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# Rheological Assessment of Liquids Offered in Paediatric Videofluoroscopy Swallowing Study

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**Abstract**

Regarding neonates and infants, the videofluoroscopy swallowing study is always conducted with liquids impregnated with a radiopaque material in varied proportions and thickenings. Variations in thickening and barium concentration are known to change the swallowing function. The present study aimed to analyze the rheological and macroscopic properties of barium contrast and liquids commonly used in Brazil with infants under six months old. This study was approved by the Ethics Committee under certificate number 63361616.2.0000.5482. Rheological measurements were performed on samples of breast milk and infant formulas, pure, with thickener, impregnated with liquid barium sulfate, as well as a pure barium sulfate sample. The data collected showed similar viscosity rates between breast milk and the infant formulas Aptamil and Enfamil. Impregnating them with 20% and 33% liquid barium sulfate increased their viscosity. However, they remained in the same classification, despite the quantitative differences in their apparent viscosity. The regular products, in formulation with thickener and thickener plus 20% barium, showed an increase in apparent viscosity close or twice to that of Enfamil A.R. impregnated with 33% barium sulfate. The study allowed a more in-depth understanding of how the products behave at strain rates consistent with the conditions when swallowing. The results indicated in this study confirm the need for knowledge and care in preparing liquids to be offered in videofluoroscopy swallowing studies with neonates and infants. They also emphasize the importance of objectively measuring the viscosities of videofluoroscopic fluids, matching them with the liquids to be prescribed in their diets.

***Keywords:*** Dysphagia; Videofluoroscopy; Viscosity; Infant; Formula; Breastmilk

## 1 Introduction

The precise diagnosis of swallowing difficulties is essential to prevent deleterious conditions to the quality of life and for the survival of people with dysphagia (Arvedson, 2008; Bae et al., 2014). The videofluoroscopy swallowing study (VFSS), whose main objectives include establishing conditions for greater feeding safety, has been pointed out as the gold standard complementary examination to aid this task.

The reliability of the results depends on the technique used in the examination, the examiner's experience, and the adequate control of variables that influence the swallowing dynamics - e.g., feeding method and order, presentation, temperature, volumes, and consistency of foods, type of radiopaque material, and consequently the degree of viscosity of the formulations (Baron & Alexander, 2003; Dantas et al., 1989; Kuhlemeier et al., 2001; Lefton-Greif et al., 2018; Leonard et al., 2014; September et al., 2014).

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Several studies point out the influence of variables such as food temperature and consistency (Ekberg et al., 2010; Gosa & Dodrill, 2017; Steele et al., 2015) salivary $\alpha$-amylase activity, (Haward et al., 2011; Sukkar et al., 2018) tongue strength and pressure, (Geddes et al., 2012; September et al., 2014) and barium-impregnated liquids used in VFSS, causing an impact on the swallowing dynamics (Fink & Ross, 2009; Frazier et al., 2016; Logemann et al., 2005; Stuart & Motz, 2009).

Additional studies provide further evidence for the significance of taking these variables into account in the swallowing assessment (Hernandez & Bianchini, 2019; Hernandez et al., 2020; Lefton-Greif et al., 2018; Leonard et al., 2014).

Knowing how liquids behave is crucial when assessing swallowing function in paediatric VFSS, this provides confidence that the liquids offered replicate the patient's typical diet. It is even more significant concerning newborns and infants up to six months old, whose nutrition and hydration depend exclusively on liquid foods. The VFSS diagnosis establishes the management and indicates the safest diet prescription, which may however lead to early weaning - an undesired outcome when it is unnecessary, withholding from the newborn the components that contribute to their overall development and health. Given these aspects, we highlight the importance of knowing the behaviour of liquids indicated to the 0-to-6-month age group by the World Health Organization (WHO), namely: breast milk and/or infant formulae, in the specific and adequate dilution and thickener concentration for the examination, especially associated with radiopaque element. Mainly because the specialised literature has indicated that the addition of barium sulphate to liquids alters the density and the viscosity of the original liquid (Barbon & Steele, 2019; Stokely et al., 2014), and may influence swallowing physiology.

Barium sulphate is widely used as this radiopaque element in Brazil, despite the knowledge that are other X-ray hydrosoluble contrasts with less complications in use (From, From et al. (2010) and Siddiqui et al. (2017), probably to maintain better taste, enabling greater acceptance during the evaluation.

The knowledge of the behaviour of liquids, isolated and in association with radiopaque substance is of greater importance in countries and institutions without access to products available on the market, in a range of consistencies from thin to honey-thick and clinicians need to prepare the VFSS stimuli, mixing barium sulphate liquid or powder with regular liquids and solid elements in a subjective method. The incorrect and unreproducible matching to the viscosity of the regular infant's diet may lead to an incorrect assessment (Frazier et al., 2016; Hernandez & Bianchini, 2019). Hence, we must obtain objective data that can be replicated in assessments, helping establish the safest diet, diminishing the risk of aspiration, and maintaining the newborns' and infants' nutritional and overall health status and physical and emotional well-being.

Rheology, the science that studies the deformation and flow of solid and liquid bodies, can contribute to this end by characterizing food behaviour in complex deformations, such as those encountered during swallowing. The rheological studies assess the response of each substance to pressure or compression, thus furnishing objective data on the viscosity of foods, including the liquids used in VFSS (Almeida et al., 2011; de la Fuente et al., 2019; Hanson et al., 2019).

Only in recent decades has research been specifically approaching the behaviour and stability of the typical liquids taken by newborns and infants, considering the risk of using subjective methods to assess the consistency and viscosity of the stimuli in VFSS.

Research using the Advanced Rheometric Expansion System (ARES) has demonstrated significant differences in all rheological and material properties between six infant formulae and two liquid barium sulphate contrast samples (Cichero et al., 2011). All infant formulae had lower viscosity rates than barium sulphate in its original undiluted formula. Another study aimed to verify the variation in viscosity of breast milk and first infant formulae (intended for the first 6 months of life) with the addition of different thickener concentrations. They observed different viscosity according to time since preparation, temperature, and percentage of thickener used. The viscosity of infant formulae increased with time, unlike breast milk, whose viscosity decreased (Almeida et al., 2011). Another study assessed infant formulae and verified a varied increase in viscosity according to the lower or higher thickener concentration (September et al., 2014).

Frazier et al. (2016) compared the viscosity of formulae impregnated with liquid and powder barium sulphate, regular formula, anti-regurgitation formula, and breast milk both alone and in formulations with thickeners and barium sulphate. They concluded that both the regular formula and the breast milk impregnated with powder barium sulphate, diluted in water in concentrations of 20%, had their viscosity increased, although still classified as thin liquids according to the *National Dysphagia Diet (NDD)* (National Dysphagia Diet Task Force & American Dietetic Association, 2002).

Despite counting on studies that characterise and describe the rheological behaviour of typical liquids in the diet of children up to six months old, in formulations with thickeners and radiopaque material, the products used in each country where the studies were carried out are quite specific. Since the products available in the market change from one country to the other and the stimuli preparation often depends on the examiner's subjective criteria, we must know the behaviour of liquids in established and adequate dilutions for the examinations - i.e. that both enable us to visualise the image and are similar to those indicated to the patient's diet.

