The study of comminution behavior of food on buccal and lingual side during mastication

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In this study, we observed comminution behavior of food on buccal and lingual side by sieve method. Six dentate subjects participated in this study. Peanuts were used as the test food and chewed for 1-8, 10, 12, 14, 16, 18, 20, 22 and 24 strokes on their preferred chewing side. Peanuts were gathered separately from buccal and lingual sides after varying number of chewing strokes. The crushed peanuts were sieved through a stack of eight level sieves (0.85 to 5.6mm). The comminution of coarse particles above 4.75 mm was almost finished within 10 strokes. The dynamic change in the median particle size also disappeared about 10 strokes. This suggested that we should pay attention to the initial phase of the chewing when we observed about mastication. As a result, comminution behavior of lingual coarse particles better conformed to fluctuation of median particle sizes of whole mouth, expressing masticatory performance precisely, than that of buccal coarse particles.

Key words: initial phase of mastication, sieve method, Rosin-rammler equation, median particle size

(1) Introduction

Comminution process in the initial phase of mastication is consisted of the composite result of repeated two processes, selection and breakage. Selection is defined as the chance that food particles are placed between the upper and lower teeth by cheek, tongue and jaw. Selection depends upon factors such as particle shape, particle size and the total amount of food in the mouth. Selected food particles are fractured between the teeth into fragments of variable number and size. This is called the breakage process. Nakajima and Fujii studied about function of tongue during mastication. However, these experiments used large equipments which may influence the other function of the mouth. To explain how the cheek and the tongue participate in these selection and breakage processes in natural condition, we measured the amount and particle size of test food in the buccal and lingual side separately at variable chewing strokes according to the method of Kido.

In the previous studies, dimensions of chewed food particles have been observed by many procedures using various test foods and techniques. In this study, peanuts, typical fractural food, were used for test food to determine particle size distribution with mastication progress by sieve methods. Multiple sieve method was used which was said to have more stability than the single sieve method. The size distribution of particles of a comminuted food could be described by a Rosin-Rammler distribution function in accordance with Olthoff and Tanaka. The equation to describe each particle size distribution and the median particle size which describes the central value of the size distribution of the particles were derived.

In most studies, the data of the initial phase of mastication involving rhythm and pathways has been...
apt to be excluded because of extreme fluctuation. However, the initial phase of mastication was considered important because there are major changes in the properties of food at this stage and heavy loading is required among the succession of mastication.

The purpose of this study was to compare variations of the particle size distribution with mastication progress between the buccal and lingual side. The null hypothesis to be tested was that the variations of the particle size distribution are similar in the buccal and lingual side.

(2) Materials and methods

Subjects
Six subjects with normal dentition (4 males and 2 females; average age, 29 ± 4.4 years) were tested. The criteria for including the subjects in this experiment were as follows: (a) normal dentition with natural teeth, (b) free from restorations covered with cusps, (c) no missing teeth (excluding the third molars), (d) absence of acute dental disease, (e) no history of treatment for masticatory muscle problems, temporomandibular joint pain, or related problems, and (f) no experience of orthodontic treatment.

The subjects were recruited from staff and students of the Tokyo Medical and Dental University, Faculty of Dentistry. Sufficient explanation about this study was given to all the subjects and informed consent was obtained from each of them. This study was approved by the Ethics Committee of Tokyo Medical and Dental University.

Determination of the preferred chewing side
The preferred chewing side was determined from the side of the first chewing stroke according to the method of Pond et al. The examiner put temporary filling material (Temporary Stopping; Shofu, Kyoto, Japan) on the center of the tongue of each subject according to the method of Kato. Then, the subjects were asked to bite once at the side they preferred. The subjects were instructed to perform this step up to five times. Then the chewing side over three times was determined as the preferred chewing side.

Mastication of peanuts
The test food was six pieces of half peanut (Roasted peanuts; Kinka, Tokyo, Japan) weighing 2.45-2.54g. The subjects were instructed to chew peanuts for 16 specified number of strokes (1-8, 10, 12, 14, 16, 18, 20, 22, 24) on the preferred chewing side in random order and not to swallow any of particles for the evaluation of the initial phase of mastication. Particles in buccal side were gathered by the examiner, and then particles in lingual side were expectorated. Particles on occlusal surface were gathered with particles in lingual side because of their small amount. Gathered peanuts were washed with water on the drying sieve (56μm) respectively and dried by freeze-dry machine (Dura-Dry; FTS Systems, USA.) at -40℃ for 12 hours. This procedure was repeated for three times on each subject.

