Relationship between Flow Properties of Thickener Solutions and Their Velocity through the Pharynx Measured by the Ultrasonic Pulse Doppler Method

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The effect of viscosity $\mu$ of thickener solutions on their velocity through the human pharynx measured using the ultrasonic pulse Doppler method was investigated to develop an index for thickener solutions used as foods for dysphagic patients. The B-type viscometer determined an approximated value of viscosity at a selected shear rate $\dot{\gamma}$. The maximum velocity $V_{\text{max}}$ of water, which is often aspirated into trachea of patients with dysphagia, was about 3 times higher than that of yogurt, which is rarely aspirated. Moreover, the velocity spectra for water and thickener solutions of low concentration tended to be distributed over a wider range than those of yogurt and thickener solutions of high concentration. The maximum velocity $V_{\text{max}}$ of the thickener solutions approached that of yogurt as concentration increased. The maximum velocity $V_{\text{max}}$ correlated well with $\mu$; the correlation coefficient at the shear rate of 10 s\textsuperscript{-1} was somewhat larger than those at the shear rate of 1 s\textsuperscript{-1} and 100 s\textsuperscript{-1}.

Keywords: ultrasonic, pulse-Doppler, aspiration, thickener, swallowing, pharynx

Introduction

With the advent of an aged society, the incident of dysphagia has increased. Patients with dysphagia often aspirate food, which is one of the factors causing pneumonia among elderly people (Igarashi \textit{et al.}, 2002; Crary & Groher, 2003; Nishinari, 2004). Human beings chew foods, mix them with saliva, and lubricate the foods sufficiently to form a bolus before swallowing. The mobility of the food samples through the pharynx is closely related to aspiration. Liquid, which is swallowed with little mastication and mixing with saliva, flows readily with small cohesion between particles and therefore is easily deformed during swallowing. Thus, liquid may penetrate the larynx and enter the trachea if brisk laryngeal closure does not occur. Thicker (more viscous) liquids are easier to control during swallowing for many patients with dysphagia, because such viscous liquids are less readily deformed (Palmer, 1997; Palmer \textit{et al.}, 2003). Consequently, thickeners such as xanthan gum and guar gum have been used for these patients, and many commercial foods and powders containing thickeners have been developed. However, the appropriate range of the physical properties of these thickeners has yet to be determined.

In 1994, the Ministry of Health, Labour and Welfare in Japan defined the diet criterion (hereinafter referred to as “the Criterion”) of sol for patients with difficulties in masticating and swallowing as the value of viscosity (steady shear viscosity) $\mu$ of sol to be $\geq 1.5 \times 10^3$ mPa·s measured 2 min after the revolution of the rotor has started with a B-type viscometer, a rotational viscometer with a vertical cylindrical rotor, (rotor rotation rate, 12 rpm; 20 $\pm$ 2°C) (Sakai and Kayashita, 2006); the Japan Care Food Conference organized by various Japanese food companies also defined a similar criterion for universal design foods in 2003. Although many liquid-type foods have been developed for patients with dysphagia on the basis of the Criterion, the rationale for its value of viscosity and rotation rate is unclear. Viscosity $\mu$ for many thickener solutions such as xanthan gum, guar gum, and starch decreases with increasing shear rate $\dot{\gamma}$ (so-called shear thinning; Morris \textit{et al.}, 1981; Richardson \textit{et al.}, 1989; Rinaudo, 1993; Ross-Murphy, 1995). Thus, viscosity is a function of $\dot{\gamma}$. However, the B-type viscometer does not give an accurate
value of $\mu$, except for Newtonian fluids, whose viscosity is constant irrespective of $\dot{\gamma}$. Although the approximated value of $\dot{\gamma}$ can be empirically calculated with the B-type viscometer, it depends on the type of rotor and size of the sample container even at the same rotational rate.

