Influence of Ingested Food Texture on Jaw Muscle and Tongue Activity during Mastication in Humans

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[Received on August 3, 1998 : Accepted on November 25, 1998]

Key words: food texture/EMG/tongue activity/chewing stage/humans

Abstract: To investigate the effect of ingested food texture on tongue activity during mastication in humans, the electromyographic (EMG) activity was recorded by surface electrodes from the skin over the mylohyoid muscle (MH), masseter muscle (M) and anterior digastric muscle (Da) during mastication of three kinds of food (gumi candy: G, peanuts: P, rice cake: RC) in eleven adult subjects. The texture of these foods was measured according to the texture profile analysis. P was the hardest food, while RC was the most adhesive of the three. The amplitude of M-EMG decreased significantly during P mastication, while the amplitude of Da-EMG decreased significantly according to the progress of mastication of G, P and RC. The amplitude of MH-EMG decreased significantly during mastication of G. In contrast, the amplitude of MH-EMG increased significantly during mastication of P and RC, with an especially marked increase in amplitude observed in the late stage of chewing during mastication of RC. These results suggest that tongue activity in the late stage of chewing just before swallowing may be affected by the texture of the triturated food in the oral cavity.

Introduction

The whole process from ingestion to swallowing, known as the masticatory sequence\(^1\), is divided into several stages: ingestion and stage I transport (the ingested food is moved to the posterior oral cavity by the tongue), chewing stage, stage II transport (the triturated food is transported for swallowing), and swallowing\(^2,3\). The effect of the physical property (texture) of ingested food on the masticatory behavior of humans has often been noted. In effect, an increase in the hardness of food leads to an increase in the number of chewing cycles until swallowing and also
an increase in jaw-closing muscle activity during each cycle\(^4\)\(^--\)\(^6\). In addition, an increase in the adhesiveness of food prolongs the total duration of this sequence\(^7\). The texture of the ingested food may also exert a strong influence on tongue activity during mastication, given the coupled relationship between tongue and jaw movement as observed during chewing in humans\(^8\)\(^,\)\(^9\). However, the precise nature of this influence, especially in the actual chewing stage, has not been clearly defined.

In previous studies, we reported that the electromyographic (EMG) activity recorded from the skin over the mylohyoid muscle with bipolar surface electrodes can reflect the tongue movement in the oral cavity\(^7\)\(^,\)\(^10\). We also suggested that this recording may be useful for the study of tongue function during mastication of food as an index of tongue activity without invasive EMG recording techniques such as the insertion of needles or wire electrodes. In the present study, then, the EMG activity recorded from the skin over the mylohyoid muscle and jaw muscles during mastication of three kinds of food was investigated in adult human subjects.

**Materials and Methods**

Eleven healthy adult volunteers (three male, eight female, mean 30.6 yrs) with functionally normal occlusion participated in this study. All eleven gave their informed consent to participate after receiving a full explanation of the aims and design of the study.

EMG activity was recorded with bipolar surface electrodes (SEB 101, NEC Medical Systems, JAPAN) from the masseter muscle (M), the anterior digastric muscle (Da) on the habitual chewing side and the mylohyoid muscle (MH). Bipolar electrodes (M: 20 mm apart, Da and MH: 10 mm apart) were placed on the skin over each muscle (Fig. 1). The M and the Da were identified by palpation during chewing and resisted jaw opening, respectively. In the case of the MH, the hyoid was palpated, and then bipolar electrodes were placed 5 mm superior to the hyoid across the midline as we described in a previous report\(^10\).

Three kinds of food (gumi candy: G, peanuts: P and rice cake: RC) were used as chewing material in this study. Each had approximately the same weight (5 g). The G and RC were both circular in shape. G was made of gelatine. Gelatin powder (MARUHA Co., JAPAN) was dissolved in water at a concentration of 10% (w/v), and added sugar (5%) and a small amount of coffee-flavored powder. RC was made from rice flour (Miki-kokufun Co., JAPAN). After mixing the rice flour (100 g) with water (90 ml), the mixture was boiled for 5 minutes. The texture of the food was measured by the creep meter (RE 2-33005, YAMADEN, JAPAN) according to a texture profile analysis (double-bite test)\(^11\). Each sample was tested using a 5 mm diameter plunger with a 67% strain (strain was the ratio of the compression distance to the initial height of the sample), and the following parameters were derived. Hardness: the maximum peak height for the first bite, Adhesiveness: the area under the first negative peak (i.e. the work required to pull the plunger from the sample), Cohesiveness: the ratio of the area under the second peak to the area under the first peak, and Gumminess: Hardness times Cohesiveness. Table 1 shows the texture parameters of the foods (G, P and RC) obtained from eight samples of each food. As shown, P was the hardest while RC was the most adhesive of the three.