## 2 Objectives

The objective of this exploratory study was threefold: to analyse the rheological and macroscopic properties and stability of breast milk and infant formulae frequently used in Brazil to feed newborns and infants up to six months old, both alone and impregnated with liquid barium sulphate (Bariogel); to interpret the results of the rheological assessment based on the liquid viscosity classification with the criteria recommended by the National Dysphagia Diet (NDD), (2002), and on rheological parameters (apparent viscosity) and classification indicated by the *International Dysphagia Diet Standardisation Initiative - flow test (IDDSI)* (Cichero et al., 2017) and to furnish objective viscosity measures of pure, thickened, and barium sulphate-impregnated liquids (breast milk, regular and anti-regurgitation infant formulae, which make up the diet of newborns and infants up to six months old), collaborating with the adequate preparation of the liquids used in VFSS as close as possible to the infants' feeding routine.

## 3 Method

This study followed the guidelines and regulating norms of Resolution 196/96 of the Brazilian Ministry of Health's National Health Council (2013) and was approved by the Ethics Committee under certificate number 63361616.2.0000.54. The participants volunteered for the research, which was conducted after the mothers had agreed to donate their expressed milk and signed the informed consent form specifically developed for this study.

This was an experimental study on the rheological analysis of liquids used in VFSS of newborns and infants.

### 3.1 Materials

We used the following samples in the study: samples of two first infant formulae, commonly used in Brazil in the first months of life (Aptamil Pro 1 and Enfamil Premium 1); one sample of anti-regurgitation formula (Enfamil A.R.); two samples of natural breast milk, whose donating mothers had similar gestation and breastfeeding time (39 weeks of pregnancy time and lactation time of 90 days). These products were also assessed in formulations with barium sulphate, in two proportions (20% and 33%), besides pure liquid barium sulphate (manufactured by Bariogel) at 100%. Also, we used a specific thickener for breast milk (Nutrícia, manufactured by Aptamil), a product indicated for newborns and infants from 42 weeks corrected gestational age (CGA), which can also be used with infant formulae. It is made with maltodextrin, carob seed flour, calcium carbonate, iron sulphate, and zinc sulphate (Duncan et al., 2019).

Based on studies whose findings indicated the possibility of using lower proportions of contrast in the food without decreasing the visibility in

VFSS (Baron & Alexander, 2003; Fink & Ross, 2009; Queiroz et al., 2015), it was decided to use the proportion of 20% contrast in the rheological assessment.

### Preparation

The contents used in the rheological assessment were prepared in the laboratory at the Institute of Food Technology (*Instituto Tecnológico de Alimentos*-1 - ITAL), following the manufacturer's specifications for use and the assessment approach with the barium proportions (Table 1). The samples of natural breast milk were collected and assessed from two donors. The material was collected, stored, and defrosted following the norms of the Breastfeeding Scientific Department of the Brazilian Ministry of Health's National Health Paediatrics Society (da Silva et al., n. d.).
All the formulae, both alone and impregnated with barium contrast, were shaken to completely dilute the mixtures, pumping them with a syringe.

## 3.2 Procedures

The rheological measurements, performed in triplicate, were taken in a concentric cylinder rheometer model R/S (Brookfield Engineering Laboratories Inc, 2012), using double-gap system (Ratio of radii 1.0244). The sample temperature was stabilized for 10 minutes prior to analysis and controlled through the circulation of water in the jacket of the sample cup, coming from a Marconi thermostatic bath, model MA-184.
The rate sweep was performed linearly at shear rates of 0-700 1/s followed by 700-0 1/s, including part of typical range related articles: 20-100 1/s and 0-1000 1/s (Almeida et al., 2011; de la Fuente et al., 2019; 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).
The Power Law model, or Ostwald-de Waele model (Eq.1) was fitted to the rheograms, shear stress versus shear rate experimental data, adjusting the consistency index and flow behaviour index. For these pseudoplastic fluids, the apparent viscosity is a function of shear rate (Eq.2). In the cases whose flow behaviour index was fitted to one unit (n=1), the fluid is Newtonian(Eq.3), and the proportional constant of is the fluid dynamic viscosity ($\eta$).

$$\tau = K(\gamma^n) \quad (1)$$

$$\eta_{ap} = K(\gamma^{n-1}) \quad (2)$$

$$\tau = \eta\gamma \quad (3)$$

K=Fluid consistency index (Pa.s)
n=Flow behaviour index (nondimensional)
$\tau$=Shear stress (Pa)
$\gamma$= Strain rate ($s^{-1}$)
$\eta_{ap}$=Apparent viscosity (Pa.s)
$\eta$=Viscosity of the fluid (Pa.s)
The statistical parameters used to evaluate the fitted models were the correlation coefficient ($R^2$), standard deviation between repetitions, and residual standard deviation (RSD). $R^2$ values close to one-unit are generally desired. In bioprocess modelling process RSD values below 10% represent a satisfactory mathematical model (Atala et al., 2001), but previous studies carried out by the authors have show that values lower than 3% were a better fit to the rheological models.
The question of the similarity or differences between the viscosities of different products and formulations was interpreted by associating to the fundamental rheological data (dynamic rheological evaluation), the liquid flow categories proposed in the NDD, which is based on only one rheological parameter – viscosity, and the IDDSI classification, which assesses the flow of liquids by gravity through a syringe (Barbon & Steele, 2019). For this purpose "drinks currency converter" was used (Table 2).
We divided each classification into three thresholds, namely: the initial 33% was the low threshold, the intermediate 33% was the medium threshold, and the last 33% was the high threshold. Specifically, in the classification from 1 to 50 cP, the low threshold ranged from 1 to 16.4 cP, the medium threshold, from 16.5 cP to 33 cP, and the high threshold, from 33.1 cP to 50 cP. The same method was used in all categories.

Table 1: Preparation of the liquid samples

| Samples | Preparation |
|---|---|
| Breast milk | 600 mL of breast milk from a donor who had been breastfeeding for 12 weeks. |
| Breast milk + 20% barium | 400 mL of breast milk + 80 mL of Bariogel. Vigorously shaken for 60'. |
| Breast milk + 33% barium | 600 mL of breast milk + 132 mL of Bariogel. Vigorously shaken for 60'. |
| Breast milk + thickener Nutrícia | 400 mL of breast milk at 40ºC+4 measures of thickener (4 x 1.7 g.). Vigorously shaken for 60'. |
| Breast milk + thickener + 20% barium | 400 mL of breast milk at 40ºC+4 measures of thickener (4 x 1.7 g.)+ 80 mL of Bariogel. Vigorously shaken for 60'. |
| Aptamil Pro 1 | 20 measures of the powder formula (90 g) for 540 mL of water. Shaken as indicated by the manufacturer. |
| Aptamil Pro 1 + 20% Bariogel | 450 mL of the formula Aptamil prepared as described above + 90 mL of Bariogel. Vigorously shaken for 60'. |
| Aptamil Pro 1 + 33% Bariogel | 450 mL of the formula Aptamil prepared as described above + 150 mL of Bariogel. Vigorously shaken for 60'. |
| Aptamil Pro 1 + thickener Nutrícia | 400 mL of the formula Aptamil at 40ºC+4 measures of thickener (4 x 1.7 g.). Vigorously shaken for 60'. |
| Aptamil Pro 1 + thickener + 20% barium | 400 mL of the formula Aptamil at 40ºC+4 meaures of thickener (4 x 1.7 g.) + 80 mL of Bariogel. Vigorously shaken as mentioned above. |
| Enfamil Premium 1 | 21 measures of the powder formula (94.5 g) for 630 mL of water. Shaken as indicated by the manufacturer. |
| Enfamil + 20 % Bariogel | 450 mL of the formula Enfamil, prepared as described above + 90 mL of Bariogel. Vigorously shaken for 60'. |
| Enfamil + 33 % Bariogel | 360 mL of Enfamil prepared as described above + 120 mL of barium. Vigorously shaken for 60'. |
| Enfamil A.R. | 21 measures of the powder formula (94.5 g) for 630 mL of water. Shaken as indicated by the manufacturer. |
| Enfamil A.R. Premium + 20% Bariogel | 450 mL of the formula Enfamil A.R. prepared in the proportion of 3 measures (4.5 g) for 90 mL of water + 90 mL of Bariogel. Vigorously shaken for 60'. |
| Enfamil A.R. Premium + 33% Bariogel | 360 mL of the formula prepared in the proportion of 3 measures (4.5 g) for 90 mL of water + 119 mL of Bariogel. Vigorously shaken for 60'. |
| Liquid barium sulphate (Bariogel) | 600 mL of the product, manufactured ready for use. |

