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Food oral processing: Recent developments and challenges

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ABSTRACT

As the very first step of food consumption, food oral processing is not only of great importance to food intake and the following digestion and adsorption, but also provides the necessary sensory attributes that please the consumer. Starting from the first bite, to oral manipulation including mastication and transportation, until bolus formation and swallowing, food products undergo a variety of physical and biochemical changes over a wide range of time and length scales. A number of efforts had been made to uncover the mechanisms in each oral processing step; some of which are still poorly understood. This review covers some of the most recent progress made in the area of food oral processing, with an emphasis on eating and swallowing difficulties in the elderly and the corresponding model food development. It also includes the oral surface coating and lubrication and the dynamic textural perception during food oral processing. The authors hope that this will facilitate food scientists, psychologists, dentists and other clinical researchers to further understand and reveal the detailed controlling mechanisms and governing principles of food oral processing.

1. Introduction

The manipulation and processing of food in the mouth, i.e., food oral processing, is the very beginning of food digestion. By the mastication using the teeth and mixing using the tongue, plus the enzymatic actions of saliva, food is broken down into smaller pieces and converted to a bolus which is then transported (swallowed) through the esophagus into the stomach for further digestion. At the completion of food oral processing these physical and biochemical changes mean that the consumed food is very different from the food before it was ingested. The complex process of oral processing has not been fully studied and its controlling mechanisms are still not understood, although there have been increasing attempts in recent years and several informative reviews have appeared [1••,2,3,4••,5•]. The purpose of this review is to provide the readers with an up-to-date summary of these efforts. Key areas and issues include: (1) food provision to elderly populations and those with eating and swallowing difficulties; (2) the use of model foods for eating and swallowing studies; (3) food oral breakdown and compound residuals and release; (4) food and saliva interactions and bolus formation, and (5) the dynamic textural perceptions during textural attribute evaluations.

2. Food provision to elderly populations and patients with eating and swallowing difficulties

With the increasing population of elderly people all over the world, the issue of the elderly's decreased oral processing capability has caught the attention of researchers. Table 1 summarizes the sorts of eating and swallowing problems associated with elderly people.

Laguna et al. [6] started with a study on the relationship between the physical measurement of the consumed food and perceived difficulty of consumption within the age groups of healthy young adults. The researchers measured individuals' hand grip force, isometric tongue pressure and the biting force and evaluated their appreciation of food products including carrot, banana, mozzarella cheese, potato, soft and hard cheddar cheeses. They observed a linear relationship between the physically measured break force of food and the perceived difficulty and oral processing time ($r = 0.729$). Additionally, the number of instrumentally measured peaks and the gradient of the penetrometer force readings were linearly correlated with the mastication duration and number of chews. However, the typically observed relationships between human physical strength (hand gripping and oral chewing) and the consumption difficulty and texture perception of the food seen in the elderly were not found in young subjects. This could be largely because healthy young adults have high eating and swallowing capacity which is strong enough to deal with daily food. In order to further understand the controlling factors of perceived difficulty and liking among elderly populations, a video recording technique was used to analyze the chewing and swallowing processes [7]. Within 30 elderly subjects (79 ± 9.4 years old), three different groups were identified based on their eating capability. However, objective measurements including the hand gripping force, tongue pressure, biting force and hand dexterity were surprisingly found to be related to neither the oral residing time nor the perceived eating difficulty of the food. The biting force was found to be related to the liking and number of chews during oral processing, and significantly influenced by subject's dental status. Hardness, however, was found to be significantly correlated

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Table 1
Eating difficulties of elderly people, possible causes and suggested solutions.

Symptoms	Possible causes	Suggested non-medical solutions
Chewing difficulty	Lack of functional teeth Reduced tongue & jaw muscles Reduced bite force	Size reduction of food Texturally modified food
Dry mouth	Lack of saliva secretion Reduced saliva flow rate Open mouth respiration	Artificial saliva application Moisturized/liquidized food Saliva stimulation (physically and bio-chemically)
Oral manipulation difficulty	Reduced lip sealing pressure Reduced tongue muscle strength Reduced touching sensitivity (tactile)	Size reduction of food Texturally modified food
Tasting difficulty	Dry mouth Reduced saliva secretion Change of saliva composition	Artificial saliva application Addition of flavoring compounds in food
Swallow difficulty	Tongue displacement Reduced muscle activities	Texturally modified food
Aspiration or suffocation	Reduced laryngeal movement	Increase in oral transit duration Thickened liquid intake (rather than thin liquid intake)
Choking	Insufficiently processed food intake Reduced laryngeal muscles	Texturally modified food
Loss of appetite	Dry mouth or tasteless	Orally and aromatically multi-stimulation

with the number of chews. Based on these observations and analyses, it was concluded that the main factors determining eating capability were dental status and the biting force measurement.