Subjects were instructed to ingest each of the three foods, chew and then swallow in their usual manner. They were also instructed to raise their right hand at the point they commenced swallowing during the masticatory sequence. This sign was useful for confirming the onset of swallowing when taking the EMG recordings.
Table 1  Texture parameters of gumi candy (G), peanuts (P) and rice cake (RC). mean value±standard deviations, n=8

<table>
<thead>
<tr>
<th>Food</th>
<th>Hardness (kPa)</th>
<th>Cohesiveness</th>
<th>Adhesiveness (KJ/m²)</th>
<th>Gumminess (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G</td>
<td>11.491±1.292</td>
<td>0.430±0.068</td>
<td>0.644±0.182</td>
<td>4.909±0.765</td>
</tr>
<tr>
<td>P</td>
<td>1855.250±638.433</td>
<td>0.002±0.001</td>
<td>2.939±1.895</td>
<td>1.666±1.961</td>
</tr>
<tr>
<td>RC</td>
<td>74.366±12.846</td>
<td>0.862±0.102</td>
<td>25.175±4.792</td>
<td>63.774±12.212</td>
</tr>
</tbody>
</table>

EMG activity was amplified (1253 A, NEC Medical Systems, JAPAN) and integrated by an integrator (1332, NEC Medical Systems, JAPAN, time constant 0.1 s). The EMG and integrated EMG were recorded simultaneously by a thermal-pen recorder (8 K 23, NEC Medical Systems, JAPAN).

The interval between each phase of M-EMG activity (discharges) was measured, and a reciprocal number of intervals was calculated as the chewing rhythm. The maximum height of integrated EMG in each chewing cycle was measured as the amplitude of EMG activity. An average value for both the chewing rhythm and the amplitude was calculated in the first five chewing cycles (early stage of chewing: E stage), the middle five chewing cycles (middle stage of chewing: M stage) and the final five chewing cycles (late stage of chewing: L stage), and then compared statistically. Initially, data obtained by the measurement of EMG recordings were tested using an analysis of variance (ANOVA) method. Subsequent to the ANOVA, pairwise differences between means were tested using Bonferroni’s multiple comparison (level of significance 0.05). Statistical analysis was performed with SPSS (SPSS Inc. Chicago, IL, USA).

**Results**

Prior to taking the EMG recordings, we compared the EMG activity of the three areas to confirm whether the MH–EMG activity reflected tongue movement in the oral cavity. One recording was taken from the dorsal surface of the anterior region of the tongue (T) with miniature bipolar surface electrodes in accordance with Kim’s method, another was taken from the skin over the Da, and the third was taken from the skin over the MH. Subjects were instructed to move the tongue tip forward and press it against the lower incisors, retract the tongue, and then press it against the palate. Subjects were then instructed to open their jaws and clench their teeth with maximum force. Figure 2 shows some examples of EMG recordings. The T-EMG was active during the protrusive movement of the tongue (protrusive) and when the tongue was pressed against the palate (press). The Da–EMG was active during maximum jaw opening (opening). In contrast, the MH–EMG was active when the tongue was pressed against the palate (press).

Figure 3 shows three typical EMG recordings, obtained from one subject, during mastication of the three different foods. At the beginning of the EMG recordings (left side of EMG in Fig. 3), M–EMG activity was completely absent (G) or present to only a small degree (RC), whereas both the Da–EMG and MH–EMG activity were high. This phase was thought to have been during the ingestion and stage I transport stages. A regular EMG burst in the M–EMG was observed in subjects during periods of chewing. In contrast, a fluctuation in EMG activity was observed in both the Da–EMG and MH–EMG during stages of chewing. Single swallowing was observed most frequently but double or triple swallowings were also often observed during mastication of P and RC, as shown in Figure 3. The chewing time and the number of chewing cycles until first swallowing, obtained from eleven subjects, were averaged and compared between the three foods (Fig. 4). The chewing time was significantly (p<0.01) longer for P than G. The number of chewing cycles was also significantly (p<0.05) higher for P than G.

Figure 5 shows the mean value for chewing rhythm, obtained from eleven subjects, in the three stages of chewing for all three foods. During mastication of G, the rhythm increased significantly according to the
progress of mastication (from the E to L stage). During mastication of P, the rhythm increased from the E to M stage. In contrast, during mastication of RC, no significant difference in the rhythm between the three stages was observed.

Figure 6 shows the mean value in the amplitude of EMG activity, obtained from the eleven subjects, in all three chewing stages. During mastication of G, the amplitude of both the Da-EMG and MH-EMG decreased significantly from the E to L stage. During mastication of P, the amplitude of both M-EMG and Da-EMG decreased significantly according to the progress of mastication, while the amplitude of MH-EMG increased significantly from the E to L stage. During the mastication of RC, the amplitude of Da-EMG decreased significantly from the E to L stage, where the amplitude of MH-EMG increased significantly. This increase in amplitude was greatest from the M to L stage.

