Textural Evaluation of Rice Cake by Chewing and Swallowing Measurements on Human Subjects

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The difficulty in masticating and swallowing rice cake was quantified. Healthy subjects ate pieces of rice cake (9 g and 3 g) and a modified product (9 g). We used electromyography to measure the activity of the jaw-closing and -opening muscles during chewing, as well as the suprathyroid muscle activity, laryngeal movement, and sound during swallowing. The smaller the rice cake, the shorter the mastication time, the fewer the number of chews, and the less the jaw-closing muscle activity. A modified rice cake product (9 g) was consumed with less mastication effort than the standard rice cake (9 g) and with the same effort as the standard (3 g). Both the sample amount and texture influenced mastication, although neither factor caused a significant difference in swallowing characteristics. These observations suggest that swallowing was induced when the bolus properties became suitable for swallowing, as healthy subjects could adjust their mastication technique according to the food amount and texture.

Key words: rice cake; texture; mastication; swallowing; electromyography

Cooked rice cake (mochi) is difficult to chew and swallow. The chewing force measured by using a small pressure transducer embedded in an artificial molar was higher with rice cake than with any other food.1) Numerous elderly people have suffocated while attempting to eat rice cake. Although cooked rice cake is easy to deform, it is tough to cut off completely. Standard rice cake is made from glutinous rice containing scarcely any amylase, and exhibits a unique texture with extreme adhesiveness and toleration to elongation. Rice cake products that are easy for the elderly to eat have recently been developed by the food industry. Some of those products for the elderly have been modified so that they are softer in texture, are less adhesive, and can be cut with smaller deformation. Non-glutinous starch containing some amylase forms a gel with poorer ability to adhere and stretch than that of glutinous rice. Substituting non-glutinous rice flour for glutinous rice or adding amylase may make rice cake easier to masticate.

A simple compression test using an Instron-type instrument has been commonly adopted to determine the firmness of food.2) To evaluate the ease of mastication, the guidelines on food for elderly people by the Ministry of Health, Labour and Welfare is commonly used in Japan.3) With this method, a sample is compressed at a constant speed of 10 mm/s until 67% of the initial sample thickness is achieved. Food firmness is defined as the maximum stress detected during the test. However, rice cake is not broken by this test and exhibits less mechanical resistance under a compressive strain of 67% than that produced by real mastication in which a very large deformation is applied to food. Although rice cake is difficult to chew, it sometimes shows a lower stress value than the guidelines (5.0 × 10^4 N/m^2) for people with chewing difficulty.3)

Texture includes the sensory properties perceptible by means of mechanical and tactile receptors from the mechanical, geometrical, and surface properties of food.2,4) The textural properties of food are assessed mainly during mastication.5) A sensory evaluation expressing the perceived texture and mechanical tests describing physical properties have been used to evaluate food texture. Wilkinson et al.5) have pointed out the necessity of analyzing the oral process to connect both methods. Masticatory variables obtained from electromyography (EMG) of the masticatory muscles, kinematic and/or force measurements, and sensory assessment are strongly modified by the food texture.2,6–10) Actual human measurements are superior in numerically expressing a difficulty in mastication, as an instrumental method alone cannot assess ease or difficulty, and quantitative treatment in a sensory evaluation is sometimes difficult. We also introduced in this study a swallowing measurement in addition to EMG during chewing to quantify the whole eating properties of rice cake. The mastication analysis using EMGs has been well established,2,6–10) while swallowing that follows the mastication of solid food has not previously been analyzed.

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Masticatory muscles can be classified into those for jaw closing muscles, which elevate the mandible, and those for jaw opening which withdraw it. Both these muscles alternate to perform rhythmic chewing. The masseter muscle, one of the jaw-closing muscles, works more when a hard food is chewed. The EMG amplitude from the masseter muscle therefore becomes greater and the level of muscle activity represents the degree of chewing difficulty. In contrast, the suprathyroid musculature, which includes the anterior belly of the digastric, mylohyoid and geniohyoid muscles, comprises jaw-opening muscles. When an adhesive food is chewed, the EMG activity recorded from the suprathyroid musculature increases. The suprathyroid musculature also elevates the hyoid at the early stage of swallowing.