Considering that a thin (low viscosity) liquid flows through the pharynx too rapidly for patients with dysphagia to control, it is very important to analyze the velocity distribution of the liquid (or bolus) in the pharynx. Videofluorography (VF) is a well-known method for directly observing the bolus flow through the pharynx. Hasegawa et al. (2000) were the first to apply the ultrasonic pulse Doppler method to measure the velocity of a bolus of boiled rice through the pharynx, followed by Nagatoishi et al. (2001), who measured the velocity of various types of food in the pharynx. The ultrasonic pulse Doppler method is safe, without the need for a contrast medium for velocity measurement. In addition, since a contrast medium such as barium sulfate must be added to foods examined by VF, the physical properties of the foods ingested may be altered. Nakazawa et al. (2000) were the first to apply the ultrasonic pulse Doppler method to measure the velocity of a bolus of boiled rice through the pharynx, followed by Nagatoishi et al. (2001), who measured the velocity of various types of food in the pharynx. The ultrasonic pulse Doppler method is safe, without the need for a contrast medium for velocity measurement. Hasegawa et al. (2005) used the ultrasonic pulse Doppler method to measure the velocity of water, which patients with dysphagia often aspirate into their trachea; yogurt, which is rarely aspirated by them; and jellies prepared from gelatin or gellan. As a result, the maximum velocity of water through the pharynx was determined to be about 0.5 m/s and that of yogurt to be about 0.2 m/s; and they concluded that this velocity difference would make it difficult for patients with dysphagia to swallow water and relatively easy for them to swallow yogurt. In addition, Hasegawa et al. (2005) confirmed that the maximum velocity of gels, with storage modulus $G'$ of $\times 100$ Pa (at a 1 Hz frequency) and dynamic viscosity $\eta'$ of $> 2$ Pa·s, was similar to that of yogurt; however, the relationship between these rheological properties $G'$ and $\eta'$ (at 15°C for gelatin gels and at 23°C for the other samples) and the bolus flow through the pharynx is unclear. Thus, the ultrasonic pulse Doppler method can quantitatively compare the velocity of various foods passing through the pharynx.

In this study, the viscosity of solutions prepared from widely used thickeners was measured using 2 viscometers, the B-type viscometer and a cone-and-plate viscometer, with which an accurate value of $\mu$ even for non-Newtonian liquids can be obtained as a function of $\dot{\gamma}$ (Bird et al., 1960). In addition, the effect of the flow properties of thicker solutions on their velocity through the pharynx measured by the ultrasonic pulse Doppler method was investigated in order to develop an index of physical properties for thickener solutions used as foods for patients with dysphagia. The Criterion of sol for dysphagic individuals was also discussed for preventing aspiration into the trachea.

**Materials and Methods**

**Materials** Four widely used thickeners, carboxymethylcellulose (CMC; MG-1 (T. P. T), Nippon Paper Chemicals Co., Ltd., Tokyo, Japan), xanthan gum (NeoSoft XD, Lot. 707110, Taiyo Kagaku Co., Ltd., Mie, Japan), guar gum (NeoSoft G, Lot. 707110, Taiyo Kagaku Co.), and pregelatinized starch (Tapioca TP-2, Sanwa Cornstarch Co., Ltd., Nara, Japan) were used without further purification.

**Sample Preparation** CMC and pregelatinized starch were each dissolved into distilled and deionized water by stirring with an impeller at room temperature at the desired concentrations. Xanthan gum and guar gum were each dispersed into distilled and deionized water by stirring with an impeller; and the solutions were then kept at 70°C for 10 min in a water bath. All solutions were degassed in a desiccator with an aspirator for a few minutes to remove bubbles in the solutions. Guar gum solutions were centrifuged to remove insoluble particles: at 3000 rpm for 30 min for the solutions above the concentration of 0.7% and at 1000 rpm for 10 min for the solutions below 0.7%. All the samples were kept at 15°C overnight before use in the experiments.

**Viscosity measurement with a B-type viscometer** A B-type viscometer BL/50 (Toki Sangyo Co., Ltd., Tokyo, Japan) was used with the following rotors: No. 1 (65 mm in height and 19 mm in diameter), No. 2 (6.8 mm in height and 18.8 mm in diameter), No. 3 (1.5 mm in height and 12.8 mm in diameter), and No. 4 (30 mm in height and 3.2 mm in diameter). The approximated $\dot{\gamma}$ was calculated by the method described by the manufacturer. The shear rate $\dot{\gamma}$ [s$^{-1}$] is related to the rate of rotation $N$ [rpm] as follows:

$$\dot{\gamma} = KN$$

where $K$ [s$^{-1}$ rpm$^{-1}$] is the empirical parameter (the shear rate constant); its value is 0.233, 0.259, 0.244, and 0.215 for rotor No. 1, No. 2, No. 3, and No. 4, respectively. The temperature of each sample solution in a 500-mL beaker (85 mm in inner diameter) was kept at 25°C in a water bath. The viscosity of the sample solution was measured with an appropriate rotor and at a selected rotor rotation rate; and $\mu$ was obtained as a function of the approximated value of $\dot{\gamma}$.

