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An alternative elongational method to study the effect of saliva on thickened fluids for dysphagia nutritional support

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ABSTRACT

Powder thickeners are used to modify liquid consistency in dysphagia management. These thickeners may contain starches, gums or their mixtures. Since the salivary α-amylase enzyme favours starch hydrolysis, this might affect the overall rheology of thickened fluids. This study provides a first insight into the impact of salivary α-amylase on the elongational properties of different types of thickened fluids, differentiating between gum-based and starch-based fluids, when considering the axial force developed during uniaxial elongation. The experimental results obtained in this study showed a dramatic decrease in the axial force as a result of salivary α-amylase addition to a pudding-like starch-based thickened fluid, while no significant change was observed after addition to a pudding-like gum-based thickened fluid. Monitoring axial forces during the stretching phase of CaBER was found to be a quick alternative method to identify structural changes of pudding-like thickened fluids in the presence of saliva, for which the conventional CaBER experiments are technically limited.

1. Introduction

Dysphagia is a highly prevalent medical condition related to any dysfunction of the swallowing process. Thickened fluids (TFs) for dysphagia management are, in general, complex non-Newtonian dispersions of starches and gums, prescribed to patients as a safer nutritional alternative to liquids. There are many criteria to be considered when selecting a proper thickened fluid: patient's medical condition, functional properties of the product, such as water absorption, as well as flavour release, sensorial feeling and acceptance, and of course interaction with medication. This is a complex task that requires complex decision and is usually the work of the health professionals and speech pathologist. (Cichero, 2007, 2013).

From a rheological perspective, TFs are considered beneficial in dysphagia management given that the thickened bolus has a lower transit speed than liquids during the swallowing process. This provides more time during the oropharyngeal phase of the swallowing process to secure the airways and to guide the bolus directly to the oesophagus. In this sense, in addition to considering the right nutritional quality and acceptance, it is very important to ensure an adequate and safe bolus viscosity level when designing TFs.

Even though there is not a common international standard for dysphagia fluids yet available, the most accepted guideline (National Dysphagia Diet Task Force) classifies TFs only according to their shear viscosity, at a shear rate of 50 s^{-1} at 25 °C, into four different stages: thin (1–50 mPa s), nectar (50 – 350 mPa.s), honey (350 – 1750 mPas) and spoon-thick or pudding-like (>1750 mPas) (Cichero et al., 2013; Gallegos et al., 2012). Obviously, many key factors are omitted from the current classification, such as the broad range of shear rates developed during the swallowing process and the role of bolus viscoelasticity, for instance (Gallegos et al., 2017, 2012; Zargaraan et al., 2013).

During oral processing, saliva is mixed with the thickened bolus. This favours a strong interaction of salivary α-amylase enzyme with the thickener that, in the case of starch, results in an almost instantaneous hydrolysis of the macromolecules, yielding a dramatic decrease in viscosity. If the viscosity of a TF significantly changes during the oral processing, it could have serious implications on patient safety and therefore needs to be quantified.

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To assess the effect of saliva on different thickened fluids, Hanson et al. (2011a) used shear rheology to measure their shear viscosities, at a constant shear rate and 25 °C, and showed that starch-based TFs were significantly more affected by α-amylase than the mixtures of starches and gums (Hanson et al., 2011a). Even though shear viscosity at a single shear rate is useful as a preliminary indication of the suitability of a given TF for dysphagia management, it provides very limited information, taking into account the wide range of shear rates at which a bolus is submitted during the oropharyngeal transit. Nevertheless, shear viscosity at 50 s^{-1} and 25 °C is widely accepted by the scientific community as a standard value to classify dysphagia products, without taking into consideration any other rheological assumption.

In order to better mimic the clinical practice encountered in dysphagia management, Vallons et al. (2015) used a Texture Analyser to measure the compression force of different TFs in the presence of saliva. The study confirmed the results of Hanson et al. (2011a), showing that GB TFs preserve better their consistency in the presence of saliva than SB TFs. In addition to rheology, axial compression studies could add reliable information regarding bolus structure, but yet does not provide the entire view of the real fluid complexity.

A key parameter, elasticity, is rather ignored when characterizing thickened fluids for dysphagia management, as discussed elsewhere (Gallegos et al., 2017, 2012; Zargaraan et al., 2013).

Since TFs may undergo elongational deformations during the pharyngeal phase of the swallowing process, elongational flow should also be considered when designing dysphagia products (Chen, 2009; Gallegos et al., 2017; Nguyen et al., 1997; Salinas-Vasquez et al., 2014; Zargaraan et al., 2013). It is worth to mention that such characterization does not exclude the need of a proper shear rheological characterization of the TFs, since it is already acknowledged that complex fluids behave differently during shear and elongational deformations (Morrison, 2001; Gallegos et al., 2017).

