Influence of Thickeners on the Fragmentation of Fish Meat Sausage by Mastication

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Received April 26, 2011; Accepted July 18, 2011; Online Publication, November 7, 2011

The influence of food thickeners (potato starch, guar gum, and xanthan gum) on the breakdown of solid food was numerically analyzed, and an investigation was made into the cumulative size distribution of food fragments, textural properties, sensory evaluation and maximum transit velocity of a bolus in the pharynx.

The results suggest that evaluating the breakability into small pieces was easily influenced by the addition ratio of the dispersion medium. However, in respect of the destruction process for the solid body, each sample was more strongly affected by the type of the dispersion medium than by the addition ratio of this medium.

The destruction process was strongly influenced by the history of the breakdown caused by mastication when a liquid dispersion medium was added to the solid. However, when a high-viscosity sol was added to the solid, the destruction process was random and not affected by any history.

Key words: thickener; mastication; fragment size; rheological property; log-normal distribution

Pre-chopped and modulated food is provided for people with reduced masticatory function in such institutions as homes for the elderly. However, pre-chopped food tends to remain in the oral cavity and pharyngeal region and does not easily form a food bolus for those with reduced lingual function. In the case of a food bolus with a higher flow rate, the possibility of aspiration becomes higher in people with lower masticatory and swallowing functions, since the timing of closing the epiglottis is not appropriate and part of the bolus enters the trachea. There are food thickeners on the market that aim to reduce the risk of aspiration for people who have swallowing difficulty. Several papers have reported that the food bolus formed more easily when these agents were added, and that the texture of the food was also improved. Pre-chopped foods to which these food thickeners are added have been offered in hospitals and homes for the elderly. It is important to develop foods that are easy to swallow in an aged society with increasing numbers of people with reduced masticatory and swallowing functions. Prinz et al. have reported that swallowing was induced when food fragments formed an appropriate bolus in the mouth. There are several conditions that must be met before swallowing; for example, the food must be broken into smaller particles by mastication and the surface of the bolus must be coated with saliva. Food taken into the oral cavity changes in its shape and physical properties due to mastication, becoming a swallowable bolus. In order to offer easily swallowed food for people with reduced masticatory and swallowing functions, it is essential to analyze the physical properties of the food bolus in the oral cavity upon mastication. Although there have been studies on measurements of the break of solids such as those by Suzuki et al. and Kobayashi et al. to the best of our knowledge, there has been no study yet that investigated the effect of added thickeners on the fragmentation of solids. The present study analyzes the food fragment size by a numerical method, using samples of solids with added thickeners as the model. The influence of post-mastication food size on the textural properties of the bolus, sensory properties, and transport velocity of the bolus in the pharyngeal region is also examined.

Materials and Methods

Sample preparation. Fish meat sausage (FS; Nippon Suisan Kaisha) was used as the solid food in the samples. Table 1 shows its nutritional content. Fish meat sausage was selected as the solid sample due to two important features: the color of the solid sample was easily distinguishable from that of the dispersion medium in order to calculate the area of the food fragments, and the fibrous and hard grain structure of the sample did not influence the process of destruction by chewing. No influence from the constituents of fish meat sausage was apparent, since the sample and dispersion medium were mixed just before chewing. The fish meat sausage was cut into pieces measuring 1 × 1 × 0.2 cm³ (0.19 g) based on reports by Kohyama and Kobayashi et al. and giving a hardness of (0.79 ± 0.12) × 10² Pa.

The thickeners used for people with dysphagia are classified into three basic groups: starch, guar gum and xanthan gum. Potato starch (PS; lot 41222, San-ei Gen F.F.1), guar gum (GG; lot 508302, San-ei Gen) and xanthan gum (XG; lot 4HF363K, San-ei Gen) were used as thickeners in the present study, and deionized water (W) was used for comparison with the thickener. The three types of thickener and deionized water are subsequently each referred to as the dispersion medium. The hardness of gelled foods offered to the elderly has ranged from 1 to 3 × 10³ Pa, so that the three types of thickener were prepared into sols with the same values as those for 4% w/w PS (1.063 × 10³ Pa hardness, 4.46 × 10³ Pa storage modulus), 2% w/w GG (0.907 × 10³ Pa hardness, 4.66 × 10³ Pa storage modulus) and 5% w/w XG (0.984 × 10³ Pa hardness, 4.36 × 10³ Pa storage modulus). Each of these three thickeners was dispersed in deionized water and left for 24 h at room temperature, before dissolution at 98 °C for 1 h.
The prepared thickener was added to the pre-chopped fish sausage in proportions of 0, 25, 50, 75 and 100% w/w. Each sample of fish meat sausage with the thickener weighed 6 g and was mixed just before measurements were taken. The subjects pre-measured mastication rates were 1.36–1.67 chews per second, so the timing was set at one chew per second for each type of thickener in order to standardize the influence of digestion by amylase in the saliva. The total number of chews was set to 5, given that the average number of chews before swallowing by the subjects was approximately 7 times in a preliminary experiment.