## 4 Results

The fitted rheological parameters and the viscosities are given as means of the triplicates with their respective standard deviations. The model fittings were assessed with the $R^2$ correlation indices and the RSD statistical parameter. The rheological model is shown in Table 3, with the respective parameters fitted to the ascending data of the rheogram: dynamic viscosity ($\mu$) fitted to the Newtonian model, and consistency index (K) and flow behaviour index (n) fitted to the pseudoplastic or Power Law model. A comparison of the apparent viscosities is shown in Table 4, calculated at the strain rates of 10, 50, and 100 $s^{-1}$, which, according to the literature, is the strain range present when swallowing or chewing (Steffe, 1996).
To make visually clear the comparative data, table 5 summarizes the results, showing the model fitted to the samples, their viscosities at the strain rate of 50 $s^{-1}$, and the classification of the viscosity of the liquids according to NDD and IDDSI criteria related to the rheological data.

### 4.1 Breast milk

Figure 1 shows rheological behaviour of breast milk in its various formulations, while Figure 2 details rheological behaviour of pure breast milk and barium-added breast milk, which apparent viscosities were lower than 50 mPa.s. The viscosity of breast milk increased with the addition of 20% barium sulphate (4.65 times) (Table 3) in relation to the pure product and the rheological behaviour changed from Newtonian to Pseudoplastic in the formulation with 33% barium sulphate, with an increase in viscosity by 18 times in relation to pure breast milk, at the strain rate of 50 $s^{-1}$ (Tables 3 and 4, and Figure 1).
Adding one measure of thickener Nutrícia (1.7 g per 100mL) to breast milk resulted an increase in viscosity (Table 3 and 4, Figure 2), though still classified as liquid flow (Table 5). With exception of barium sulphate and the anti-reflux formula, the formulation of breastmilk thickened plus 20% barium sulphate had the higher viscosity values of the samples (Table 4 and 5, Figures 1 and 2).

### 4.2 Infant Formulae

#### Aptamil Pro 1

The Aptamil Pro 1 with the addition of one measure of thickener (1,7 g per 100mL), both impregnated and not with 20% barium sulphate, showed pseudoplastic behaviour, with higher apparent viscosity values (Tables 3, 4 and 5, Figure 3).
Likewise, as for the breastmilk, the Power Law model fitted adequately to the ascending and descending experimental data of Aptamil Pro 1 impregnated with 33% barium sulphate (Table 3, Figure 4). This resulted in significantly higher viscosity values than those of the pure sample, but maintaining similar classifications, according to NDD and IDDSI (Table 5).

#### Enfamil Premium 1

Enfamil Premium 1, in all formulations gave Newtonian behaviour (Table 3), and all of them classified as thin (NDD) and slightly thick liquids (IDDSI), although at different thresholds (Table 5, Figure 5).

#### Enfamil AR

All samples of Enfamil AR showed pseudoplastic behaviour (Table 3). In a formulation with 33% barium sulphate there was an increase in apparent viscosity in relation to the pure product (twice) and in a formulation with 20% barium (1.75 times), at a strain rate of 50 $s^{-1}$ (Table 4, Figure 6).

#### Barium Sulphate (Bariogel)

Barium sulphate showed pseudoplastic behaviour (Table 3), with high apparent viscosities at the rates of 10, 50, and 100 $s^{-1}$, in thresholds of honey-thick (NDD) and moderately thick liquids (IDDSI) (Table 4 and 5). Pure barium apparent viscosities were also much higher compared to the pure products (Figure 7).
This explains the change in rheological behaviour and the increased viscosities of the samples impregnated with this product, though not in the same intensity. Accordingly, the greater the

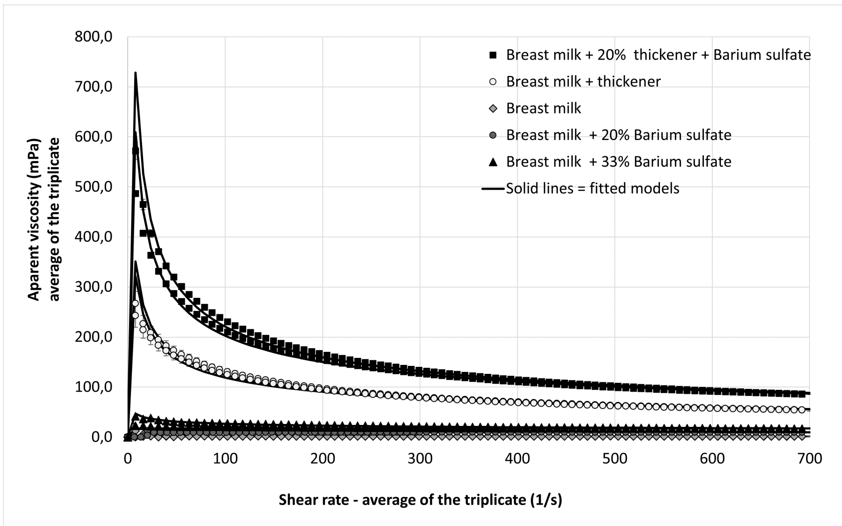


Figure 1: Rheological behaviour of breast milk and its various formulations

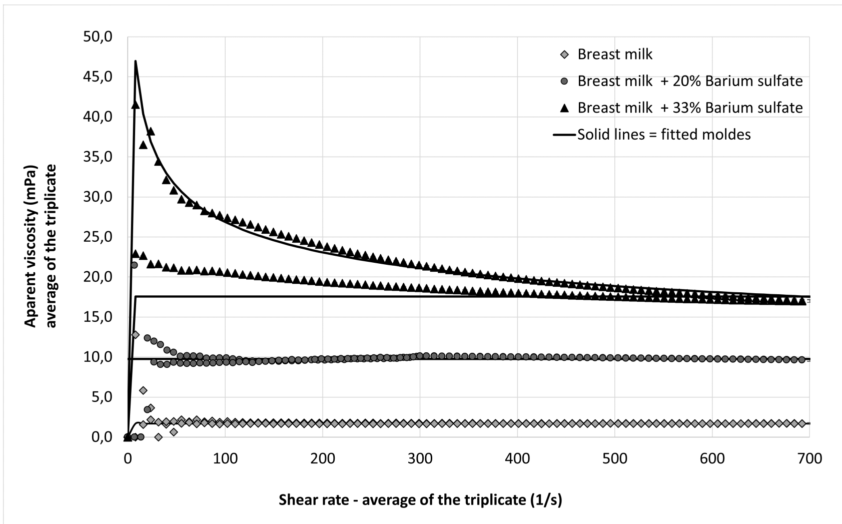


Figure 2: Rheological behaviour of pure breast milk for the formulations with apparent viscosity peak below 100mPas

