Relationship between Physical Properties of a Food Bolus and the Swallowing Threshold during Mastication of Gel Type Food

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Abstract: To study which physical properties of a food bolus trigger swallowing during mastication of gelatinous food, we measured the texture of a bolus immediately prior to swallowing by texture profile analysis. Filter paper soaked in 0.2M tartaric acid (acid stimulation) or distilled water (DW stimulation) was placed on the dorsal surface of the tongue of 10 healthy adult participants for 1 minute before they masticated rice cake (RC) or gummy candy (G). The G bolus was significantly (p<0.05) harder immediately prior to swallowing after acid stimulation than after DW stimulation. On the other hand, hardness, adhesiveness and cohesiveness of the RC bolus did not differ significantly between the two masticatory conditions (after acid stimulation and DW stimulation). After DW stimulation, the texture of the RC bolus during the middle stage of mastication was compared with that just before swallowing. The RC bolus at the middle stage was significantly harder (p<0.001) and more adhesive (p<0.05) than just before swallowing. These results suggest that the degree of adhesiveness of a bolus might be closely related to the swallowing threshold for gelatinous food such as rice cakes.

Introduction

At the late stage of mastication just prior to swallowing, a food bolus is formed by the movement of the dorsal surface of the tongue against the palate1-2). The initiation of swallowing is thought to be related to two major factors: food particle size and particle lubrication1-4). Recently, Printz and Lucas5) proposed a new model for the initiation of swallowing, where the peak cohesive force between the food particles in a bolus determines the optimum time for swallowing. This model was based on masticating and swallowing two types of foods; Brazil nuts and raw carrot. These foods are hard and brittle, and must be broken down into fine particles by the teeth. However, various
types of foods are ingested in our diet. Gel type food, such as gummy candy or rice cake, is a good example of food that is soft and adhesive, and mastication can not produce small particles from such gels. Therefore, we believe it is somewhat hasty to conclude that Printz and Lucas's new model can explain the initiation of swallowing per se.

Salivation can be increased reflexively by acid stimulation of the tongue and under such a condition, swallowing can be induced earlier. Therefore, if only some physical properties of the food bolus just before swallowing relate to the swallowing threshold, there should be no differences between the physical properties of the bolus swallowed under normal masticatory conditions and those under increased salivation. To test this hypothesis, in this study, adult participants masticated two globular gelatinous foods of different texture under both the normal masticatory condition and that in which increased salivation was elicited by acid stimulation of the tongue. We compared the texture of the food bolus immediately prior to swallowing, in order to elucidate which of its physical properties initiate swallowing during the mastication of gel type food.

**Materials and Methods**

1. Subjects
   Ten healthy adult volunteers (two males and eight females; mean age, 33.4 yrs) with functionally normal occlusion participated in this study after giving informed consent.

2. Food samples
   We used two gelatinous foods in this study: rice cake (RC) and gummy candy (G) prepared in 5 g samples as described. Briefly, RC was made by steaming a mixture of 100 g of rice flour (Miki-ko-ku-fun Co., Japan) and 90 ml of water for 20 minutes, while G was made from gelatine powder (MARUHA Co., Japan) dissolved in water at a concentration of 7% (w/v) with added sugar (5%). Table 1 gives the values of three texture parameters obtained from ten respective samples of RC and G. RC was confirmed to be more adhesive than G.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Texture parameters of gummy candy (G) and rice cake (RC)</th>
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<tr>
<td></td>
<td>Hardness (kPa)</td>
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<tr>
<td>RC</td>
<td>159.15±24.93</td>
</tr>
<tr>
<td>G</td>
<td>85.10±14.75</td>
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<tr>
<td>mean±standard deviation, n=10</td>
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3. Experimental procedure
   Prior to ingestion, filter paper (20 mm x 20 mm, Toyo Roshi, Japan) soaked in 0.2 M tartaric acid was placed on the dorsal surface of the tongue for 1 minute to stimulate the reflexive secretion of saliva (acid stimulation). Filter paper soaked in distilled water was placed on the dorsal tongue for 1 minute to act as a control (DW stimulation). To confirm that acid stimulation of the tongue did increase salivation in each subject, we compared the volume of saliva produced while chewing a dental cotton ball (diameter, 10 mm; length, 30 mm; Taketora, Japan) for 30 sec immediately after acid stimulation with that immediately after DW stimulation in each subject. Subjects spat the ball into a cup and the volume of saliva during chewing was estimated according to the subtraction method, i.e. the volume of saliva during cotton ball chewing was determined by subtracting the initial weight of the ball from the weight of the chewed cotton ball. Figure 1 shows the mean volume of saliva secreted during chewing in each subject. The mean volume of saliva after acid stimulation was significantly (p<0.001) higher than that after DW stimulation, thus confirming that acid stimulation increases salivation during mastication.

   After the acid or DW stimulation, participants masticated each of the food samples before swallowing as usual. This mastication was repeated more than three times for each of the food samples. During this time, electromyographic activities (EMG) were recorded from the masseter and the mylohyoid muscles using bipolar surface electrodes as previously described. From these records of masticatory behavior, the number of chewing strokes until swallowing commenced was counted and averaged for each participant after acid or DW stimulation. To collect the food bolus from the oral cavity just before swallowing,
participants subsequently chewed each food sample for the prescribed number of chewing strokes in each condition before spitting the food bolus into a cup. This collection of the food bolus was done at least three times for each of the food samples in each participant.

