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Influences of food hardness on the particle size distribution of food boluses

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ABSTRACT

Objectives: Bolus swallowing or deglutition is a vital oral action which transports orally processed food from the oral cavity to the stomach for further digestion. Swallowing is routine to most health individuals, but it could be highly hazardous to many elderly and dysphagia patients. In order to provide proper food for safe consumption by these disadvantaged populations, a fundamental understanding of how bolus swallowing is triggered and is based on what criteria is urgently needed. Main objective of this work was to understand the physical properties of food boluses, in particular the bolus particle size distribution in relation to the hardness of the food.

Methods: Food samples were chewed in free style by subjects and boluses were expectorated when subjects felt they were ready to be swallowed. Altogether seven different types of food were used and 10 health subjects participated in this study. Bolus particles were carefully washed and spread out on a flat surface. Images of bolus particles were taken using a digital camera and analysed using Image Pro Plus software for particle size quantification. Food hardness was measured using a Texture Analyser by a puncture test.

Results: It was observed that bolus particle size decreased with the increase of food hardness. The correlation between the two properties can be described by a power-law relationship. This relationship was also found applicable to literature results reported by Peyron et al. and Jalabert-Malbos et al.

Conclusions: Food hardness has a direct influence on its bolus particle size. The harder the food, the smaller the bolus particle size.

1. Introduction

Bolus swallowing or deglutition is a vital part of an eating and drinking process. It pushes orally processed food (the bolus) out of the oral cavity and transports it to the stomach for further digestion and nutrients intake.[1] A swallowing action is often modelled as a three phase process consisting of an oral phase, a pharyngeal phase, and an oesophageal phase,[2] though it is commonly acknowledged that the boundaries between different phases are much less clear in reality. During a normal bolus swallowing, a sequence of highly coordinated tasks will have to be performed orderly and timely, including coordinated actions of oral and facial muscles, controlled bolus dynamics, transition of the pharynx from its respiratory form to digestive form, relaxing and opening of the upper oesophagus sphincter, continuous sequential contraction of

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oesophagus muscle, and etc.[3] While the triggering of a swallow is an action of volition, most others are reflexive in nature. Therefore, once a swallow is triggered it goes to completion and cannot be stopped/suspended in the middle. To most individuals, actions of bolus swallowing are just simply routines and expose no health risk. However, to many disadvantaged populations, e.g. elderly people, infant babies, patients of dysphagia, and patients recovering from hospital operations, bolus swallowing could be a highly challenging and hazardous task.

To ensure the general wellbeing and the quality of life of these disadvantaged populations, food industries are under an increasing pressure to provide quality food which are not only nutritious but also tasty and safe to consume by these vulnerable consumers. In the past few years, an increased number of commercial products and recipes have become available from food and pharmaceutical companies.[4] These products are mostly provided in powder form which can be reconstituted at use to a desirable consistency (viscosity) at either nursing homes or hospital sites. Guidance about food consistency varies in different countries. One of the most frequently referred guidance is the one produced by American Dietician Association, which categorises fluid food systems simply based on the viscosity: thin (1–50 mPa s), nectar-like (51–350 mPa s), honey-like (351–1750 mPa s), and spoon-thick or pudding-thick (>1750 mPa s),[5] based on the unconfirmed assumption that viscosity is the main determining factor of bolus swallowing. However, real causes to various swallowing problems could be very different for different individuals. For example, for elderly people, this could be caused by the weakened oral/facial muscles, declined masticatory efficiency, deteriorated muscle coordination, reduced saliva secretion, and etc. A recent study on the rheology of polysaccharide gels and polysaccharide solutions in relation to their swallowing clearly showed that ease and smooth swallow is far more complicated than a simple viscosity measurement.[6,7] Therefore, a good understanding of the underpinning physical and physiological principles of bolus formation and swallowing is needed for both healthcare services and food manufacturing industry. Without such knowledge, food provision to disadvantaged consumers will inevitably continue to be a practice of trial and error.

The oral mastication and bolus formation has been of great interests to food scientists in the past half century, in particular in food–saliva interactions, the dynamics of bolus formation, the critical properties of a food bolus, and the controlling mechanisms (physical and physiological) of a swallowing process. One earliest work was conducted by Hutchings and Lillford,[8] who used three degrees (parameters) to describe the dynamics of oral mastication and bolus formation (degree of food structure, degree of lubrication, and the time), largely based on the sequential development of food oral processing. Another well referred theory about the triggering a bolus swallowing was the criterion of maximum consistency proposed by Prinz and Lucas.[9] By treating a food bolus as a cluster of fine particles, this theory assumes that there are two different forces acting on food particles: the adhesion force which attracts food particles to the oral surface due to surface tension of oral fluid and the viscous force which drags food particles forward due to viscous flow. Both forces are highly dependent on the size of the food particles and the balance between the two determines whether the particle would stay at oral surface or move forward. The theory states that bolus at its maximum consistency will be the most suitable status for swallowing. A counter-argument to this theory is that, at its maximum consistency, a bolus will be most difficult to deform and will inevitably require a much greater oral effort to push it through the oral-pharyngeal-oesophagus track and therefore, should not be a naturally favoured point of swallowing. Very recently, Peyron et al.[10] studied the changing physical properties of food particles/bolus and evolving sensory features during an eating process of wheat-flake cereals, based on the belief that sensory inputs from the bolus are crucially involved in the triggering of swallowing. They observed that, among all sensory features (brittleness, crispness, crackliness, dryness, grittiness, hardness, lightness, stickiness), sensed stickiness was identified as the most dominant feature immediately before swallowing and believed that stickiness could be the main sensory feature used in triggering a swallow action for this kind of bolus.[10]

By assuming that bolus swallowing could be seen as a process of fluid flow through a pipe, we tend to believe that the most important criterion for a smooth swallow is the matching of the oral pressure (or the tongue pressure) with that required for bolus flow. That is the pushing force needed for bolus flow has to be comfortably lower than one's capability in creating such a force or pressure. There have been extensive researches on oral pressure measurements. Measured oral pressures range from as small as 10 kPa[11] to as large as over 50 kPa and vary among population groups.[12] These studies suggest that human individuals have a limited capability in creating oral pressure for bolus pushing and, therefore, boluses have to be carefully constituted for an optimised smooth flow. As a part of an ongoing project on bolus formation and swallowing, this work aimed to investigate the basic features of a food bolus and to understand how the mechanical properties of the food influence bolus formation. This study was largely inspired by previous studies conducted in Peyron's group, who have studied particle size of six food boluses and later expanded to include 10 different types of foods.[13,14] They found that particle size distributions were highly food dependent but had less significant variation among human subjects. We see this as a strong indication that subjects may apply same criteria when trigger a swallow and, for this reason, food of very different mechanical nature have to be broken down to different particle size (and also probably with different amount of saliva) in order to constitute into a status which meets the set criteria for swallowing. By studying the particle size distributions of boluses formed from food of very different mechanical strength (hardness), this work would provide direct experimental evidences about the influence of food properties on bolus formation and swallowing.

2. Materials and methods

Seven food samples of varying mechanical strengths were selected for this study. Jelly samples were constituted in the food tech laboratory from Dr. Oetker's Vege Gel (purchased from local supermarket Morrison, Leeds, UK). Two gels of different strength were prepared at two different composi-