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Electromyographic texture characterization of hydrocolloid gels as model foods with varying mastication and swallowing difficulties

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ABSTRACT

Eating difficulty of solid foods was analyzed using electromyography (EMG) of five hydrocolloid gels with varying textures. Eleven subjects ate gel samples under normal conditions and EMG activities of both sides of masseter (jaw-closing) and suprahyoid (jaw-opening) muscles were recorded during eating. Differences in EMG variables among samples were analyzed separately before and after the first swallow using repeated-measure statistics. The time before the first swallow was related to chewing effort and was estimated according to numbers of chewing actions, masseter muscle activities per chew and the sum of masseter muscle activities during chewing. EMG variables were also correlated with resistance to fracture, which was extracted as the first principal component from sensory evaluations of gel texture, but did not directly relate to any single parameter from mechanical tests or sensory evaluations. The time after the first swallow to the end of eating corresponded with the number of swallows, the EMG amplitude of suprahyoid muscles during chewing, the sum of masseter activity and suprahyoid muscle activity during the period after the first swallow. These EMG variables corresponded with sensory evaluations of adhesiveness but not with other single mechanical and sensory parameters or principal components. The present data suggest that at least two independent factors affect eating difficulty. Although differences among the five gels were predominantly reflected by chewing difficulty, these remained significant after the first swallow.

1. Introduction

Textures of food products are known to be very important determinants of palatability, quality, and safety of eating (Nishinari, 2009). Because texture is a sensory property (Szczesniak, 2002), sensory evaluations are the most direct method for assessing the effects of texture (Foegeding et al., 2011). Nonetheless, instrumentally measured mechanical parameters have been widely used to characterize and control the quality of food (Bourne, 2002) because they are objective and easy to manage in the food industry (Wilkinson, Dijksterhuis, & Minekus, 2000).

Because eating difficulty is a human perception, sensory evaluations are conducted for quantitative analyses of eating difficulty. In our previous study (Hayakawa et al., 2014), we evaluated the texture of twenty hydrocolloid gels in healthy adults. We gathered basic data of eating difficulty, which was quantified by the effort required to consume a food sample during the period between oral intake and the end of swallowing. Instrumental tests showed the twenty gels widely varied mechanical characteristics to be used as models of semi- and soft-solid foods. The panelists also evaluated the twenty gels in terms of the texture attributes (firmness, cutting effort, elasticity, extensibility, adhesiveness, and melting rate in the mouth). Definitions for these attributes are described in our previous paper (Hayakawa et al., 2014). Principal component analysis aptly characterized the texture attributes of sample gels on the resulting scatter diagram, with the axes of first principal component (PC1) corresponding to resistance to fracture and that of the second principal component (PC2) indicating stickiness and flexibility.

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These two principal components were critical determinants of eating difficulty of gel type foods.

Texture-controlled foods that can be easily chewed and swallowed are increasingly required (Funami, Ishihara, Nakauma, Kohyama, & Nishinari, 2012; Nishinari, 2009; Zargaraan, Rastmanesh, Fadavi, Zayeri, & Mohammadifar, 2013), particularly for dysphagic patients and elderly people. Dysphagia literally means difficulty while eating foods and often reflects functional disorders in swallowing. Dysphagic people may perceive eating difficulty differently from young adults, and in most cases only dysphagic people sense eating difficulty. Indeed, people involved in the food industry, including farmers, food manufacturers, caterers, and food servicemen are generally healthy adults, and thus cannot be used as good sensory panelists for such foods. Although elderly people, patients with dysphagia and people with mastication difficulties are important subjects for studies of eating difficulty, their individual conditions vary considerably. Moreover, training of panelists with dysphagia is extraordinarily difficult because people with dysphagia have trouble in eating foods and suffer unstable conditions.

To develop an alternate method for evaluating eating difficulty, physico-chemical evaluations of foods using instruments are also inadequate because the measured parameters are independent of consumers, and food textures change drastically during eating. Human masticatory measurements that are based on oral physiology have been recently introduced to evaluate food textures and to integrate physical, physiological, and psychophysical approaches (van der Bilt, 2009; Boyar & Kilcast, 1986; Chen, 2009; Foegeding, Çakir, & Koç, 2010; Foegeding et al., 2011; Wilkinson et al., 2000). Electromyography (EMG) of masticatory muscles has been widely used in food texture studies (reviewed by Espinosa & Chen, 2012; Funami, Ishihara, & Kohyama, 2014; González, Montoya, & Cárcel, 2001; Kemsley, Defernez, Sprunt, & Smith, 2003; Woda, Foster, Mishellany, & Peyron, 2006).

Previous studies indicate that the amplitude of EMG activities of masseter muscles correlates with food hardness (Çakir et al., 2012; Espinosa & Chen, 2012; Foegeding et al., 2010, 2011; González et al., 2001; Kemsley et al., 2003; Woda et al., 2006) and the total muscle activity of both sides of masseter muscles prior to swallowing indicates mastication effort (Kohyama, Yamaguchi, et al., 2005).

