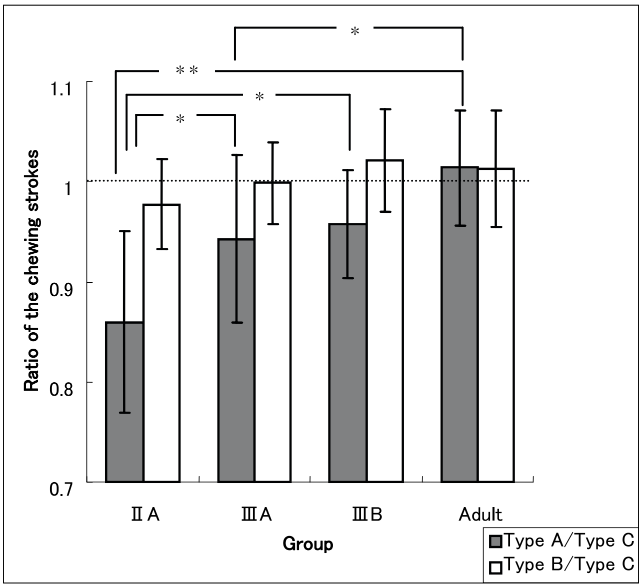

Fig. 1. Ratio of the number of chewing strokes per minute in Type A and Type B gum chewing to that in Type C gum chewing. Vertical bars indicate standard deviation. (**P*<0.05, ***P*<0.01)

The results of the measurements of the numbers of chewing strokes per minute in hard gum chewing are shown in Table 5. The number of chewing strokes in hard gum chewing increased from IIA group (70.4±13.7) to adult group (94.9±9.6). There were significant differences in the numbers of chewing strokes between IIA group and IIIA group (P<0.05), IIA group and adult group (P<0.01), IIIA group and adult group

Table 5. Number of chewing strokes per minute for all the groups in hard gum chewing (SD: standard deviation)

Gum type	Group	Mean± SD
Hard	IIA	70.4 ± 13.7
	IIIA	81.7 ± 12.1
	IIIB	82.4 ± 10.8
	Adult	94.9 ± 9.6

Table 6. Multiple comparisons of numbers of chewing strokes per one minute in hard gum chewing
(*$P<0.05$, **$P<0.01$, ns: not significant)

Hard chewing gum	IIIA	IIIB	Adult
IIA	*	ns	**
IIIA		ns	*
IIIB			*

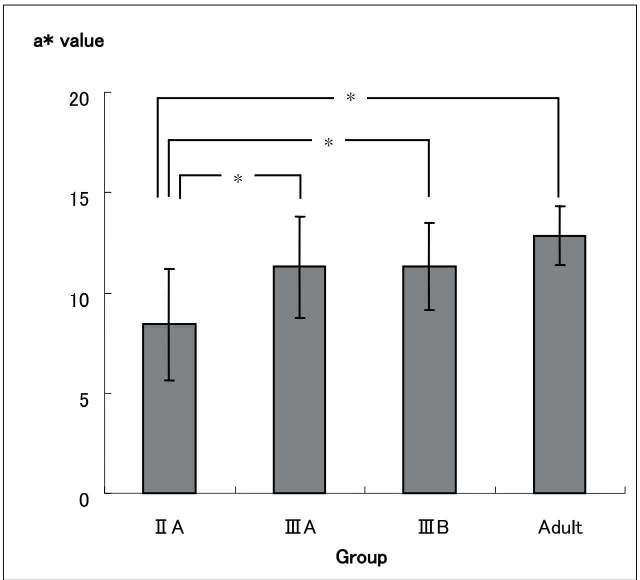

Fig. 2. The a* value of Type A gum in each group. Vertical bars indicate standard deviation. (*$P<0.05$)