Capillary Breakup Extensional Rheometer (CaBER) uses a fast method (order of seconds) to monitor the evolution of a filament diameter over time in order to extract extensional (elastic) properties of fluids. A CaBER measurement is structured in 3 phases: a loading phase, a stretching phase and the actual CaBER experiment, which starts when the imposed stretching ends. More information on the capillary breakup technique is given elsewhere (Clasen et al., 2006; Miller et al., 2009; Niedzwiedz et al., 2009).

Choi et al. (2014) used CaBER to study the effect of saliva on the elongational properties of xanthan gum and carboxymethyl cellulose thickened fluids. Therefore, CaBER measurements of TFs seem promising, but are sometimes limited for highly concentrated fluids by the formation of non-cylindrical and poorly reproducible or unbreakable filaments during uniaxial elongation (Mackley et al., 2013). Due to their complex structure and low surface tension, these concentrated dispersions do not always respect the ideal filament assumptions, which leads to improperly developed capillary flows that are difficult to interpret (Klein et al., 2008; Mackley et al., 2013).

In this context, the axial force measurement is introduced as an alternative for monitoring the elongational behaviour of highly concentrated (pudding-like) TFs before and after their contact with human saliva. The axial force measurement (using a force sensor) in CaBER was previously used by Klein et al. (2008, 2009) to study the forces developed in honey, polystyrene and some types of glue. To our knowledge the measurement of axial forces developed in TFs during uniaxial elongation in a CaBER device is addressed for the first time.

Table 1
Thickening powders used and concentrations per dysphagia stage.

Sample code	Thickening agent	Thickener concentration (wt %)		
		nectar	honey	pudding
SBTF	Modified maize starch (E1442)	4.21	6.18	8.08
GBTF	Fresubin Clear Thickener®	1.72[a]	4.99[a]	9.50[a]

[a] Amounts according to the manufacturer recommendations.

2. Material and methods

2.1. Materials

Two different thickening powders were purchased and classified, according to the thickening agent used, as a starch-based (SB) or a gum-based (GB) thickener. Modified maize starch (E1442, soluble in cold water) was kindly provided by Fresenius Kabi Deutschland GmbH and was used as SB thickener, whereas a commercially available thickening powder for dysphagia management (Fresubin Clear Thickener®, Fresenius Kabi Deutschland GmbH) was used as GB thickener. Different amounts of thickening powder (see Table 1) were manually dissolved in deionized water at room temperature, in order to achieve nectar-like, honey-like and pudding-like consistencies, in the viscosity ranges recommended by the American Dietetic Association (Cichero et al., 2013). Although it was previously showed that TFs hydration time is dependent on thickener concentration (Turcanu, 2017), a common practice is to hydrate the TFs according to the commercial label (which, in the case of the GB TFs is 1 min[1]). Nevertheless, the authors considered that more time was needed for a complete hydration. Therefore, in order to minimize any inherent variation in homogeneity, each thickened fluid was left to complete the hydration process for 15 min prior to the rheological testing. This time was considered sufficient for the purpose of this work, and in accordance with the realistic time frame used in practice.

2.2. Preparation of the reconstituted salivary α-amylase fluid

A reconstituted salivary α-amylase fluid (saliva) was prepared, at room temperature, by dissolving α-amylase lyophilized powder from human saliva (*LEE SM BioSolution, USA, batch W71283B, powder activity: 230 U/mg of protein*) in deionized water. The α-amylase activity was measured and adjusted to a value of 150 U/mg (Amylase Assay Kit KA0875, Abnova®), a value close to the average activity of human saliva, as previously reported for healthy individuals (Takai et al., 2004). Once reconstituted, the solution was immediately used. Deionized water was furthermore used as a negative control solution.

2.3. Rheological characterization of thickened fluids

2.3.1. Shear viscosity

Viscous flow measurements were performed, at 25 °C, using a stress-controlled rheometer (*Haake Mars, Thermo Scientific GmbH, Germany)* equipped with concentric cylinder geometries (Z20/DG41). All the samples had a resting time of 5 min in the measuring geometry prior to testing and each measurement was performed in duplicate. The viscous flow curves of the neat TFs were determined at shear rates between 0.1 and 300 s^{-1} and the fluids were classified according to their shear viscosity at a shear rate of 50 s^{-1}, as

[1] Fresubin Clear Thickener® product info document: https://www.caringforlife.hk/filemanager/product/44/product_info_en.pdf.