4. Measurement of bolus texture

The food bolus collected immediately prior to swallowing was placed in a glass ring (inner diameter, 20 mm; height, 10 mm) on a glass disc before being placed in a small box fixed to a moving stage of a creep meter (RE-33005, YAMADEN, Japan). The temperature and the humidity inside the box were maintained at 36.6–36.8°C and at about 70% respectively. These conditions mimicked those of the human oral cavity. To determine the texture of the bolus, it was subjected to texture profile analysis\(^{10,11}\). Each sample was compressed twice using a plunger of 5 mm diameter to 67% strain at a constant speed of 1 mm/s, before hardness, adhesiveness and cohesiveness were determined.

5. Statistical analysis

Data are expressed as means± standard deviations. The differences between the means in each condition (acid and DW) were determined using the t-test for paired samples (\(\alpha=0.05\)). Statistical analysis was performed using computer software (SPSS 7.5J, SPSS Inc., Chicago, IL., USA).

Results

1. Chewing strokes

Figure 2 shows the mean number of chewing strokes until swallowing in each subject during mastication of G and RC under acid or DW conditions. Significantly fewer chewing strokes were required for both G (p<0.001) and RC (p<0.001) after acid stimulation than after DW stimulation.

2. Texture parameters

Figure 3 shows the mean values of hardness, adhesiveness and cohesiveness of G and RC boluses collected from the oral cavity immediately prior to swallowing. The G bolus was significantly harder (p<0.01) after acid stimulation than it was after DW stimulation. However, differences in adhesiveness and cohesiveness of the G bolus according to the masticatory condition were not significant (upper graph in Fig. 3). There was no significant difference in
hardness, adhesiveness or cohesiveness of the RC bolus after acid or DW stimulation (lower graph in Fig. 3).

To determine which of the texture parameters for the RC bolus might be closely related to the initiation of swallowing, we compared the texture of the RC bolus at the middle stage of mastication with that immediately prior to swallowing after DW stimulation (Fig. 4). We found that both hardness and adhesiveness of the RC bolus in the middle stage of the masticatory sequence were significantly greater than those of the RC bolus immediately before swallowing (p<0.001 and p<0.05, respectively). However, the difference in cohesiveness of the RC bolus at these stages was not significant.

**Discussion**

In this study, the texture of a food bolus immediately prior to swallowing, produced after acid stimulation, was compared with that produced after DW stimulation in order to elucidate whether the physical properties of the food boluses related to the swallowing threshold. The G bolus after acid stimulation was significantly harder than that after DW stimulation (Fig. 3), implying that hardness of the bolus is unlike-
ly to be strongly associated with the swallowing threshold. It is well known that food particles are gradually reduced in size during solid food mastication\(^{12,13}\). This study reveals that acid stimulation prior to the mastication of G decreased the number of chewing strokes until swallowing. This indicates that after acid stimulation, the G bolus just before swallowing contains relatively large particles, which could be the main cause of such considerable hardness. In contrast, adhesiveness and cohesiveness of both the G bolus and the RC bolus after acid and DW stimulation did not differ significantly (Fig. 3). These results imply that adhesiveness and/or cohesiveness of a bolus may be associated with the swallowing threshold. However, in this study, we found that after DW stimulation, cohesiveness of the RC bolus at the middle stage of mastication did not differ significantly from that just before swallowing (see Fig. 4). This finding suggests that cohesiveness of a bolus may not directly influence the swallowing threshold, since such a direct relationship would involve the commencement of swallowing during the middle stage of mastication, which did not occur in any of our ten subjects. On the other hand, adhesiveness of the RC bolus during the middle stage of mastication differed significantly from that immediately prior to swallowing (Fig. 4), which indicates that adhesiveness of a bolus might be related to the swallowing threshold.

A significant decrease in the adhesiveness of the RC bolus was observed between the middle stage of mastication (M) and just before swallowing (C) (Fig. 4). This reduction may be due to salivation during mastication. During bolus formation, the tongue makes churning movements designed to mix and coat the triturated food with saliva\(^{1}\). An increase in secretion during mastication (as in mastication after acid stimulation in this study; Fig. 1) may rapidly mix and coat the triturated food with saliva, causing a rapid reduction in adhesiveness. When adhesiveness is sufficiently reduced, the swallowing threshold may be reached. This might also be the main reason for the significant reduction in the number of chewing strokes until swallowing after acid stimulation (Fig. 2).

Printz and Lucas proposed their new model for the initiation of swallowing based on the mastication of brittle food that is easily triturated, such as nuts and raw carrot. They concluded that swallowing commenced when the food particles bound together as a coherent bolus\(^{5}\). However, in this study, we found that adhesiveness of the RC bolus decreased significantly
from the middle stage of mastication to just before swallowing. In addition, we speculate that it is the parameter of adhesiveness that contributes to the formation of a cohesive bolus. We previously reported that a reduction in adhesiveness of rice starch paste and cooked rice can induce earlier swallowing. Taken together, these findings suggest that Printz and Lucas’s new model does not always indicate the commencement of swallowing, especially of gelatinous foods such as rice cake.

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References