**Subjects.** The subjects in this study were healthy female volunteers in their twenties, with normal occlusion and without any abnormality in the shape or function of their stomatognathic system. Thirteen subjects participated in the sensory evaluation, and 10 participated for the other measurements. The study followed the Declaration of Helsinki, and the experimental protocol was approved by the Ethical Committee of Showa Women’s University. All subjects were informed of the intent of the experiment and provided their written consent.

**Post-mastication food size.** A test piece (6 g) of a sample was taken, chewed 5 times and then spat out into a beaker. The mouth was rinsed with deionized water, which was then also spat out into the beaker, in order to recover every food fragment. The food fragments in the beaker were passed through a 50-mesh sieve to eliminate the carrier fluid. The collected food fragments down to a size of 0.01 cm² were laid out flat on a transparent plastic board and scanned at 1200 dpi (Epson PM-A840). Each subject chewed 15 sample pieces. The surface area size of each food fragment image was numerically analyzed by the method of Kobayashi et al.22,23) have reported that chewing breakdown is a destruction phenomenon of log-normality in which the size of food fragments is affected by the destruction history, and not consecutive destruction with large impact energy. We therefore examined in the present study whether food fragments created by a continuous breakdown process met a log-normal distribution function.

Log-normal distribution20) is determined by a stochastic process in which the breakdown point depends multiplicatively on the fragment size prior to that point and is expressed by the following equation:

\[
N(s) = (N_0/2)[1 - \text{erf}((\log(s/x_0))/(2\sigma^2))] \\
\text{erf}(x) = (2/\sqrt{\pi}) \int_{0}^{x} \exp(-y^2)dy
\]

\[N(s)\] in Eq. 1 represents the cumulative distribution function of surface size \(s\), \(s\) represents the surface size, \(x_0\) represents a parameter related to the average value of the size, \(\sigma\) represents a parameter related to the distribution, \(N_0\) represents the total number of fragments, and \(\text{erf}(x)\) represents the error function.

**Textural properties.** The rheological properties of a uniform liquid and sol were evaluated by viscosity according to a previous report.20) However, the textural properties were also measured in the present study, because the samples were a sol with dispersed fish meat sausage, and the correlation coefficient has been reported to be very high between the food transport velocity in the pharyngeal region and hardness.22) Since the shape and mechanical properties of food are greatly changed by mastication, it is thought that the mechanical properties of a post-mastication sample are important in developing an understanding of chewing and swallowing.20) The post-mastication samples were therefore used for measuring the textural properties. The textural properties were measured with a Rheometer RE-3300S instru-

**Table 1. Materials and Nutrition Sample**

<table>
<thead>
<tr>
<th>Nutritional data (100 g)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>calories</td>
<td>39 kcal</td>
</tr>
<tr>
<td>protein</td>
<td>8.9 g</td>
</tr>
<tr>
<td>fat</td>
<td>9.1 g</td>
</tr>
<tr>
<td>carbohydrate</td>
<td>13.7 g</td>
</tr>
<tr>
<td>sodium</td>
<td>735 mg</td>
</tr>
<tr>
<td>calcium</td>
<td>467 mg</td>
</tr>
<tr>
<td>sodium chloride</td>
<td>1.9 g</td>
</tr>
</tbody>
</table>

The influence on swallowing of a food bolus containing solids fractured by chewing was examined. The flow velocity distribution (flow velocity spectrum) of food particles passing through the pharyngeal region was calculated from the measurements obtained. The maximum velocity and transit time were computed from this flow velocity spectrum. The ultrasonic beam was radiated at an angle of 30° to the food bolus that was moving within the subject’s pharyngeal region, this angle being selected according to the method of Nakazawa et al.23,25) in the B-mode of the ultrasonic diagnostic imaging system. The velocity of the bolus in the pharynx was obtained after correcting for the radiation angle of the ultrasonic beam.

Each subject was asked to sit right back on the measuring chair with a straight back, measurements being conducted 30 times for each sample on different days. Similarly to the sensory evaluation, 6-g portions were chewed 5 times and then swallowed.

**Data analysis.** Excel 2007 and SPSS 16.0J were used for a two-way analysis of variance, and the interactions and simple main effects were verified. The Bonferroni correction for multiple comparisons was used to verify each group, and statistical significance was set at 5%.

