Determination of a Suitable Shear Rate for Thickened Liquids Easy for the Elderly to Swallow

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Thickening agents are usually added to thin liquids administered to dysphagic patients to prevent aspiration. In this study, we aimed to identify the viscosity best suited for easy swallowing in elderly people and to examine the optimal shear rate for measuring, through sensory evaluation, these thickening liquids. Ten elderly participants were selected for sensory evaluation of diluted solutions for ease of swallowing and stickiness. Diluted solutions containing > 2.0% xanthan gum-based product were judged to be significantly more difficult to swallow than solutions containing < 2.0%. Fifty-two healthy panelists were selected for sensory evaluation of oral viscosity to compare sensory evaluation with instrument-based viscosity measurement. We found that the optimal shear rate was approximately 100 s⁻¹. These findings indicate that the thickening agent-diluted solutions that the elderly found difficult to swallow exceeded 120 mPa·s at a shear rate of 100 s⁻¹.

Keywords: viscosity, thickening agents, TOROMI, shear rate

Introduction

Dysphagic patients with delayed pharyngeal swallow response or reduced lingual control find it difficult to swallow thin liquids safely (O’Gara, 1990). Thickening agents may promote safer swallowing as they lower the risk of aspiration (Kuhlmeier et al., 2001). Compared to thin liquids, thickened liquids are associated with higher values of some swallowing parameters, such as the total swallowing duration (Chi-Fishman and Sonies, 2002), number of swallowing movements (Hamlet et al., 1996), and peak lingual force amplitude (Miller and Watkin, 1996); however, the range of liquid viscosity suitable for dysphagic patients remains unclear.

In Japan, thickeners in a dry mix powder form are used to provide instant viscosity to liquids, and the products formed are called “TOROMI”. Although Japanese people favor thinner liquids, clinical staff prepare thicker TOROMI to prevent aspiration in dysphagic patients; however, they are often unsure how to adjust the liquid consistency for each individual dysphagic patient.

In 1994, the Japanese Ministry of Health, Labour and Welfare defined the “Foods for the elderly with difficulty in masticating or swallowing,” and categorized them as “Food for Special Dietary Uses (FOSDU).” This criterion indicates a lower limit of viscosity and states that the viscosity of sol-type foods should be measured using a Brookfield-type viscometer, commonly known as the B-type viscometer, at a rotor rotation rate of 12 rpm at 20°C. This rotor rotation rate is calculated to an approximate shear rate of 2 – 3 s⁻¹ (Kumagai et al., 2009). In 2009, FOSDU was changed to “Foods for the elderly with difficulty in swallowing,” which denotes a new measuring standard for gel-type foods, but the sol-type foods criterion was excluded because there was insufficient evidence for the measuring method of sol-type foods in Japan. As a result, the old method involving measurement at 12 rpm by a B-type viscometer is still widely used to mea-
sure the viscosity of sol-type food. The National Dysphagia Diet (NDD) has adopted the shear rate of 50 s⁻¹ (National Dysphagia Diet Task Force, 2002) based on Wood’s report (1968). Based on oral evaluation of viscosity, Shama and Sherman (1973) indicated that the condition of shear rate and shear stress judged as viscous by the mouth changed depending on the samples’ viscosity, and estimated the shear rate to be between 10 and 1,000 s⁻¹. They studied the oral shear rates of certain liquids by taking advantage of the difference in “shear thinning,” i.e., the decrease in viscosity with an increase in shear rate (National Dysphagia Diet Task Force, 2002), among these liquids (Wood, 1968; Shama and Sherman, 1973). Steele et al. (2003) proposed that packaging of texture-modified products for dysphagia should list viscosity values over a wider range of shear rates, beginning as low as 6 – 15 s⁻¹. Although 2 – 3 s⁻¹ (rotor rotation rate, 12 rpm) is a much lower shear rate than that stated in the above studies, it is the common method of determining fluid viscosity for dysphagic patients in Japan. This may not be the optimal method for measuring fluid viscosity; therefore, we aimed to determine the suitable shear rate for measuring TOROMI viscosity. In Japan, certain reports have discussed that the shear rate of 2 – 3 s⁻¹ is too slow to evaluate viscosity and velocity through the pharynx (Kumagai et al., 2009; Tashiro et al., 2010a; Tashiro and Ono et al., 2010b). As the condition of shear rate changes with the evaluation of viscosity in the mouth, which would in turn depend on the viscosity of a liquid (Shama and Sherman, 1973), it appears that there are suitable shear rate ranges to measure viscosities that are easy to swallow in dysphagia.