Discussion

In the present study, the chewing time until first swallowing during mastication of P was longer than that during mastication of G. The number of chewing cycles until first swallowing during mastication of P was also larger than that during mastication of G (Fig. 4). A constant number of chewing cycles has been reported to be necessary to prepare the food bolus for swallowing in humans. When ingesting harder food (e.g., peanuts in this study), a longer time for chewing and a greater number of chewing cycles is needed to bring it to a "swallowable consistency". The amplitude of M-EMG decreased according to the progress in mastication of P (Fig. 6). Horio and Kawamura reported that the hardness of a food was expressed by the amplitude of M-EMG. Thus, a decrease in the amplitude of M-EMG may be related...
Fig. 3 An example of EMG recordings during mastication of gumi candy (G), peanuts (P) and rice cake (RC) from ingestion to swallowing.

Lower three records in each EMG recording were integrated EMG.

Arrows indicate the onset of swallowing. M: masseter muscle EMG.

Other abbreviations are same as in Fig. 2.

to a reduction in the hardness of the peanut bolus in the oral cavity while chewing. In contrast, no significant decrease in the amplitude of M-EMG was observed during mastication of G and RC. The level of hardness of G and RC was substantially lower than that of P (Table 1). Lower value in the hardness of the ingested food leads to a lower amplitude of M-EMG in the early stages of chewing\(^5\)\(^15\). In the present study, the amplitude of M-EMG in the E stage during mastication of G and RC was about 50% of that observed during mastication of P (Fig. 6). This lower amplitude in the E stage may mask the significant decrease in amplitude seen during mastication of G and RC.

The amplitude of Da-EMG decreased according to the progress of mastication of G, P and RC (Fig. 6). The maximum amplitude of vertical jaw movement (maximum gape) tends to decline gradually during mastication in humans\(^9\)\(^16\). This decline is attributed to such physical changes in the food in the oral cavity as the reduction of food particle size\(^17\) or the reduction of food volume placed between the upper and lower teeth\(^18\). The contraction of suprahyoid muscles induces jaw-opening and the digastric muscle is one of the major suprahyoid muscles. When a reduction in particle size or a reduction in particle volume occurs during chewing, a wider opening of the jaw is no longer necessary. This may then lead to a decrease in the amplitude of Da-EMG.

The amplitude of MH-EMG decreased from the M to L stage during mastication of G, where it had increased during mastication of P and RC (Fig. 6). The L stage includes the stage II transport\(^2\) or clearance period\(^16\) since it was defined in the present study as the final five chewing cycles before the first swallowing. Palmer et al.\(^19\) studied the relationship between the movement of the tongue, jaw and hyoid during mastication in humans with videofluorography. They reported that the tongue and hyoid moved upward and forward, and that the tongue compressed the triturated food against the palate and squeezed a portion of the food into the pharynx for one or more cycles before swallowing. In the present study, when the subject pressed his or her tongue against the palate, the MH-EMG was very active (Fig. 2). This fact and other observations made in the present study strongly suggest that the activity of MH-EMG in the L stage may reflect tongue action, such as compression and squeezing the triturated food before swallowing. It also suggests that the amplitude of the MH-EMG in the L stage may be related to the force of the tongue during the compression or squeezing of triturated food before swallowing. When the tongue compresses or squeezes the triturated food in the L stage, the physical property (texture) of the triturated food may reflect the force of tongue. In effect, highly adhesive triturated food may require forceful movements of the tongue. Thus, the difference in changes in
Fig. 4 Mean value of chewing time (left) and the number of chewing cycles (right) until first swallowing. Vertical bars indicate standard deviations. * = \( p < 0.05 \), ** = \( p < 0.01 \), n = 11.
G: gumi candy, P: peanuts, RC: rice cake

Fig. 5 Mean value of chewing rhythm in the early stage (E), middle stage (M) and late stage (L) of chewing. Vertical bars indicate standard deviations. * = \( p < 0.05 \), ** = \( p < 0.01 \), n = 11.
G: gumi candy, P: peanuts, RC: rice cake
the amplitude of MH-EMG from the M to L stage between the mastication of G and the mastication of P and RC may be related to the difference in the texture of the triturated food in the oral cavity before swallowing. If so, a remarkable increase in the amplitude of MH-EMG from the M to L stage during mastication of RC (Fig. 6) indicates that the triturated RC in the oral cavity before swallowing may be highly adhesive.

In the present study, the chewing rhythm in the L stage during mastication of P and RC did not increase, whereas it did during the mastication of G (Fig. 5). This suggests that chewing rhythm, together with the tongue motion in the L stage, may be influenced by the texture of the triturated food in the oral cavity before swallowing.

**Acknowledgement**

This study was supported in part by the Special Coordination Funds for Promoting Science and Technology of the Science and Technology Agency of the Japanese Government.

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