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Liquids offered in pediatric videofluoroscopy swallowing study: A preliminary rheological analysis

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Abstract

The videofluoroscopy swallowing study is considered a gold standard for the precise diagnosis in feeding/swallowing disorders. Regarding neonates and infants, the evaluation is conducted exclusively with barium sulfate-impregnated liquids. This exploratory study aimed at analyzing the rheological and macroscopic properties of liquids usually presented during videofluoroscopy swallowing studies in Brazil, considering that products often differ from one country to another. Rheological measurements were taken of one sample of infant formula, one of the breast milk, and another two of these liquids impregnated with barium sulfate. Considering the value of 50 s-1, average shear rate, the addition of barium sulfate made breast milk 18 times more viscous, and Aptamil 18.5 times more viscous, reaching thresholds close to that of mildly thick. The use of liquids in viscosity as close as possible to what will be proposed in the patient's diet indication is crucial for their safety.

Practical applications

This exploratory study highlighted the importance of the knowledge of the macroscopic properties of liquids usually presented during videofluoroscopy swallowing studies. Knowing the flow behavior obtained through rheological studies of untreated breast milk and infant formula, both alone and impregnated with barium sulfate, it provides quantitative information from specific products of routine use in Brazil that can assist speech-language-hearing therapists and radiologists cope with the challenging issue of making examination conditions as close as possible to the infant's feeding routine. Such information can contribute to more accurate results which will ensure better treatment indications.

1 | INTRODUCTION

The importance of precise diagnosis in feeding/swallowing disorders is indisputable. Accurate detection and prompt intervention can prevent sequelae from dysphagia. For such, the videofluoroscopy swallowing study (VFSS) is considered the gold standard. A primary goal of the VFSS is to determine what textures the patient can safely consume. It is well known that the food texture plays an important role in swallowing. Beyond this, the temperature (Ekberg et al., 2010), thickening variations, and barium concentration imply changes in the time of oral preparation, ejection, and viscosity, as well as the action of the main enzyme in the oral cavity, α-salivary amylase. These variables can impact on the pharyngeal phase of swallowing (Dantas, Dodds, Massey, & Kern, 1989; Leonard, White, McKenzie, & Belafsky, 2014; September, Nicholson, & Cichero, 2014; Sukkar, Maggi, Travalca Cupillo, & Ruggiero, 2018; Yoon & Yoo, 2017). Many other aspects impact on swallowing function, for example, the effects of the time on the viscosity of cold drinks prepared for the VFSS (Kim & Yoo, 2015). Another relevant issue is the action of the α-salivary amylase, the main enzyme in the oral cavity, that can produce significant changes, affecting the viscosity of the bolus. As well as the pressure exerted by the tongue against the hard palate on the flow of the food in the oral cavity. Nevertheless, recent studies on the necessary motor action for extracting milk in breastfeeding children point out the greater importance of intraoral negative pressure (vacuum), thus indicating less significance of tongue pressure against the surface of the palate when directing the oral flow. Research with computerized ultrasound (CUS) demonstrated that milk flows in the oral cavity when the posterior region of the tongue is displaced downward, creating negative pressure. When the vacuum dissipates, the anterior region of the tongue rises slightly, and the milk passes on the palate toward the pharynx (Geddes et al., 2012; Geddes, Kent, Mitoulas, & Hartmann, 2008).

Regarding neonates and infants, the VFSS is always conducted with liquids, using either breast milk or infant formula, associated with a radiopaque element, in varied proportions and thickenings. Barium sulfate is widely used as this radiopaque element, despite the knowledge that are other X-Ray hydrosoluble contrasts with less complications in the use (Siddiqui et al., 2017, p. 4), probably to maintain better taste, enabling greater acceptance during the evaluation, especially for infants and because the iodinated agents at lower concentrations are less radiopaque, have lower viscosity, and can cause contrast nephropathy (From et al., 2010).

Products available on the market often differ from one country to another, even offered in a range of consistencies from thin to honey-thick. Nevertheless, for countries and institutions without access to these products, clinicians need to prepare their own VFSS stimuli, mixing barium sulfate liquid or powder with regular liquids and solids elements in a subjective method. The incorrect and unreproducible matching to the viscosity of the routine infant's diet may lead to an incorrect assessment. Moreover, the specialized literature has indicated that the addition of barium sulfate to liquids changes the density and the viscosity of the original liquid (Stokely, Molfenter, & Steele, 2014, p. 78), and may influence swallowing physiology.

Hence, the validity of the VFSS diagnosis with neonates and infant rests on previous knowledge of the viscosity and flow characteristics of the fluids offered and how closely they replicate the viscosity and flow of the typical infant's diet. This will ensure an accurate and safe diet indication. This similarity will hardly be reached by only the subjective assessment, as, for instance, in contrast to the flow of food from the bottle or from a spoon.

