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Exploring the role of rheology in bolus flow using an in-vitro approach

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Fakultetsopponent är professor Peter Fischer, ETH Zürich, Switzerland.

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ABSTRACT

Swallowing disorders, termed ‘dysphagia’, are more common in the elderly but can also affect younger persons. Approximately, 8% of the world’s population suffers from dysphagia. A Texture Modified Diet (TMD), which increases bolus viscosity to adjust for the sluggish bolus handling mechanism, is the most common intervention. Other rheological properties, such as bolus elasticity, shear rate, and yield stress, are often ignored. TMDs, which often comprise gum- and starch-based thickeners, were characterised for their rheological properties. The gum-based thickeners were considerably more elastic and exhibited a mild yield stress, showing a fine-stranded network structure on the nanoscale length when visualised by electron microscopy, as compared to the starch-based thickeners. Among the rheological properties, elasticity is cited as the most important for safe swallowing. Therefore, an *in vivo* study was performed in which fluids that have elastic properties were assessed for efficacy of safe swallowing in patients with dysphagia. These fluids showed easy swallowability, in terms of the sensory response and transit times during the oral and pharyngeal stages. While clinical examination is the standard and most appropriate way to diagnose dysphagia, difficulties arise in relation to the use of contrast media, ethics, and patient discomfort. To overcome these difficulties and to reduce the frequency of clinical analysis, an *in vitro* approach was adopted. And an *in vitro* swallowing model was developed that can be used to perform experimental bolus visualisation and manometry, mimicking the *in vivo* counterpart of video fluoroscopy and manometry. To study bolus transport, Pulsed Ultrasound Doppler Velocimetry was used. Pressure sensors were embedded in the model pharynx body to measure the bolus pressure during transit. The device delivers the bolus, at an appropriate speed and volume, and can handle boluses with different consistencies. In the device, bolus velocities ranging from 0.04 m/s to 0.48 m/s were measured, while bolus consistency was varied from nectar-thick to pudding-thick following National Dysphagia Diet scale. These velocities are within the range that is often reported for *in vivo* experiments. The acquired velocities yielded shear rates in the range of 13–229 s^{-1}, which is both lower and mostly higher shear rates than $50s^{-1}$ commonly referred to for deglutition. Similarly, when gum and starch-thickened boluses were injected into the model pharynx, the starch-thickened bolus often disintegrated, leaving residues in the model pharynx. When thickened boluses were analysed using manometry, by varying the bolus composition, shape, and volume, the pressure values at different locations in the model pharynx were in the range often noticed in clinical assessments. The device can simulate abnormal swallowing conditions, such as delayed epiglottis and Upper Esophageal Sphincter (UES) closure. Simulations of abnormal UES conditions, i.e. reduced UES area, yielded different pressure values in the lower pharynx. Therefore, the device can be used as a pre-clinical study tool to elucidate the relationship between bolus rheology and deglutition.

Keywords: Bolus rheology, dysphagia, *in vitro* simulations, *in vivo* analysis, ultrasound viscometry, extensional rheology, *in vitro* manometry, microstructure analysis, thickened fluids