This study aimed to: (1) identify the TOROMI viscosity that the elderly would find easy to swallow, and (2) determine, by sensory evaluation, the shear rate suitable for determining the TOROMI viscosity that elderly people find easy to swallow. We evaluated which shear rate ranges were best suited for mouth feel of TOROMI viscosity and would enable comparison of the viscosity value obtained by instrumental measurement to that sensed in the mouth (sensory evaluation) in a manner similar to that of Shama and Sherman (1973).

**Materials and Methods**

**Materials**  
We used a xanthan gum-based product (Tsururinko-Quickly, Clinico Co., Ltd., Tokyo, Japan) for sensory evaluation of ease of swallowing and stickiness. Two commercially available thickening agents were used in the sensory evaluation of oral viscosity: a xanthan gum-based product (Tsururinko-Quickly) and sodium carboxymethyl cellulose (CMC; Serogen F-3H, Dai-ichi Kogyo Seiyaku Co., Ltd., Kyoto, Japan). Ion-exchanged water was used to dilute these thickeners. Flavoring (peach flavor FL54512; Ogawa & Co., Ltd., Tokyo, Japan; 0.01 w/w%) was used to mask the taste of the thickening agents in the sensory evaluation of oral viscosity.

**Sample Preparation**  
The xanthan gum-based product was dissolved in water by stirring with a medicine spoon, and the flavoring was stirred in 30 min later. Similarly, the CMC was dissolved in water by stirring at room temperature at the desired concentrations, and the flavoring was stirred into the water-swollen CMC 60 min later. We prepared 0.5%, 1.0%, 1.5%, 2.0%, and 3.0% xanthan gum-based product solutions, and 0.26%, 0.35%, 0.49%, 0.62%, 0.77%, and 1.00% CMC solutions. All the samples were stored at 20 ± 2°C before instrumental measurement and sensory evaluation of viscosity.

**Instrumental Measurement of Viscosity**  
Each TOROMI was tested with a rheometer (RheoStress 6000; Thermo Scientific HAARKE, Germany). The mode used was that of a cone-and-plate viscometer and 2 different cone sizes were used: (1) cone diameter, 35 mm; cone angle, 1°, with a 47-µm truncation gap, and (2) cone diameter, 60 mm; 1° cone angle, with a 52-µm truncation gap, which was used only for water because the former could not measure very thin liquids such as water. The viscosity was measured over an increasing shear rate range of 0.1 – 1,000 s⁻¹ for 60 s. We evaluated viscosity at specific shear rates of 50 s⁻¹ and 100 s⁻¹ (for example, at 50 s⁻¹, the viscosity was measured at 50 s⁻¹ for 60 s after an increasing shear rate range of 0.1 – 50 s⁻¹ for 60 s) and recorded the last data point of the viscosity. The samples were equilibrated at 20 ± 0.1°C in the rheometer based on Shama and Sherman (1973) and “Foods for the elderly with difficulty in swallowing”.

**Sensory Evaluation of Ease of Swallowing and Stickiness**  
Ten elderly people (women, 9; mean age, 84.0 ± 3.4 years) constituted the evaluation panel. They attended an adult daycare center and possessed the abilities for conversation and judgment. They usually ate normal-form meals and did not use thickening agents for any drinks. None of the patients had dementia, but 3 panelists had a history of stroke. The panelists’ characteristics are listed in Table 1 and include denture usage, main illness, Repetitive Saliva Swallowing Test (RSST) (Tamura et al., 2002) score, and Barthel Index score (Barthel ADL score). Experiments were carried out with approval from the Ethics Committee of Social Welfare Juridical Person, Atugijikoukai Mutuaihome.

Five samples (approximately 50 mL of TOROMI in a plastic cup) were prepared at room temperature (20 ± 2°C) for the sensory panel. These five samples contained xanthan gum-based products at concentrations of 0%, 0.5%, 1.0%, 2.0%, and 3.0%, respectively. Sample labels were randomly...
assigned and the samples were laid out. Panelists were seated in chairs or non-reclining wheelchairs. A mouthful of the sample was measured out with a spoon (4 mL) and swallowed. Samples were ranked based on ease of swallowing and stickiness. Friedman’s test and the Steel-Dwass test were used for statistical analysis. A statistically significant difference was indicated when \( p < 0.05 \).

