**ORIGINAL**

Food Bolus Texture and Tongue Activity Just before Swallowing in Human Mastication

Kouichi Shiozawa, Kaoru Kohyama* and Keiji Yanagisawa

*Department of Physiology, Tsurumi University School of Dental Medicine

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**Abstract**: We investigated the effects of the physical properties of food boluses on tongue activity just before swallowing during food mastication in humans. Electromyographic (EMG) activity was recorded from the skin over the mylohyoid muscle (MH) of eight adult subjects during mastication of three kinds of food (gummi candy: G, peanuts: P, rice cake: RC). The texture of food boluses collected from the oral cavity just before swallowing was measured using a creep meter according to a texture profile analysis. The amplitude of the MH-EMG just before swallowing was significantly (p<0.001) larger during mastication of RC than of G and P. Adhesiveness was significantly (p<0.001) higher in the RC boluses than in the G and P boluses. These results suggest that highly adhesive triturated food requires forceful movements of the tongue to form a bolus just before swallowing.

**Introduction**

The masticatory process prior to swallowing has been described as consisting of three intra-oral stages: stage I transport, chewing stage, and stage II transport[1-3]. During the late part of chewing just before swallowing, a bolus is formed by tongue movement[4]. Electromyographic (EMG) activity recorded from the skin overlying the mylohyoid muscle (MH) can reflect human tongue activity in the oral cavity[5,6]. We reported previously that the amplitude of MH-EMG just before swallowing differs depending upon the ingested food type, and suggested that tongue activity just before swallowing is affected by the physical properties (texture) of the food bolus in the oral cavity[7]. However, the texture of the food bolus immediately before swallowing has not been investigated. In the present study, therefore, we initially recorded EMG activities from the masseter muscle.
(M), the anterior digastric muscle (Da) and the MH during mastication of food in adult humans. Next, we actually collected the food bolus from the oral cavity just before swallowing, and measured the texture of the food bolus.

Materials and Methods

1. Subjects

Eight healthy adults (4 male and 4 female, mean age 33.4 yrs) with functionally-normal occlusion gave their informed consent to participate in this study after receiving a full explanation of its aims and design.

2. EMG recording

EMG activity was recorded with bipolar surface electrodes placed on the skin overlying M, Da, and MH as previously described\(^7\). EMG activity was amplified (1253 A, NEC Medical Systems, JAPAN, time constant 0.01 s, high cut 1 kHz) and integrated with an integrator (1332, NEC Medical Systems, JAPAN, time constant 0.1 s). EMG and integrated EMG were recorded with a thermal pen recorder (8 K 23, NEC Medical Systems, JAPAN). The peak height of integrated EMG in each chewing cycle at the final five chewing cycles (late part of chewing stage : L stage) just before the first swallow was measured as the amplitude of EMG activity and averaged. In the case of the lack of a clear peak such as the integrated MH-EMG during mastication of gumi candy (G) at the L stage (e.g. Fig. 2, G), the maximum height of integrated EMG in each chewing cycle was measured as the amplitude of EMG activity.

3. Chewing food

The chewing foods were 5 g each of G, peanuts (P) and rice cake (RC). Since the making process and the texture parameters of these foods have been described\(^7\), only a brief account is given here. G is made of gelatine (MARUHA Co., JAPAN), and RC is of rice flour (Miki-Kokufun Co., JAPAN). G and RC were both globular. P was the hardest and RC was the most adhesive among the three foods.

4. Experimental procedure

Participants ingested each of the three foods, chewed, then swallowed as usual. They were also asked to push a button (swallowing signal\(^\text{P}_\text{1}\)) at the moment of commencement of swallowing. The swallowing signal was recorded together with EMGs using a pen-recorder. The number of chewing strokes until the first swallow was counted on the EMG record. Participants chewed each food again in the prescribed number of strokes until the first swallow. Before swallowing, they spat the triturated food bolus into a cup.

5. Texture measurement

The food bolus collected from the oral cavity was placed in a glass ring (the inner diameter : 20 mm, height : 10 mm) as shown in Figure 1. The base of the glass ring was covered by a glass disc. Both the ring and the disc had been heated to 37°C in an electric incubator (TS-420, Toyo Kagaku, JAPAN). The texture of the food bolus was measured using a creep meter (RE-33005, YAMADEN, JAPAN) according to a texture profile analysis (double-bite test)\(^8,9\). The ring containing the food bolus was set into a small constant-temperature box (the inside measurement, 60×60×50 mm) fixed on a moving stage of the creep meter. The temperature inside the box was maintained at 36.6—36.8°C by circulating water at a constant temperature through the insides of the side walls and bottom of the box throughout texture measurement. In addition, humidity was maintained.
at about 70% by pipetting 2 ml of water into the box. These procedures allowed the texture of the food bolus to be measured under conditions similar to those in the human oral cavity. Each sample was tested using a cylindrical plunger (diameter: 5 mm) with a 67% strain (strain is the ratio of the compression distance to the initial height for first bite). Three parameters were obtained: hardness (peak stress during the first bite), adhesiveness (area surrounded by stress strain curve and the base line for the first bite, and the work necessary to pull the plunger away from the sample), and cohesiveness (ratio of the work for the second bite to that for the first bite).

