

## Original Article



# Standard Recipes for the Preparation of Thickened Barium Liquids Used in the Diagnosis of Dysphagia

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### Conflict of Interest

The authors declare that they have no competing interests.

## ABSTRACT

Barium sulfate is commonly used to prepare contrast media for videofluorography. The flow characteristics of thickened liquids formulated for oropharyngeal imaging are known to be greatly affected by the addition of barium. In this study, thickened barium liquids were prepared by mixing a commercial xanthan gum (XG)-based thickener (Visco-up<sup>®</sup>) at different concentrations (0.1%–3.0%) with barium powder (Baritop HD<sup>®</sup>), and differences in the viscosity between thickened non-barium and thickened barium liquids were investigated. In addition, the thickness levels of thickened barium liquids, which are based on the National Dysphagia Diet (NDD) and International Dysphagia Diet Standardization Initiative (IDDSI) guidelines, were classified by measuring the viscosity (NDD) and gravity flow through a syringe (IDDSI) with 0.1%–3.0% thickener concentrations. The apparent viscosity ( $\eta_{a,50}$ ) values of thickened barium liquids were much higher than those of thickened non-barium liquids, indicating that the addition of barium to the XG-based thickener resulted in further thickening. Standard recipes for preparing thickened barium liquids with desirable thickness levels were also established, showing the different thickener concentrations corresponding to the different NDD and IDDSI levels.

**Keywords:** Barium; Viscosity; Dysphasia

## INTRODUCTION

A radiographic contrast agent must be used when conducting a videofluoroscopic swallowing study (VFSS), which is commonly performed by clinicians to assess swallowing safety and efficiency with a bolus in the management of dysphagia. In a standard VFSS, a barium sulfate (BaSO<sub>4</sub>) suspension is mixed with food to allow the visualization of a bolus as it passes from the oral cavity to the upper esophagus [1]. Commercial gum- or starch-based food thickeners are usually added to the barium suspension to prepare thickened barium liquids with various viscosity levels for videofluoroscopy [2]. These thickened barium liquids with specific viscosities are prepared for videofluoroscopic observation during swallowing to analyze the flow velocity of the bolus, and presence/absence of penetration of material into the larynx, which are related to viscosity [1].

The thickness of the thickened barium liquid should be accurately characterized to provide desirable thickness levels for dysphagic patients. Generally, the guidelines of the National Dysphagia Diet (NDD) have been used for characterizing the thickness levels of liquids based on the viscosity at a shear rate of  $50 \text{ s}^{-1}$  [3, 4]. The NDD defines thickened liquids as thin (1–50 mPa·s), nectar-thick (51–350 mPa·s), honey-thick (351–1,750 mPa·s), and pudding-thick ( $> 1,750 \text{ mPa}\cdot\text{s}$ ). Several researchers have studied the flow characterizations of various thickened liquids based on NDD thickness levels [5–7]. Recently, the International Dysphagia Diet Standardization Initiative (IDDSI) developed a standard framework for classifying thickened fluids by levels with a syringe flow test. In the IDDSI flow test, the thickened liquids are classified into 5 different levels (0–4): level 0 (thin), level 1 (slightly thick), level 2 (mildly thick), level 3 (moderately thick), and level 4 (extremely thick) [8]. The Baritop HD<sup>®</sup> barium powder (99% w/w barium sulfate; Kaigen Pharram Co., Ltd., Osaka, Japan) used in this study is the only commercial product on sale in Korea. Thickened barium liquid was prepared by adding the commercial xanthan gum (XG)-based thickener Visco-up<sup>®</sup>, which is manufactured in Korea, to water mixed with barium powder. In general, XG-based thickeners retain the clarity of clear liquids and possess a range of desirable properties for dysphagia food formulation including: high low-shear viscosity with a strong shear-thinning character for easy swallowing; stable viscosity within a wide range of pH, temperature, and salt content that can be applied in a variety of foods [9]. It is known that the viscosity of thickened barium liquids prepared for a VFSS does not represent the viscosity of real thickened liquids [2,8]. However, thus far, no study has compared the viscosities between thickened non-barium and thickened barium liquids prepared with both Baritop HD<sup>®</sup> barium powder and the XG-based thickener Visco-up<sup>®</sup> at different concentrations in the range of 0.1%–3.0%. In addition, no study has presented a standard recipe for clinicians to prepare thickened barium liquids with desirable thickness levels according to the NDD and IDDSI guidelines for use in the diagnosis and treatment of dysphagia.

