Description for a problem studied at the UK Mathematics-in-Medicine Study Group Strathclyde 2010
< http://www.maths-in-medicine.org/uk/2010/swallowing/ >

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Mathematical modelling of the normal swallow

There are an estimated 40% of people who have dysphagia (eating, drinking and swallowing problems) following stroke. This figure does not include populations who develop dysphagia due to other disease processes such as Parkinson’s disease and dementia. The risks of dysphagia include; developing aspiration pneumonia, malnutrition and dehydration. Management of dysphagia includes provision of modified foods and drinks to attempt to address this problem. This management is based on the assumption that these foods/liquids have the best rheological properties for people with dysphagia, based on current knowledge of the normal swallowing process.

There is currently no complete mathematical model of the whole of the dynamic swallow process to allow us to consider the following questions:

a) What occurs during the normal swallow at each stage and how do the stages interrelate and interact with each other?
b) What impact do food and drinks have on the whole of this process?
c) What occurs during swallow breakdown?
d) What impact do the rheology of adapted foods and drinks have on the dynamic swallow process (and is this the effect we predict at present)?

A model of the normal swallow would allow us to introduce specific types of disorder into the swallow such as difficulty with anterior posterior tongue movement, a common feature found in Parkinson’s disease and model the impact of this on other parts of the dynamic process. In addition, modelling of the normal swallow could help us look at the impact of modified foods and liquids. Previous studies and common practise considering the consistency of liquids used with disordered swallowing are based on an assumed oral shear rate of 50 l/s. This figure was derived from the late 1960’s where sensory panels correlated perception of viscosity with actual viscosity measurements. Modelling swallowing using physiological measures will hopefully allow specific shear rates at different points in the oral cavity and the swallowing process to be identified.

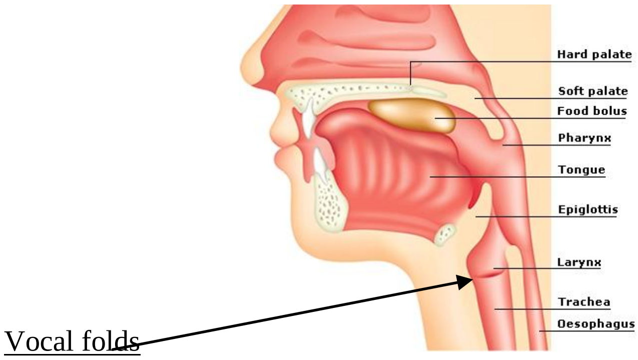
This has both clinical and commercial relevance. Clinically, thickened fluids are given to patients based on what is known about the normal swallow and the assumed shear rates which are used to produce commercial thickeners for fluid and pre prepared thickened drinks. A model will allow us to input liquids and foods with different rheological properties into the swallow process in a non clinical and thus non risk environment. It will also allow us to try to determine the most effective rheological properties to use with different swallowing disorders.

A brief review of the literature reveals only one dynamical mathematical model which has focused on modelling muscle tension during parts of a normal swallow (Nicosia and Brasseur, 2002). There is currently no complete dynamical model of the swallowing process.

The swallow

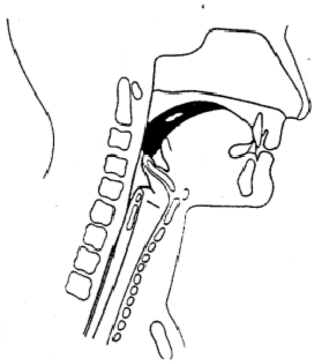
The normal swallow is a dynamic process. It is normally divided up into 4 stages:

Oral preparatory stage- food and drink is taken into the mouth, controlled within the oral cavity by the lingual, buccal, palatal and lip musculature. In this stage the food is manipulated and chewed, and mixed with saliva to form a bolus. Liquids are held in place ready to be moved to the posterior of the oral cavity.



Oral stage: the bolus has been formed and the bolus is propelled posteriorally in the oral cavity both mechanically by the tongue, with lip, palatal and buccal musculature aiding in the control, and formation of pressure differentials. The head of the bolus reaches the posterior tongue at the faucal arches when the next stage of the swallow begins. The palate rises in this stage to prevent food being regurgitated through the nose.

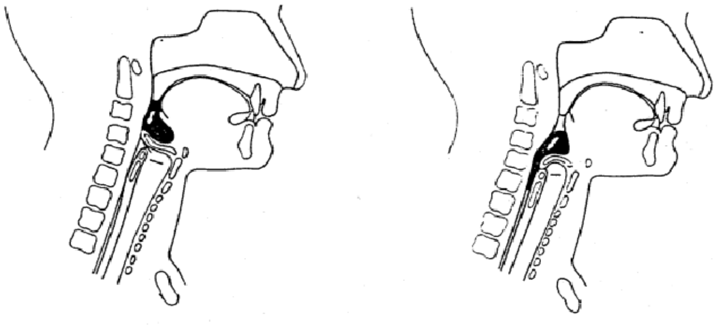
Figure 2: Diagram showing the oral phase of swallowing (Logemann, 1983)



These first two stages are under voluntary control, respiration continues during chewing and bolus movement.

Pharyngeal stage: - this stage is the first reflex stage. As the bolus passes the faucal arches a sequence of events begins. The hyoid bone begins to elevate and then move anteriorally thus moving the larynx up and forwards. Within the larynx, closure to protect the trachea begins with this movement. The false vocal folds close followed by the true vocal folds and then tilting of the epiglottis takes place. As the larynx raises and tilts, this supports the opening of the cricopharyngeal sphincter which is the first sphincter opening into the oesophagus. Food/liquid then passes into the oesophageus and the larynx and hyoid bone return to their resting position and respiration recommences.

Figure 3: Diagram showing the pharyngeal stage of swallowing (Logemann, 1983)



Oesophageal stage – this is also a reflex stage and is where the food/liquid is moved down to the lower oesophageal sphincter by peristalsis. This stage has already been modelled to some extent and is not the focus of this modelling.

The normal swallow however is a dynamic event with a number of processes occurring at the same time. For example when chewing a large mouthful, some parts of this are swallowed before others so more than one stage occurs at the same time. This is however dependent on coordinated intact musculature and neurological innervation.

Why mathematical modelling is possible now:

Over the past few years more information has been gathered about the normal swallow but in quite a piecemeal manner. This includes the following, for example;

- The impact of bolus size on the swallow and relationship to age,
- The timing of parts of the swallow-via videoflouroscopy, manometry,
- The measurement of pressures in specific parts of the swallow such as the pharyngeal stage,
- Production of models of fluid flow at the point of ejection of the oral cavity,
- Adaptation of dental appliances to measure intraoral pressures from a range of locations in the oral cavity to measure pressure flow dynamics during swallowing.

These studies tend to look at one aspect of the swallow such as timing, or look at one particular stage in isolation such as the pharyngeal stage rather than as a dynamic model. This does not allow us to identify the whole swallow and also the impact of food/drink on the swallowing process in the normal swallow. However, this information may enable a mathematical model of the whole swallowing process to be established which can be used to inform the current incomplete knowledge of the swallowing process.

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