Multiple sieve method
The dried particles were sieved through a stack of eight sieves with apertures (0.85, 1.0, 1.4, 1.7, 2.0, 3.35, 4.75, 5.6mm) and a bottom plate. The sieves were vibrated simultaneously on a dry type full automatic sonic sifter (ROBOT Shifter RPS-8S; Seishin, Japan) set at the possible maximum vibration for five minutes. And the pulse interval was set at one second. After vibration, the particles remained on each sieve were weighed and averaged on the three tests for each subject.

Analysis of data
Median particle size
The cumulative weight percentages undersized as a function of the each sieve aperture which combined buccal part and lingual part were obtained and fitted to the Rosin-Rammler equation in accordance with the methods of Olthoff et al. On this regression curve, median particle size is the aperture of a theoretical sieve through which 50% weight of particles can pass. Median particle size represents particle size distribution of the sample. (Fig. 1)
Based on the sieve’s aperture and cumulative relative frequency distribution for the weight of particle captured, two performance measures ($x_{50}$ and $b$) which indicated masticatory progress were calculated. The form of the Rosin-Rammler equation was chosen:

$$R_w = 100 \cdot \exp[-(x/x_{50})^b \cdot \ln2] \quad (1)$$

- $R_w$: the weight percentage of particles with a size bigger than $x$
- $x_{50}$: median particle size
- $b$: constant

The variables $x_{50}$ and $b$ were determined by curve-fitting the data on equation (1) using the method of maximum likelihood estimation. All $R$ squares of the model were above 0.9 and indicated reasonably good fit.

**Masticatory performance**

The median particle size before comminution was set as default. And the equation which expresses the relationship between masticatory progress and median particle size was derived:

$$x_{50}(t) = A_m \cdot e^{-\alpha_m \cdot t} + C_m \quad (2)$$

- $t$: the number of chewing strokes
- $x_{50}(t)$: median particle size at times
- $A_m$: (The median particle size before comminution) - $C_m$
- $C_m$: constant
- $\alpha_m$: attenuation rate of median particle size to the number of chewing strokes

Substituting 0 for $t$, $x_{50}(t = 0)$ gets into $A_m + C_m$. This is equal to the median particle size before comminution. The median particle size before comminution was set as follow.

The particle size which becomes determination factor of passing the sieves is the breadth maximum of minimum projected profile of particles. In case of half piece of peanut, this is equal to the minor axis of torn surface. So the minor axes of 30 half pieces of peanuts were measured and averaged. $A_m + C_m$ was set as 7326 $\mu$m as a result.

The variables $C_m$ and $\alpha_m$ were determined by curve-fitting the data on equation (2) using the method of maximum likelihood estimation. All $R$ squares of the model were above 0.9 and indicated reasonably good fit.

Tanaka revealed that $\alpha_m$ was equivalent to the masticatory performance \(^{18}\). So in this experiment, the values of $\alpha_m$ were used as the representative value of masticatory performance.

**Particles observed on buccal part and lingual part separately**

In the previous study, tongue has been said to have function of selection and it was thought that particles distribution had difference between buccal side and lingual side. Therefore, the observation on lingual part and buccal part separately was done about coarse particles which remain on sieves with apertures of 4.75 and 5.6mm.

The relationship between masticatory progress and the residual weight of coarse particles at lingual part ($C_{L}(t)$) and buccal part ($C_{B}(t)$) was accounted. The following equations, expressing the relationship between masticatory progress and coarse particles at the lingual part and buccal part were obtained.

$$C_{L}(t) = A_L \cdot e^{-\alpha_L \cdot t} \quad (3)$$
$$C_{B}(t) = A_B \cdot e^{-\alpha_B \cdot t} \quad (4)$$

- $A_L$, $A_B$: constant
- $t$: the number of chewing strokes
- $C_{L}(t)$: residual weight of coarse particles at the lingual part
- $C_{B}(t)$: residual weight of coarse particles at the buccal part
- $\alpha_L$: attenuation rate of coarse particles of lingual part to the number of chewing strokes
- $\alpha_B$: attenuation rate of coarse particles of buccal part to the number of chewing strokes

$A_L$, $A_B$, $\alpha_L$ and $\alpha_B$ were calculated using the method of maximum likelihood method. All $R$ squares of the model were above 0.9 and indicated reasonably good fit.

The relationship between $\alpha_m$ and $\alpha_B$ and the relationship between $\alpha_m$ and $\alpha_L$ were estimated by linear regression analysis.

All statistical analyses were performed using statistical analysis software (STATISTICA 03J; StatSoft Japan, Tokyo) and significant level was set at 0.01.

(3) Results

**Weight of particles by multiple sieve method**

The transition of the weight of particles remained on each sieve with progression of the number of chewing strokes, for buccal and lingual side respectively, is afforded in Fig.2 (one subject). This figure shows the tendency that the particle size distributions are different between buccal side and lingual side.
Median particle size
The calculated values of $x_{50}$ were plotted versus the number of chewing strokes (t) in Fig. 3 for each subject. Fig. 3 shows that dynamic change of median particle size disappeared about 10 strokes.