Swallowing characteristics can be simply divided into three stages (oral, pharyngeal, and esophageal). The oral stage is the transfer of the food bolus from the mouth to the oropharynx, and is considered the late stage of mastication. The pharyngeal stage is the highly coordinated transport of the bolus away from the oropharynx into the upper esophagus. Tongue movements that initiate the act of swallowing require concomitant contraction of the mylohyoid, geniohyoid, and digastric muscles. As pharyngeal swallowing begins, the anterior portion of the tongue is retracted and depressed. Retraction of the tongue and its elevation against the hard palate force the bolus into the upper part of the pharynx. The tongue then moves posteriorly to drive the bolus into the pharynx, while the entire larynx is pulled upward and forward. This action causes the epiglottis at the back of the tongue to depress and protect the airway. The food bolus is then directed to either side of the epiglottis. The cricopharyngeal muscle relaxes and the bolus is propelled into the esophagus. In the esophagus, the bolus is carried toward the stomach by gravity and peristalsis. Therefore, the esophageal stage is controlled reflexively and cannot be changed consciously.

Videofluorography is commonly used to monitor the whole swallowing movement. Ultrasonic techniques have also recently been utilized mainly for observing the oral stage. Manometers or other pressure sensors inserted into the esophagus can detect the swallowing characteristics during the esophageal stage. Those techniques, however, are difficult to apply in food science because they require large and expensive equipment and/or medical techniques; moreover, the first method employing x-rays is invasive.

We describe here non-invasive, safe, and inexpensive sensors for monitoring the swallowing characteristics of humans. Previous research has used a small pressure sensor attached over the thyroid cartilage to monitor the movement of the larynx during the swallowing of liquid. Another technique to detect swallowing activity of the submental or suprathyroid muscles uses surface electrodes. Swallowing sounds picked up by a vibration sensor also provide the timing and number of swallows. The swallowing monitor system we used was composed of three pressure sensors placed on the larynx, a contact microphone attached to the cricoid cartilage, and a pair of surface electrodes for EMG from the suprathyroid musculature. A similar system has recently been used to measure the flow properties of beer and other alcoholic beverages through the human throat. Previous methods has been useful to detect the swallowing movement for liquid or semi-solid foods which can be swallowed early without chewing. However, many solid foods involving rice cake cannot be swallowed in their initial form, but can be swallowed after appropriate chewing by the teeth. No measurements have been reported of natural swallowing that follows the mastication sequence.

A small piece of rice cake has been recommended for elderly people to prevent suffocation. Although this recommendation seems quite reasonable, scientifically quantified evidence has never been presented. This study was designed to objectively determine the effects of sample size and texture on mastication and swallowing by measurements on human subjects who were actually eating different-sized pieces of rice cake. We tested two sizes of standard rice cake samples and a modified product produced for elderly people with mastication and swallowing difficulties.

Materials and Methods

Samples. Rice cake (Kirimochi, Sato Food Co., Ltd., Niigata, Japan) as the standard and a modified product for the elderly (Yawaraka Fukumochi, kindly donated by Kissei Pharmaceutical Co., Ltd., Nagano, Japan) were used. Table 1 presents the components of both samples. The standard type was cut into pieces of 20 × 20 × 15 mm (9 g) and 20 × 20 × 5 mm (3 g). Yawaraka Fukumochi was provided in cylindrical bars of 25 mm diameter and was cut into pieces 15 mm thick (9 g). Each piece was cooked for 75 s in boiling water.