**Viscosity measurement with a cone-and-plate viscometer** A rheometer AR-G2 (TA Instruments Japan, Tokyo, Japan) was used in the mode of a cone-and-plate viscometer with either of two cones (one with a 40-mm diameter and 1° cone angle and the other with a 60-mm diameter and 0.5° cone angle). In this study, the viscosity of solutions prepared from widely used thickeners was measured using 2 viscometers, the B-type viscometer and a cone-and-plate viscometer, with which an accurate value of $\mu$ even for non-Newtonian liquids can be obtained as a function of $\dot{\gamma}$ (Bird et al., 1960). In addition, the effect of the flow properties of thicker solutions on their velocity through the pharynx measured by the ultrasonic pulse Doppler method was investigated in order to develop an index of physical properties for thickener solutions used as foods for patients with dysphagia. The Criterion of sol for dysphagic individuals was also discussed for preventing aspiration into the trachea.
Each sample solution was loaded between the cone and the plate, and a solvent trap, which was a wet paper, was placed over the cone to prevent water evaporation. Stress $\tau$ was measured under an increasing $\dot{\gamma}$ range of $1 \text{s}^{-1}$ to $300 \text{s}^{-1}$ for 270 s, and $\mu (= \tau / \dot{\gamma})$ was obtained as a function of $\dot{\gamma}$. Viscosity measurements were made at $25^\circ \text{C}$, based on a preliminary test (a thickener solution placed in the mouth was spit out just before swallowing, and its temperature was measured).

**Measurement and analysis of the velocity of thickeners through the pharynx** The velocity of thickeners through the pharynx was measured and analyzed by the method similar to that described by Hasegawa et al. (2005):

1. **Subject** A young female subject (height, 155 cm; circumference of the neck, 31 cm; age, 23) without difficulty in swallowing, pharyngolaryngeal and cervical lesions participated in the study. We adhered to the Helsinki Declaration and carried out the experiments after they had been approved by the in-house Ethics Committee of Kyoritsu Women’s University.

2. **Measurement of the velocity through the pharynx by the ultrasonic pulse doppler method** An ultrasonic apparatus for diagnosis, ECCOCEE (SSA-340 A type; Toshiba Medical Systems Co., Tokyo, Japan) equipped with the linear scan probe, PLF-703NT, for pulse Doppler measurement was used at 6.0 MHz, the frequency suitable for measuring a relatively shallow part of the body. The subject sat on a chair with her head fixed and back straightened, at room temperature ($23^\circ \text{C}$). An ultrasonic probe was set against the subject’s neck as shown in Fig. 1, so that the ultrasonic pulse was directed at an upward angle of $60^\circ$. The subject scooped up a 6-g sample, placed it in her mouth, and swallowed it in a single swallowing movement. Immediately thereafter, measurements were taken in the B-mode and color Doppler mode. The B mode was used to confirm a region of the pharynx, on the basis that the reflection of ultrasound is different among organs. In the color Doppler mode, the signal obtained by the pulse Doppler method is illustrated in color. A velocity distribution spectrum, the brightness being a function of the passage of time and velocity through the pharynx, was obtained, where the brightness is proportional to the volume fraction of the food particles (small part of food detectable by the ultrasonic probe) at a given passage of time and velocity.

3. **Analysis of the velocity distribution spectra** Twenty to 30 velocity distribution spectra were averaged using Image-Pro Plus software ver. 5.0 (Nippon Roper Co., Ltd., Tokyo, Japan) to obtain a color velocity distribution spectrum. In the color spectrum, the volume fraction of the food particles is higher in the order of red, green, and blue. From the spectra, the maximum velocity $V_{\text{max}}$ [m/s] and the mean velocity $v_{\text{m}}$ [m/s] were calculated. In order to reduce background noise, we defined $V_{\text{max}}$, as the velocity at which the value of brightness was 12 dB lower than that of brightness at the statistical mode of the velocity (Hasegawa et al., 2005; Hasegawa et al., 2008).