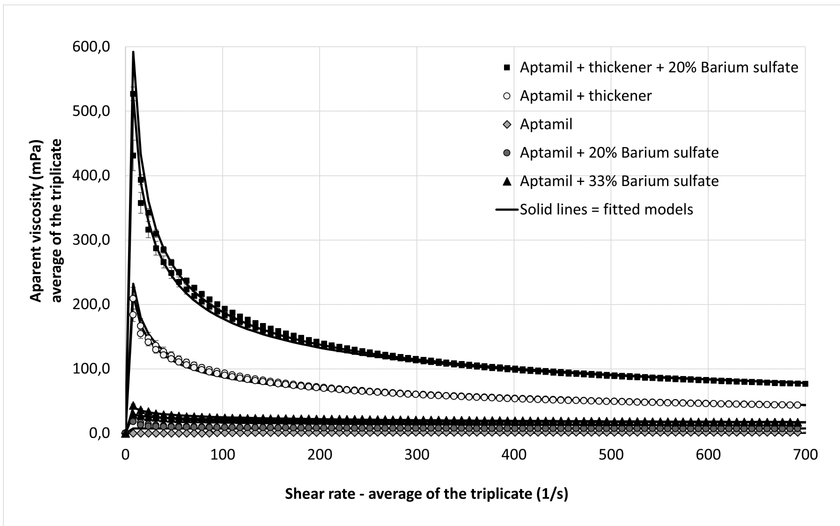


Figure 3: Rheological behaviour of Aptamil Pro 1 in its various formulations

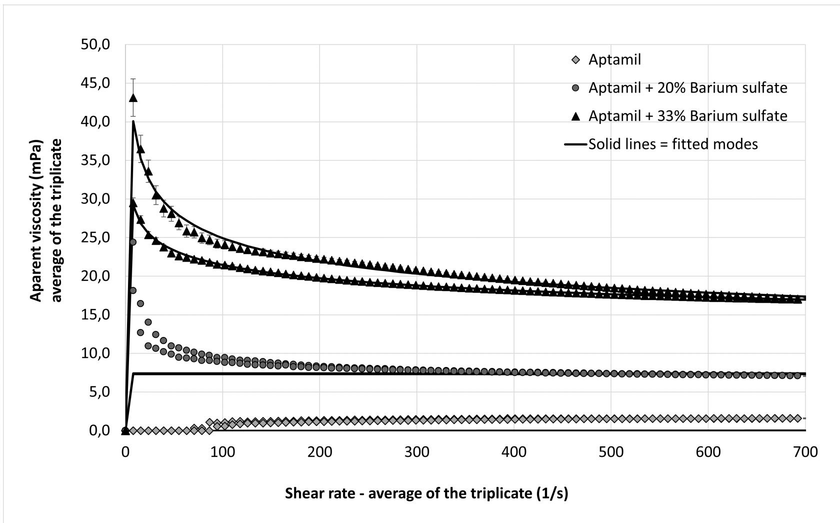


Figure 4: Rheological behaviour of Aptamil Pro 1 for the formulations with apparent viscosity peak below 100mPas

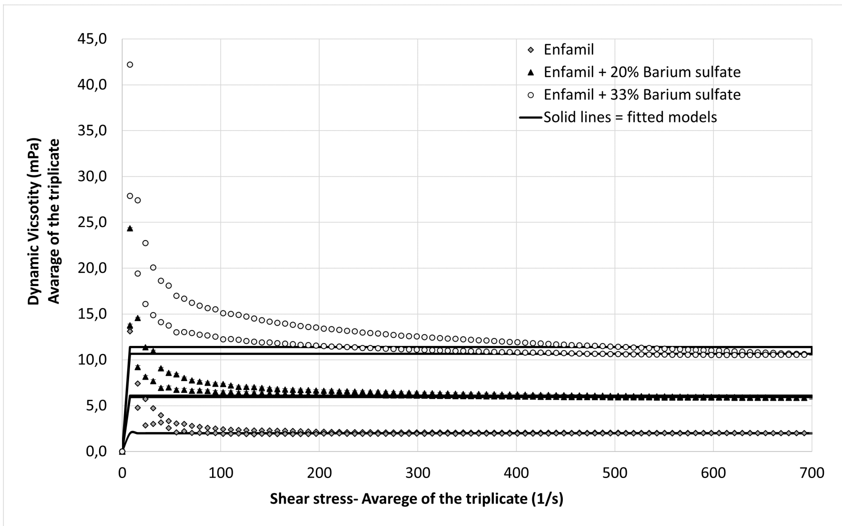


Figure 5: Rheological behaviour of Enfamil Premium 1 in its various formulations

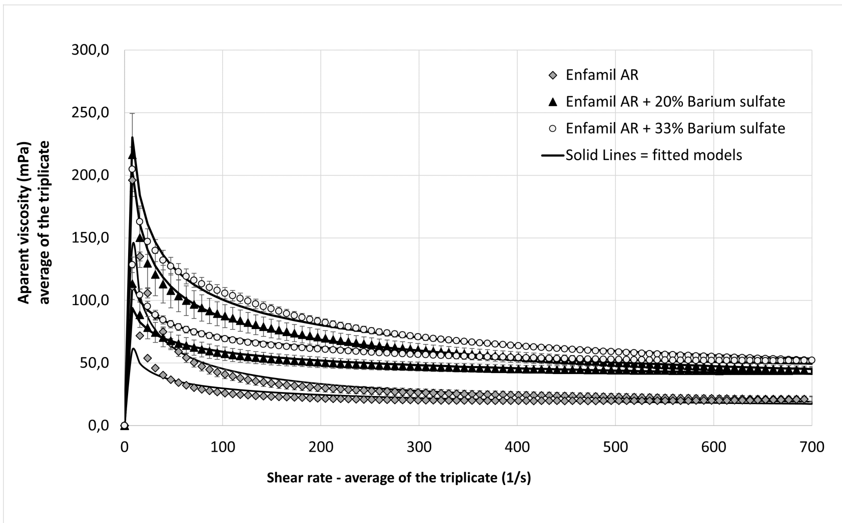


Figure 6: Rheological behaviour of Enfamil AR in its various formulations

Table 2: NDD and IDDSI Classification of Liquids

| NDD Centipoise | Classification | IDDSI Fluid remain | Classification |
|---|---|---|---|
| 0 - 50 cp | Thin | 0 | Thin |
| | | up to 4 ml | 1 - Slightly thick |
| 51 - 350 cP | Nectar thick | 4 to 8 mL | 2 - Mildl thick |
| 351 - 1750 cP | Honey thick | 8 to 10 mL | 3 - Moderately thick |
| >1751 cP | Spoon thick | >10 mL | 4 - Extremely thick |

amount of barium added (20 or 33%), the higher the final viscosity of the mixture (Figures 9, 10, 11 and 12)

## 5 Discussion

Except for Enfamil AR, the pure breast milk, Aptamil Pro 1 and Enfamil Premium 1 samples had very close fitted viscosities, with a little variability of Enfamil Premium 1 (Figure 8). All of them were in the low threshold of thin (according to the current NDD classification) and slightly thick liquid (in the IDDSI classification). Those samples impregnated with 20% barium sulphate (brand Bariogel) had a slight increase in their viscosity. On average, these increases were in the order of 6.92 mPa.s at 50 $s^{-1}$, between 5.87 to 8.07 mPa.s (Table 4, Figures 9-10).