It should be said, then, that studies need to be conducted with the purpose of evaluating the viscosity of the liquids offered in VFSS of the neonates and infants and possible impact on swallowing performance. Considering that it is crucial for them to consume sufficient energy in their first year of life, with nutrition and hydration leading to the brain and overall development, which depends on liquids intake exclusively (Frazier et al., 2016; Cichero, Nicholson, & Dodrill, 2011).

In the literature, there are few studies on the rheological analysis of foods offered during pediatric VFSS. Research on the influence of temperature, thickening concentration, and setting time on the viscosity of foods highlighted the importance of precise thickening liquids preparation offered in the exam, considering that the effect of the time the bolus is kept in the oral cavity. The longer the time of oral preparation and ejection, greater is the possibility of changes in the viscosity of the thickened liquid (Ekberg et al., 2010; Gosa & Dodrill, 2017; Yoon & Yoo, 2017). A study of Sukkar et al. (2018), taking into account, the rheological properties of food, analyzed the effect of saliva on the bolus, where elapsed time can also maximize the changes in viscosity.

Concerning the infant population, specifically, research using the Advanced Rheometric Expansion System (ARES) compared six samples of infant formulas and two of liquid barium sulfate contrast (Polibar). Each sample was evaluated separately. The results demonstrated significant differences in all rheological and material properties between the liquids. All infant formulas presented lower viscosity rate than barium sulfate in its original undiluted formula (Cichero, Nicholson, & Dodrill, 2011, p. 269). Another research, using a viscometer, evaluated the viscosity of breast milk, both pasteurized and untreated, thickened in percentages of 2%, 3%, 5%, and 7%, with powder 0-to-6-month infant formula. It indicated the variability of viscosity according to the time elapsed, from 20 to 60 min, temperature and percentage of thickening, suggesting perspectives to seek alternatives for thickening human milk with human milk components; however, without evaluating them as liquid with barium sulfate added (de Almeida, de Almeida, Moreira, & Novak, 2011).

September et al. (2014) conducted research on the rheological behavior of infant formulas with the addition of Kericare thickener, in different levels of concentration. They concluded that there is a significant difference in viscosity between low and high concentration level of the thickener ($p < .05$).

Frazier and colleagues (2016) compared the viscosity of barium sulfate in powder, liquid, regular, and antiregurgitation infant formulas, both alone and in combination. They concluded that both the regular formulas and breast milk impregnated with powder barium sulfate, diluted in water in a concentration of 20%, presented an increase in viscosity, but were still classified as thin liquid according to the NDD. On average, such an increase was of 3 mPa.s, varying from 0.2 to 1.3 mPa.s increase in viscosity in comparison with liquids without contrast added.

In performing VFSS with neonates and infants, despite the possible variability in breast milk composition, it is appropriate to use the logic indicated in studies by Baron and Alexander (2003) and by Fink and Ross (2009). They offered a contrast with and without dilution, seeking to use the least amount of radiopaque substance (20%) necessary for exam visualization, diminishing the flavor, temperature, and viscosity influence of the stimulus offered. However, in the present research, it was decided to use 33% contrast, taken into consideration that, in VFSS with trans-lactation technique (Hernandez & Bianchini, 2019), the breast stimulated by suction could possibly associate a greater volume of breast milk to the sample already prepared, thus making the visualization of the bolus trajectory to be lost.

Based on these considerations, this exploratory study aims at knowing physical phenomena associated with the flow behavior of the liquids offered in neonate and infant's diet through rheological studies. The present research sought to evaluate breast milk and milk formula, the diet advocated by the World Health Organization (WHO) to infants up to six months old, both alone and impregnated with barium sulfate in specific and adequate dilution for the exam to be performed, being similar to what would be indicated for the patient's diet.

Hence providing quantitative information from specific products of routine use in Brazil that can assist speech-language-hearing therapists and radiologists cope with the challenging issue of making examination conditions as close as possible to the infant's feeding routine. Such information can contribute to more accurate results which will ensure better treatment indications.

2 | PURPOSE

This study aims to analyze the rheological and macroscopic properties, as well as the stability of breast milk and infant formula, both alone and impregnated with liquid barium sulfate, comparing the results of the rheological evaluation with classification recommended by the National Dysphagia Diet (NDD) 2002, based on rheological parameters (apparent viscosity) and that from the International Dysphagia Diet Standardization Initiative (IDDSI)—flow test, a proposal which uses gravity action technique to classify the density of liquids—cinematic viscosity (Cichero et al., 2017). Moreover, sought to provide knowledge of objective viscosity measures capable of being reproduced of the liquid that can compose neonate and infant diet up to six months of life, collaborating for the proper preparation of the stimulus used in pediatric VFSS, especially as it concerns neonates and infants whose feeding routine includes breastfeeding.

Additionally, aims to highlight the possible impact of the choice of the liquid and its dilution on VFFS diagnosis, on the indication and approval of the patient's diet, thus collaborating with speech-language-hearing clinical intervention.