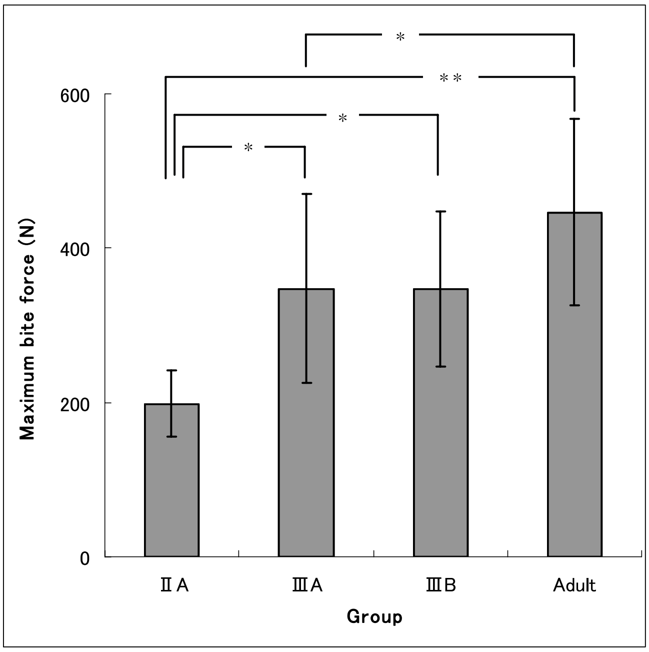

Fig. 3. Maximum bite force of each group. Vertical bars indicate standard deviation. (*$P<0.05$, **$P<0.01$)

Table 7. Correlations between number of chewing strokes per minute and a* value
(*$P<0.05$, **$P<0.01$)

Group	Correlation coefficient
IIA	0.837**
IIIA	0.552*
IIIB	0.059
Adult	0.779*

($P< 0.05$), IIIB group and adult group ($P< 0.05$) respectively. (Table 6)

The a* values of type A gum are shown for each group in Fig. 2. The value of a* increased from IIA group (8.4±2.8) to IIIA group (11.3±2.5) and from IIIB group (11.3± 2.2) to adult group (12.9± 1.5). Significant differences were found between IIA group and IIIA group, IIA group and IIIB group, IIA group and adult group ($P<0.05$) respectively.

Correlations between the number of chewing strokes per minute and a* value are shown in Table 7. Significant correlations were found in IIA group ($P< 0.01$), IIIA group and adult group ($P<0.05$).

Maximum bite forces for each group are shown in Fig. 3. Maximum bite force increased from IIA group (198.4±43.3N) to IIIA group (347.7±121.9N) and from IIIB group (346.9 ±100.8N) to adult group (446.2±120.7N). Significant differences were found between IIA group and IIIA group ($P<0.05$), IIA group and IIIB group ($P<0.05$), IIA group and adult group ($P< 0.01$), IIIA group and adult group ($P< 0.05$) respectively.

Correlations between maximum bite force and the ratios of the number of chewing strokes in the hard gum chewing to that in the soft gum chewing are shown in

Table 8. Correlations between maximum bite force and ratio of number of chewing strokes in hard gum chewing to that in soft gum chewing. (**P*<0.05)

Group	Correlation coefficient
IIA	0.557*
IIIA	0.280
IIIB	0.082
Adult	-0.051

Table 8. A significant correlation was found in IIA group (P<0.05).

Discussion

Various volumes of testing material have been used for the analyses of masticatory function in adults, and samples of approximately 3.0 g of testing materials have often been used for the evaluation of masticatory efficiency[19,20,27,28]. In the study of children, samples of 1~2 g of testing materials have been used for the analysis of masticatory function[5,6,18,29,30] because the volumes of their oral cavities are smaller than those of adults.

There have been many reports regarding the influences by food volume on masticatory function in adults[21,24,31]. Bhatka *et al*. reported that there were no differences in the cycle duration of gum chewing among the experiments using different volume of the gums from 1 g to 4 g[24]. Lucas and Luke also reported that changing food volume had no effect on masticatory function when the food volume was less than 5 g[31].