Table 1. Composition and Instrumentally Measured Texture of the Rice Cake Samples

<table>
<thead>
<tr>
<th>Composition</th>
<th>Standard</th>
<th>Yawaraka Fukumochi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy (kcal/100 g)</td>
<td>231</td>
<td>161</td>
</tr>
<tr>
<td>Water (g/100 g)</td>
<td>42.3</td>
<td>60</td>
</tr>
<tr>
<td>Protein (g/100 g)</td>
<td>4.2</td>
<td>2.6</td>
</tr>
<tr>
<td>Lipid (g/100 g)</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Carbohydrate (g/100 g)</td>
<td>51.8</td>
<td>36.3</td>
</tr>
</tbody>
</table>

Two-bite texture profile analysis

<table>
<thead>
<tr>
<th>Property</th>
<th>Standard</th>
<th>Yawaraka Fukumochi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firmness (kPa)</td>
<td>210 ± 7</td>
<td>90 ± 2 **</td>
</tr>
<tr>
<td>Energy for first bite (kJ/m^3)</td>
<td>62.9 ± 2.2</td>
<td>52.8 ± 1.1 **</td>
</tr>
<tr>
<td>Adhesiveness (kJ/m^3)</td>
<td>17.1 ± 0.5</td>
<td>17.9 ± 0.7 ns</td>
</tr>
<tr>
<td>Cohesiveness</td>
<td>0.660 ± 0.009</td>
<td>0.523 ± 0.001 ***</td>
</tr>
</tbody>
</table>

*Mean and standard error values of 6 replicates.

ns, not significant; **(p < 0.01) or ***(p < 0.001), differed significantly from standard by t-test.
water, and then cooled in a covered plastic Petri dish for 15 min at room temperature (22 °C).

Instrumental measurements. A two-bite test of each sample (9 g) was performed by using a food rheometer (RE-33005, Yamaden, Tokyo, Japan) with a cylindrical plunger (5 mm diameter).\(^{14,30,31}\) The speed was 1.0 mm/s, and the final sample deformation was set at 80% of the original height. Six measurements were taken for each sample. The firmness determined by the first peak height in the load-time curve, the area under the first compressive peak, adhesiveness (the work required to pull the probe from the sample), and cohesiveness (the ratio of the second compressive peak to the first) were calculated.\(^2,14\) Firmness is expressed as the stress after the load value had been divided by the plunger cross-sectional area, and the work values (first peak area and adhesiveness) were determined per unit volume.

Subjects. Eleven volunteers (mean age of 26.7 years), who were free from functional mastication problems and required no dental treatment, participated in the mastication and swallowing measurements. Large inter-subject variation was reported and we intended to test the differences in masticatory variables caused by the size of the subject's mouth, we selected females aged 20 to 42 years with a height of 152 to 166 cm and a body mass index of 18 to 23. They gave their informed consent prior to the experiment.

Masticatory EMG and swallowing measurements. Three rice cake samples with two replicates were randomly served to the subjects. Each sample was cooked individually 15 to 16 min before consumption. The subjects took a sample into the mouth with chopsticks by themselves, and started to eat it in a normal way according to instruction from an experimenter. They freely rinsed their mouths with water before or between the trials. The recording session lasted for about 30 min.

The EMG activities were recorded from both the left and right masseter muscles, and the suprahyoid musculature with bipolar surface electrodes (NE-155A, Nihon Kohden, Tokyo, Japan) and an MEG-6108 amplifier with three AB-610J units (Nihon Kohden, Tokyo, Japan), as previously reported.\(^{13,14}\) All the subjects were right-handed, so a ground electrode was placed on the left wrist.

The larynx movement during swallowing was monitored by an array of pressure sensors.\(^{26,27}\) Three small pressure sensors (PS-2KA, Kyowa Dengyo, Tokyo, Japan) with a diameter of 6 mm were arranged in a row 8 mm apart on polyethylene foam (30 × 27 × 5 mm thickness). A belt (400 × 27 mm width) was used to put the sensors around the subject’s neck with the center of the lowest sensor placed on the thyroid cartilage of each subject.\(^{26,27}\) The position and tightness of each sensor were determined while the subject swallowed a small amount of water. Signals were output through an MEG-6108 amplifier with three AP-610J units (Nihon Kohden, Tokyo, Japan), and converted to kPa units after calibration with known loads applied by a rheometer (RE-33005 as already described).