We hypothesized that the viscosities of thickened liquids prepared with different thickener concentrations might be strongly affected by the addition of barium powder, and that the different concentrations of thickener required to achieve the different NDD or IDDSI levels would result in significant differences in viscosity values between thickened non-barium and thickened barium liquids. Therefore, the objective of this study was to investigate the differences in viscosity values between thickened non-barium and thickened barium liquids with various thickener concentrations (0.1%–3.0%), which were prepared using both the commercial barium powder and XG-based thickener marketed only in Korea. Furthermore, the study aimed to develop standard recipes of thickened barium liquids that would meet the NDD and IDDSI levels. The results of this study could provide Korean clinicians with valuable information for preparing the thickened barium liquids that have the correct NDD and IDDSI levels for a VFSS.

## MATERIALS AND METHODS

### Materials and preparation of thickened non-barium and thickened barium liquids

Barium sulfate powder (Baritop HD<sup>®</sup>, 99% w/w; Kaigen Pharram Co., Ltd.), which is the only product on sale in Korea, and the most popular XG-based food thickener (Visco-up<sup>®</sup>; Rheosfood Inc., Seoul, Korea) manufactured in Korea were used to prepare thickened barium liquids with different thickener concentrations. For the preparation of a barium suspension,

barium powder was mixed with bottled water (JPDC, Jeju, Korea) to obtain 30% w/w barium. The barium concentration used for the VFSS was consistent with that used in clinical practice, which is based on hospital recommendations for the preparation of a barium suspension. The thickened barium liquids with different thickener concentrations (0.1%–3.0%, w/w) were prepared by mixing the weighted thickeners with the barium suspension at room temperature with stirring for 5 minutes using a homogenizer (Eyela NZ-1000; Sansyo Co., Ltd., Tokyo, Japan). Thickened liquids with no added barium (thickened non-barium liquids) were also prepared for comparison with the thickened barium liquids.

### Viscosity measurement

Viscosity measurements of the thickened non-barium and barium liquid samples were conducted using a Haake RheoStress 1 rheometer (Haake GmbH, Karlsruhe, Germany). A plate-plate geometry (diameter: 35 mm) was used. All thickened samples were allowed to stand at room temperature for 1 hour before viscosity measurements. Their viscosity values were determined at a setting time of 1 hour as there were no significant differences in the viscosity data obtained after the 1 hour setting time for thickened barium samples with different thickener concentrations (**Table 1**).

Each sample was loaded between the parallel plates at 25°C and compressed to obtain a gap of 500 μm. Flow measurements were conducted after 5 minutes of equilibration to the measured temperature (25°C ± 0.1°C). Steady shear viscosity data were obtained using a power law model (Eq. 1) over a shear rate range of 0.1–100 s<sup>-1</sup>.

$$\sigma = K\dot{\gamma}^n \quad (\text{Eq. 1})$$

where  $\sigma$  (Pa) is the shear stress,  $\dot{\gamma}$  (s<sup>-1</sup>) is the shear rate,  $K$  (Pa·s<sup>n</sup>) is the consistency index, and  $n$  is the flow behavior index. The apparent viscosity ( $\eta_{a,50}$ ) at 50 s<sup>-1</sup>, a reference shear rate for swallowing, was calculated from the  $K$  and  $n$  values.

### IDDSI flow test

The IDDSI flow test was conducted using a 10 mL Luer-Lok Tip syringe (Becton Dickinson Medical Pte., Ltd., Singapore) with a measured length of 61 mm from the zero line to the 10 mL line, as described by Kim et al. [10]. The test classifies consistency based on the volume of the remaining liquid in the syringe after a period of 10 seconds. The resulting IDDSI levels are defined as level 0 (thin): 0–1 mL liquid remaining, level 1 (slightly thick): 1–4 mL liquid remaining, level 2 (mildly thick): 4–8 mL liquid remaining, level 3 (moderately thick): 8–10 mL liquid remaining, and level 4 (extremely thick): 10 mL [8,11].