3 | METHOD

This study followed the guidelines and regulating norms of the Brazilian National Health Council Resolution 196/96, of the Ministry of Health (2013) and was approved by the Institutional Review Boards of the Pontifical Catholic University of São Paulo (Pontifícia Universidade Católica de São Paulo), in São Paulo, SP, Brazil. Ethical relevant processes (CAAE: 63361616.2.0000.5482). The participation in the research was voluntary and only took place when the donating mothers agreed to participate, signing the Informed Consent Form specific for the study (Annex IV).

This is an experimental study on the rheological analysis of the liquids offered in neonate and infant VFSS.

3.1 | Materials

The following material was used: A sample of infant formula for the first months of life—Aptamil; a sample of breast milk from the mother of a 90-day-old infant, born at 39 weeks of gestational age; a sample of Aptamil with barium sulfate, Bariogel brand, in the proportion of 2:1, respectively; a sample of breast milk (mother of a 90-day-old infant, born at 39 weeks of gestational age) with barium sulfate in the proportion of 2:1, respectively.

3.2 | Preparation

The preparation of the contents for rheological evaluation was conducted in the lab at the Institute of Food Technology (Ital), following the usage specifications.

3.2.1 | Breast milk

The breast milk was collected from two donors, whose infants were born at 39 weeks of GA and were 90 days old at the moment of collection. Both samples followed the norms indicated by the Breastfeeding Scientific Department of the Brazilian Pediatrics Society for the collection, storage, and defrosting of the material (Sociedade Basileira de Pediatria, 2017).

3.2.2 | Aptamil infant formula

Twenty scoops (90 g) of Aptamil powder were used, mixed with 540 ml of water, shaken prior to use, according to the manufacturer's instructions on the label.

When preparing both the breast milk and the formula with liquid barium sulfate, the same proportion of the mixture was used, namely: 400 ml of milk and 200 ml of barium sulfate.

3.3 | Procedures

3.3.1 | Equipment and methods of the rheological analyses

The rheological measurements were carried out in a concentric cylinder Rheometer model R/S+ (Brookfield Eng. Labs Inc.), shear controlled. The tests were conducted using the double-gap system (Ratio of radii 1.0244), specified for shear rate range from 4 to 5,039 1/s; maximum shear stress of 67 Pa and indicated for rheological measurements of viscosities ranging from 1 mPa.s to 133 Pa.s (Brookfield, 2012).

The analyses were performed in triplicate at 25 ± 0.5°C. The rate sweep was performed linearly at shear rates of 0–700/s followed by 700–0 1/s, including part of typical range related articles: 20–100 1/s (de Almeida et al., 2011) 0–1000 1/s (de La Fuente, Turcanu, Ekberg, & Gallegos, 2017; Frazier et al., 2016). Apparent viscosities were presented at 10, 50, and 100 1/s, values based on the shear stress range for chewing and swallowing, 0–100 1/s (Cichero et al., 2011; Frazier et al., 2016; Steffe, 1996). Measurements of apparent viscosity at 50 1/s and 25°C were also proposed by the National Dysphagia Diet Task Force (2002) of the American Dietetic Association; therefore, it is used by several authors to compare the viscosity of this kind of fluids (de La Fuente et al., 2017). The time for each assay was 6 min. and 180 data of shear stress readings distributed linearly, were collected in each assay. The assay temperature was kept by the circulation of water in the jacket of the sample cup coming from a Marconi thermostatic bath, model MA-184. The sample was kept in the rheometer cup for approx. 10 min before start analysis, for temperature equalization.

The Power Law model, or Ostwald-de Waele model (Equation 1), was fitted to the rheograms (shear stress vs. shear rate experimental data) and consistency index (K) and the flow behavior index (n) were adjusted. For these pseudoplastic fluids, the viscosity, named as apparent viscosity, is the function of shear rate and can be calculated by Equation (2). In cases that flow behavior index was fitted to one unit ($n = 1$), the fluid is Newtonian and the proportional constant of Eq. 3 is the fluid dynamic viscosity.

$$\tau = K\dot{\gamma}^n \tag{1}$$

$$\eta_{ap} = K\dot{\gamma}^{n-1} \tag{2}$$

$$\tau = \eta\dot{\gamma} \tag{3}$$

In which: K = Fluid consistency index (Pa.s); n = Flow behavior index (nondimensional); τ = Shear stress (Pa); $\dot{\gamma}$ = Shear rate (s^{-1}); η_{ap} = Apparent viscosity at specific shear rate (Pa.s); η = Dynamic viscosity of the fluid (Pa.s).

Correlation coefficient (R^2) standard deviation between repetitions, and residual standard deviation (RSD) were the statistical parameters used to evaluate the fitted models. R^2 values close to one-unit, low average deviation values and according to Atala, Costa, Maciel, and Maugeri (2001), RSD values below 10% represent a satisfactory mathematical model.