A contact microphone (JM-0116, Ono-Sokki, Tokyo, Japan) was attached to the skin surface with double-sided adhesive tape beside the cricoid cartilage.\(^{26,27}\) The swallowing sound was detected by the microphone connected to an amplifier (SP-2200, Ono-Sokki; 0 dB Gain).

Data analysis. The seven signals (three EMGs, three pressures, and sound) were stored in a Windows\(^\text{®}\) computer by using the MP150 program (Biopac Systems, Goleta, CA, USA) at 1000 Hz for further analysis with wave-analysis software (AcqKnowledge®, ver. 3.5.7, Biopac Systems).\(^{14}\)

The signals from both masseter muscles appeared almost simultaneously as the subjects closed their jaws and freely changed chewing sides during mastication; therefore, the masseter EMG data from the left and right sides were averaged. From these masseter EMGs, i) the number of chewing strokes, ii) mastication time, and iii) mean chewing cycle time were derived.\(^{13,14}\) For each chewing cycle, iv) the amplitude or the maximum voltage, v) burst duration, and vi) muscle activity estimated as the time-integral of the EMG voltages were read. They were averaged for all the chewing cycles.\(^{14}\) The muscle activities were summed for total muscle activity, and we defined the value as the mastication effort for both the jaw-closing and jaw-opening muscles.\(^{13,14,31}\)

During the swallowing periods, nine characteristic time points were read from the suprahyoid musculature activity, pressure curves, and swallowing sound.\(^{26,27}\) Figure 1 indicates, via p1 and p9, the starting and end points of suprahyoid EMG activity, p4 and p5, the peaks for the upper pressure sensor, p3 and p6, those for the middle sensor, p2, the starting time to decrease the pressure of the lower sensor, p7, the end time to increase the pressure of the lower sensor, and p8, the starting time of the swallowing sound. The period between pi and pj is labeled tij. For example, the duration of the suprahyoid musculature was calculated as p9-p1; therefore, we labeled it t19. We used seven parameters (t12, t23, t34, t67, t28, t19, and t27). We also picked up the amplitude and muscle activity of the suprahyoid musculature, amplitude of the sound, and pressure differences at the first peak for the upper and middle sensors.

Statistics. Statistical analyses were performed with SPSS (ver. 14.0J for Windows\(^\text{®}\)) software (SPSS, Chicago, IL, USA) with the statistical significance set at p < 0.05. A t-test was conducted on the mechanical parameters, and the Wilcoxon signed-rank test was applied on human recording variables.
Results and Discussion

Mechanical properties of rice cake samples

Figure 2 depicts the two-bite curves for both samples. As the plunger speed was constant (1 mm/s), the time axis could be interpreted as the deformation within each direction and bite. Yawaraka Fukumochi™ was firmer than standard rice cake at the early stage of compression (i.e. small deformation), both the curves crossed, and then the opposite was observed when the compressive deformation became larger. On average, the point where the curves cross corresponded to 54% of the initial height. Table 1 presents the results of the texture profile analysis. The samples differed significantly in all textural parameters except for their adhesiveness.

We adopted a compressive strain of 80%, which was greater than that in previous studies using the two-bite texture analysis for rice cakes (50%\(^{32}\) and 67%\(^{12}\)); however, neither sample was torn until 80% strain. The firmness was equal to the mechanical stress at 80%. Considering that the deformation applied by a human bite would exceed the normal deformation used in the mechanical tests, the chewing force required for the standard rice cake was far higher than that for the modified product. Mechanical stress at higher strain is likely to be more important in determining a textural assessment than that at lower strain; therefore, the stress under a high compressive strain accurately expresses the mechanical properties of food in chewing. Starch gels made from glutinous starch have exhibited similar mechanical characteristics, regardless of species. Wheat noodles made from glutinous varieties displayed lower mechanical stress than those from normal varieties up to a deformation of 50%, and exhibited greater stress at a strain of 80% or more.\(^{33}\) Standard rice cake made from glutinous rice not containing amylose was easy to deform to 50% of its initial thickness, but difficult to cut off completely. The modified product made from non-glutinous rice reduced the stress at large deformation, thereby decreasing the chewing difficulty.

