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Comparison of mechanical analyses and tongue pressure analyses during squeezing and swallowing of gels

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A B S T R A C T

Dysphagic patients are fed soft meals made of gels and process them by squeezing the food with the tongue, which reduces food size. Although the gels are designed based on rheological analyses, the impact of the initial gel texture on tongue kinetics is not known. This study investigated the effect of gel consistency on tongue pressure during squeezing and swallowing and compared results of the mechanical analyses. Fifteen healthy young subjects participated in this study. Tongue pressure during squeezing and swallowing was measured by a sensor sheet with five measuring points. Five ml of water and six gel samples prepared using two gelling agents at three concentrations each were used as test materials. Subjects were instructed not to chew the food but to squeeze it using their tongue. The shape of the tongue pressure waveform during the initial squeeze was similar to the stress–time curve using a texture analyzer. However, the sequential order of tongue pressure during squeezing and swallowing was different. Tongue pressure during the initial squeeze was affected by gel consistency. The amplitude of tongue pressure during swallowing increased as gel consistency increased, but the duration of pressure was not affected. The slopes of tongue pressure generation were not affected by gel consistency, although the mechanical measurements showed increases in these slopes with increasing gel consistency. These results suggest that findings regarding characteristics of tongue movement during squeezing and textural properties of gels might be useful for food design and clarification of oral physiology.

1. Introduction

1.1. Dysphagia and food texture

Swallowing requires functional coordination of related muscle activities in the oro-facial region. In particular, the tongue plays an important role in squeezing, masticating, and propelling the bolus. In stroke patients (Ickenstein et al., 2012; Martino et al., 2005) or glossectomy patients (Logemann et al., 1993), difficulties with tongue movements are closely related to dysphagia. In the clinical setting, for the sake of safety, patients with swallowing difficulties are often fed viscoelastic foods such as jellies, puddings, and thickened liquids. Providing adequate meals is critical for patients with swallowing difficulties (Duncan et al., 2005).

The use of texture-modified diets and thickened fluids in patients with swallowing difficulties is supported by scientific literature (Penman & Thomson, 1998). O'Gara (1990) suggested guidelines for appropriate modification of food consistencies according to the symptoms of the swallowing disorder. Curran et al. (Curran & Groher, 1990) developed and disseminated an aspiration risk reduction diet that includes three choices dependent on the need for fluid alterations. As a result, the dietitian can make recommendations and adjustments to texture-modified diets.

However, in many cases, it may be difficult to supply an appropriate diet to patients with swallowing difficulties who live at home. Several food products using viscoelastic materials have been

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developed and marketed to help these patients (Wendin et al., 2010). The British Dietetic Association, in association with the Royal College of Speech and Language Therapists (NPSA, 2012), and the Swedish research project (Wendin et al., 2010), in collaboration between dietitians, speech language pathologists, and food companies, have published formal guidelines for texture-modified foods. In Japan, standards on hardness, adhesiveness, and cohesiveness have been established by the Consumer Affairs Agency of Japan as “Special foods for people with swallowing difficulty” (Consumer Affairs Agency of Japan, 2009). Most Japanese food companies are developing commercial products based on these recommendations, which were based on two-bite compression of samples using a flat cylindrical acrylic plunger, as often found in texture profile analyses. However, factors affecting ingestion in humans are more complicated than those addressed by procedures used in instrumental texture profile analyses.

