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Swallowing profiles of food polysaccharide gels in relation to bolus rheology

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ABSTRACT

Swallowing profiles of food polysaccharide gels were investigated in relation to bolus rheology. Polysaccharide gel from either gellan gum or a mixture of gellan gum and psyllium seed gum was used as a model food. Acoustic analysis and sensory evaluation were carried out to investigate the swallowing profiles using the same human subjects. Model bolus was prepared through instrumental mastication using a mechanical simulator to mimic the action of the human jaw in the presence or absence of artificial saliva and was subjected to dynamic viscoelasticity measurements to investigate the rheological properties. Bolus from the binary gel was shorter in time required to transfer through the pharyngeal phase due to mass flow and was scored higher in sensory perceived cohesiveness (bolus forming) than that from gellan gum gel. Model bolus from the binary gel showed a rheologically weak gel (or structured fluid) behavior and was higher in structural homogeneity than that from gellan gum gel. Also, dynamic viscoelasticity parameters of the binary gel were less dependent on the addition level of saliva. Results indicate that the viscoelasticity balance is a key for texture design of dysphagia foods in relation to the saliva miscibility.

1. Introduction

Texture and flavor (i.e., aroma and taste) are two major constituents of food palatability. Texture is important, particularly for solid foods, because textural changes occur more drastically in solid foods than in liquid foods during oral processing (i.e., eating or ingestion); solid foods are masticated to lower the degree of structure and should be mixed with saliva to increase the degree of lubrication before they are swallowed as illustrated by a mouth process model (Hutchings & Lillford, 1988). Recently, importance of texture has been emphasized in terms of the safety of eating (Nishinari, 2009). This is because there is an increasing demand for nursing-care foods with increasing the number of people with mastication and swallowing difficulties in recent aged society. For mastication and swallowing ease, textural properties of foods should be optimized from rheological, colloidal, and tribological aspects so that foods can be masticated and swallowed easily even by these patients. Texture design of nursing-care foods is now one of the most important tasks in the food industry in Japan and presumably throughout the world in the near future.

Physiology of swallowing has been inspected directly using videofluorography (VF), videoendoscopy (VE), and ultrasonic (ultrasound) method not only for clinical studies (Dodds, Logemann, & Stewart, 1990; Matsumi, Koshino, Hirai, Yokoyama, & Ikeda, 2005; Stephen, Taves, Smith, & Martin, 2005; Watkin, 1999) but also for texture studies (Kumagai, Tashiro, Hasegawa, Kohyama, & Kumagai, 2009; Okazawa et al., 2008; Saitoh et al., 2007) because flow speed of bolus through the pharyngeal phase relates to sensory swallowing ease, particularly for dysphagia patients with delayed closure of the epiglottis during swallowing. There are actually limitations in these physiological measurements. VE is usually low in quantitative performance. For VF, barium sulfate used as a contrast medium alters the mechanical and textural properties of test specimens, particularly when polyelectrolyte gels like carrageenan and gellan gum are used (Nishinari, 2009) as well as a risk of exposure to x-ray radiation. Ultrasonic method is applicable preferably to females due to the lack of the thyroid cartilage, which may interfere with the transit of the ultrasonic pulse. Acoustic analysis can be another approach to the swallowing profiles. This has been utilized for diagnostic purpose as a non-invasive method (Lazareck & Moussavi, 2004) but rarely for texture studies. To assess the perceived easiness of swallowing and also mastication, changes in the mechanical properties of foods during oral processing and the mechanical

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properties of bolus before swallowing should be investigated. Swallowing ease is reasonably associated with the fluidity and the deformability (i. e., rheology) of bolus. Bolus rheology has been discussed frequently in relation to cohesiveness, one of the most dominant rheological parameters in swallowing, mainly using solid foods with high elasticity with no deformability, including raw carrot and brazil nut (Lucas, Prinz, Agrawal, & Bruce, 2002). Nevertheless, difficulties in measuring the rheological properties of bolus still lie on personal physiological differences, including the mastication ability and the saliva secretion, sometimes leading to poor reproducibility of experiment. This may be one of the reasons why there has been limited research so far on the rheology of bolus by food scientists in contrast to numerous researches on the physiology of bolus flow by medical and clinical researchers (Hughes, Liu, Griffiths, Lawrie, & Wiles, 1996; Ku et al., 2007; Logemann, Rademaker, Pauloski, Ohmae, & Kahrilas, 1998; Monte, da Silva-Junior, Braga-Neto, Souza, & de Bruin, 2005; Pauloski et al., 2002). It is important for food scientists to establish an experimental procedure to prepare bolus with high reproducibility. The present study is aimed to clarify the relationship between swallowing profiles of polysaccharide gels and rheological properties of model bolus from the gels. Polysaccharide gels with different texture and fracture profile were used as a model food. Swallowing profiles were investigated from both physiological and sensory aspects using the same subjects. For bolus rheology, a mastication simulator, which has been developed for studies on the retronasal aroma release (Odake, Van Ruth, Roozen, Miura, & Akuzawa, in press), was used in the present study as a “bolus maker” to overcome personal physiological differences. Model bolus was prepared by “masticating” the gels instrumentally in the presence or absence of artificial saliva using the simulator. Rheology of model bolus was investigated by dynamic viscoelasticity measurements to know the macroscopic structural information. Our goal is to propose objective parameters representing the perceived easiness of swallowing and also mastication and to provide a strategy of texture design of nursing-care foods using polysaccharide technology.

