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Electromyography analysis of natural mastication behavior using varying mouthful quantities of two types of gels

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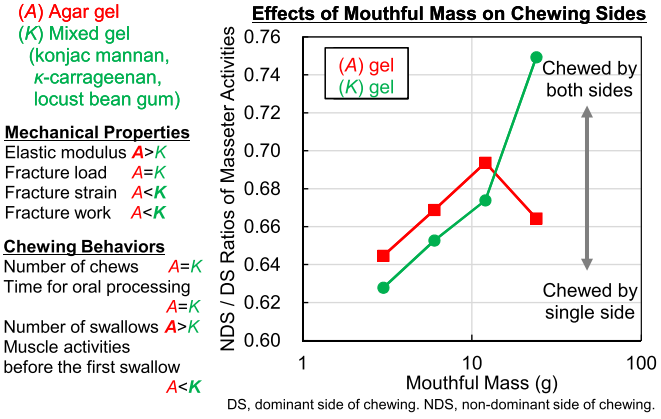
HIGHLIGHTS

- Natural mastication behavior of gel foods was measured by electromyography.
- Two-type gels with similar fracture loads and masses showed similar chewing times.
- Smaller mass and more-elastic type of gels were chewed more with a single side.
- Contribution of both sides is more effective in consuming a portion of gels.
- Smaller mouthfuls induced slower eating with more chews per portion of both types.

GRAPHICAL ABSTRACT



DS, dominant side of chewing. NDS, non-dominant side of chewing.

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ABSTRACT

The objectives of this study were to examine the effects of mouthful quantities and mechanical properties of gels on natural mastication behaviors using electromyography (EMG). Two types of hydrocolloid gels (*A* and *K*) with similar fracture loads but different moduli and fracture strains were served to eleven normal women in 3-, 6-, 12-, and 24-g masses in a randomized order. EMG activities from both masseter muscles were recorded during natural mastication. Because of the similar fracture loads, the numbers of chews, total muscle activities, and entire oral processing times were similar for similar masses of both gel types. Prior to the first swallow, the more elastic *K* gel with a higher fracture strain required higher muscle activities than the brittle *A* gel, which had higher modulus. Majority of subjects had preferred sides of chewing, but all subjects with or without preferred sides used both masseters during the consumption of gels. Similar effects of masses and types of gels were observed in EMG activities of both sides of masseters. Contributions of the dominant side of chewing were diminished with increasing masses of gels, and the mass dependency on ratio of the dominant side was more pronounced with *K* gel. More repetitions of smaller masses required greater muscle activities and longer periods for the consumption of 24-g gel portions. Reduction in the masses with an increased number of repetitions necessitated slower eating and more mastication to consume the gel portions. These observations suggest that chewing using both sides is more effective and unconsciously reduces mastication times during the consumption of gels.

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1. Introduction

Food texture plays an important role in food palatability and may thus modify natural eating behaviors [1,2]. Texture is defined as the mechanical, geometrical, and surface properties that are perceptible using human receptors [1], and food textures perceived during oral processing are greatly influenced by the mechanical properties and sizes of the food items [1–3]. Electromyography (EMG) of masticatory muscles has been widely used to quantify mastication behaviors [2,4–7]. Harder foods generally require greater EMG activities of the jaw-closing muscles, and longer mastication times with a greater number of chews have been reported in association with these [4–9]. Moreover, previous EMG studies examining the quantity of each mouthful showed that larger masses or volumes of food required longer oral processing times [4, 10–18].

Forde et al. [19] observed free-eating behaviors and reported that softer foods were generally consumed with larger bites (mouthful masses), leading to faster eating rates. Moreover, smaller bites of semi-solid foods increased oral processing times and decreased food intake [20], whereas harder foods resulted in reduced energy intake that could be sustained till the next meal [21]. Other studies that examined young subjects who ate quickly showed a significantly lower number of chews, shorter durations of chewing, and greater bite size were seen to be associated with a smaller number of bites in subjects who ate rice balls [22]. Finally, a meta-analysis showed that slow eating rates were associated with reduced energy intake [23].

In preceding studies [18,24], EMGs were recorded during natural chewing of model food gels. These experiments showed that mastication times, number of chews, and number of swallows required for gels with various textures were approximately proportional to 0.7 times to the power of gel masses ranging from 3 to 24 g, and this relationship could be used to make predictions. Studies using fixed masses of foods with different shapes reported that the geometrical characteristics of gels did not influence eating behaviors [14]. Specifically, blocks, small pieces, and thin slices of apples with a fixed mass did not showed significant differences in EMG variables during natural mastication [25].