We also noted the curve shape in the minus-load region. Although the adhesiveness values (i.e. upper area of the curve and below 0 in load) were similar and

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**Fig. 1.** Schematic Drawing of Swallowing Data.
From the top: EMG activity from the suprahypoid musculature; pressure output from the upper, middle, and lower sensors; and swallowing sound from a contact microphone. Characteristic points (p1–p9) for the swallowing parameters are given.

**Fig. 2.** Texture Profile Curves for the Rice Cake Samples.
Each initial sample was 15 mm thick. It was cooked for 75 s and cooled for 15 min at room temperature. The sample was bitten twice by a plunger of 5 mm diameter at a constant speed of 1 mm/s. The black line represents the standard rice cake, and the grey line represents Yawaraka Fukumochi™ for elderly people.
the minimum loads occurred during the first tensile stage, the plunger separated earlier in Yawaraka Fukumochi\textregistered\textsuperscript{C212} than in the standard rice cake, which adhered for a longer time (Fig. 2). This result suggests that the modified product was easier to remove from the oral organs.

**Mastication parameters**

We evaluated the mastication difficulties of rice cake samples by electromyography (Fig. 3). When the size of the rice cake piece was decreased from 9 g to 3 g, the number of chewing strokes, mastication time, and amplitude of the masster muscles became significantly smaller (Table 2). The result was significantly decreased total mastication activity for both the jaw-closing and jaw-opening muscles. The chewing-cycle time, duration of contraction expressed as the duration of the masster muscles, and amplitude of the jaw-opening muscles were similar for both pieces. Those parameters, all influenced by texture, were significantly smaller in the texture-modified rice cake (Yawaraka Fukumochi\textsuperscript{TM}).

When the sample amount was decreased to one third (from 9 g to 3 g), the total muscle activities were decreased by 44% for the masster muscles and by 30% for the suprahyoid musculature. The activity for the 3 g samples was evidently far larger than a third of that for 9 g. Eating with a reduced mouthful increased the mastication effort per unit food weight, as has been reported previously.\textsuperscript{14,31} The smaller size could effectively decrease the chewing effort per piece; however, the larger piece and fewer mouthfuls reduced the total muscle activity per sample weight.

The total muscle activities were reduced by 48% for the masster muscles and 37% for the suprahyoid musculature with Yawaraka Fukumochi\textsuperscript{TM}, compared with those for the standard rice cake of the same quantity. This modified product had an alternative or greater effect compared with the 3 g rice cake in reducing the mastication effort without decreasing the mouthful amount.