**Table 1.** Effect of setting times (0, 0.5, 1, 2, and 3 hours) on the apparent viscosity ( $\eta_{a,100}$ ) of thickened barium liquids with different thickener concentrations (1%, 2%, and 3%)

Setting time (hr)	Concentration (%)		
	1	2	3
0	0.46 ± 0.00 <sup>c</sup>	1.28 ± 0.00 <sup>c</sup>	2.03 ± 0.02 <sup>c</sup>
0.5	0.52 ± 0.00 <sup>b</sup>	1.36 ± 0.01 <sup>b</sup>	2.08 ± 0.01 <sup>b</sup>
1.0	0.55 ± 0.01 <sup>a</sup>	1.40 ± 0.01 <sup>a</sup>	2.11 ± 0.01 <sup>a</sup>
2.0	0.55 ± 0.01 <sup>a</sup>	1.40 ± 0.02 <sup>a</sup>	2.12 ± 0.01 <sup>a</sup>
3.0	0.54 ± 0.01 <sup>a</sup>	1.41 ± 0.01 <sup>a</sup>	2.12 ± 0.00 <sup>a</sup>

<sup>a,b,c</sup>Mean values in the same column with different letters are significantly different ( $p < 0.05$ ).

### Statistical analysis

All results are expressed as the mean  $\pm$  standard deviation. Analysis of variance was performed using Statistical Analysis System software (version 9.2; SAS Institute, Cary, NC, USA). Differences in the mean were determined using Duncan's multiple range test.

## RESULTS

The thickening of a contrast agent to different viscosities was evaluated in mixtures of an XG-based food thickener and a barium suspension prepared by mixing barium powder with water. The apparent viscosity ( $\eta_{a,50}$ ) of thickened barium liquids with different thickener concentrations (1%, 2%, and 3%) was varied over time, as shown in **Table 1**. Their  $\eta_{a,50}$  values gradually increased with an increase in the setting time between 0 and 1 hour and remained constant after 1 hour of setting. This indicated that the thickened barium liquids, irrespective of the thickener concentration, exhibited viscosity stability after 1 hour of setting. **Table 2** shows the  $\eta_{a,50}$  values of thickened non-barium and thickened barium liquids. Their  $\eta_{a,50}$  values increased with an increase in the thickener concentration (0.1%–3.0%). The  $\eta_{a,50}$  values (0.04–2.10 Pa·s) of thickened barium samples were significantly higher compared with those (0.02–1.63 Pa·s) of thickened non-barium samples at the same thickener concentration. This result demonstrated that the presence of barium in the thickened liquids used for dysphagia evaluation increased the thickness level. This pattern was similar to that observed in IDDSI flow test, as shown in **Table 3**. There were large differences in the thickener concentration at IDDSI level 3 and 4 between thickened non-barium and thickened barium samples. The thickener concentrations of thickened barium samples at level 3 and 4 were 0.70% and 2.30%, respectively, whereas those of thickened non-barium samples were 0.84% and 3.00%, respectively. This result demonstrated that lower thickener concentrations were required for the preparation of thickened barium liquids at a certain IDDSI level. Therefore, a standard recipe is needed for the preparation of thickened barium liquids with desirable thickness levels in a VFSS. **Table 4** shows the thickener concentrations of standard recipes for preparing thickened barium samples according to NDD and IDDSI levels based on  $\eta_{a,50}$  and IDDSI flow test values. These findings suggest that in the preparation of thickened barium liquids for the diagnosis and treatment of dysphagia by clinicians, standard recipes with the appropriate NDD and IDDSI levels should be used.

**Table 2.** Apparent viscosity ( $\eta_{a,50}$ ) values of thickened non-barium and thickened barium liquids prepared with barium sulfate (Baritop HD<sup>®</sup>) and XG-based thickener (Visco-up<sup>®</sup>) at different thickener concentrations