As a classification model for the degree of consistency of liquids, the parameters recommended by the National Dysphagia Diet (NDD), 2002, and by the International Dysphagia Diet Standardization Initiative (IDDSI)—flow test were used. We follow the NDD to IDDSI Drinks_currency converter. (Table 1).

TABLE 1 NDD and IDDS flow test classification of liquids

Current NDD liquids		IDDSI	
Centipoise	Classification	Fluid remain	Classification
0	Thin	0	Thin
1–50 cP	Naturally thick	up to 4 ml	1—Slightly thick
51–350 cP	Nectar thick	from 4 to 8 ml	2—Midly thick
351–1,750 cP	Honey thick	from 8 to10 ml	3—Moderatily thick
>1,751 cP	Spoon thick	>10 ml	4—Extremely thick

4 | RESULTS

4.1 | Breast milk at 25°C

Because of the low viscosity fluid, measurable shear stress values were registered only at a shear rate above 94 1/s. The breast milk product presented Newtonian behavior in the range from 94 to 700 1/s. Table 2 presents the fitted viscosity values in each assay (R1, R2, R3.), the average values of triplicate assays, standard deviation (*SD*), and the fitting assessment statistical parameters (R^2 and RSD).

4.2 | Aptamil at 25°C

As noticed for breast milk, the Aptamil product presented Newtonian behavior. Table 3 presents the values of the dynamic viscosities fitted in each assay, the average values, standard deviation, and the fitting assessment statistical parameters (R^2 and RSD).

Figure 1 show the rheograms of breast milk and Aptamil using average data values of the triplicate.

4.3 | Breast milk + barium sulfate at 25°C

For breast milk added with barium sulfate at 33%, the pseudoplastic behavior best represented the upward-sloping data, whereas the

TABLE 2 Dynamic viscosity (Newton behavior) of breast milk at 25°C

Upward-sloping curve					Downward-sloping curve		
Rep.	Counter	η (mPa.s)	R^2	RSD(%)	η (mPa.s)	R^2	RSD(%)
R1	1,648	1.80	.9903	0.78	1.60	.9998	1.09
R2	1,649	1.80	.9926	0.66	1.70	.9996	0.94
R3	1,650	1.60	.9997	0.76	1.60	.9996	1.15
	Mean	1.73			1.63		
	SD	0.12			0.06		

Newtonian model, the downward-sloping data (Figure 2). The parameters of the fitted models are shown in Table 4, while the apparent viscosities calculated on the shear rates of 10, 50, and 100 1/s for the upward-sloping data are presented in Table 5. This shear rate values belong to the typical shear rate range for chewing and swallowing foods of 10 to 100 1/s (Steffe, 1996).

TABLE 3 Dynamic viscosity of the Newton model fitted for Aptamil at 25°C

	Upward-sloping curve			Downward-sloping curve		
Rep	η (mPa.s)	R^2	RSD (%)	η (mPa.s)	R^2	RSD (%)
R1	1.60	.9984	0.83	1.50	.9994	1.03
R2	1.50	.9995	0.76	1.50	.9990	1.25
R3	1.50	.9895	0.66	1.50	.9993	1.17
Average	1.53			1.50		
SD	0.06			0.00		

4.4 | Aptamil + barium sulfate at 25°C

According to results, the Power Law model was fitted to the experimental upward-sloping and downward-sloping data of Aptamil with barium sulfate. Rheogram is presented (Figure 2) and Table 6 shows rheological parameters (K and n) fitted to the experimental data of each trial; the average values, standard deviation, and the statistical parameters of this fit (R^2 and RSD).

Table 7 shows the apparent viscosity values calculated with 10, 50, and 100 1/s shear rates values.

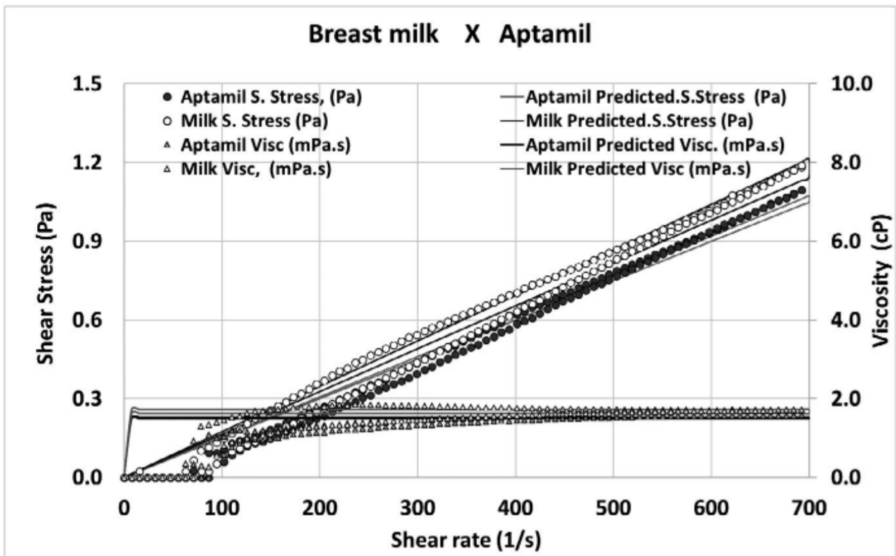

FIGURE 1 Rheological behaviour of breast milk and Aptamil at 25°C, using average data of the triplicate