**Results**

Figure 2 shows representative data of the flow properties, i.e., the dependence of $\mu$ on $\dot{\gamma}$ for the thickeners, measured with the cone-and-plate and B-type viscometers. The values of $\mu$ measured with the B-type viscometer were similar to those measured with the cone-and-plate viscometer; however, the $\dot{\gamma}$ range measured with the B-type viscometer was narrower than that with the cone-and-plate viscometer. Using Eq. (1), $\dot{\gamma}$ was calculated to be 2 to 3 $\text{s}^{-1}$ over the viscosity range examined when 12 rpm (from the Criterion) was employed for the rotation rate. Shear thinning, the decrease in $\mu$ with increasing $\dot{\gamma}$, was observed for all the thickeners examined; however, the degree of shear thinning was different among the thickeners. The value of $\mu$ for xanthan gum decreased about 1 order of magnitude as the value of $\dot{\gamma}$ increased 1 order of magnitude, whereas the values for guar gum and pregelatinized starch decreased about 1 order of magnitude as the value of $\dot{\gamma}$ increased 2 orders of magnitude. The shear rate dependence of xanthan gum and guar gum solutions was similar to that reported previously (Milas et al., 1990; Richardson et al., 1987). Shear thinning for CMC was slight, and the CMC solutions showed behavior similar to Newtonian flow in the range of concentrations examined.
CMC solutions have usually been reported to show Non-Newtonian behavior, but shear thinning was not prominent at low concentrations according to the studies by Ismail et al. (1980) and Tako and Nakamura (1984).

In Fig. 3, $\mu$ measured with the cone-and-plate viscometer is compared with that measured with the B-type viscometer. As for the cone-and-plate viscometer, the value of $\mu$ at a specific value of $\dot{\gamma}$ was evaluated by the linear interpolation of $\mu$. These values coincided considerably well with those measured with the B-type viscometer in the viscosity range of $10^{-2}$ to 10 Pa·s for the thickener solutions examined. Thus, the B-type viscometer can approximate the value of viscosity at a specific value of $\dot{\gamma}$ using the empirical equation (1) and the shear rate constant $K$.

Figure 4 shows representative velocity distribution spectra of thickeners, as well as those of water and yogurt. The spectra for thickener solutions of low concentration were distributed over a wider velocity range than those of thicker solutions of high concentration. Hasegawa et al. (2005) have also reported that the spectrum for water was distributed over

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**Fig. 2.** Shear rate dependences of viscosity measured with the cone-and-plate (open symbols) and B-type (closed symbols) viscometers.

**Fig. 3.** Comparison between viscosities measured with the cone-and-plate and B-type viscometers at 25°C. ○, CMC; □, xanthan gum; ◇, guar gum; Δ, gelatinized starch.
a wider velocity range than that of yogurt.

In Fig. 5, the dependences of the mean ($v_m$) and the maximum ($V_{\text{max}}$) velocities of the thickener solutions through the pharynx calculated from the velocity spectra (Fig. 4) on thickener concentrations are shown; the data on water (0% concentration on the abscissa) and yogurt are also shown for comparison. The decrease in $v_m$ with increasing concentration of all the thickeners was slight. The maximum velocity $V_{\text{max}}$ of the thickeners, however, decreased as the thickener concentrations increased, approaching that of yogurt. Thus, the risk of patients with dysphagia aspirating thickener solutions can be predicted by $V_{\text{max}}$ obtained from the ultrasonic measurement, as reported by Hasegawa et al. for gels (2005). Being more concentration dependent than $v_m$, $V_{\text{max}}$ is a better
Figure 6 shows the relationship between $V_{\text{max}}$ of the thickener solutions through the pharynx and the solution viscosity $\mu$ at $\dot{\gamma}$ of 1, 10, and 100 s$^{-1}$. The maximum velocity $V_{\text{max}}$ of the thickener solutions correlated well with $\mu$ on the semi-logarithmic plots ($V_{\text{max}}$ vs. log $\mu$); and the value of the correlation coefficient $R$ at 10 s$^{-1}$ was somewhat higher than those at 1 s$^{-1}$ and 100 s$^{-1}$.

**Discussion**

In the study of Hasegawa et al. (2008), the velocity distribution was different among different subjects; but $V_{\text{max}}$ of all subjects decreased with increasing thickener concentration and approached those of yogurt, a result similar to that obtained in this study (Fig. 5). The velocity data on a specific subject is more appropriate for understanding the dependence of the velocity on the thickener concentration (or the viscosity) than those on many subjects, due to the difference in the magnitude of $V_{\text{max}}$ and the optimal amount of foods for swallowing among the subjects (Hasegawa et al., 2008). In the present study, the velocity distribution of the thickener solutions through the pharynx of a single subject was therefore investigated.