**Results and Discussion**

**Cumulative fragment-size distribution**

Figure 1 shows a typical image of fish sausage fragments in the dispersion medium chewed 5 times. Figure 2 shows the size of the food fragments in five groups of the dispersion medium: 0.01 < \(S\) ≤ 0.05 (cm²), 0.05 < \(S\) ≤ 0.1 (cm²), 0.1 < \(S\) ≤ 0.3 (cm²), 0.3 < \(S\) ≤ 0.5 (cm²) and 0.5 < \(S\) ≤ 1.0 (cm²). The vertical axis is \(N_s/N_T\), the ratio of those sizes (\(n_s\)) for the total number of food fragments (\(N_T\)). A comparison of the kind of dispersion medium showed that \(n_s/N_T\) for food fragments sized 0.01 < \(S\) ≤ 0.05 (cm²) was higher in the 50% and 75% w/w addition samples of PS and W.
Fig. 1. Images of Chewed Food Fragments of the Samples. a, 75% w/w water; b, 75% w/w xanthan gum.

Fig. 2. Distribution of Each Size of Broken Fish Sausage. a, Potato starch; b, Guar gum; c, Xanthan gum; d, Water. ①, 0.01 < S ≤ 0.05; ②, 0.05 < S ≤ 0.1; ③, 0.1 < S ≤ 0.3; ④, 0.3 < S ≤ 0.5; ⑤, 0.5 < S ≤ 1.0, △, 25% w/w, □, 50% w/w, ■, 75% w/w fish sausage. a, p < 0.05, ④, 25% w/w, FS < 50, 75% w/w, □, 50% w/w < 50, 75% w/w, FS, ②, 25% w/w > 50, 75% w/w, FS, ②, 25% w/w, FS > 50, 75% w/w; b, p < 0.05, ④, 25% w/w < 50, 75% w/w, FS, ②, 25% w/w < 50, 75% w/w, FS, ②, 25% w/w < 50, 75% w/w, FS; c, p < 0.05, ④, 75% w/w < FS; d, p < 0.05, ④, FS < 75% w/w, ②, 25% w/w < 50% w/w, FS, 25% w/w > 50% w/w.

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(50% w/w PS, 36.3%; 75% w/w PS, 37.3%; 50% w/w W, 33.2%; 75% w/w W, 35.7%), and lower in the 50% and 75% w/w addition samples of XG (50% w/w XG, 23.1%; 75% w/w XG, 30.3%).

The main chain of xanthan gum is made up of β-1,4-linked glucose, with side chains of two molecules of mannose and one molecule of glucuronic acid positioned at every other glucose residue of the main chain. The proportion of the side chain to the main chain was high in XG. The water solution of XG showed strong pseudoplastic viscosity. The main chain of GG is a D-mannose and the lateral chain has a D-galactose chain connecting α1,6-glycoside to two mannose molecules of the main chain. The GG water solution showed high viscosity and strong adhesiveness. In contrast, PS was digested by salivary amylase during chewing and then became liquid. A solid body dispersed in a medium of XG or GG therefore resulted in more limited of the solid body than when dispersed in a PS medium. The difference in the rheological properties of these dispersion media affected the movement of the solid body in the sol. We hypothesize that the destruction efficiency of the solid body was decreased by chewing in a dispersion medium in which movement was obstructed. Our comparison of the addition ratio of the dispersion medium shows that the ratio of food fragments of 0.01 < S ≤ 0.05 (cm²) to the 50% and 75% w/w dispersion media additions was high, while that to the 25% w/w dispersion medium addition was the lowest in all samples. Since the ratio of the solid body decreased with increasing ratio of the dispersion medium, we believe that the chewing efficiency of the solid body became higher. This result suggests that the influence of the adhesive strength between the solid body and the mixture of saliva was strong when chewing a 100% w/w solid body, and that the factor affecting chewing was different from that affecting chewing of a sample with the added dispersion medium.

Application to cumulative size distribution functions

Direct observation is difficult to achieve in studying the mastication process, so it is common practice to model the breakdown process and compare it with experimental results in order to understand the phenomenon.22,23) The fragment size and cumulative number for each sample were respectively plotted on the horizontal and vertical axes as shown in Fig. 3. The purpose of the present examination is to investigate the influence of added thickeners and not to clarify differences in the chewing process for each subject, so the data for each sample are presented as total data from ten subjects.