These findings were not different from those in the study by Frazier et al. (2016), in which impregnating breast milk and regular infant formulae with barium sulphate did not significantly increase their viscosity (from 0.2 to 1.3 times). However, in the present research, although the viscosity of the products remained below 12 mPa.s, it increased from 3.85 times (Enfamil Premium 1) to 5.75 times (breast milk). This was probably due to two variables, the first one concerning the viscosity of the pure infant formulae, which in the cited study had somewhat higher values than those evaluated in the present research. The other variable was the use of the E-Z-Paque powder contrast diluted in water, whose viscosity was lower than that of the liquid E-Z-Paque - data obtained evaluating the pure products. Hence, evaluating the products impregnated with liquid contrast could have led to different results (Hernandez et al., 2020).

When impregnated with 33% barium sulphate, all products showed viscosity increases from 5.6 to 18.5 times higher the non-barium product (Table 4, Figures 11 and 12). Despite the quantitative increase in viscosity, the classification of the products, both alone or impregnated with barium contrast, remained the same according to the NDD and IDDSI criteria (Table 5). These values were close to those obtained by de Almeida et al. (2011) in a study with pasteurised breast milk and infant formulae with the addition of 2% and 3% thickener, with an increase of 8.7 mPa.s and 27.73 mPa.s. However, we were comparing thickened products with barium-impregnated products, which at 20% had a mean increase of 7 mPa.s (from 5.87 to 9.07 mPa.s) and at 33%, a mean increase of 26.5 mPa.s (from 17.4 to 29.6 mPa.s). At a concentration of 7%, the increase was 6 to 9 times that of the pure product, while in the present research the mean increase was of 16.5 times when impregnating with barium sulphate, without thickener.

The high viscosity of pure liquid barium sulphate (Bariogel) partly explains the changes that occurred in the viscosity of the products. However, there was no linearity in the changes.

Considering the nonlinearity of the viscosity increase according to the volume of barium sulphate added and the data indicated in the specialised literature (Baron & Alexander, 2003; Frazier et al., 2016; Hernandez et al., 2020) and in the present research, it is worth pointing out that different barium sulphate products react differently when presented alone or in combination with other substances. Therefore, characterising a specific barium sulphate product based on the concentration information provided by the manufacturer clearly does not ensure enough in-

Table 3: Rheological models of the fluids, mean apparent viscosity fitted to the Newtonian model, mean consistency index (K) and mean flow behaviour index (n) fitted to the pseudoplastic model, with respective standard deviations values, and the respective statistical parameters of the fittings ($R^2$ and RSD).

| **Samples** | **Rheological behaviour** | **Dynamic Viscosity $\mu$(mPa.s)** | **Consistency index K ($Pa.s^{-1}$)** | **Flow behaviour index n (dimensionless)** | **$R^2$** | **RSD (%)** |
|---|---|---|---|---|---|---|
| Breast milk | Newtonian | 1.70 ± 0.10 | | | 0.9903 | 1.15 |
| Breast milk + 20% barium | Newtonian | 9.77 ± 0.21 | - | - | 0.9960 | 0.46 |
| Breast milk + 33% barium | Pseudoplastic | - | 0.0739 ± 0.0054 | 0.7804 ± 0.0019 | 0.9987 | 0.22 |
| Breast milk + thickener | Pseudoplastic | - | 0.8164 ± 0.0704 | 0.5913 ± 0.0087 | 0.9972 | 0.31 |
| Breast milk + thickener + 20% barium | Pseudoplastic | - | 1.9180 ± 0.0650 | 0.5308 ± 0.0052 | 0.9968 | 0.30 |
| Aptamil | Newtonian | 1.53 ± 0.06 | - | - | 0.9984 | 0.84 |
| Aptamil + 20% barium | Newtonian | 7.40 ± 0.10 | - | - | 0.9992 | 0.61 |
| Aptamil + 33% barium | Pseudoplastic | - | 0.0589 ± 0.0054 | 0.8140 ±0.0152 | 0.9988 | 0.23 |
| Aptamil + thickener | Pseudoplastic | - | 0.4985 ±0.0510 | 0.6303 ± 0.0127 | 0.9993 | 0.18 |
| Aptamil + thickener + 20% barium | Pseudoplastic | - | 1.5013 ± 0.0294 | 0.5491 ± 0.0034 | 0.9985 | 0.21 |
| Enfamil Premium 1 | Newtonian | 2.03 ± 0.06 | - | - | 0.992 | 0.46 |
| Enfamil Premium 1 + 20% barium | Newtonian | 6.10 ± 0.10 | - | - | 0.9982 | 0.44 |
| Enfamil Premium 1 + 33% barium | Newtonian | 11.40 ± 0.10 | - | - | 0.9952 | 0.79 |
| Enfamil A.R. | Pseudoplastic | - | 0.3593 ± 0.0117 | 0.5510 ± 0.0242 | 0.9724 | 0.92 |
| Enfamil A.R. + 20% barium | Pseudoplastic | - | 0.4055 ± 0.0850 | 0.6669 ± 0.0210 | 0.9992 | 0,21 |
| Enfamil A.R. + 33% barium | Pseudoplastic | - | 0.4509 ± 0.0464 | 0.6751 ± 0.0133 | 0.9981 | 0.30 |
| Bariogel | Pseudoplastic | | 4.0758 ± 1.4287 | 0.5247 ± 0.0634 | 0.9977 | 0.18 |

