Rheology of the bolus during pharyngeal transport

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ABSTRACT

Human swallowing taking place in the pharynx is a complex process demanding precise co-ordination amongst the organs involved. People suffering from swallowing disorders are restricted to texture altered foods/drinks which are shear thinning necessitating the knowledge of shear deformation during pharyngeal transport. In this work, the shear rate during bolus transport using shear thinning boluses was measured and reported both during *in-vivo* and *in-vitro* experiments.

INTRODUCTION

Eating and drinking are two of the most enjoyable acts humans perform. During oral processing the food/fluid is mixed with saliva in order to make the food in an easily transportable form through the pharynx toward the stomach. The pharynx plays an important role during swallowing and is shared by the airways and the swallowing tract[1]. Individuals suffering from swallowing disorders, i.e. dysphagia, experience problems in transporting the bolus toward the stomach which is estimated to influence 8% of the world population.[2]. The liquids might e.g. go toward the airways (aspiration) which may lead to pneumonia. People suffering from dysphagia cannot handle the fast flow of fluids and hence are restricted to rheologically modified fluids and foods.

Texture modification of fluids is performed by adding commercially available thickeners which increase the bolus shear viscosity and thereby reduce the velocity during pharyngeal transport allowing more time for the slow responding swallowing apparatus[3].

Thickened liquid foods are all shear thinning which demands an accurate determination of the shear rate during pharyngeal bolus flow. Shear rate during pharyngeal transport to date is not very well understood and a rough estimation of $50s^{-1}$ is often used as an indicator. Mathematical modelling and simulations studies have been performed to determine the shear rate but they assume highly idealized conditions which might be different from reality.

This work is aimed at determining the shear rate during pharyngeal bolus transport using both the *in-vivo* and *in-vitro* approaches in order to understand the effect of bolus rheology during pharyngeal transport.

MATERIAL AND METHODS

The results presented are based on a commercially available thickener, Nutilis (Nutricia Nordic AB, Stockholm, Sweden) used in the management of dysphagia.

In-vivo and in-vitro experiments

The *in-vivo* experiments were performed on three healthy subjects (1 female, 2 males), age range 34-55 years. The results reported from the *in-vivo* experiments are an average of the velocity profiles measured for the given subjects. The ultrasound beam was

directed to the lower pharynx of the subjects (Fig. 1 top panel) to capture the velocity profile of the bolus flow (Fig. 1 lower panel).

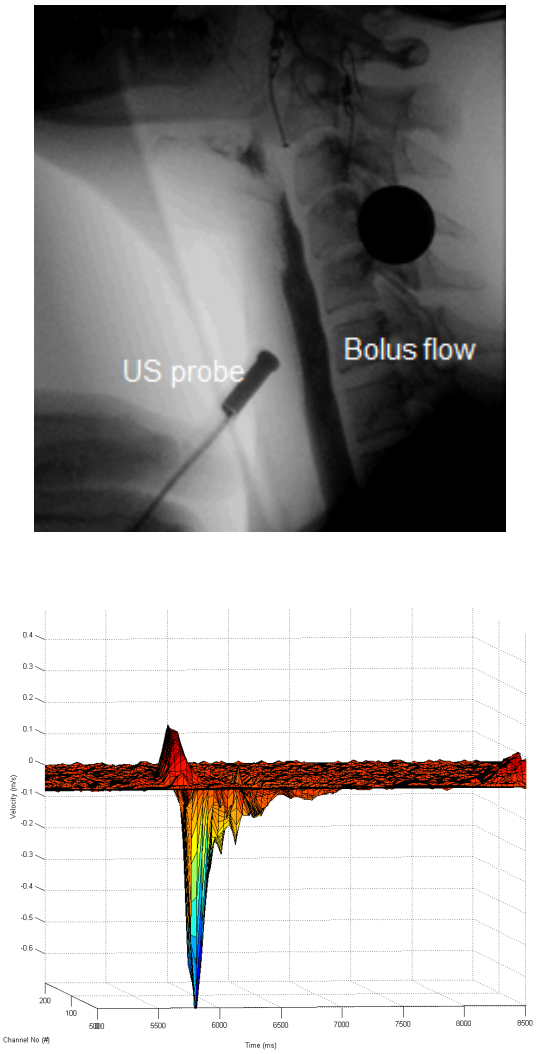

Figure 1: Image showing an example of the probe position in the pharynx, the bolus flow (top panel) and the resulting velocity profile during pharyngeal transport (bottom panel).