Concentration (%)	Apparent viscosity ( $\eta_{a,50}$ ) of thickened water	
	Non-barium	Barium
0.1	0.02 $\pm$ 0.00 <sup>b</sup>	0.04 $\pm$ 0.00 <sup>a</sup>
0.2	0.07 $\pm$ 0.00 <sup>b</sup>	0.10 $\pm$ 0.00 <sup>a</sup>
0.3	0.11 $\pm$ 0.00 <sup>b</sup>	0.14 $\pm$ 0.00 <sup>a</sup>
0.5	0.20 $\pm$ 0.00 <sup>b</sup>	0.26 $\pm$ 0.01 <sup>a</sup>
0.7	0.29 $\pm$ 0.00 <sup>b</sup>	0.35 $\pm$ 0.02 <sup>a</sup>
0.8	0.32 $\pm$ 0.01 <sup>b</sup>	0.43 $\pm$ 0.02 <sup>a</sup>
0.9	0.41 $\pm$ 0.01 <sup>b</sup>	0.49 $\pm$ 0.01 <sup>a</sup>
1.0	0.47 $\pm$ 0.02 <sup>b</sup>	0.55 $\pm$ 0.01 <sup>a</sup>
1.5	0.77 $\pm$ 0.01 <sup>b</sup>	1.09 $\pm$ 0.02 <sup>a</sup>
2.0	1.05 $\pm$ 0.00 <sup>b</sup>	1.40 $\pm$ 0.03 <sup>a</sup>
2.3	1.27 $\pm$ 0.02 <sup>b</sup>	1.76 $\pm$ 0.02 <sup>a</sup>
2.5	1.40 $\pm$ 0.02 <sup>b</sup>	1.92 $\pm$ 0.02 <sup>a</sup>
3.0	1.63 $\pm$ 0.01 <sup>b</sup>	2.10 $\pm$ 0.03 <sup>a</sup>

XG, xanthan gum.

<sup>a,b</sup>Mean values in the same row with different letters are significantly different ( $p < 0.05$ ).

**Table 3.** IDDSI flow test values of thickened non-barium and thickened barium liquids prepared with barium sulfate (Baritop HD®) and XG-based thickener (Visco-up®) at different thickener concentrations

Concentration (%)	Non-barium		Barium	
	IDDSI flow measure (mL)	IDDSI level	IDDSI flow measure (mL)	IDDSI level
0.10	0.10 ± 0.00 <sup>b</sup>	0	0.20 ± 0.00 <sup>a</sup>	0
0.20	1.15 ± 0.07 <sup>b</sup>	1	1.60 ± 0.00 <sup>a</sup>	1
0.30	2.45 ± 0.05 <sup>b</sup>	1	2.60 ± 0.00 <sup>a</sup>	1
0.40	3.20 ± 0.00 <sup>b</sup>	1	3.60 ± 0.00 <sup>a</sup>	1
0.50	4.50 ± 0.00 <sup>b</sup>	2	4.75 ± 0.07 <sup>a</sup>	2
0.65	7.10 ± 0.00 <sup>b</sup>	2	7.20 ± 0.00 <sup>a</sup>	2
0.70	7.20 ± 0.10 <sup>b</sup>	2	8.03 ± 0.05 <sup>a</sup>	3
0.80	7.60 ± 0.10 <sup>b</sup>	2	8.53 ± 0.06 <sup>a</sup>	3
0.90	8.40 ± 0.00 <sup>b</sup>	3	8.80 ± 0.00 <sup>a</sup>	3
1.00	8.67 ± 0.06 <sup>b</sup>	3	9.00 ± 0.00 <sup>a</sup>	3
2.00	9.72 ± 0.03 <sup>b</sup>	3	9.80 ± 0.00 <sup>a</sup>	3
2.25	9.78 ± 0.03 <sup>b</sup>	3	9.90 ± 0.00 <sup>a</sup>	3
2.30	9.90 ± 0.00 <sup>b</sup>	3	10.0 ± 0.00 <sup>a</sup>	4
2.50	9.90 ± 0.00 <sup>b</sup>	3	10.0 ± 0.00 <sup>a</sup>	4
3.00	10.0 ± 0.00 <sup>a</sup>	4	10.0 ± 0.00 <sup>a</sup>	4

IDDSI, International Dysphagia Diet Standardization Initiative; XG, xanthan gum.

<sup>a,b</sup>Mean values in the same row with different letters are significantly different ( $p < 0.05$ ).

**Table 4.** Thickener concentration for standard recipes of all thickened barium liquids by NDD and IDDSI levels

NDD level	Thickener concentration (%)	IDDSI level	Thickener concentration (%)
Thin	< 0.2	1 (slightly thick)	0.2–0.4
Nectar-thick	0.2–0.7	2 (mildly thick)	0.5–0.65
Honey-thick	0.8–2.3	3 (moderate thick)	0.7–2.25
Pudding-thick	> 2.3	4 (extremely thick)	> 2.25

NDD, National Dysphagia Diet; IDDSI, International Dysphagia Diet Standardization Initiative.