**Table 2.** Results of Mastication Measurements for the Rice Cakes

<table>
<thead>
<tr>
<th>EMG parameter</th>
<th>Standard (9 g)</th>
<th>Standard (3 g)</th>
<th>Yawaraka Fukumochi\textsuperscript{TM} (9 g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of chewing strokes</td>
<td>49.0 ± 3.4</td>
<td>32.8 \textsuperscript{*} ± 2.9</td>
<td>33.1 \textsuperscript{**} ± 3.5</td>
</tr>
<tr>
<td>Mastication time (s)</td>
<td>37.4 ± 3.4</td>
<td>24.3 \textsuperscript{*} ± 3.1</td>
<td>23.0 \textsuperscript{**} ± 2.8</td>
</tr>
<tr>
<td>Chewing cycle (s)</td>
<td>0.754 ± 0.039</td>
<td>0.717 ns ± 0.046</td>
<td>0.677 \textsuperscript{**} ± 0.042</td>
</tr>
<tr>
<td>Masster muscles</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplitude (mV)</td>
<td>1.144 ± 0.167</td>
<td>0.983 \textsuperscript{**} ± 0.139</td>
<td>0.866 \textsuperscript{**} ± 0.148</td>
</tr>
<tr>
<td>Duration (s)</td>
<td>0.232 ± 0.013</td>
<td>0.214 ns ± 0.015</td>
<td>0.215 \textsuperscript{*} ± 0.012</td>
</tr>
<tr>
<td>Muscle activity (mV s)</td>
<td>0.0297 ± 0.0050</td>
<td>0.0247 \textsuperscript{**} ± 0.0039</td>
<td>0.0231 \textsuperscript{**} ± 0.0036</td>
</tr>
<tr>
<td>Total muscle activity (mV s)</td>
<td>1.475 ± 0.292</td>
<td>0.836 \textsuperscript{**} ± 0.172</td>
<td>0.774 \textsuperscript{**} ± 0.149</td>
</tr>
<tr>
<td>Suprahyoid musculature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Amplitude (mV)</td>
<td>0.561 ± 0.048</td>
<td>0.535 ns ± 0.061</td>
<td>0.512 \textsuperscript{*} ± 0.056</td>
</tr>
<tr>
<td>Duration (s)</td>
<td>0.436 ± 0.053</td>
<td>0.451 ns ± 0.036</td>
<td>0.409 ns ± 0.032</td>
</tr>
<tr>
<td>Muscle activity (mV s)</td>
<td>0.0453 ± 0.0071</td>
<td>0.0445 ns ± 0.0099</td>
<td>0.0398 ns ± 0.0083</td>
</tr>
<tr>
<td>Total muscle activity (mV s)</td>
<td>2.137 ± 0.401</td>
<td>1.502 \textsuperscript{**} ± 0.414</td>
<td>1.358 \textsuperscript{**} ± 0.344</td>
</tr>
</tbody>
</table>

Mean and standard error values of 11 subjects.

ns, not significant; \textsuperscript{*}(p < 0.05) or \textsuperscript{**}(p < 0.01), differed significantly from Standard (9 g) by Wilcoxon signed-ranks test.
The substituted product contained more water (60%) than the standard rice cake (42%) (Table 1). Katsuta et al. have commented that a greater amount of water was required for making rice starch gel (dango) from non-glutinious starch flour than from glutinious flour. Substitution by non-glutinious rice increased the water level, and the energy per weight of product became low (Table 1). However, the mastication effort per unit energy (i.e., based on a similar solid content) as previously discussed for cooked rice was still lower in the modified product.

In Japanese daily life, the rice cake is sometimes substituted for cooked rice as a staple food with meals; sometimes it is served as a snack between meals. If the rice cake is assumed to be essential as a staple food that must be eaten in a large amount with each meal for energy intake, textural modification of rice cake would help provide enough energy without greatly reducing the mouthful size. If rice cake is considered a non-essential confectionery or snack, the nutritional value may be less important; thus, serving it in small pieces may be appropriate for the elderly.

**Swallowing parameters**

We also measured swallowing by following the chewing sequence from the suprahyoid EMG activity, larynx movement, and swallowing sound. Figure 4 presents an example of the recorded data. Before swallowing, the electrodes on the suprahyoid musculature, the upper two pressure sensors, and the microphone detected no signal; but the lowest pressure sensor exhibited positive pressure because it was pressed by the mound of the thyroid cartilage. When swallowing started, the suprahyoid musculature began to work, perhaps to move the bolus from the oral cavity to the oropharynx with the tongue. The output of the lower pressure sensor then decreased, followed by the peak of the middle sensor, and then that of the upper one. This sequence corresponded to the elevation of the larynx. After a short signal of the swallowing sound had been observed, the EMG activities diminished, followed by the second peaks from the upper and middle pressure sensors; finally, the pressure of the lower sensor increased again to the initial level. This observation was similar to previous findings for male subjects swallowing rice gruel without chewing. The output patterns of the EMG and the early part (<1 s) of the lower pressure sensor were similar to those of submental EMG and laryngeal movement detected by a different type of sensor while the subject was drinking liquid.