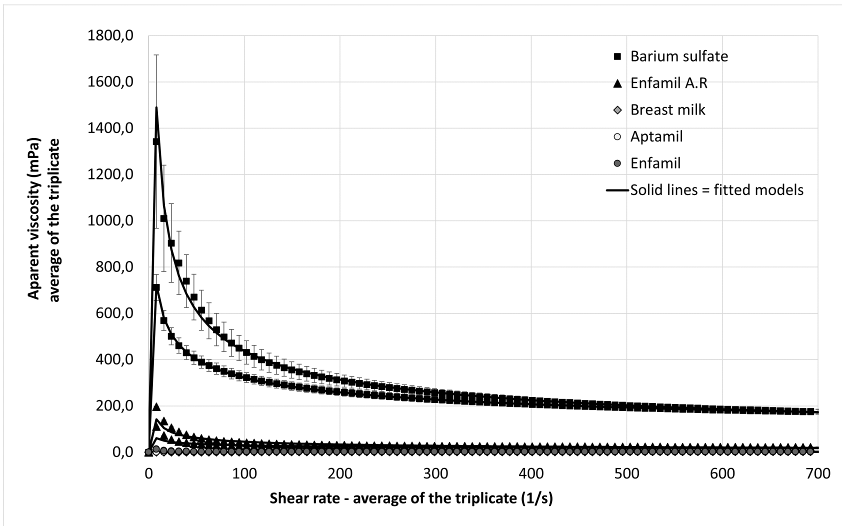


Figure 7: Rheological behaviour of pure barium sulphate and pure products

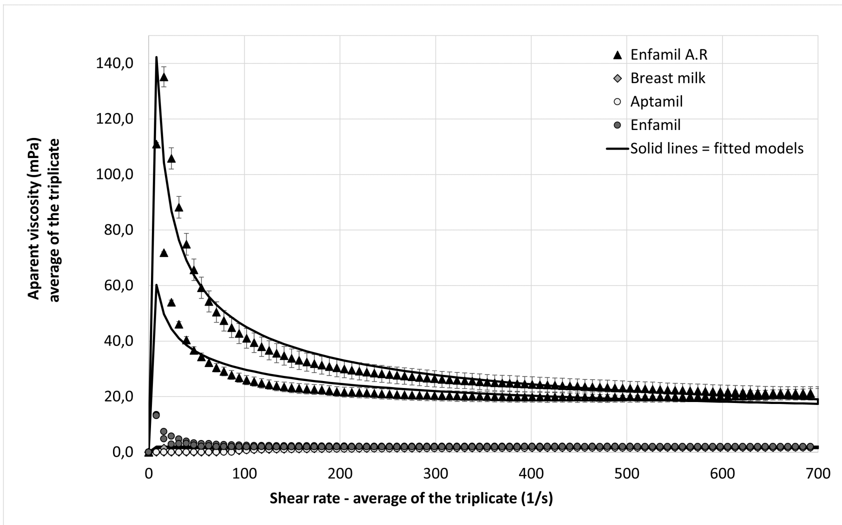


Figure 8: Rheological behaviour of pure products

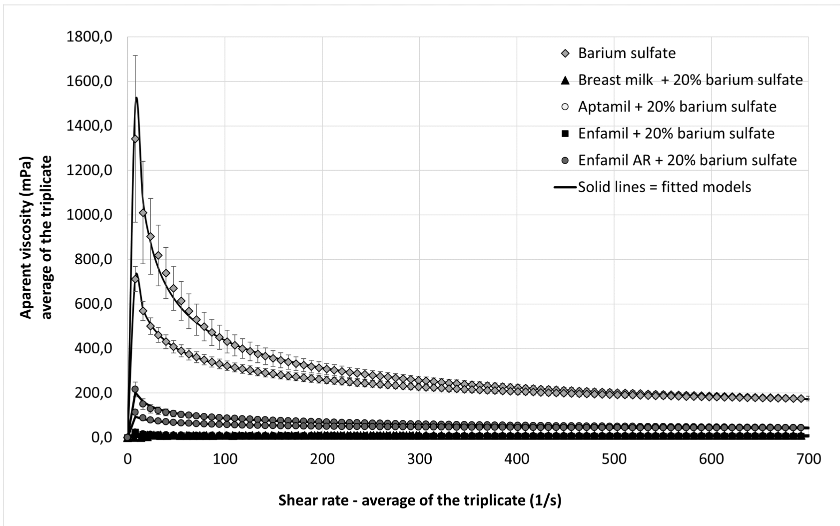


Figure 9: Comparison between the rheological behaviour of all the products impregnated with 20% barium sulphate versus pure barium sulphate

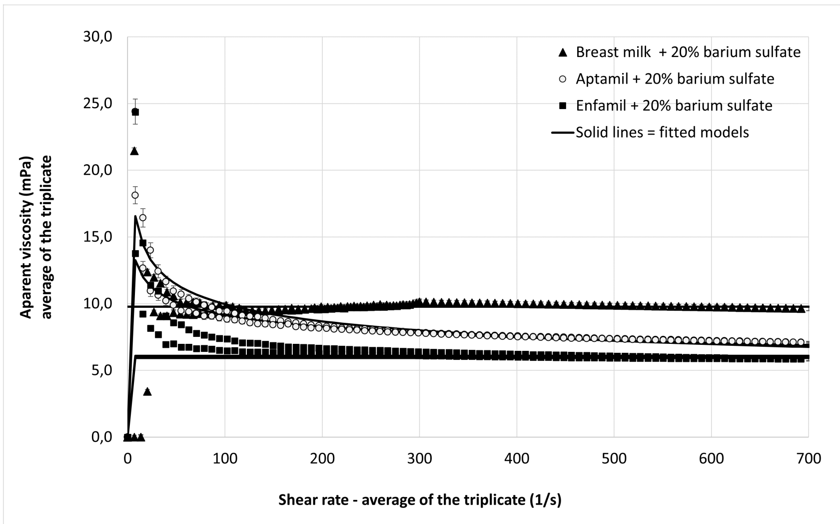


Figure 10: Comparison between the rheological behaviour of all the products impregnated with 20% barium sulphate, only for the formulations with viscosity peak below 100 mPas

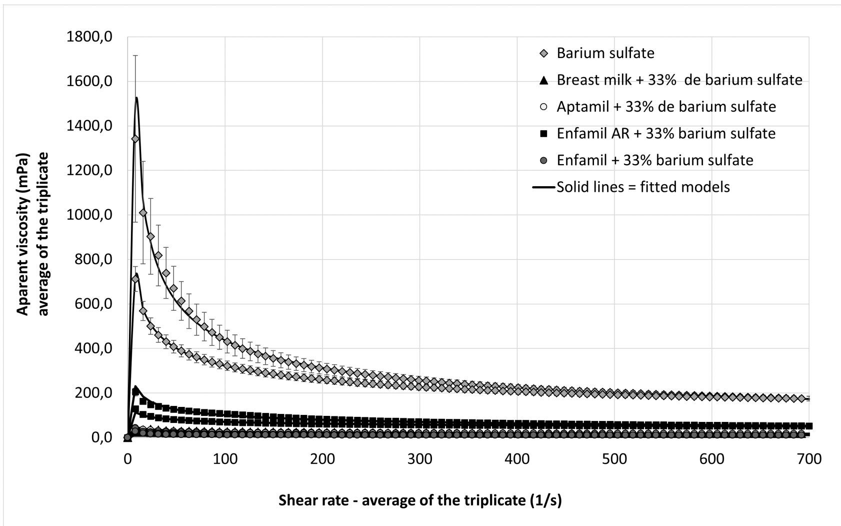


Figure 11: Comparison between the rheological behaviour of all the products impregnated with 33% barium sulphate