Mastication of more adhesive foods such as caramels and Japanese rice cakes, leads to greater activity of the suprahyoid muscles, which act in the jaw-opening phase (Çakir et al., 2012; Kohyama, Ohtsubo, Toyoshima, & Shiozawa, 1998; Kohyama et al., 2007; Kohyama, Yamaguchi, et al., 2005; Sakamoto, Harada, Matsukubo, Takaesu, & Tazaki, 1989). Soft foodstuffs such as jellies are eaten through compression between the tongue and the hard palate without chewing, and whereas the associated masseter activity is very weak, suprahyoid activity is more significant (Ishihara et al., 2011; Nakazawa & Togashi, 2000). Suprahyoid muscles also coordinate with tongue movements such as pressing against the hard palate, protrusion, and transportation of food bolus at the beginning or during the oropharyngeal phase of swallowing (Ishihara et al., 2011; Shiozawa, Kohyama, & Yanagisawa, 1999; Taniguchi, Tsukada, Ootaki, Yamada, & Inoue, 2008). Although suprahyoid muscles are active in swallowing water (Taniguchi et al., 2008), their EMG activities increase with the viscosity of liquids (Takahashi, Tsuge, & Ogoshi, 2011), and semi-solid or soft gels (Ishihara et al., 2011). These observations suggest that swallowing effort can be estimated using suprahyoid EMG.

In this study, food textures were characterized in relation to eating difficulty using EMG parameters. Eating difficulty comprises several factors such as difficulty in deforming, cutting off, crushing, moving, gathering chewed fragments, flowing, difficulty in chewing, forming a bolus, and swallowing. Hydrocolloid gels made with various gelling agents provide varying textures and are therefore a useful model of solid foods (Banerjee & Bhattacharya, 2012; Ishihara et al., 2011; Koç et al., 2014). Thus, we evaluated five hydrocolloid gels from different groups of previous cluster analyses of twenty gels that varied widely in texture and characterized by sensory evaluations (Hayakawa et al., 2014).

2. Materials and methods

2.1. Sample gels

Twenty hydrocolloid gels were prepared on the basis of texture design (Funami et al., 2012) to mimic a wide variety of food textures. Ingredients, preparation methods, mechanical testing, and sensory evaluations were reported previously (Hayakawa et al., 2014). Food-grade sucralose sweetener (SAN SWEET® SU-100, San-Ei Gen F.F.I. Inc., Osaka, Japan). was added to hydrocolloid gels at 0.1% (w/v). Sensory scores of the six attributes, i.e., firmness, cutting effort, elasticity, extensibility, adhesiveness, and melting rate in the mouth, as determined in our previous paper, were subjected into cluster analysis (Hayakawa et al., 2014). Subsequently, five gels (#4, #6, #12, #14, and #16) were selected after a discussion with gel texture experts to represent each cluster for the EMG study (Fig. 1). To record varying eating behaviors, the criteria for the selection were demonstrations of different textural attributes and higher hydrocolloid concentrations if the hydrocolloids were identical, because longer oral processing was expected. Ingredients, mechanical properties, eating difficulties, and principal component scores derived from the six textural attributes (Hayakawa et al., 2014) of the five gels are shown in Table 1. Six textural attributes of the five gels are also presented in Fig. 2 (Hayakawa et al., 2014).

All mechanical tests and EMG measurements were conducted at 20 ± 2 °C because gels were served at this temperature in the sensory evaluation. Five kinds of gel were prepared using identical ingredients but on different days to those used in sensory evaluations. Sample gels were stored in a refrigerator and were placed in a test room at 20 °C for 1 h before EMG recordings. Subsequently, samples were cut into specimens of 20-mm diameter and 10-mm thickness and consumed within 1 h. Mechanical properties of gels were confirmed to be similar to those of previous preparations for sensory evaluations using puncture test. The central parts of specimens were compressed at 1 mm/s using a cylindrical probe of 3 mm in diameter.

2.2. EMG measurement

The present study design was approved by the National Food Research Institute Ethics Committee. Eleven volunteers (four men and seven women, mean age 40 years old) participated in this study and gave written informed consent prior to EMG measurements. No subject suffered from symptoms of masticatory or swallowing dysfunction or pain during eating, and none wore dental prostheses. To evaluate eating difficulty using EMG data, subjects were asked to eat normally, which was the most effective mastication because imposed eating resulted in increased muscle work (Kohyama, Hanyu, Hayakawa, & Sasaki, 2010; Mioche, Bourdiol, Martin, & Noël, 1999). Ingredients and mechanical and sensory characteristics of samples were double-blinded. Each sample was served randomly to all subjects at least twice using a plastic spoon.

EMG activities were recorded using bipolar surface electrodes (EL503, Biopac Systems Inc., Goleta, CA, USA) from the left and right masseter muscles (LM and RM) (jaw-closing muscles) and from the suprahyoid muscles (SH) (active in jaw opening and tongue movement). After filtering (10–500 Hz), removal of 50 Hz noise from the power supply and amplification of the original level to 1000 times using three EMG 100C amplifiers (Biopac Systems Inc.),