The *in-vitro* experiments were performed in the *in-vitro* model for swallowing "The Gothenburg Throat" developed at RISE, the construction of which is published elsewhere[4]. The ultrasound beam was directed towards the upper part of the pharynx (meso-pharynx) to capture the velocity profile.

Shear rate determination

To perform the shear rate measurement, the velocity profiles of the bolus during transport were captured using the technique Ultrasound Velocity Profiling (UVP) developed by Incipientus Ultrasound Flow Technologies AB, Gothenburg, Sweden.

In this short communication, the fluid viscosities was adjusted in the Nectar-thick (0.05-0.35 Pa.s at $50s^{-1}$) range defined by the NDD (National Dysphagia Diet of the American Dietetic Association)[5] using Nutilis thickener (bolus volume 15ml).

During the *in-vivo* examinations, only Nectar-thick viscosity was used.

RESULTS AND DISCUSSION

Figure 2 presents a typical velocity profile used to calculate the shear rate during the *in-vitro* measurements. The ultrasound transducer is directed towards that bolus flowing through the model pharynx. The velocity profile presented was measured from the transducer side to the center of the model pharynx, with the bolus flow measured away from the direction of the ultrasound beam resulting in negative values for the velocities.

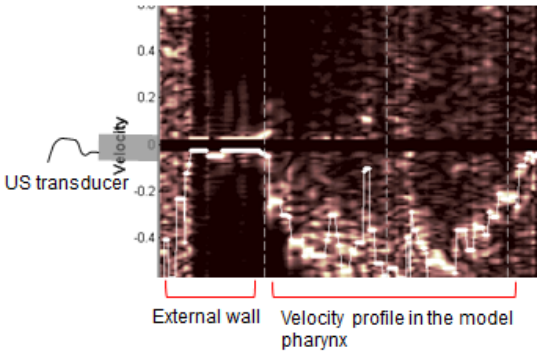

Figure 2: Figure showing the ultrasound transducer directed towards the bolus flow and the resulting velocity profiles acquired with ultrasound velocimetry using the Nutilis thickener during *in-vitro* measurements. (Negative values are acquired as the fluid flow is taking place away from the transducer).

The highest velocities recorded were 0.48 m/s (Table 1) which yielded a wall shear rate of 230s^{-1} calculated from the gradient of the velocity profile at the wall. Similarly, the shear rate in the lower pharynx reported here is from the *in-vivo* measurements. Even higher velocities were recorded in the *in-vivo* experiments, up to (0.70 m/s). The wall shear rate resulting from the gradient of the velocity profiles was around 300 s^{-1} indicating that the bolus is exposed to quite high shear rate during pharyngeal transport. The current understanding is that shear rate during pharyngeal swallowing is around 50s^{-1}. However, the measured shear rates are based on only three subjects and the study need to be expanded.

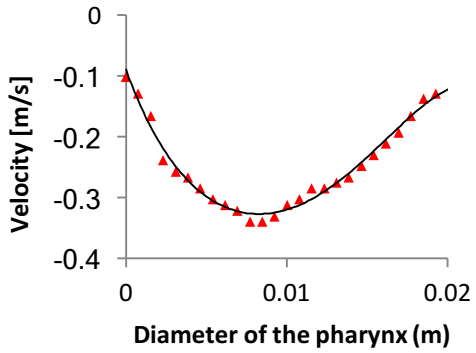

Figure 3: An example of a fitted polynomial on the acquired velocity profile from the *in-vivo* experiments.

During the *in-vivo* experiments, a number of issues were confronted such as: determination of the correct angle of insonification, correct determination of the pharyngeal wall and the changing geometry during pharyngeal bolus transport. Hence not all the data sets acquired were taken into account for shear rate determination during *in-vivo* swallowing.

Moreover, the shear rate varied a great deal among the individuals subjects as depicted in very high standard deviation (Table 1). During the *in-vitro* measurement the velocity profile was difficult to measure in the lower pharynx due to the mechanical structures hindering the path of the ultrasound beam. These difficulties will be addressed in future work.

Table1: Average velocities and resulting shear rate during the *in-vivo/in-vitro* experiments.

Location	Velocity (m/s)	Max shear rate measured (s^{-1})	Method
Upper pharynx	0.48±0.05	230±45	*In-vitro*
Lower pharynx	0.70±0.09	335±264	*In-vivo*

Nevertheless, from both the *in-vivo* and *in-vitro* examination we were able to determine the entire range of shear rate distribution that is relevant during swallowing of boluses in the nectar-thick consistency range.

CONCLUSION

In this work, we have demonstrated the shear rate distribution during pharyngeal transport using both *in-vivo* and *in-vitro* examination of swallowing using a shear thinning fluid.

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