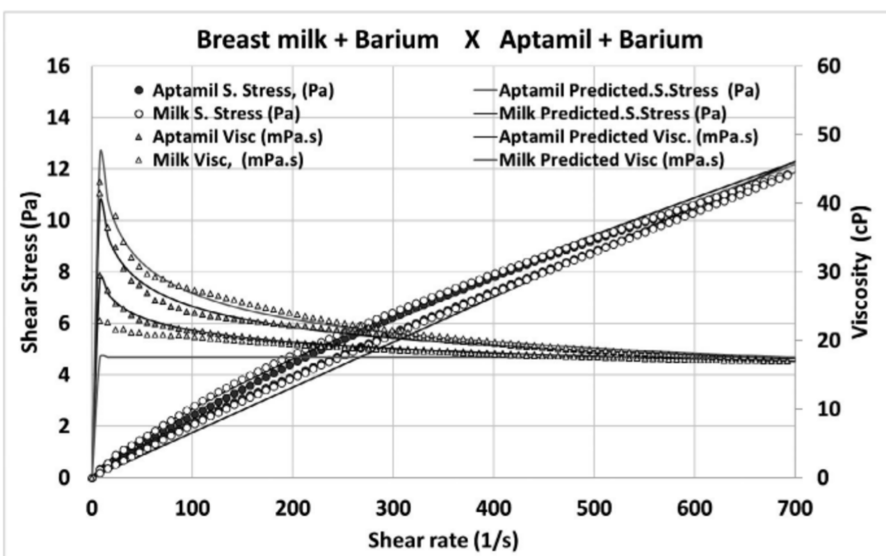

FIGURE 2 Rheological behaviour of breast milk + barium and Aptamil + barium at 25°C, using average data of the triplicate

TABLE 4 Power law parameters fitted to upward-sloping curve and dynamic viscosity fitted to downward-sloping curve (Newton behavior) of breast milk + barium at 25°C

	Upward-sloping curve				Downward-sloping curve		
Rep.	K (Pa. s^{-1})	*n*	R^2	RSD (%)	η (mPa.s)	R^2	RSD (%)
R1	73.40	0.7792	.9989	0.2506	17.30	.9982	0.45
R2	73.90	0.7825	.9987	0.2734	17.70	.9983	0.44
R3	74.40	0.7794	.9992	0.2139	17.70	.9984	0.44
Average	73.90	0.7804	.9989	0.2460	17.57		
SD	0.50	0.0019			0.23		

TABLE 5 Apparent viscosities—upward-sloping data: breast milk + barium at 25°C

	Upward-sloping curve		
Shear rate (1/s)	10	50	100
Rep.	η_{ap} (mPa.s)	η_{ap} (mPa.s)	η_{ap} (mPa.s)
R1	44.15	30.94	26.55
R2	44.79	31.56	27.14
R3	44.77	31.39	26.94
Average	44.57	31.30	26.88
SD	0.36	0.32	0.30

TABLE 6 Rheological parameters of Aptamil + barium at 25°C—power law fit

	Upward-sloping curve				Downward-sloping curve			
Rep	K ($Pa.s^{-1}$)	*n*	R^2	RSD (%)	K ($Pa.s^{-1}$)	*n*	R^2	RSD (%)
R1	64.20	0.7998	.9993	0.1437	36.20	0.8849	1.0000	0.0532
R2	53.40	0.8301	.9988	0.2266	38.80	0.8732	1.0000	0.0267
R3	59.10	0.8121	.9992	0.1494	37.30	0.8798	1.0000	0.0244
Average	58.90	0.8140	.9991	0.1732	37.43	0.8793	1.0000	0.0348
SD	5.40	0.0152			1.31	0.0059		

TABLE 7 Apparent viscosities of the Aptamil + barium sample at 25°C in the shear rates of 10, 50, and 100 1/s

	Upward-sloping curve			Downward-sloping curve		
	10	50	100	10	50	100
Shear rate (1/s)	η (mPa.s)	η (mPa.s)	η (mPa.s)	η (mPa.s)	η (mPa.s)	η (mPa.s)
R1	40.49	29.34	25.53	27.77	23.08	21.3
R2	36.11	27.47	24.42	28.98	23.63	21.64
R3	38.34	28.34	24.88	28.28	23.31	21.44
Average	38.31	28.38	24.94	28.34	23.34	21.46
SD	2.19	0.93	0.56	0.60	0.28	0.17

Figure 2 shows the rheograms of breast milk and Aptamil, both impregnated with barium sulfate, at 25°C, using average data of the triplicate.

