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Food oral breaking and the determining role of tongue muscle strength

Woroud Abdulrahman Alsanei [a], Jianshe Chen [b,*], Rui Ding [a]

[a] School of Food Science and Nutrition, University of Leeds, Leeds LS2 9JT, UK

[b] School of Food Science and Biotechnology, Zhejiang Gongshang University, Hangzhou, Zhejiang 310018, China

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ABSTRACT

Some previous studies have revealed a great variation of tongue muscle strength among healthy individuals. However, the implication of different tongue muscle strengths to individuals' oral capability of food handling is yet to be determined. In this work, vege-gels (with a resilient consistency of jelly) and pastry food (mashed potato) were used to investigate tongue-only oral breaking (smashing) of these foods by individuals who have different tongue muscle strengths. The aim of the work is to determine whether a correlation exists between the tongue muscle strength and its capability of food breaking. A series of vege-gels and mashed potato samples ranging from soft to hard were constituted with increasing consistency. Mechanical/textural properties of test food samples were characterised by a texture analyser. Three experimental tasks were designed: characterisation of individual's tongue muscle strength by measuring the maximum isometric tongue pressure (MITP) (Task 1); assessment of individual's capability of tongue-only food breaking (Task 2); and measurement of tongue–palate pressure generation for food oral breaking (Task 3).

Our results confirm the great variability of tongue muscle strength among healthy individuals, with the highest MITP reaching 75 kPa and the lowest at only 17 kPa. The correlation study of tongue strength and the threshold gel/mashed potato strength for tongue-only oral breaking reveals a positive relationship between the two factors, which suggests that strong tongue muscle strength is always advantageous for oral handling (break/smashing) of viscoelastic and pastry foods. Conclusions obtained from this work can be a useful guidance to food design for elderly consumption.

1. Introduction

The oral physiological capabilities associated with eating and swallowing play a crucial role throughout the entire eating process from assessing texture, food oral handling and manipulating, to the final stage of bolus swallowing. The strength of various oral/facial muscles and their capability for coordinated actions are the key for an eating process. While healthy people maintain normal oral physiological capabilities for eating and swallowing, many disadvantaged individuals such as elderly and dysphagia patients have significantly reduced capability due to natural ageing process or often illness, showing the weakening of the tongue muscles as well as other oral/facial muscles and declined masticatory efficiency (Alsanei & Chen, 2014; Humbert & Robbins, 2008). With the predicted continuous growth of aged (older) population ($\geq$65 years) and the prevalence of dysphagia in developed countries and some fast developing countries in the coming decade, provision of healthy tasty food for safe consumption by these populations becomes a major challenge to modern societies. To overcome this challenge, a proper understanding on the relationship between the oral capability of food handling and the mechanical properties of the food is urgently needed by the food industry.

The tongue is a major skeletal muscle of the mouth floor and plays a central role in eating and swallowing. Apart from its sensory roles for taste and texture sensation, the tongue functions as a versatile mechanical device. It moves food around inside the oral cavity and helps to secure the food (bolus) in place. The tongue also helps in breaking up food particles and saliva mixing to form a proper bolus. More importantly, it generates a major compressive force against the hard palate to initiate sequential swallowing actions forcing bolus through the oral–pharyngeal–oesophagus tract (Heath & Prinz, 1999). When food is soft enough for tongue–palate compression, the tongue continues pressing until it is broken or fractured. By contrast, if the food is too hard for tongue–palate compression, oral strategy changes to teeth mastication for size reduction (Lucas, Prinz, Agrawal, & Bruce, 2002). In recent years, there have been a growing number of clinical documents reporting the influences of oral physiological functionalities (as affected by oral diseases, oropharyngeal dysphagia, reduced functional muscle reserve, and weakened orofacial muscles) on eating behaviour (Clark, Henson, Barber, Stierwalt, & Sherrill, 2003; Robbins et al., 2005; Stierwalt & Youmans, 2007; Yoshida et al., 2006). These clinical studies apply various techniques to assess the oromotor abilities and to measure the tongue–palate compression. Such techniques include the Iowa Oral

* Corresponding author. Tel.: +86 571 28008904; fax: +86 571 28008900.
E-mail address: jschen@zjgsu.edu.cn (J. Chen).

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Performance Instrument (IOPI), the Madison Oral Strengthening Therapeutic (MOST) device, and a manometry system consisting of three adhered air-filled bulbs (Hewitt et al., 2008; Utanohara et al., 2008; Yoshikawa, Yoshida, Tsuga, Akagawa, & Groher, 2011). IOPI is a rehabilitative technique developed in the 1990s for dysphagic patients. The device has been used as a reliable technique to assess tongue-strength of these patients both before and after treatment (Lazarus, Logemann, Huang, & Rademaker, 2003; Robbins et al., 2005, 2007). Furthermore, the technique has also been used to study the influence of ageing and gender on tongue performance and tongue pressure generation during swallowing (Youmans, Youmans, & Stierwalt, 2009). In one of our previous studies, it has been shown that positive correlations exist between the tongue strength and bolus physical properties (bolus size and viscosity) (Alsanei & Chen, 2014). However, so far, there is limited literature on the tongue strength and its capability of food handling (breaking and smashing food without teeth involvement).