## DISCUSSION

Thickened barium liquids prepared with commercial food thickeners and barium products are commonly used by clinicians to assess swallowing safety and efficiency with a bolus in a VFSS. Therefore, it is crucial to prepare thickened barium liquids with the correct thickness levels specified in the NDD and IDDSI guidelines considering that the addition of barium could result in the different flow properties between thickened liquids with barium and thickened liquids without barium. The purpose of this study was to evaluate the flow characteristics of liquids thickened with XG in non-barium and barium media to levels specified in the NDD and IDDSI and establish the standard recipes for preparing thickened barium liquids according to the NDD and IDDSI levels. Thickened liquids prepared with barium and commercial thickeners are often left for a short or long time at room temperature before videofluoroscopic examination. Therefore, from a clinical perspective, it is important to observe how the viscosity of thickened liquids changes over time after mixing barium with a thickener. The setting time between the preparation and administration of a thickened barium liquid can be considered as an important factor in a clinical VFSS for dysphagic patients, as indicated by Kim and Yoo [12]. The  $\eta_{a,50}$  values of all thickened barium liquids with different thickener concentrations were increased over time during setting and remained constant after 1 hour of setting, as shown in **Table 1**. These observed results indicated that the viscosity values of thickened barium samples were considerably altered during the first 1 hour of setting, and at least 1 hour of setting was required to thicken them completely. Therefore, in this study, viscosity and IDDSI flow test values were measured at a setting time of 1 hour. These results may have implications for the efficacy of videofluoroscopic examination because thickened barium liquids should not be administered immediately after mixing barium with the thickener.

There were significant differences in  $\eta_{a,50}$  and IDDSI flow test values between thickened non-barium and thickened barium liquids with different thickener concentrations ( $p < 0.05$ ) (Tables 2 and 3). This indicated that the addition of the thickener to the barium suspension changed the viscosity and caused further thickening, resulting in higher viscosity and IDDSI flow test values than those observed for real thickened liquids. This result is consistent with findings in the literature [2,13,14]. The higher  $\eta_{a,50}$  and IDDSI flow test values of thickened barium liquids may be attributed to the inherent density and viscosity of barium suspension, as indicated by Cichero et al. [15]. Barbon and Steele [13] reported that the greater viscosity and IDDSI flow test values of thickened barium liquids could result from the reconstitution of barium sulfate powders with food thickeners. They also emphasized the need to follow recipes when preparing thickened barium liquids for a VFSS because large changes in the viscosity of thickened barium liquids are caused by small differences in the thickener concentration. Therefore, the varying effects of thickener concentration and thickening time must be considered if thickened barium liquids are used for videofluoroscopic examination. In addition, the clinicians to prepare the thickened barium liquids for a VFSS must be considered for the standard recipes with appropriate viscosity levels. In the current study, we developed the standard recipes for preparing the thickened barium liquids with desirable thickness levels according to the NDD and IDDSI guidelines with 0.1%–3.0% thickener concentrations. Table 4 shows the ranges of thickener concentrations for standard recipes of thickened barium samples according to the NDD and IDDSI levels. The established thickener concentrations may be useful for clinicians to prepare thickened barium liquids for the diagnosis and treatment of dysphagia.

In conclusion, knowledge of the changes in the  $\eta_{a,50}$  values of thickened barium liquids with different thickener concentrations (1%, 2%, and 3%) over time would be of particular interest to clinicians, considering that thickened liquids with barium can become thicker after 1 hour of setting. Therefore, we recommend that for videofluoroscopic observation, clinicians should use the thickened barium liquids after sufficient setting time (1 hour). We found that a mixture of an XG-based thickener and a barium caused further thickening. Our viscosity data on thickened non-barium and barium liquids can be useful to develop standard recipes for the preparation of thickened barium liquids with consistent and accurate viscosity levels for the diagnosis and treatment of dysphagia. The results from the viscosity measurement and the syringe flow test were used to establish standard recipes for preparing thickened barium liquids according to the NDD and IDDSI levels. The findings suggest that clinicians must be cautious in the preparation of thickened barium liquids for a VFSS and should use standard recipes established according to the NDD and IDDSI levels.

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