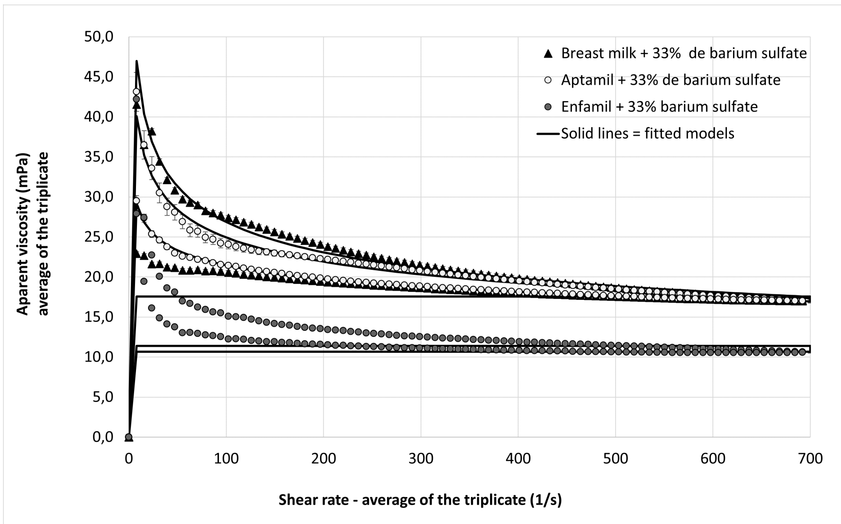


Figure 12: Comparison between the rheological behaviour of all the products impregnated with 33% barium sulphate, only for the formulations with viscosity peak below 100 mPas

Table 4: Rheological behaviour of the samples and respective, mean viscosities and standard deviations at the strain rates of 10 $s^{-1}$, 50 $s^{-1}$, and 100 $s^{-1}$

| **Sample** | **Rheological model** | **Viscosity at 10 $s^{-1}$ (mPa.s)** | **Viscosity at 50 $s^{-1}$ (mPa.s)** | **Viscosity at 100 $s^{-1}$ (mPa.s)** |
|---|---|---|---|---|
| Breast milk | Newtonian | 1.70 ± 0.10 | 1.70 ± 0.10 | 1.70 ± 0.10 |
| Breast milk + 20% barium | Newtonian | 9.77 ± 0.21 | 9.77 ± 0.21 | 9.77 ± 0.21 |
| Breast milk + 33% barium | Pseudoplastic | 44.57 ± 0.36 | 31.30 ± 0.32 | 26.88 ± 0.30 |
| Breast milk + thickener | Pseudoplastic | 318.28 ± 21.35 | 164.79 ± 8.84 | 124.11 ± 5.94 |
| Breast milk + thickener + 20% barium | Pseudoplastic | 650.91 ± 14.39 | 305.84 ± 4.24 | 220.92 ±. 2.29 |
| Formula Aptamil | Newtonian | 1.53 ± 0.06 | 1.53 ± 0.06 | 1.53 ± 0.06 |
| Formula Aptamil + 20% barium | Newtonian | 7.40 ± 0.10 | 7.40 ± 0.10 | 7.40 ± 0.10 |
| Formula Aptamil + 33% barium | Pseudoplastic | 38.31 ± 2.19 | 28.38 ± 0.93 | 24.94 ± 0.56 |
| Formula Aptamil + thickener | Pseudoplastic | 212.42 ± 15.29 | 117.07 ± 5.97 | 90.58 ± 4.04 |
| Formula Aptamil + thickener + 20% barium | Pseudoplastic | 531.52 ± 9.59 | 257.24 ± 4.85 | 188.19 ± 3.70 |
| Enfamil Premium 1 | Newtonian | 2.03 ± 0.06 | 2.03 ± 0.06 | 2.003 ± 0.06 |
| Enfamil Premium 1 + 20% barium | Newtonian | 6.10 ± 0.10 | 6.10 ± 0.10 | 6.10 ± 0.10 |
| Enfamil Premium 1 + 33 % barium | Newtonian | 11.40 ± 0.10 | 11.40 ± 0.10 | 11.40 ± 0.10 |
| Enfamil A.R. | Pseudoplastic | 127.74 ± 3.03 | 62.08 ± 3.86 | 45.51 ± 3.57 |
| Enfamil A.R. + 20% barium | Pseudoplastic | 187.24 ± 29.52 | 109.21 ± 13.33 | 86.60 ± 9.26 |
| Enfamil A.R. + 33% barium | Pseudoplastic | 213.01 ± 15.84 | 126.16 ± 6.84 | 100.69 ± 4.59 |
| Bariogel | Pseudoplastic | 1326.67 ± 317.27 | 609.62 ± 94.29 | 436.96 ± 51.68 |

formation. Different products impregnated with the same concentration of barium behave differently. Consequently, the professional must know the specific behaviour of each material they use to judiciously perform VFSS and prescribe a safe diet. When prescribing the diet, though, they must also consider aspects such as changes in viscosity due to temperature variations and time elapsed since the thickened liquid was prepared. Therefore, we must consider not only the viscosity of the liquid used in VFSS but also the temperature and time elapsed since adding thickener and barium to it. Hence, these conditions must be pointed out in the examination report.

Breast milk and Aptamil Pro 1 thickened with Aptamil Nutrícia, meant specifically for breast milk and allowed for newborns and infants from 42 weeks gestational age, not impregnated with barium sulphate, had the highest viscosity values at the strain rate of 50 $1s^{-1}$. Aptamil Pro 1 had such values increased by 76.52 times, and breast milk by 97 times that of the respective pure products, being classified as nectar-thick (NDD) and mildly thick liquid (IDDSI).

The fitted viscosity of thickened products impregnated with 20% barium sulphate (Bariogel)

Table 5: Rheological behaviour, mean viscosities and standard deviations, and classifications of the samples, according to NDD and IDDSI criteria.

| **Sample** | **Rheological behaviour** | **Viscosity 50 s-1 (mPa.s)** | **IDDSI** | **NDD** |
|---|---|---|---|---|
| Breast milk | Newtonian | 1.70 ± 0.10 | Slightly thick<br>Low threshold | Thin liquid |
| Breast milk + 20% barium | Newtonian | 9.77 ± 0.21 | Slightly thick<br>Low threshold | Thin liquid |
| Breast milk + 33% barium | Pseudoplastic | 31.30 ± 0.32 | Slightly thick<br>Medium threshold | Thin liquid<br>Medium threshold |
| Breast milk + thickener | Pseudoplastic | 164.79 ±8.84 | Mildly thick<br>Medium threshold | Nectar<br>Medium threshold |
| Breast milk + thickener + 20% barium | Pseudoplastic | 305.84 ± 4.24 | Mildly thick<br>Medium threshold | Nectar<br>Medium threshold |
| Aptamil Pro 1 | Newtonian | 1.53 ± 0.06 | Slightly thick<br>Low threshold | Thin liquid<br>Low threshold |
| Aptamil Pro 1 + 20% barium | Newtonian | 7.40 ± 0.10 | Slightly thick<br>Low threshold | Thin liquid<br>Low threshold |
| Aptamil Pro 1 +33% barium | Pseudoplastic | 28.38 ± 0.93 | Slightly thick<br>Medium threshold | Thin liquid<br>Medium threshold |
| Aptamil Pro 1 + thickener | Pseudoplastic | 117.07 ± 5.97 | Mildly thick<br>Low threshold | Nectar<br>Low threshold |
| Aptamil Pro 1 + thickener + 20% barium | Pseudoplastic | 257.24 ± 4.85 | Mildly thick<br>High threshold | Nectar<br>High threshold |
| Enfamil Premium 1 | Newtonian | 2.40 ± 0.52 | Slightly thick<br>Low threshold | Thin liquid<br>Low threshold |
| Enfamil Premium 1 + 20% barium | Newtonian | 9.23 ± 0.15 | Slightly thick<br>Low threshold | Thin liquid<br>Low threshold |
| Enfamil Premium 1 + 33 % barium | Newtonian | 19.80 ± 0.10 | Slightly thick<br>Medium threshold | ThinlLiquid<br>Medium threshold |
| Enfamil A.R. | Pseudoplastic | 62.08 ± 3.86 | Mildly thick<br>Low threshold | Nectar<br>Low threshold |
| Enfamil A.R. + 20% barium | Pseudoplastic | 109.21 ± 13.33 | Mildly thick<br>Medium threshold | Nectar<br>Low threshold |
| Enfamil A.R. + 33% barium | Pseudoplastic | 126.16 ± 6.84 | Mildly thick<br>Medium threshold | Nectar<br>Low threshold |
| Barium sulphate | Pseudoplastic | 609.62 ± 94.29 | Moderately thick<br>Low threshold | Honey<br>Low threshold |