On the other hand, there have been few reports of the influence of the food volume on masticatory function in children[32,33]. In the present study, no influence of food volume was observed on the number of chewing strokes in children when the volume of the gum was less than 2.21 g. Although the number of chewing strokes in 3.36 g gum chewing was less than those in 1.61 g and 2.21 g gum chewing, the ratio of chewing number in 3.36 g gum chewing to that in 1.16g gum chewing increased along with the development of the dental stages. These results suggested that children's mandibular movement in the gum chewing become to be adaptable to 3.36 g gum as the development proceeded. It is also considered that 3.36 g gum may be too big for children to chew, because the duration of chewing cycle of children in 3.36 g gum chewing was longer than those in 1.61 g or 2.21 g gum chewing in the child groups of the present study. It has been reported in adults that chewing cycle was delayed with the use of an oversized volume[21,24]. The present results, therefore, suggested that the optimum volume for chewing by children should be less than 2.21 g and will increase with development of the dental stage. One explanation for this finding might be due to the smaller oral cavities of children. The other might be that children's masticatory function is under development.

Anderson *et al*. reported that increasing of food hardness delayed jaw velocity of the masticatory cycle in the closing path[22]. Plesh *et al*. reported that cycle duration in hard gum chewing was longer than that in soft gum chewing[23]. The results of the present study supported the study of Plesh *et al*. indicating the number of chewing strokes per minute in hard gum chewing decreased than that in soft gum chewing in adults. It was found that the number of chewing strokes in hard gum chewing in children also decreased than that in soft gum chewing in the present study.

Bite force is one of the factors involved in the efficient chewing of hard food[34]. In the present study, there was a significant correlation between the ratio of the number of chewing strokes per minute in the hard gum chewing to that in soft gum chewing and the maximum bite force of second deciduous molars in subjects with deciduous dentition. However, no significant correlations were found after the IIIA stage. Although maximum bite force increases with age, bite force while chewing of ordinary foods may not change significantly from childhood to adulthood[35]. Thus, as the maximum bite force increases with age, the significance of bite force while chewing of ordinary foods may decrease relatively. In the deciduous dentition, however, maximum bite force seemed to be of more assistance to children to manage hard gum chewing better according to the significant correlation between the maximum bite force and the ratio of the number of chewing strokes in hard gum chewing to that in soft gum chewing. Thus, it would be meaningful to increase the maximum bite force by training the masticatory muscles to improve mastication of various foods in younger children[34].

Hayakawa *et al*. and Hirano *et al*. had reported that the a* value of color-changeable chewing gum is a good indicator of masticatory efficiency[19,20]. Hence, the a* value of one piece of gum was also used in present study.

Shiere and Manly evaluated masticatory efficiency in subjects from 6 to 18 years of age using peanuts, and found that masticatory efficiency increased from 6 to 10 years of age, and after 14 years of age[8,9]. The present results support their findings, except in IIIB stage where they reported that the masticatory efficiency decreased from 11 to 13 years old when deciduous molars were shedding. There were very few differences in the a* value indicating masticatory efficiency found during the stage at which deciduous molars are changing in the present study. The discrepancies between the results of Shiere and Manly study[8,9] using peanuts, and those of present study may be due to the different testing materials used in these studies.

Hayakawa *et al.*[19] and Hirano *et al.*[20] reported that a strong correlation was present between the number of chewing strokes and the value of a* in adults. In the present study, there were no significant correlations between the number of chewing strokes per minute and a* value in the IIIB group. This may be due to the differences in oral status, such as the number of teeth in transition, mobility of teeth, and newly erupting canines and premolars, during the IIIB stage of development.

It was noted that the order of chewing gums with various volumes might have some influence on the results of the present study, however, it was performed in this style to obtain compliances of children for the tests.

It was concluded that the adaptability of masticatory function of children to the different volume and hardness increased with the development. It should also be noted that the relationships between the number of chewing strokes and masticatory efficiency as well as maximum bite force were different between the developmental stages.

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