Masticatory performance
The values of $\alpha_m$ and $C_m$ determined from curve-fitting the data points are given in Table 1. The $R$ squares of the model indicated reasonably good fit.

Coarse particles
Figure 4 shows masticatory progress of coarse particles which combined buccal part and lingual part for all subjects. The comminution of the majority of coarse particles was completed within about 10 strokes.

Figure 3 presents that fluctuation of median particle size becomes static state about 10 strokes. Figure 4 shows that comminution of coarse particles is completed after about 10 strokes, and there appears a dynamic change in the coarse particles. Therefore coarse particles were thought to express the masticatory progress and focused on.

Coarse particles at lingual and buccal part
The values of $C_L(t)$ and $C_B(t)$ were plotted versus the number of chewing strokes (t) in Fig. 5 and Fig. 6 for each of the six subjects. The values of $C_L(t)$ and $C_B(t)$ regressed with masticatory progress exponentially.

The values of $\alpha_L$ and $\alpha_B$ determined from curve-fitting the data points are given in Table 2. The $R$ squares of the models indicated reasonably good fit, so the values of $\alpha_L$ and $\alpha_B$ were used as follows.

Relationship between masticatory performance and coarse particles
The relationship between $\alpha_m$ and $\alpha_B$ and the relationship between $\alpha_m$ and $\alpha_L$ were analyzed using the linear regression method. And following equations were derived:

$$\alpha_B = 0.23 + 0.191 \alpha_m \quad (7)$$
$$\alpha_L = -0.067 + 1.92 \alpha_m \quad (8)$$
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Figure 4: Masticatory progress of whole mouth. (coarse particles: x>4750μm, medium particles: 1700<x≦4750μm, fine particles: x≦1700μm).

Figure 5: Residual volume of coarse particles at the lingual part C(t) plotted versus the number of chewing strokes (t) for six subjects. Drawn lines are best fits through the data points according to equation (3).

Figure 6: Residual volume of coarse particles at the buccal part C(t) plotted versus the number of chewing strokes (t) for six subjects. Drawn lines are best fits through the data points according to equation (4).

Figure 7: $\alpha_B$ and $\alpha_L$ plotted versus $\alpha_m$ for six subjects.
Fig.7 shows the relationship between $\alpha_m$ and $\alpha_B$ and the relationship between $\alpha_m$ and $\alpha_L$. The lines in the Fig.7 are the linear regression line for each.

Significant correlation was observed between $\alpha_m$ and $\alpha_L$ ($R = 0.98$, $p = 0.005$, $F = 109$). And no significant correlation was seen between $\alpha_m$ and $\alpha_B$ ($R = 0.16$, $p = 0.76$, $F = 0.11$).

The null hypothesis that the variations of the particle size distribution are similar in the buccal and lingual side was rejected.

(4) Discussion

Function of tongue and cheek

In this study, significant linear relationship was seen between regression of coarse particles in lingual side and total regression of median particle size, but not seen in buccal side. When the buccal or lingual relative weight of particles for the total weight was used for the analysis, similar result was obtained. Thus, the null hypothesis that the variations of the particle size distribution are similar in the buccal and lingual side was rejected. The tongue activity involves rotation, tilting and pushing of the food. The main cheek movement is pushing the food medially. These supposed that comminution of coarse particles in lingual side was in a controlled environment and the comminution in lingual side is important to total comminution of foods. On the other hand, cheek had function not to select foods but put foods on occlusal surface and lingual side in a mass.

Previously tongue has been said to have function of selection. Nakajima reported that the artificial restriction of the tongue movement suppressed the comminution efficiency at the coarse particles. Fujii reported that the use of an experimental palatal plate inhibited the comminution of coarse particles and caused the erratic masticatory rhythm. However, these experiments involved the use of a large equipment, which may influence the other function of the mouth and thus inhibit natural mastication.

Van der Glas et al. observed intra-oral selection and breakage process, with a silicone rubber used as a test food, aided by a sieving procedure and simultaneous form- and color-labeling of particles. They said that the selection chance increased as a power function of particle size. However, they did not mention the contribution of cheek and tongue to comminution process.

Hence in our experiment, no equipment was used in the mouth during mastication and particles separated into lingual side and buccal side were investigated to.