For a pseudoplastic fluid, the viscosity is decreased as the shear rate is increased. This behavior was observed for breast milk impregnated with barium sulfate, especially for low shear rates, up to 100 1/s, which is the range cited for swallowing and chewing movements.

The Newtonian and Power Law models were fitted to the experimental data of the studied products' rheograms. For a Newtonian fluid, the shear stress is proportional to the shear rate applied, and the angular coefficient of this relationship is the fluid dynamic viscosity, valid for the shear rate experimental range. In pseudoplastic fluids, the relationship between the shear stress and the shear rate is exponential, and the exponential parameter (*n*) is smaller than one unit, causing the decrease of angular coefficient values as the shear rate increases. In this case, the angular coefficient values are the fluid's apparent viscosities, which are, therefore, the function of the applied shear rate. According to Steffe (1996), the shear rate range of the act of chewing and swallowing encompasses values from 10 to 100 1/s.

Table 8 summarizes the results of upward-sloping data fit and for comparison purposes, Figures 3 and 4 show the same y-axis rheograms of breast milk and breast milk impregnated with barium (Figure 3) and Aptamil and Aptamil with barium (Figure 4). Breast milk and Aptamil viscosities of 1.73 ± 0.12cP and 1.53 ± 0.06 cP,

TABLE 8 Summary of rheological parameters of breast milk and Aptamil, pure, and with barium added

Rheological parameters	Breast milk	Breast milk + barium	Aptamil	Aptamil + barium
Rheological behavior	Newtonian	Pseudoplastic	Newtonian	Pseudoplastic
Consistency index K (Pa.s^{-1})		73.90 ± 0.50		58.90 ± 5.40
Flow behavior index *n* (dimensionless)		0.7804 ± 0.0019		0.8140 ± 0.0152
Apparent viscosity at 50 s^{-1} (mPa)	1.73 ± 0.12	31.30 ± 0.32	1.53 ± 0.06	38.31 ± 2.19

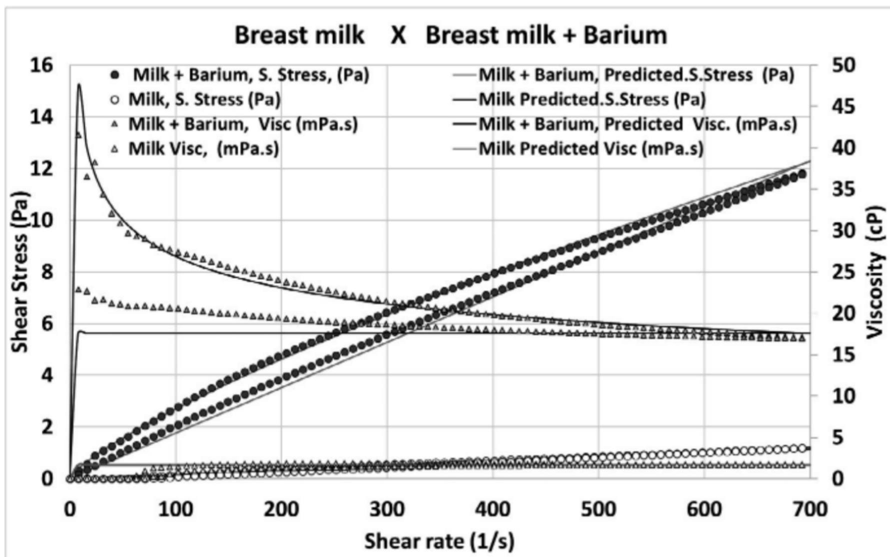

FIGURE 3 Rheological behaviour of breast milk and breast milk + barium at 25°C, using average data of the triplicate