**Sensory Evaluation of Oral Viscosity** Fifty-two students and staff members of the Prefectural University of Hiroshima (women, 48; mean age, 23.0 ± 6.0 years) were selected as panelists for this evaluation. We checked in advance whether they were able to sort TOROMI samples based on their concentrations. Five panelists were excluded because they had undergone dental treatment. We carried out the experiments after the Ethics Committee of the Prefectural University of Hiroshima had approved them.

Eight samples (approximately 30 mL of TOROMI in a paper cup) were prepared at room temperature (20 ± 2°C) for the sensory panel. Samples were labeled CMC-1 (0.26% CMC solution), CMC-2 (0.35% CMC solution), CMC-3 (0.49% CMC solution), CMC-4 (0.62% CMC solution), CMC-5 (0.77% CMC solution), CMC-6 (1.00% CMC solution), X-1 (1.00% xanthan gum-based product solution), and X-2 (1.50% xanthan gum-based product solution). Sample labels were randomly assigned, the samples were laid out, and the panelists were seated in chairs. A mouthful of the sample was measured out with a spoon (4 mL) and swallowed. Panelists ranked the samples for viscosity based only on the sensation in the oral cavity. Friedman’s test and the Steel-Dwass test were used for statistical analysis. A statistically significant difference was indicated when \( p < 0.05 \).

**Results**

**Sensory Evaluation of Ease of Swallowing and Stickiness** There was a significant difference in five samples (Friedman’s test; \( p < 0.05 \)) for both evaluation items, i.e., ease of swallowing and stickiness. Solutions of 2.0% and 3.0% xanthan gum-based product were judged more difficult to swallow compared to concentrations of 0%, 0.5%, and 1.0% (Steel-Dwass test; \( p < 0.05 \), Fig. 1-a). “Stickiness” gradually increased in tandem with that of concentration (Fig. 1-b).

**Sensory Evaluation of Oral Viscosity** Fig. 2 illustrates the rank sums of each of the eight samples in sensory evaluation of oral viscosity. There was no significant difference between the viscosity of the X-1 and CMC-2 solutions (Steel-Dwass test; \( p = 0.83 \)), and the viscosity of X-2 was evaluated to be between that of CMC-3 and CMC-4 (\( p < 0.05 \)). Instrumental measurement of the viscosity of the eight samples is illustrated in Fig. 3. It should be noted that the shear rate point at which the X-1 and CMC-2 solutions were judged to have the same viscosity was 110 s\(^{-1}\).

**Discussion**

If we were to evaluate the stickiness of TOROMI based on oral sensitivity, the value of viscosity must be obtained in the same manner. In this study, our aim was to identify the optimal shear rate for measuring viscosity and to determine the viscosity that is best suited for easy swallowing in elderly people. The elderly participants in our study found the TOROMI containing > 2.0% xanthan gum-based product difficult to swallow. Therefore, we examined oral sensations of viscosity using 1.0% and 1.5% xanthan gum-based product solutions (strong shear thinning) and CMC solutions (weak shear thinning). The shear rate of oral viscosity was 50 – 130 s\(^{-1}\) in the range where liquid thickness allowed for easy swallowing in the elderly.

The first question that we set out to address was regarding the TOROMI thickness suitable for dysphagic patients.
ing comfort”. Based on the statistical tests, there is no lower limit of viscosity for swallowing comfort, i.e., swallowing comfort is also applicable to water. However, “swallowing comfort” does not mean “no risk of aspiration”. Thickened liquids, which the elderly find uncomfortable to swallow, are considered to have a high risk of leaving residue in the oral cavity or pharynx, and aspiration might occur after swallowing. Therefore, we examined shear rates in the ranges of viscosity that were not evaluated as being “difficult to swallow” by the elderly.

We chose this xanthan gum-based product as it is widely used in clinical settings. Although we intended to select dysphagic patients for the sensory panel, we eventually selected elderly persons who attended an adult daycare center instead. Similar to a previous study, which found that the more viscous semi-liquid foods were, the more stickiness the sensory panel felt in the oral cavity (Takahashi et al., 2003). The same results are seen in Fig. 1-b; the higher the concentration of the thickener, the stickier it felt. In the sensory evaluation, the viscosity of < 2.0% xanthan gum-based product solutions were evaluated for ease of swallowing, i.e., “swallowing comfort”. Based on the statistical tests, there is no lower limit of viscosity for swallowing comfort, i.e., swallowing comfort is also applicable to water. However, “swallowing comfort” does not mean “no risk of aspiration”. Thickened liquids, which the elderly find uncomfortable to swallow, are considered to have a high risk of leaving residue in the oral cavity or pharynx, and aspiration might occur after swallowing. Therefore, we examined shear rates in the ranges of viscosity that were not evaluated as being “difficult to swallow” by the elderly.