Table 1. Values and $R$ square of variables $\alpha_m$ and $C_m$ of the relation between $x_{50}$ and number of chewing strokes $t$: $x_{50} = (7362 - C_m) \cdot \exp(-\alpha_m \cdot t) + C_m$

<table>
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<tr>
<th>Subject</th>
<th>$\alpha_m$</th>
<th>$C_m(\mu m)$</th>
<th>$R^2$</th>
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<tbody>
<tr>
<td>A</td>
<td>0.277</td>
<td>841</td>
<td>0.95</td>
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<tr>
<td>B</td>
<td>0.175</td>
<td>741</td>
<td>0.92</td>
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<tr>
<td>C</td>
<td>0.169</td>
<td>1054</td>
<td>0.98</td>
</tr>
<tr>
<td>D</td>
<td>0.139</td>
<td>722</td>
<td>0.94</td>
</tr>
<tr>
<td>E</td>
<td>0.133</td>
<td>791</td>
<td>0.93</td>
</tr>
<tr>
<td>F</td>
<td>0.112</td>
<td>434</td>
<td>0.98</td>
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Table 2. Values and $R$ square of variables $\alpha_{BL}$ and $A_{BL}$ of the relation between the residual volume of coarse particles and number of chewing strokes $t$: $C_B(t) = A_B \cdot \exp(-\alpha_B \cdot t)$; $C_L(t) = A_L \cdot \exp(-\alpha_L \cdot t)$

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<td>$\alpha_L$</td>
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<td>2.07</td>
<td>1.67</td>
<td>1.73</td>
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<td>$A_L$</td>
<td>0.454</td>
<td>0.305</td>
<td>0.245</td>
<td>0.201</td>
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<td>$R^2$</td>
<td>0.99</td>
<td>0.96</td>
<td>0.94</td>
<td>0.88</td>
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<td>0.92</td>
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**Buccal side**

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<tbody>
<tr>
<td>$\alpha_B$</td>
<td>0.826</td>
<td>0.811</td>
<td>0.695</td>
<td>1.18</td>
<td>1.34</td>
<td>1.35</td>
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<td>$A_B$</td>
<td>0.328</td>
<td>0.201</td>
<td>0.162</td>
<td>0.257</td>
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<td>0.277</td>
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<td>$R^2$</td>
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<td>0.85</td>
<td>0.8</td>
<td>0.82</td>
<td>0.94</td>
<td>0.8</td>
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The comminution behavior of food during mastication

presume the difference between the function of tongue and that of cheek.

Abd El Malek made the observations of tongue movement during mastication on subjects who had lost some of their teeth on both sides using nuts, colored gelatin food stuffs and colored chewing gums. They reported that tongue movement was changing into 'bolus formation' stage through 'sorting out' stage in which stage the tongue sort out the larger particles of food that still need crushing.

In the research using ultrasonography made by Imai et al., the vertical motion of the tongue during mastication was said to be shown in two stages from the stability of tongue stroke, the 'sorting out' and the 'bolus formation stages'. Foods could be separated into two groups, one of which was that sorting out stage and bolus formation stage could be separated definitely including peanuts and another was that only bolus formation stage could be seen. Imai also reported that the lack of stability of the tongue stroke during the 'sorting out stage' was because of the variety of food size in initial phase of mastication which caused irregularity of tongue movement for sorting out food particles.

In the recent years, Kato et al. have reported that crushing of food is performed not in a random manner but in the circumscribed region between the functional cusps of first molars in the initial stage of mastication.

These observations of the tongue movement and the result that the regression of coarse particles in lingual side were seen in conjunction with the total regression of median particle size suggest that comminution of coarse particles in lingual side progressed systematically as a result of the selection function of coarse particles of tongue. There are only a few researches about relationship between cheek movement and mastication. Mazari et al. reported that the amount of mixing was halved and resulted in increase in bolus length with the cheek guard but did not mention the relation between comminution and cheek movement.

This study revealed the regulated change of food particles in natural condition, but the roll of tongue and cheek remain a matter of speculation. So farther study is needed.

Initial phase of mastication

Traditional research about mastication excluded the initial phase and focused on the stage occurring after the initial ten chewing strokes; this is because of the substantial fluctuation during the initial stage and difficulty in analysis. However, in this study, the fluctuation of median particle size became static state within 10 strokes. Tanaka observed peanut mastication using electromyography and the data from the initial phase of mastication during the first 10 strokes showed dynamic movements. Morikawa investigated the occlusal force on the lower first molar during mastication and found that the force during the initial phase was the highest. Therefore, to evaluate mastication of fractural foods like peanuts, rather it is the initial phase of the chewing that we should pay attention to. And in the initial phase of mastication, it is tongue that smooths the linkage of comminution stroke.

(5) Conclusion

- Comminution behavior of lingual coarse particles better conformed to fluctuation of median particle sizes of whole mouth, expressing masticatory performance precisely, than that of buccal coarse particles in people with normal dentition.
- Comminution of coarse particles and the dynamic change in the median particle size were almost finished within 10 strokes in people with normal dentition.

References