Proposed terms for liquids and correlating viscosity ranges from the NDD classification: Thin: 1 - 50 cP; Nectar-thick: 51 - 350 cP; Honey-like: 351 - 1,750 cP; Spoon-thick: > 1,750 cP.

was higher than that of the pure product - Aptamil Pro 1 was 168 times and breast milk, 179 times higher. Comparing the two presentations, impregnated and not impregnated with barium sulphate, showed that they remained in the same classification of nectar-thick (NDD) and mildly thick liquids (IDDSI), even with the quantitative increase of 141.05 mPa.s and 140 mPa.s in fitted viscosity at the strain rate of $50s^{-1}$ (Table 5).

The apparent viscosity of breast milk and Aptamil Pro 1 with thickener added was close to, or a little above, that of Enfamil A.R. impregnated with 33% barium sulphate (Bariogel) at the shear rate of 50 $s^{-1}$, in thresholds of nectar-thick (NDD) and slightly thick liquids (IDDSI). These thickened products impregnated with 20% barium sulphate (Bariogel) had an increased viscosity, though still classified as nectar-thick (NDD) and slightly thick liquids (IDDSI).

In the study by Frazier et al. (2016), the authors concluded that an adequate performance in examination using formulations impregnated with 20% powder barium sulphate (E-Z-Paque powder) diluted in water allows clinicians to safely prescribe thin liquid diets.

In the present research, the milk products impregnated with 20% barium sulphate (Bariogel), except for the anti-regurgitation formula, behaved likewise similarly to the study by Frazier et al. (2016), remaining in thresholds of thin (NDD) and slightly thick liquids (IDDSI), although none of these liquids have the viscosity of water (1 mPa.s). However, in the present study, the increase in viscosity in the samples with 20% barium sulphate, despite the maintenance in the same category of classification of the flow of liquids, did not seem to guarantee the safe indication of the diet based only on the classification, since further studies are necessary to conclude to what extent small differences in apparent viscosity may affect the dynamics of swallowing, especially in individuals with suspected dysphagia.

Just as the increase in viscosity, more significant in formulations impregnated with 33% barium sulphate (Bariogel). An adequate swallowing performance in VFSS using milk impregnated with 33% liquid barium contrast does not ensure the safe prescription of the above mentioned pure infant formulae or breast milk - despite their remaining in the same classification of thin (NDD) and slightly thick liquids (IDDSI), similar to the classification of the pure products. The relevant issue at hand is to what extent such differences in viscosity between the products, even though classified in the same category, have an impact on the newborn's or infant's swallowing performance.

We presently know the greater importance of negative intraoral pressure for sucking milk (Geddes et al., 2012). Nevertheless, we can assume that the increased viscosity due to barium impregnation requires greater tongue pressure to push the liquid (Steele et al., 2015) and perhaps a longer oral transit time, partly ensuring greater swallowing safety. On the other hand, they may be affected by salivary $\alpha$-amylase, modifying the rheological behaviour of the stimulus (Sukkar et al., 2018).

Previous studies with dysphagic adults have already reported that little differences, such as between tomato juice and orange juice, have an impact on the physiology of swallowing (Robertson & Pattillo, 1993).

Another important aspect to consider is related to adequate visibility during the examination. Some studies, such as those by Baron and Alexander (2003) and Fink and Fink and Ross (2009), have verified that the proportion of 20% barium sulphate has enough radiopacity to carry out VFSS. Nonetheless, considering that different products react differently when impregnated with barium sulphate, the reaction of breast milk impregnated with 20% barium may not provide the best conditions for examination. A study comparing thickened infant dairy formulae impregnated with barium sulphate concluded that decreasing the contrast dilution to 25% did not make a clinically significant change in the quality of the image. (Queiroz et al., 2015) However, breast milk was not included in the samples. Moreover, the visibility of the stimulus was observed only in the syringe, instead of in examinations with newborns and infants.

This aspect is particularly important if we consider the performance of the VFSS test with neonates and infants in breastfeeding way, in which the flow of spontaneous breast milk is diluted in the supply of external stimulus (Hernandez & Bianchini, 2019).

The results pointed out in this study confirm

the need for knowledge and care when preparing the stimuli for VFSS. Using liquids whose consistency and viscosity are as close as possible to the diet prescribed to the patient is essential to ensure their safety.
We can infer that the clinician's subjective evaluation when choosing a liquid and preparing it for the newborns and infants undergoing VFSS is not safe regarding either the diagnosis or especially the diet prescription to be made to the patient. The rheological assessment furnishes objective measures of viscosity, density, and strain rates of the foods, contributing to an accurate diagnosis, leading to the indication of safer therapy, and aiding in speech-language-hearing clinical practice. However, it is a complex technique, often not accessible to the health professionals and population at large. For this very reason, the approach of this study is justified, as it indicates the characteristics of products normally used in Brazil in both VFSS and diets of newborns and infants up to six months old.

## 6 Limitations

The possible variability in the composition of breast milk prevented us from generalising the results we obtained, as well as distinguishing between the various infant formulae available in the market. Comparing the objective data obtained in this study with more accessible techniques, such as the one proposed by the International Dysphagia Diet Standardisation Initiative (IDDSI) - flow test, can complement the present study, corroborating or not the data and favouring a more accurate preparation of the liquids offered in VFSS.

## 7 Conclusion

This study made it possible to reach both the rheological characterization of the samples and a more in depth understanding of how their viscosities behave at strain rates consistent with the conditions when swallowing.
The rheological assessment provided objective data about the behaviour and macroscopic properties of the viscosity and strain rate of liquids that usually make up the diet of newborns and infants up to 6 months old, in Brazil.
It also allowed the interpretation of the results of the rheological assessment based on the liquid viscosity classification with the criteria recommended by the National Dysphagia Diet (NDD), 2002, and on classification indicated by the *International Dysphagia Diet Standardisation Initiative (IDDSI)*. The data showed that the liquids varied in their behaviour and the increase in viscosity did not occur linearly according to the added volume of barium sulphate. These data support the need for knowledge and care in preparing liquids to be offered in VFSS with neonates and infants, emphasizing the importance of objectively measuring the viscosities of videofluoroscopic fluids, matching them with the liquids to be prescribed in their diets.

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