Our second research question involved determining the

![Fig. 1. Sensory evaluation of (a) Easy-to-swallow and (b) Sticky feeling. The lowercase letters above each column represent the significant differences between the findings (Steel-Dwass test; \( p < 0.05 \)).](image1)

![Fig. 2. Sensory evaluation of oral viscosity. The lowercase letters above each column represent the significant differences between the findings (Steel-Dwass test; \( p < 0.05 \)).](image2)

![Fig. 3. Shear rate versus instrumental measurement of viscosity of CMC (open circles) and the xanthan gum-based product (closed triangles).](image3)
suitable shear rates suitable for TOROMI viscosity measurement. The parameters used to describe the thickness of materials include viscosity, viscoelasticity, fluid density, and yield stress. Although it is not clear to what extent these parameters contribute to the ease of swallowing, stickiness, and perception of viscosity, we utilized viscosity in this study because it is widely used for the evaluation of parameters in the NDD (National Dysphagia Diet Task Force, 2002) and other dysphagia studies (Hamlet et al., 1996; Miller and Watkin, 1996; Chi-Fishman and Sonies, 2002; Takahashi et al., 2003; Kumagai et al., 2009). The study of the oral shear rate of thickened liquids, pioneered by Wood (1968) and subsequently extended by Shama and Sherman (1973), utilizes sensory and instrumental methods of texture evaluation. Shama and Sherman showed that oral shear rates were higher in low-viscosity liquid samples, but they also indicated an asymptotic shear rate value of 10 s⁻¹ for highly viscous liquids. Houska et al. (1998) reported a slightly different result that predicted that “the higher the viscosity, the lower the shear rate”. Thus, the best shear rate varies with liquid viscosity. We aimed to determine the shear rates best suited for measuring TOROMI viscosities that elderly people find easy to swallow.

In 1994, the Ministry of Health, Labour and Welfare in Japan defined the diet criterion for sol for the elderly with difficulty in masticating or swallowing as a viscosity of < 1,500 mPa·s as measured by a Brookfield-type/B-type viscometer at a rotor rotation rate of 12 rpm. This viscometer does not provide an accurate value of the viscosity for non-Newtonian fluids because it cannot define an accurate shear rate. However, the corresponding (average) value of a shear rate can be calculated with the B-type viscometer (Mitschka, 1982). Kumagai et al. (2009) indicated that the viscosity measured with two types of viscometers, i.e., the B-type and cone-and-plate viscometers, coincided considerably well at the same shear rate. The B-type viscometer is widely used in Japan because it is cheaper than the cone-and-plate viscometer and is easy to operate. The 12-rpm rotor rotation rate of the B-type viscometer calculates a shear rate of 2 – 3 s⁻¹, which appears low as compared to that of previous studies (Wood, 1968; Shama and Sherman, 1973; Houska et al., 1998). Despite this, it is the norm in Japan to measure TOROMI viscosity at 12 rpm with the B-type viscometer. As each thickened liquid has varying shear thinning ratios, the order of viscosity derived from sensory evaluation differs from that derived from instrumental measurement. Thus, we determined which shear rates were best suited for the measurement of TOROMI viscosity.

The shear thinning of xanthan gum-based product solutions was prominent (Fig. 3). On the other hand, CMC solutions did not exhibit prominent shear thinning. We considered these behaviors when analyzing human sensory evaluation of TOROMI viscosity. The order in which the panelists ranked sensory evaluation of TOROMI viscosity is as follows: No. 1; CMC-1, No. 2; X-1 and CMC-2, No. 4; CMC-3, No. 5; X-2, No. 6; CMC-4, No. 7; CMC-5, No. 8; CMC-6 (Fig. 2). The rankings showed a matched shear rate range of 50 – 130 s⁻¹ and a shear rate better than 2 – 3 s⁻¹ was present within this range. If these TOROMI viscosities were measured at 2 – 3 s⁻¹, the measured viscosity of X-1 would rank very similarly to that of CMC-5, and that of X-2 would rank similarly to CMC-6; however, we did not record such rankings from the sensory evaluation panelists.