The solid line shows the log-normal distribution function. The inset within a figure expresses the part that deviates from the log-normal distribution function, the solid line in the inset being an adapted stretched exponential distribution function.23) The cumulative numbers of food fragments for the PS and W samples (Fig. 3b–d and k–m) fit the log-normal distribution by more than 90%, and no influence of the addition ratio of the dispersion medium was apparent. Kobayashi et al.22,23) have reported that cumulative numbers of food fragments fitting a log-normal distri-
Fig. 3. Distribution of the Accumulation Size of Broken Fish Sausage.

Fish sausage: a, 0% w/w, $N_r = 10.268$, $T = 0.0866$, $\sigma = 1.3575$; Potato starch: b, 25% w/w, $N_r = 8.518$, $T = 0.1360$, $\sigma = 1.5037$; c, 50% w/w, $N_r = 10.695$, $T = 0.1047$, $\sigma = 1.3541$; d, 75% w/w, $N_r = 7.224$, $T = 0.0999$, $\sigma = 1.3330$; Guar gum: e, 25% w/w, $N_r = 7.431$, $T = 0.1307$, $\sigma = 1.6572$; f, 50% w/w, $N_r = 8.464$, $T = 0.0980$, $\sigma = 1.3592$; g, 75% w/w, $N_r = 10.079$, $T = 0.0856$, $\sigma = 1.3825$; Xanthan gum: h, 25% w/w, $N_r = 7.581$, $T = 0.1168$, $\sigma = 1.5227$; i, 50% w/w, $N_r = 7.936$, $T = 0.1739$, $\sigma = 1.3854$; j, 75% w/w, $N_r = 9.102$, $T = 0.0913$, $\sigma = 1.4843$; Water: k, 25% w/w, $N_r = 7.437$, $T = 0.1039$, $\sigma = 1.5334$; l, 50% w/w, $N_r = 10.368$, $T = 0.103$, $\sigma = 1.2500$; m, 75% w/w, $N_r = 9.622$, $T = 0.0681$, $\sigma = 1.3404$. 

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bution by more than 90% can explain the destruction process of a solid body by chewing as a log-normal distribution. The destruction process of a solid body by chewing in the present PS and W samples was therefore consistent with a log-normal distribution function, suggesting that the size of food fragments was strongly influenced by history of the breakdown caused by mastication.

The fit to the log-normal distribution function for the 100% w/w fish meat sausage and GG and XG samples (Fig. 3a, e–g, and h–j) was less than 90% of the cumulative number of food fragments, so those samples were not modeled as a log-normal distribution function. The size range of food fragments not fitting the log-normal distribution function did fit a stretched exponential distribution function, as shown by the insets. The fragment-size distribution of the 100% w/w fish meat sausage and GG and XG samples can be expressed by a double-size-group structure, i.e., the smaller group fits the log-normal distribution, while the larger group behaves as an exponential distribution. These results suggest that chewing these solid samples involved both destruction affected by the past destruction history and random destruction not affected by any history. The destruction process of a solid body dispersed in a medium was strongly affected by the type of dispersion medium.

Textural properties

The textural properties of samples that had been chewed 5 times were investigated, the results for the hardness, adhesiveness and cohesiveness being shown in Fig. 4. A two-way analysis of variance was performed on the types of dispersion medium and the ratios of the addition. Statistical significance was found in the main effect of the types of dispersion medium on the hardness, adhesiveness and cohesiveness, the main effect of the ratio of the substances added to the dispersion medium, and the interaction between types of dispersion medium and ratios of addition. The hardness of all samples to which greater than 25% w/w of the dispersion medium had been added decreased as the ratio of the dispersion medium was increased. The PS and W samples showed significantly higher hardness than the samples to which GG and XG had been added at the same ratios. The reason for this result is probably that the hardness of the solid body in the PS and W samples was more strongly sensed than the dispersion medium because this medium was liquid. Conversely, the hardness of the dispersion medium in the GG and XG samples was more strongly sensed than the solid body because the dispersion medium was a strongly coherent sol. The cohesiveness of all samples to which the dispersion medium had been added at a ratio of 50% w/w or less showed similar values, but the sample to which GG had been added showed a significantly higher value than the 75% w/w PS and 50% w/w W samples. The adhesiveness of the GG and XG samples showed significantly higher values than the PS and W samples at the same ratios. We believe that these results for cohesiveness and adhesiveness did not depend on the influence from the size of the food fragment, but rather on the influence from the physical properties of the dispersion medium. The adhesiveness of the PS and W samples showed similar values, possibly because starch was digested by salivary amylase and then converted from a sol to liquid.

The food fragment size therefore easily influenced the hardness of the food bolus when a fluid dispersion medium was added to the solid. However, when a high-viscosity sol was added to the solid, the food fragment size tended to have little influence on the hardness of the food bolus.