More information was acquired from elderly individuals with different physical conditions and various cultural backgrounds [8]. About 100 elderly individuals in both the UK and Spain, were evaluated with physical measurements including the hand gripping force, finger gripping force, biting force, lip sealing pressure, tongue pressing and the touching sensitivity. It was observed that the biting force was greatly influenced by the dental status of the subjects. Additionally, there was a strong linear relationship between the biting force and the hand gripping force. Moreover, based on a previous study demonstrating a positive correlation between tongue pressure and food oral handling capability [9], this study is of great importance given that the gripping force provides researchers with an easier alternative method for assessing eating capability. Another study conducted among an even wider population in Europe evaluated the 'meals on wheels' (MoW) system [10]. The study involved 405 elderly subjects from several European countries including Finland, France, Poland, Spain and the UK. By dividing the elderly into three categories based on their levels of 'dependency', with category 1 being the most independent and category 3 being the least, researchers demonstrated mutual difficulty in opening food packaging among all groups within all countries. Glass was found to be the most preferable packaging material overall, but the category and country had a significant difference — French and Spanish elderly prefer glass while Finnish prefer plastic materials; for both British and Polish participants the results were highly category-dependent. Overall, this cross-country assessment provided information for better design of the MoW system as well as for manufacturing specialized food products for elderly consumption.

In addition to the decreased eating capability with aging, another accompanying phenomenon commonly seen in the elderly is the possible reduction of lingual tactile acuity. There have been studies indicating a correlation between tongue strength and age [11,12]. Steele et al. [13] suspected that there was a potential correlation between tongue strength and the lingual tactile acuity. The researchers evaluated lingual tactile acuity in both young and old adults, and they found a reduced lingual tactile acuity with advanced age. However, the variations in tongue strength suggested hardly any relationship between lingual tactile acuity and the tongue strength. However, the authors partially attributed the results to the precision of the Essick spatial resolution acuity test used (a letter-recognition neurosensory test) [14] and suggested more investigations on the potential effect of intra-oral viscosity or tongue behavior during swallowing on the Essick spatial resolution acuity test.

A more serious risk on aging is dysphagia [15••]. Dysphagia is often under-diagnosed and its measurement even omitted from healthcare programs due to the lack of feasible and rapid evaluation tools for screening and assessment. The conventional method is videofluoroscopy (VFS). Although VFS is the 'gold' standard measurement, VFS examination takes a great amount of time and requires specific skills to conduct the screening test, therefore is not suitable for rapid clinical diagnosis. Rofes et al. [16] evaluated the eating and swallowing capability of dysphagia patients using a volume–viscosity swallow test (V-VST), and compared results with those obtained from VFS. With 120 patients who had swallowing difficulties and 14 healthy subjects, the V-VST test showed 0.94 sensitivity and 0.88 specificity for dysphagia patients, 0.79 sensitivity and 0.75 specificity for impaired efficacy patients, 0.87 sensitivity and 0.81 specificity for impaired safety level, and 0.91 sensitivity and 0.28 specificity for aspirations. Accompanied with the 10-item eating assessment tool, EAT-10 [17•], the researchers were able to demonstrate that both V-VST and EAT-10 had high screening and discriminating capability and could be applied in clinical trials for rapid evaluation and diagnosis. This possible universal application, once validated on a larger number of patients of different culture background and age levels, could be hugely beneficial in avoiding dysphagia-related nutritional and respiratory complications and in improving living quality of these patients.

Kohyama et al. [18] took a different approach and made a series of investigations on the quantitative effect of the food mouthful size on mastication and potential swallowing safety. Electromyography (EMG) was applied as the major evaluation technique throughout the studies. Small (3 ml) or large (6 ml) mouthfuls of gel samples were freely consumed by the subjects and their oral processing was recorded using EMG for masseter muscles and suprahyoid muscles. When the consumed food was reduced from large to small portion size, there was a 30% reduction of the oral processing time, number of chews and number of swallows. Correspondingly, the sum of muscle activities during gel consumption was reduced to 80% of the level used for large size. However, during each chewing motion, there was no significant difference in EMG variables between small and large gel consumption. Moreover, similar results were also found in four other different types of gels. The authors thus concluded that an estimated mastication effort could be achieved for different textures of hydrogels when a 'small enough' mouthful size was consumed. This 30% reduction was validated using two other types of gels, of similar fracture loads and different elastic module and fracture strains in a further study [19]. The authors found that gels with higher fracture strain required more mastication effort and less swallowing effort, compared to the more elastic gels. Searching for the most suitable parameter to describe the mastication effort during natural eating of soft gels, the authors noted that among fracture stress, fracture load, fracture strain and modulus, true fracture stress measured via video imaging during instrumental compression might be the best single explanatory parameter [20]. Such experimental evaluations, however, need to be further expanded to other types of consumed foods, especially non-cohesive food products. However, using physical parameters to quantify the concept of 'mouthful' is nevertheless a successful innovation and should be promoted.

Whilst seeking innovative techniques for the formulation and manufacturing of food that is safe for consumption by the elderly will be a core task for the food industry in the future, two imminent challenges remain: (1) proper understanding of the physiological/