Forced mastication with a fixed number of chews has also been tested by multiple researchers. In general, more chews per mouthful of food were seen to be associated with reduced eating rates [26–29]. Recently, Smit et al. [27] confirmed "Fletcherism," an idea initially propagated by Fletcher which suggests that chewing one mouthful of food many times reduces the food intake and the eating rate despite faster chewing cycles. Increased number of chews also reduced the energy intake of one meal and modulated the plasma gut hormones, insulin and glucose [26,28]. Slow eating with a greater number of chews reportedly increased diet-induced thermogenesis, postprandial blood flow [29], and postprandial glucose responses in glycemic indices measurements [30,31]. However, if fixed modes of chewing were imposed, subjects could control chewing forces and rates of eating that were unnatural.

Eating small masses of gel-type foods appeared to be effective in preventing overeating, which often leads to obesity and other health problems [7]. Moreover, to avoid risk of suffocation in children, preparation of gels in cup volumes greater than the size of their mouth [32] and serving in small spoonful masses were recommended.

The objectives of this study were to quantify the effects of gel masses on natural mastication behaviors using portions of gel foods. We hypothesized that smaller mouthful masses and greater number of the mouthfuls increase mastication efforts and reduce rates of eating fixed amounts of food portions. In addition, the chewing side may change more frequently with food items that are more difficult to masticate. The subjects performed natural mastication without being instructed to control chewing forces so as to allow investigation of habitual eating behaviors instead of under controlled conditions such as fixed number of chews and side of chewing.

Two types of gel foods with similar fracture loads (agar gel and konjac jelly) were prepared as the present food samples. Previous studies have reported that the number of chews and mastication times were alike for the gels with similar masses [18,33]. Accordingly, hydrocolloid gels provide models of solid or semi-solid foods consumed by mastication using the back teeth as the mechanical properties and sizes of these gels can be easily controlled [34–37]. Moreover, gel alternatives for food items such as cooked rice are extensively consumed as staple foods, and jellies are often served to dysphagic patients and elderly people with mastication difficulties [7,35,38,39]. The chemical components of these hydrogels do not change during oral processing, as salivary enzymes do not decompose non-starch ingredients. In addition, these hydrogels contain sufficient water to minimize the amount of saliva required for bolus formation and lubrication. Hence, size reductions with respect to structural threshold [40] are the main requirement for oral processing, and reduction of mouthful masses is easy and does not require changes in the method of food preparation. Finally, EMG recordings provide quantitative evidence of the effects of serving sizes, and also allow simultaneous evaluation of how the mechanical properties of foods influence mastication efforts and rates.

2. Materials and methods

2.1. Participants

This study design was approved by the National Food Research Institute Ethics Committee. Eleven women volunteers (mean age, 36.5; range, 22–49 years) participated in this study were common in our previous study [18]. Women were selected as there may be gender differences in mastication behavior [18]. Their heights and body mass indices ranged from 150 to 170 cm and 18 to 23 kg/m^2, respectively. The subjects were free of any masticatory or swallowing dysfunctions and did not use removable denture prostheses. Moreover, they were all right-handed. Written informed consent was collected before EMG recordings, and the subjects were asked to eat sample gels as they normally would to allow assessment of habitual eating behavior.

2.2. Sample gels

Two types of hydrocolloid gels were prepared in cups (diameter 60 mm and height 25 mm) as described in the preceding study [18]. All ingredients were food grade and provided by San-Ei Gen F. F. I., Inc. (Osaka, Japan). Type one (*A*) gel contained a 1.2% w/w agar (GEL UP® J-3531), while type two (*K*) gel was a mixture of 0.26% w/w konjac mannan (VIS TOP® D-2134), 0.46% w/w κ-carrageenan (CARRAGEENAN CS-606), and 0.46% w/w locust bean gum (VIS TOP® D-2050). Both gels contained 25% w/w sucrose, 0.15% w/w sodium citrate, and 0.22% w/w anhydrous citric acid. The fracture load of both types of gels was similar, the elastic modulus was about 30-fold higher in *A* gel, fracture strain and work were much higher in *K* gel (Table 1), as reported previously [18]. The load at 90% strain and work until 90% strain in *A* gel have not been reported previously and are significantly greater than those in *K* gel (Table 1).

2.3. EMG measurements

The EMG activities were recorded from the left and right masseter muscles (LM and RM, respectively) using bipolar surface electrodes (EL503, Biopac Systems Inc., Goleta, CA, USA) [17,18,24]. Briefly, the skin was wiped with cotton soaked in 70% ethanol, masseter electrodes were carefully placed along the muscle fibers on both sides symmetrically and approximately 2 cm apart, and a ground electrode was placed on the left wrist. Subjects were asked to clench their jaw, tap their teeth several times, and swallow a small amount of water to check conditions prior to testing the gels. The electrodes were replaced if unstable baseline signals and/or significant noises were detected, or if the magnitudes