2. Materials and methods

2.1. Gel samples preparation

Two types of gelling agent were used, including SAN SUPPORT® G-1014 (a mixture of gellan gum and psyllium seed gum) and KELCOGEL® (de-acylated gellan gum), both of which was provided by San-Ei Gen F.F.I., Inc. (Osaka, Japan). The label says that SAN SUPPORT® G-1014 contained 90% psyllium seed gum, 3.3% deacylated gellan gum, 0.8% trisodium citrate, and 5.9% maltodextrin. Concentrations of SAN SUPPORT® G-1014 were 1.0% and 1.5%, whereas concentrations of KELCOGEL® were 0.075% and 0.15%. These concentrations were determined preliminarily to yield gel strength of approx. 1000 Pa (for 1.0% SAN SUPPORT® G-1014 and 0.075% KELCOGEL®) and approx. 4000 Pa (for 1.5% SAN SUPPORT® G-1014 and 0.15% KELCOGEL®) at 20 °C. Gel strength is defined here as the compression stress at 67% strain according to a testing protocol issued by Japanese Ministry of Health, Labor, and Welfare (1994) for “Foods for the elderly with difficulty in masticating or swallowing” in the regulation of Food for special dietary uses. According to the protocol, test specimens of 40 mm in dia. and 15 mm in height were compressed using a coaxial cylindrical plunger of 20 mm in dia. at a table speed of 10 mm/s to determine the gel strength. Pre-mixture of each gelling agent, sugar (12%), and trisodium citrate (food grade, DSM Nutrition Japan, Tokyo) (0.1% in total) in powder form were dissolved in de-ionized water at 80 °C for 10 min with mechanical stirring, followed by the addition of calcium lactate (food grade, Taihei Chemical Industrial Co., Ltd., Osaka, Japan) (0.05% as pentahydrate) and citric acid (food grade, DSM Nutrition Japan) (0.18% as anhydrous) in this order. The solutions obtained were heated further at 85 °C for 30 min in a container of 60 mm in dia. and 25 mm in height, followed by curing at 8 °C for 2 h to form gels. Gels were refrigerated at 5 °C before use. As a reference, refined grade of psyllium seed gum, VISTOP® D-2074 (San-Ei Gen F.F.I., Inc.), a constituent of SAN SUPPORT® G-1014, was used to prepare gels in the same manner as described at 1.0% and 1.5%. These concentrations corresponded to the gel strength of approx. 300 and 500 Pa, respectively. Gels at above 1.5% were not prepared due to high viscosity of the solutions. Artificial saliva, consisting of $NaHCO_3$ (5.208 g/L), K_2HPO_4-$3H_2O$ (1.369 g/L), NaCl (0.877 g/L), KCl (0.477 g/L), $CaCl_2$-$2H_2O$ (0.441 g/L), and mucin (2.160 g/L) dissolved in de-ionized water (Machiels, van Ruth, Posthumus, & Istasse, 2003), was used within 3 days at the longest after preparation. Mucin used was reagent grade from pig stomach (Wako Pure Chemical Industries Ltd., Osaka, Japan).

2.2. Instrumental mastication (formation of model bolus)

Gels were molded in 20 mm in dia. and 10 mm in height (4.5 g) as a test specimen, subjected to the mastication simulator to prepare model bolus. Configuration of the mastication simulator is illustrated in Fig. 1. Briefly, the simulator consists of a cylindrical chamber made of acrylic resin and a flat plunger (50 mm in dia.) made of acetal resin. Instrumental mastication was carried out in the presence or absence of 0.5 or 1.0 ml artificial saliva by processing the test specimen in a reciprocating manner using the flat plunger: 10 cycles of vertical compression at 17.8 mm/s with 2.0 mm-clearance and simultaneous rotational shearing by 12°/s.

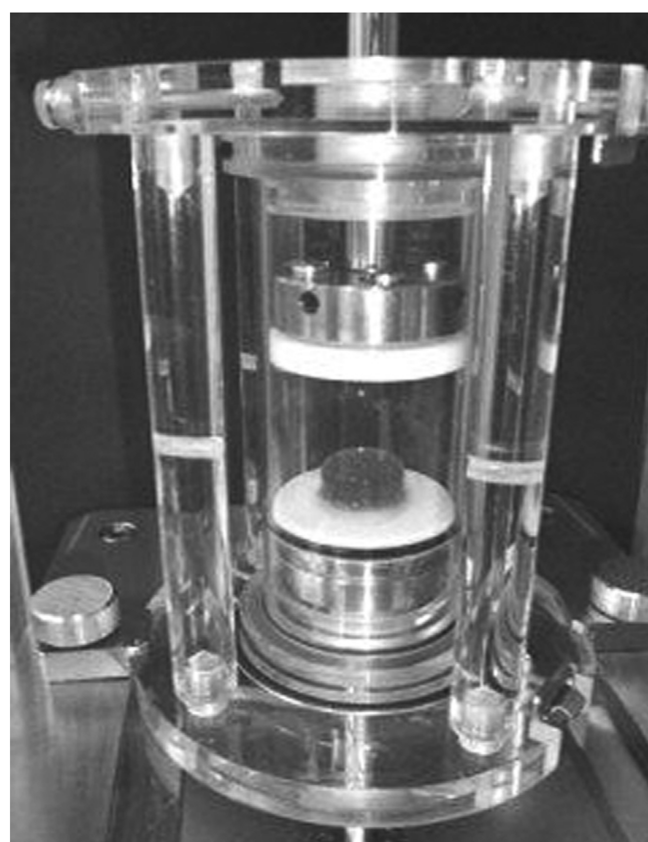

Fig. 1. Instrumental mastication simulator to prepare model bolus.