There was no significant difference between X-1 and CMC-2, so these solutions were judged as being identically viscous. A comparison of statistical rank of sensory evaluation and the value of viscosity at a shear rate range of 50 – 130 s⁻¹ was judged in order of sensory evaluation of viscosity; in particular, these shear thinning lines crossed at a shear rate of 110 s⁻¹. Therefore, we believe that the optimal shear rate is approximately 100 s⁻¹. In this study, we discussed the optimal shear rate range for mouth feel of TOROMI viscosity that the elderly would find easy to swallow, whereas several other studies have reported on the shear rate best suited for velocity through the pharynx. Similar results have also been reported in studies showing a correlation between viscosity at a shear rate of 100 s⁻¹ and liquid bolus flow in swallowing, as evaluated by a 3D throat model (Mizunuma et al., 2004). It was determined that the relationship between the time during which the bolus front moved from the middle to the inferior pharynx and the viscosity of non-Newtonian fluids was approximate to that of Newtonian fluids, whose viscosities range from 10 to 1,000 mPa·s, if the non-Newtonian fluid viscosity was evaluated for the characteristic shear rate of 100 s⁻¹ under a liquid bolus volume of 30 mL in a vertical direction. However, it was reported that 10 – 30 s⁻¹ is the best shear rate (Kumagai et al., 2009; Tashiro et al., 2010a). As this was based on the evaluation of different regions, using 10 s⁻¹ as reported by Kumagai et al. (2009) in our study would mean that the rank order from low to high viscosity would be: No. 1; CMC-1, No. 2; CMC-2, No. 3; CMC-3, No. 4; CMC-4, No. 5; X-1, No. 6; CMC-5, No. 7; X-2, No. 8; CMC-6. This ranking is obviously different from that of the sensory evaluations.

A comparison of the shear rate between our findings (50 – 130 s⁻¹) and the data of Shama and Sherman (1973) is shown in Fig. 4. The values (denoted by the broken line) were obtained by Shama and Sherman (1973) (Fig. 3 in Cutler et al. [1983] and Fig. 3 in Houska et al. [1998]), and were obtained using an oral method. The broken line and X-2 crossed within the same shear rate range we had identified,
whereas the same broken line and X-1 crossed in the upper range of the shear rate (approximately 200 s\(^{-1}\)). These data and our findings were identical in that X-1 and X-2 should measure at a shear rate higher than 2 – 3 s\(^{-1}\).

The aim of having the elderly carry out sensory evaluation was to determine which samples the elderly would find easy to swallow. As we would obtain values that differed according to the shear rate if the samples were measured, the aim of having young subjects carry out sensory evaluation was to determine which shear rate is better for indicating viscosity. The aim of the sensory evaluation by young subjects was not to determine what takes place in a clinical setting, but to evaluate which shear rate range the human mouth would rank as being viscous. Thus, panelists did not have to be elderly; rather, we believed that it would be more accurate to have a judging panel composed of those with sensitive mouth feel.

Measurement of the viscosity of xanthan gum-based product solution samples (0 – 3.0\%) at shear rates of 50 s\(^{-1}\) and 100 s\(^{-1}\) are shown in Table 2. Xanthan gum-based product concentrations exceeding 2.0\% were not easy for the elderly panelists to swallow, so there is a possibility that any solution exceeding approximately 120 mPa·s at 100 s\(^{-1}\) is not easy to swallow. The viscosity of solutions containing 2.0\% xanthan gum-based product measured at 50 s\(^{-1}\) was 211 mPa·s, categorized as “nectar-like” by NDD standards. Xanthan gum forms the basis of most thickening agents in Japan. Thus, our results may be different from those from countries where the main material in thickening agents is different, for example, starch.

In conclusion, the data in our study determined the following: (1) the optimal shear rate for measuring TOROMI viscosity was approximately 100 s\(^{-1}\), rather than 2 – 3 s\(^{-1}\) (12 rpm rotor rotation rate by B-type viscometer), and (2) the viscosity of TOROMI utilizing xanthan gum-based products that the elderly found difficult to swallow exceeded 120 mPa·s at a shear rate of 100 s\(^{-1}\). These findings indicated that the shear rate of 2 – 3 s\(^{-1}\) in Japan is too low, and that the elderly may find it difficult to swallow very thick liquids.

Viscosity varies among thickening agent products (Garcia et al., 2005). The limitations of our study included the use of xanthan gum-based products alone and the selection of elderly panelists who were not dysphagic. Additionally, there was a high possibility that panelists tasted slowly rather than using natural drinking actions to judge the characteristics of the samples during the sensory evaluation; therefore, there is the potential that these orally judged viscosities were not judged normally, with the result of shear thinning. Further studies need to be undertaken to examine other types of thickeners, and dysphagic patients should be selected as panelists. Moreover, the sensory evaluation of oral viscosity by elderly panelists is necessary, because elderly and young people are not likely to feel viscosity at the same shear rate.

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