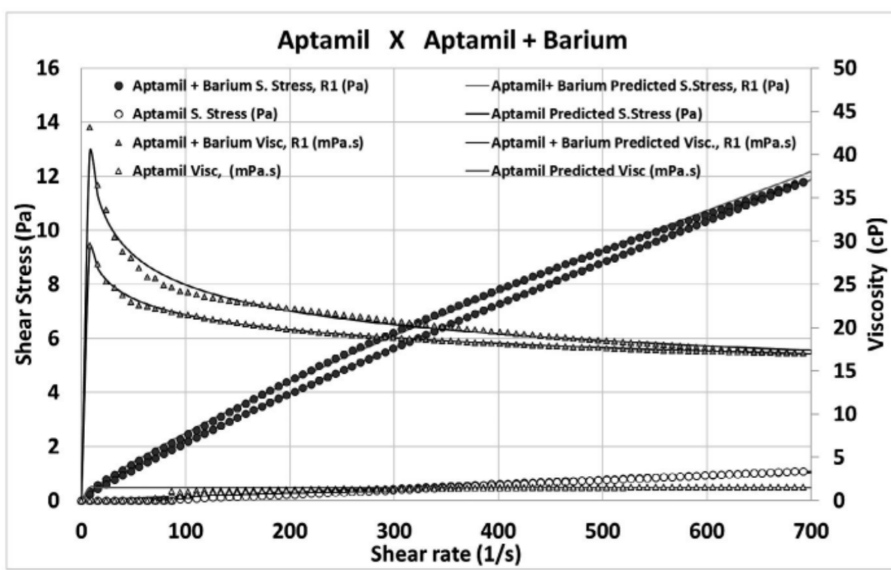

FIGURE 4 Rheological behaviour of Aptamil × Aptamil + Barium at 25°C

respectively, were quite similar. It is also observed no great difference between the apparent viscosities of these two products mixed with barium sulfate: 31.30 ± 0.32 cP for breast milk + barium sulfate, and 38.31 ± 2.19 cP for Aptamil + barium sulfate.

Although rheological behavior of breast milk and Aptamil be similar, as well the behavior of both impregnated with barium, Figures 3 and 4 make clear that barium sulfate that has a great influence on the flow behavior of this fluids, occasioning significant raising of viscosities. Considering the value of 50 1/s (shear rate used by NDD for classifying consistencies and average value of shear range for the act of chewing/swallowing), the addition of barium sulfate in the proportions used in this study increased 18 times breast milk viscosity, from 1.73 ± 0.12 cP to 31.30 ± 0.32 cP, and increased 25 time Aptamil viscosity, from 1.53 ± 0.06 to 38.31 ± 2.19 cP.

The evaluation of upward-sloping and downward-sloping data accomplished in this study, allowed a better understanding of fluid flow behavior and viscosity values determination according to the shear rate. Important and detailed information when compared to results of a viscosity analysis that does not take into account of the shear conditions.

5 | DISCUSSION

In this study, both the infant formula Aptamil and the untreated breastmilk presented similar results, with approximate viscosity rates as at the low end of the NDD naturally thick liquid range, and slightly thick as the IDDSI flow test classification. With the addition of liquid barium sulfate, in the proportion of 33%, the classification remained the same, namely: Naturally thick (NDD) and slightly thick (IDDSI), despite the increase in viscosity between 18 and 18.5 times in relation to the same pure products, approximating to the 50 mPa s, considered as nectar-thick liquids (NDD) and mildly thick (IDDSI). These values are similar to that obtained by de Almeida et al. (2011) in a study in which the infant lactose formula thickened at concentrations of 2% and 3% produced viscosities of 8.7 and 27.73 cP, respectively, and both untreated pasteurized human milk and infant formula thickened at a concentration of 7%, kept at 37°C, had their viscosity increased six to ninefold. These data indicate that both breastmilk and infant formula with barium sulfate, tested in this research, present higher viscosity rates than those of the study by de Almeida, using thickener at 7%, without barium.

The findings of the present study differ from that by Frazier et al. (2016), in which the addition of barium sulfate to breast milk and to regular infant formulas did not represent an expressive increase in viscosity (from to 0.2 to 1.3 times more viscous), remaining in thresholds below 12 mPa.s, value that the study, using the NDD classification, considered as a thin liquid. This is probably due to the fact that the contrast used was powder barium sulfate—E-Z-Paque Powder, diluted in water, in a concentration of 20%, whose viscosity has proved to be smaller than that of the liquid contrast—Liquid E-Z-Paque, in the isolated assessment. The study cited did not assess the milks with liquid contrast added, which could indicate different results. In the current research, as in the study by Frazier et al. (2016), when barium sulfate is added to the milk, the fluid does not behave as Newtonians, for the viscosity is altered, with values decreasing as the shear rate increases, a behavior typical of pseudoplastic fluids. For this reason, it is said in this case that the viscosity is apparent, because there is viscosity for each shear rate.

Frazier and colleagues, in their study, indicated the similarity of viscosity between several regular infant formula brands available, either impregnated or not with barium contrast, all of them within the NDD range for thin liquids (classification cited in the study, before the current naturally thick nomenclature). Considering that the products' viscosity differs little with the addition of barium, they stated that it provides reassurance that the clinicians can have confidence in indicating these formulas, using the same product and same proportion of preparation.

According to the present research, the unaltered performance at VFSS with breast milk or infant formula impregnated with barium sulfate at 33%, considered as a naturally thick liquid by NDD and slightly thick by IDDSI classification, cannot be approved for routine use, once they presented viscosities increased 18 to 18.5 times when compared to breast milk 100% and Aptamil 100%. Despite all products fall in the same classification label, naturally thick (NDD) and IDDSI mildly thick range, it is not yet known whether a viscosity difference of this magnitude has clinical significance. Actually, ancient studies already indicated that even small viscosity differences, such as that between orange juice and tomato juice, can modify the swallowing performance of adult dysphagic patients (Robertson & Pattillo, 1993).