Many elderly people, who edentate or have lost some of their natural teeth, have to adopt tongue-only strategy for food oral breaking and handling. They have limited food choices due to restrictive oral capability. In an effort to design an artificial tongue, a group of Japanese scientists observed that the tongue can only deform to a certain extent (Ishihara et al., 2013). Beyond its limit, pain will be felt and no further tongue deformation will be made in order to prevent permanent damage to the soft tissues. Therefore, choosing the right texture of food is critically important for the health and well-being of the disadvantaged elderly population.

Food oral handling means a wide range of oral actions for the purposes of proper bolus formation and safe swallowing. This study focused on the oral breaking of soft foods by tongue-only compression. By assuming that food deforms and breaks under the stress created by tongue muscle contraction, we propose that a proper matching of food mechanical strength (textural properties) by the maximum tongue strength is critically essential for tongue-only food oral processing. That is, the need of oral stress for food breaking must be met by the available tongue capability. Gels and mashed potato samples were chosen for this study because of their common availability and easy preparation. Such foods are categorised as Level 1 Dysphagia Pureed Diet as found in the National Dysphagia Diet (NDD). These types of foods are usually recommended for people suffering from age-related teeth loss, reduced chewing ability, swallowing difficulties (dysphagia) and for people who are under the risk of choking as a result of weakened oral/facial muscles. A series of vege-gels and mashed potato samples ranging from soft to hard with increasing consistency were constituted and their mechanical/textural properties were characterised by the instrumental texture analyser. Three main experimental tasks were designed: characterisation of individuals' physiological capability of oral food handling by measuring the maximum isometric tongue pressure (MITP) using IOPI technique (Task 1); assessment of individuals' capability for tongue-only food breaking (Task 2); and measurement of tongue–palate pressure generation during food oral breaking (Task 3). The main purpose of the present study is to establish, in a more precise manner, the correlations between individuals' tongue muscle strength and oral capability of tongue-only food breaking.

2. Materials and methods

2.1. Subjects

Thirty four healthy male and female subjects of different ages and sociocultural backgrounds were recruited for these tasks. Table 1 summarises the general profile of sample sizes, age distributions, and the oral physiological property (the maximum isometric tongue pressure (kPa) for both male and female subjects involved in each task). The criteria of subject selection were non-smokers, self-assessed as capable of independent living, not under any medical treatment and not suffering from any oral (dysphagia) and dental diseases. Before the tests, subjects were briefed about the aims, methods, and safety issues of the experiment and informed consent was obtained from all subjects. Each test session lasted about 40 min and no longer than 1 h. A voucher of 5 pounds was awarded to each subject after each session. Ethical approval has previously been granted by the Faculty Ethics Committee at the University of Leeds.

2.2. Food sample preparation

Vege-gel powder (Dr. Oetker, Leeds, U.K.) was purchased from a local supermarket (Morrison, Leeds, UK). The product is made from vegetable sources of carrageen (seaweed) and locust bean gum, capable of forming a semi-rigid, transparent, elasticised, and thermally reversible jelly. Altogether a total of 13 gel samples of different strengths were constituted into various consistencies according to the manufacturer's written instruction. The powder was firstly dissolved into cold water, and then heated to above 65 °C for 4–5 min. The completely dissolved solution was poured into cylindrical ice moulds (15 mm diameter and 15 mm length). Samples were then left to set in the refrigerator at 7 °C for up to 2 h for gel formation. Gel samples were then carefully moved to room temperature and thermally equilibrated before being tested.

Packed commercial dehydrated potato flakes (Instant Mashed Potato [Smash brand], Premier Foods PLC., St Albans, Hertfordshire, U.K.) were also purchased from a local supermarket (Morrison, Leeds, UK) and a pastry food (mashed potato) was prepared according to manufacturer's instruction. Altogether 10 mashed potato samples of different strengths were prepared by mixing potato powder into boiling water for 5 min. Mixtures were then compressed into the same ice matrix multi-mould used for vege-gel gelation and then stored at room temperature (25 °C) for 1–2 h until firm. All test samples were prepared at the same day of test and were used fresh.

2.3. Sample characterisation

A compression test was performed to determine the mechanical strength of both gel (fracturability and elasticity) and mashed potato (deformability) by using the TA XT-Plus texture analyser instrument (Stable Micro Systems Ltd., Surrey, UK) equipped with a 25 kg load cell. The obtained results were calculated using the Exponent software provided by the instrument manufacturer. For gel samples, compression

Table 1
Demographic features of participants regarding sample sizes, age ranges, the averages and standard deviations (SD) of age and the oral physiological property (MITP [kPa]) for both male and female subjects recruited for different tests in this work.

Task	Sample size (n)	Gender (n)			Age (years) (Average ± SD)			*MITP (kPa) (Average ± SD)		
		M	F	Age range	M	F	Average	M	F	Average
1 & 2	34	11	23	17–62	41 ± 17	31 ± 13	34 ± 15	51 ± 17	49 ± 12	50 ± 14
3	30	11	19	21–60	40 ± 14	31 ± 9	33 ± 10	48 ± 14	49 ± 9	49 ± 10

* Maximum isometric tongue pressure (MITP), M: male, F: female.