As shown in Fig. 4, two peaks were observed in most velocity spectra, as seen previously (Hasegara et al., 2005). In the previous study, young female subjects took liquid samples up to 15 g at one swallow, compared to 6 g in this study that allowed for easier swallowing. Since the liquid flowing through the pharynx did not completely fill the space, the flow monitored within the narrow range of about 1 mm in width in the pharynx by the ultrasonic probe was thought to be non-uniform.

Hasegawa et al. (2005) reported that the maximum velocity of water was about 0.5 m/s and that of yogurt was about 0.2 m/s, indicating difficulty for patients with dysphagia to swallow water and relatively easy to swallow yogurt. As shown in Fig. 5, $V_{\text{max}}$ of the thickeners decreased as the thickener concentrations increased, approaching that of yogurt. Thus, the threshold concentration of the thickeners as food for patients with dysphagia can be predicted from the value of $V_{\text{max}}$. In addition, as was seen in Fig. 6, the logarithm of solution viscosity, log $\mu$, correlated well with $V_{\text{max}}$ through the pharynx, indicating that $\mu$ is useful for predicting the risk of aspiration of the thickener solutions.

The criterion set by the Ministry of Health, Labour and Welfare in Japan in 1994 stated that the $\mu$ of sol measured with a B-type viscometer at a rate of rotor rotation of 12 rpm after 2 min at 20°C is ≥ 1.5 Pa·s (Sakai and Kayashita, 2006); but this criterion was empirically determined. Although the viscosity of the Criterion is 20°C, in this present study, viscosity was measured at 25°C; the temperature of food just before swallowing was measured to be around 25°C based on a preliminary test. Based on this temperature just before swallowing, 25°C would be more appropriate than 20°C for measuring viscosity. As the difference in viscosity between 20°C and 25°C was below 5% for xanthan gum and guar gum and approximately 20% for CMC solutions and pregelatinized starch (data are not shown), these differences between temperatures may not be influential.

As shown in Fig. 6, log $\mu$ correlated well with $V_{\text{max}}$ through the pharynx. Using Eq. (1) with the rotor rotation rate of 12 rpm, $\dot{\gamma}$ was calculated to be 2 to 3 s$^{-1}$ in the viscosity range examined in this study. The correlation coefficient $R$ at the shear rate of 10 s$^{-1}$ was, however, higher than those...
at 1 s$^{-1}$ and 100 s$^{-1}$. Thus, $\mu$ at a shear rate of 10 s$^{-1}$ appears to be more suitable as an index of liquid-type foods for people with dysphagia than the value set by the Criterion; that is, the Criterion value is too small to obtain an appropriate solution viscosity for liquid-type foods.

The degree of shear thinning was different among the thickeners (Fig. 2). Therefore, the viscosity at a shear rate $\dot{\gamma}$ of 10 s$^{-1}$, which correlated better with $V_{\text{max}}$ than 1 s$^{-1}$ and 100 s$^{-1}$ (see Fig. 6), may vary among the solutions examined, even when $\mu$ is close to each other at 2 to 3 s$^{-1}$ (at a rotor rotation rate of 12 rpm). In the case of 0.5% xanthan gum solution, the values of viscosity were 3.93, 1.77, 0.52, 0.060 Pa·s at the shear rates of 1.0, 2.5, 10, 100 s$^{-1}$, respectively. The value of $\mu$ at 2.5 s$^{-1}$ was 1.77 Pa·s, thus satisfying the Criterion; the value of $V_{\text{max}}$ of the solution was 0.37 ± 0.13 m/s. On the other hand, the values of $\mu$ for the 1.8% CMC solution were 0.13, 0.13, 0.12, 0.11 Pa·s at the shear rates of 1.0, 2.5, 10, 100 s$^{-1}$, respectively. Since the value of $\mu$ at a shear rate of 2.5 s$^{-1}$ was 0.13 Pa·s, it does not satisfy the Criterion, as it was below 1/10 of the value of 0.5% xanthan gum solution at the same shear rate. Although the values of $\mu$ were different with each other, the value of $V_{\text{max}}$ of the 1.8% CMC solution (0.37 ± 0.09 m/s) was close to that of 0.5% xanthan gum solution. The value of $\mu$ at 10 s$^{-1}$ for 0.5% xanthan gum solution was 0.52 Pa·s, which is about 1/4 to 1/3 of that at 2.5 s$^{-1}$. On the other hand, since the shear thinning of 1.8% CMC solution was slight at 1 to 100 s$^{-1}$ (Fig. 2), the value of $\mu$ at 10 s$^{-1}$ (0.12 Pa·s) was close to that at 2.5 s$^{-1}$ (0.13 Pa·s). Therefore, the shear rate, where the difference in $V_{\text{max}}$ among the thickeners is small, is a suitable index for liquid-type foods for patients with dysphagia. These results also suggest that a suitable value of the shear rate is somewhat larger than 10 s$^{-1}$. At this shear rate, the value of $\mu$ of 0.5% xanthan gum solution would be smaller and close to that of 1.8% CMC solution, while its $V_{\text{max}}$ would be close to that of the CMC solution.