Our observation method detected different swallowing patterns while the subject was drinking a beverage from a beer mug, when the larynx moved up and down repeatedly. Such continuous drinking has also been observed by EMG measurement. Table 3 presents the results for 11 subjects. No significant differences were caused by piece size or texture. However, the swallowing sound and peak pressures for the upper and middle sensors tended to be greater for both 9 g samples than for the 3 g standard sample.

As measured by the instrumental methods (Fig. 2 and Table 1), the two samples differed significantly, but the difference in texture decreased during mastication. The bolus texture sometimes differs for various types of food. The two rice cake samples used in this study were close in texture; therefore, the bolus properties would become similar at the beginning of swallowing, since chewing modified the initial texture, as shown for cooked rice samples. We did not detect any significant difference between the two sample sizes of rice cake in any swallowing variables. This result may have been due to the small size of the bolus. Neither the 9 g nor 3 g sample was difficult to swallow after enough chews by healthy subjects. Previous reports on rice gruel have also stated that similar measured periods were not influenced by the properties of bolus after elevation of the larynx began, as swallowing is a reflex response. Another possibility is that it may be derived from the present trend without any statistical significance of the swallowing sound and larynx movement upward of the bolus.
adjust their mastication to different foods. Must be applicable for such subjects who cannot easily dangerous to eat standard rice cake. This methodology chewing and swallowing difficulties and who find it if textural modification is required for people who have finally, a future study should be conducted to determine swallowing characteristics of various foods. Indicating the physical properties of food are required to clarify the swallowing characteristics of healthy humans has not yet been clarified. Modified rice gruel for dysphagic patients exhibited smaller swallowing EMG activities and shorter duration of the suprahypoid musculature with a faster rise of the larynx at the beginning of swallowing than with standard gruel, since it was easier to swallow.27) As the subjects swallowed rice gruel without chewing, a clear textural effect was observed. Normal subjects displayed greater amplitude and duration of pharyngeal transit times decreased significantly as bolus volume increased.16) The texture of the food or bolus could adjust their mastication method to the food amount and texture.

The relationship between the bolus nature and swallowing characteristics of healthy humans has not yet been clarified. Modified rice gruel for dysphagic patients exhibited smaller swallowing EMG activities and shorter duration of the suprahypoid musculature with a faster rise of the larynx at the beginning of swallowing than with standard gruel, since it was easier to swallow.27) As the subjects swallowed rice gruel without chewing, a clear textural effect was observed. Normal subjects displayed greater amplitude and duration of submental EMGs when they swallowed a larger volume of water; however, the differences between 3 ml and 10 ml were small.25) In contrast, videofluoroscopical observations of healthy women swallowing liquid barium (1 to 10 ml) have revealed that the oral and pharyngeal transit times decreased significantly as bolus volume increased.10) The texture of the food or bolus was likely to have influenced the different results in the literature, but most previous reports have lacked detailed information about the food texture. Further studies indicating the physical properties of food are required to clarify the swallowing characteristics of various foods. The sensor system described here will be able to determine whether or not a bolus is difficult to swallow, when more difficult-to-swallow food is to be tested. Finally, a future study should be conducted to determine if textural modification is required for people who have chewing and swallowing difficulties and who find it dangerous to eat standard rice cake. This methodology must be applicable for such subjects who cannot easily adjust their mastication to different foods.

Conclusion

Both a small sample amount and textural modification of rice cake reduced the mastication effort up to swallowing; however, no significant differences were observed in the swallowing parameters. Swallowing was likely to have been induced when the bolus properties became suitable for swallowing as healthy subjects could adjust their mastication method to the food amount and texture.

Acknowledgments

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