6. Statistical analysis

Data were expressed as means ± S.D. The analysis of variance (ANOVA) was used to assess the statistical significance of differences between chewing the three foods (G, P, RC). Thereafter, all pairwise differences between means were tested using Bonferoni's multiple comparison (α = 0.05). Statistical procedures were performed with SPSS (SPSS 7.5 J, SPSS Inc. Chicago, IL, USA).

Results

Figure 2 shows examples of EMG records obtained from one participant at the L stage of G, P, and RC mastication. The bottom trace (S) of each EMG record shows a swallowing signal. EMG burst activity in the M was regular in rhythm until swallowing in all records. On the other hand, fluctuating activity in the Da was observed in all records. The amplitude of the MH-EMG was very small at the L stage during mastication of G. In contrast, the amplitude of the MH-EMG remarkably increased during the L stage of RC mastication, and the peak of the MH-EMG was approximately identical to that of the M-EMG burst. As shown in Figure 1, single-swallow action occurred most frequently in the present study. Double or triple actions were observed in two individuals during mastication of P and RC.

Figure 3 shows the mean value of amplitude of EMG activities obtained from all participants at the L stage of G, P, and RC mastication. One-way ANOVA was performed on the amplitude of EMG activity at

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**Fig. 2** An example of EMG recordings at the late part of chewing stage (L) during mastication of gummi candy (G), peanuts (P) and rice cake (RC).

M, masseter EMG; Da, anterior digastric EMG; MH: mylohyoid muscle EMG. Lower three records (M, Da, MH) are integrated EMGs. S is a swallowing signal (see text).
the L stage to test for differences among the three foods (G, P, RC). The difference in the amplitude of Da-EMG was significant \((F=5.188, p=0.015)\). The difference in the amplitude of MH-EMG was also significant \((F=203.948, p<0.001)\). However, the difference in the amplitude of M-EMG was not significant \((F=3.468, p=0.05)\). As shown in Figure 3, the amplitude of Da-EMG was significantly larger \((p<0.01)\) during mastication of RC than of G. The amplitude of MH-EMG was significantly \((p<0.001)\) larger during mastication of RC than G and P. The amplitude of MH-EMG was also significantly \((p<0.001)\) larger during mastication of P than of G.

Figure 4 shows the mean values of the three texture parameters of food boluses collected from the oral cavities of eight participants just before swallowing. To test for differences among three food boluses, one-way ANOVA was performed on each texture parameter. The differences in hardness \((F=15.264, p<0.001)\), adhesiveness \((F=33.718, p<0.001)\), and cohesiveness \((F=3.968, p=0.035)\) were significant. As shown in Figure 4, hardness of the G boluses was significantly lower than that of the P and RC boluses \((p<0.001\) and\(<0.01,\) respectively). Adhesiveness of the RC boluses was significantly \((p<0.001)\) higher than that of both the P and G boluses. Cohesiveness of the G boluses was significantly \((p<0.05)\) higher than that of the P boluses.

**Discussion**

A bolus is formed by tongue movement between the dorsal surface of the tongue and the palate\(^{10}\). During this formation and stage II transport, the tongue compresses triturated food against the palate and squeezes it into the pharynx in one or more cycles\(^{11}\). In the present study, the amplitude of the MH-EMG was the largest at the L stage of RC mastication (Fig. 3). This suggests that tongue activity at the L stage of RC mastication may be very active and forceful in a bolus formation, since the MH-EMG activity recorded from the skin overlying the MH actually reflects the tongue compression against the palate\(^{8-7}\). In the present study, we actually measured the texture of triturated food boluses just before swallowing, and revealed that the adhesiveness of RC boluses was significantly higher than that of G and P boluses (Fig. 4). When the tongue compresses and squeezes the triturated food to mix with saliva and form a bolus just before swallowing, highly-adhesive triturated food such as RC requires more forceful movements of the tongue than lower-adhesive triturated foods such as G and P. This may be the main cause of a remarkable increase in the amplitude of MH-EMG at the L
stage of RC mastication (see Fig. 2, RC).

The process of chewing during the mastication of solid and semi-solid foods has been often regarded simply as the reduction of ingested food until the food is mechanically reduced to meet an internal criterion of "consistency" for swallowing\(^2\). It has therefore been inferred that the consistency of any food bolus just before swallowing is similar regardless of the food type. Palmer \textit{et al.} observed that the motion of the tongue and jaw in the late transport and swallowing cycles during the mastication of a hard biscuit were similar to that during the mastication of chicken spread, and they suggested that once the biscuit was thoroughly chewed, its consistency might be similar to that of the chicken spread\(^4\). Contrary to these conjectures, the texture of the food bolus just before swallowing varied with food types in the present study (see Fig. 4). This finding implies that factors other than the consistency of the food bolus are associated with the threshold for swallowing during mastication in humans. The salivary flow rate during mastication can affect the amount of times a food is chewed before it is swallowed\(^6\). Prints and Lucas studied swallowing thresholds during human mastication, and identified a lubrication threshold that is required to initiate swallowing\(^9\). During bolus formation prior to swallowing, the tongue makes alternating side-to-side churning movements designed to mix and coat the triturated food with saliva\(^9\). Once the surface of the triturated food bolus is sufficiently lubricated by the saliva, the swallowing action may occur, whether or not the inside of the bolus is sufficiently lubricated. This may be related to different texture parameters among the three kinds of food boluses, and may be related to the differences in the adhesiveness of the foods in the present study.

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References