When comparing the data obtained in the present research and the literature, it must be highlighted that different barium sulfate products react differently when alone and when in combination with other substances. Therefore, it is becoming increasingly clear that characterizing a particular barium sulfate product based on its manufacturer's reported barium sulfate concentration does not give enough information. Different products added with the same barium sulfate concentrations seem to behave differently. Consequently, the specific behavior of each material used needs to be known for the analyses to be carefully conducted, as well as the diet indications.

6 | CONCLUSION

Based on the methodology employed in this study, the findings lead to the conclusion that Aptamil infant formula and untreated breast milk present similar viscosity rates. Samples with the addition of liquid barium sulfate in the proportion of 33% also showed similarity. All of them displayed thresholds considered naturally thick liquids, according to the classification by NDD, and slightly thick by IDDSI classification, despite the quantitative differences in their apparent viscosity. It is of interest to know how small differences in viscosity between products, even classified in the same category, impact on the swallowing performance of the newborn or infant.

The results indicated in this study confirm the need for knowledge and care in preparing liquids to be offered in pediatric VFSS, especially with neonates and infants. Emphasizes the importance of objectively measuring viscosities of videofluoroscopic fluids, matching them with the liquids to be indicated to their diets. This "match" is not always easily reached, but the use of liquids in consistency and viscosity as close as possible to what will be indicated for the patient's diet is fundamental for their safety, thus contributing to clinical decision-making and speech-language-hearing practice. This will ensure greater confidence that VFSS represents the infant swallowing function, minimizing risks in their treatment.

The rheological evaluation allows the viscosity, density, and shear rate of foods to be objectively measured. However, neither the equipment nor the expertise required to measure viscosity at controlled shear rates is accessible to clinicians and the instrumentation is expensive.

The NDD project was conceived to standardize all dysphagia diets on a national basis to enhance communication among professionals, based on rheological parameters. According to some researchers, the NDD definitions are "obscure" and the most important lack of this guideline is to consider only one single point, viscosity, as a classification criterion. (Sukkar et al., 2018) Besides, the objective data obtained in this research show the large quantitative range of shear rate in one same NDD definition category.

Studies have proposed alternative ways to determine the flow of fluids in a universally recognized way. (Steele et al., 2015) The empirical test proposed by IDDSI is intended to provide a standard terminology by some rapid and easy to perform the test. The major advantages of empirical tests are the simplicity and rapidity of performing, moreover, the disadvantages are that the procedures are arbitrary and it is not possible to convert data to other systems. (Sukkar et al., 2018) Actually, a recent study sought to overcome this challenge. (Hanson, Jamshidi, Redfearn, Begley, & Steele, 2019).

The data pointed out in the present study is that the classification in the same category of liquids with quantitative differences in the order of eighteen to eighteen and a half times of viscosity occurs in the same way in the classification proposed by NDD as by IDDSI.

What is necessary to know is the extent to which these small differences in viscosity and the elastic and density properties of the different liquids, isolated and in addition to the barium sulphate, impact on the performance of the swallowing function. Although the established knowledge that modified foods with a higher degree of thickening can avoid aspirations, it is important to understand that the indication of the diet for dysphagic individuals, must be unique and individualized. Therefore, it is only a matter of matching the contrasted food on offer in the VFSS with that which will be indicated as a home-use diet. It is not so easy, but knowing the specific rheological properties of the stimuli offered and the dietary proposed it can be reached.

7 | LIMITATIONS

The possible variability of the composition of breast milk, more than the use of more than different milk breast samples is a limitation of the study because the data cannot ensure the generalization of the results. The specialized literature has pointed out that the composition of breast milk can vary according to several factors, such as the baby's age, time of the day, and the mother's diet. Although using breast milk samples from mothers with babies born at the same gestational age and on similar days of life, the data are not sufficient to ensure evidence.

Another limitation seems to be that there are other parameters besides the viscosity, which may be relevant, like the yield stress, density, and elongational flow. (Frazier et al., 2016; de La Fuente et al., 2017) These properties were not measured in the present study. More accessible techniques can complement future studies.

CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTIONS

Ana Maria Hernandez, Methodology, Writing-original draft, Writing-review & editing; Ana Maria Hernandez and Maria Isabel Berto, Conceptualization; Esther Mandelbaum Gonçalves Bianchini, Supervision.

ETHICAL STATEMENT

This study does not involve any human or animal testing and was approved by the Institutional Review Board of the Pontifical Catholic University of São Paulo (Pontifícia Universidade de São Paulo). The ethical relevant process (CAAE: 63361616.2.0000.54820) included the Informed Consent Form obtained from the mothers donating breast milk.

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