Sensory evaluation

Figure 5 shows the results of the sensory evaluation after chewing 5 times. A two-way analysis of variance was conducted on the hardness, adhesiveness, cohesiveness, chewability and whether or not the subject was able to chew and break the sample into small pieces. Significant differences (p < 0.05) were found for all interactions and the main effects for every parameter, except for the interaction between the type of dispersion medium and ratio of the added thickener in respect of the hardness (F(9, 1024) = 0.58, p > 0.05). The samples with the 75% w/w dispersion medium were deemed to be significantly harder than those with only the 25% w/w dispersion medium. These results are
consistent with the food fragment size (Fig. 2), i.e., the ratio for the larger food fragments (0.5 < S ≤ 1 cm²) of the 25% w/w samples was higher than that of the 75% w/w samples. With respect to chewability and breakability, the 25% w/w samples were considered easier to chew and break into small pieces than the 75% w/w samples, possibly because the former were easier to recognize as solids in the oral cavity than the 50% and 75% w/w samples. The 75% w/w W samples were evaluated as significantly more difficult to chew than the 25% and 50% w/w W samples (p < 0.05). This was probably due to the greater fluidity of water as the dispersion medium which made the solid scatter within the oral cavity. The 50% and 75% w/w XG samples were considered to be significantly more difficult to chew than the 25% w/w XG sample (p < 0.05), possibly due to the larger amount of sol surrounding the solids and preventing them from directly touching the teeth. However, the results of the sensory evaluation were different from those of the food fragment size, the degree of fragmentation by chewing of the 50% and 75% w/w samples being higher than that of the 25% w/w samples in the sensory evaluation (Fig. 2). It is possible that recognition of the solid was reduced with increasing ratio of the dispersion medium. The evaluation of easiness to bite showed similar scores with no significant differences (p > 0.05) for the 75% w/w samples. However, the difficulty of chewing the solid in the dispersion medium depended on whether the dispersion medium added was liquid or sol.

No samples other than the W samples showed significant differences of adhesiveness and cohesiveness in the dispersion media of 25% w/w or more. We believe that the physical properties of the dispersion medium had stronger influence than the food-fragment size on the results of the sensory evaluation.

Transport velocity of the bolus in the pharyngeal region

Figure 6 shows the maximum transport velocity obtained from the flow velocity spectrum. A two-way analysis of variance showed significance for interaction between the types of dispersion medium and the ratios of addition, as well as for both the main effects of type and ratio (p < 0.001); the higher the ratio of the dispersion medium of more than 50% w/w for the PS and W samples, the faster the maximum transport velocity of the bolus in the pharyngeal region (p < 0.05). It is thought that, as the addition ratio of the dispersion medium increased, the fluid part of the medium more greatly influenced the transport velocity. The GG and XG samples showed significantly lower transport velocity than the PS and W samples. It may accordingly be said that the physical properties of the food bolus (Figs. 4 and 5) contributed more to the maximum velocity than did the food fragment size (Fig. 2).
The maximum transport velocity of the samples with 25% w/w PS, 25% w/w GG and 25% w/w XG was slower than that of the equivalent 100% w/w solid samples, suggesting that these former samples were more easily bunched up by adding the dispersion medium; the food-fragment size of the samples with 25% w/w PS, 25% w/w GG and 25% w/w XG was larger than that of the other samples.

**Conclusion**

The destruction by chewing of fish meat sausage with the PS and W dispersion media was consistent with a log-normal distribution function. However, the fragment-size distribution of the 100% w/w fish meat sausage, GG and XG samples could be classified as having a double-size group structure, i.e., the smaller group fitted a log-normal distribution, while the larger group behaved with exponential distribution. It is therefore suggested that chewing these solid samples involved both destruction that was affected by a past destruction history and random destruction not affected by any history. However, the results of the sensory evaluation were different from those of the food fragment size, for which the degree of fragmentation by chewing the 50% and 75% w/w samples was higher than that of the 25% w/w samples. The 25% w/w samples were evaluated as being more easy to chew and break into small pieces than the 75% w/w samples. These results suggest that the evaluation of breakability into small pieces was easily influenced by the addition ratio of the dispersion medium. However, the destruction process for each sample of the solid body was more strongly affected by the type of the dispersion medium than by the addition ratio of the medium.

The destruction process was strongly influenced by the history of the breakdown caused by mastication when a liquid dispersion medium was added to the solid. However, when a high-viscosity sol was added to the solid, the destruction process was random and not affected by any history. The relationship between the breakability and the destruction process of the solid body was therefore not necessarily consistent.

**References**