The suitable shear rate varies with the suitable viscosity. Although the threshold viscosity in the Criterion is 1.5 Pa·s, the results of Fig. 6(a) where $\dot{\gamma}$ is 1 s$^{-1}$ indicates the value of $V_{\text{max}}$ at 1.5 Pa·s around 0.3 m/s and $\mu$ at 0.3 m/s, where $\dot{\gamma}$ is 10 s$^{-1}$, around 1.0 Pa·s. Therefore, when the shear rate of 10 s$^{-1}$ is adopted, the suitable viscosity would become lower than 1.5 Pa·s, probably around 1.0 Pa·s. Thus, when the suitable shear rate is estimated to be higher than 10 s$^{-1}$, the suitable viscosity would be lower than 1.0 Pa·s.

As for the good correlation between $\log \mu$ and $V_{\text{max}}$ at a shear rate ($\dot{\gamma}$) of 10 s$^{-1}$, the values of $v_{\text{a}}$ of the thickeners solutions through the pharynx was 10$^{-1}$ m/s (Fig. 5); whereas the diameter of the pharynx of the subject would be $\sim$1.5 × 10$^2$ m at the narrowest part (Kawahara and Sasaki, 2000). Consequently, the averaged value of $\dot{\gamma}$ would be $\sim$10$^{-3}/(0.75 \times 10^5) \simeq 13$ s$^{-1}$, which also supports our view that the value of the suitable shear rate for determining appropriate value of viscosity for liquid-type foods for patients with dysphagia should be somewhat larger than 10 s$^{-1}$. This result of $v_{\text{a}}$ also indicates that the rotor rotation rate of 12 rpm, corresponding to the shear rate of 2 to 3 s$^{-1}$, set by the Ministry of Health, Labour and Welfare in Japan, is somewhat low for obtaining appropriate viscosity for liquid-type foods for patients with dysphagia.

Conclusions

The effect of the flow properties of thickener solutions on their velocity through the pharynx measured by the ultrasonic pulse Doppler method was investigated in order to develop an index of physical properties for thickener solutions used as foods for patients with dysphagia. The viscosity was measured with 2 types of viscometers, the B-type and cone-and-plate viscometers with which an accurate value of $\mu$ can be obtained as a function of $\dot{\gamma}$. In addition, we discussed the diet criterion of sol for patients with difficulty in mastication or swallowing set by the Ministry of Health, Labour and Welfare in Japan. In conclusion we found the following:

1. The rate of rotor rotation (12 rpm) in the criterion set by the Ministry of Health, Labour and Welfare in Japan was calculated to give a $\dot{\gamma}$ of 2 to 3 s$^{-1}$ in the viscosity range used as thickener solutions for patients with dysphagia.

2. The maximum velocity $V_{\text{max}}$ of the thickeners correlated well with $\mu$ on semi-logarithmic plots ($V_{\text{max}}$ vs. log $\mu$); and $R$ at the shear rate of 10 s$^{-1}$ was larger than those at the shear rate of 1 s$^{-1}$ and 100 s$^{-1}$. The rotor rotation rate of 12 rpm set by the Ministry of Health, Labour and Welfare in Japan corresponds to the shear rate of 2 to 3 s$^{-1}$, which seems to be too low to obtain appropriate viscosity for liquid-type foods for patients with dysphagia.

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