1.2. Squeezing

Dysphagic patients might be given soft meals such as jellies and puddings made of gels, and they process these foods by squeezing them with the tongue to reduce the size of the pieces. In general, soft and homogeneous foods are preferred over hard and inhomogeneous foods due to the ease of bolus formation. Solid foods are chewed to a lesser degree than soft foods and should be mixed with saliva to increase lubrication before swallowing, as illustrated by the mouth process model (Hutchings & Lillford, 1988). To change the mechanical properties of foods, oral processing methods, including mastication by teeth and pressing the tongue against the hard palate, are important. Though modulation of masticatory movements had been clarified using measurement of electromyographic (EMG) activity and jaw movements, only few reports (Ishihara et al., 2011; Nakazawa & Togashi, 2000; Takahashi & Nakazawa, 1991) have focused on the squeezing behavior between the tongue and the hard palate. Arai et al. demonstrated that soft gels containing agar or gelatin at low concentrations were compressed between the tongue and the hard palate without chewing, but high concentration gels were chewed (Arai, Yamada, & Nishizaka, 1992). Thus, it is likely that tongue squeezing is affected by food texture. However, it is difficult to precisely assess the functional involvement of the tongue during squeezing due to its complexity and highly flexible movements.

We developed a novel sensor sheet to measure tongue pressure simply and evaluate tongue movements during chewing and swallowing (Hori et al., 2009). The ultra-thin sensor sheet in this system does not inhibit tongue movement or occlusal contact and enables us to clarify the influence of food texture on tongue kinetics. The device has been used in young and elderly healthy subjects (Hori et al., 2011; Tamine et al., 2010) and stroke patients (Hirota et al., 2010; Hori, Ono, Iwata, Nokubi, & Kumakura, 2005; Konaka et al., 2010).

1.3. Purpose

We hypothesized that tongue movement during squeezing and swallowing would be modulated by food texture. Furthermore, we assumed that some findings regarding tongue pressure would be identical to findings of mechanical assessments by the uniaxial compression test. In this study, we evaluated tongue squeezing and bolus propelling to the pharynx by tongue pressure using gels from two kinds of gelling agents with different textural properties. The purpose of the present study was to investigate differences in tongue pressure during squeezing and swallowing of different gels and to compare tongue pressure analyses with mechanical analyses.

2. Methods

2.1. Subjects

Fifteen healthy subjects participated in this study (11 men and 4 women, mean age 27.6 ± 2.0 years, range 24–32 years). Participants did not have any disturbances in mastication or deglutition, abnormalities in the number or position of teeth (except wisdom teeth), a history of orthodontic treatment or temporomandibular disorders, or abnormalities in occlusion. Written informed consent was obtained from each subject after explanation of the aims and methodology of the study. All study protocols were approved by the ethics committee at Niigata University Faculty of Dentistry.

2.2. Tongue pressure measurement

We used a tongue pressure measuring system and a T-shaped pressure sensor sheet with five measuring points (Hori et al., 2009) (Swallow Scan, Nitta, Osaka, Japan, Fig. 1). This sensor sheet comprises two 0.05 mm resin film sheets. Special electro-conductive ink is formed into a film over an electrode. Two resin sheets were attached together with adhesive applied to edge of sheet, so the thickness of the sensor sheet is about 0.1 mm. Electrical resistance of sensor cells under no load is almost infinite and decreases in inverse proportion to applied force. Each electrode reads changes in electric resistance values at a sampling rate of 100 Hz. Pressure measured by the sensors is thus transmitted in real time to a personal computer in which the data are displayed and saved. The conducting cable between electrodes is narrow enough to be attached closely to the curvature of the hard palate.

Three measuring points or channels (Chs. 1–3) were placed along the median line (Ch. 1 was set at the anterior-median position, Ch. 2 was set at the mid-median position, and Ch. 3 was set at the posterior-median position), and two sensors (Chs. 4 and 5) were placed on the posterior-circumferential region of the hard palate. The size of all sensing points was 3 mm diameter. A small, medium, or large sensor sheet was selected for each participant so as to standardize the location of each measuring point on the hard palate. The lengths between sensing points were showed in Fig. 1. The subject who had extremely large or small palate was avoided in this experiment. The medium or large size of sensor sheet was used in this experiment for placing suitable position. Before recording, the sensor sheet was attached to the palatal mucosa with a sheet-type denture adhesive (Touch Correct II, Shionogi Co., Osaka, Japan), with the cable connected to the computer exiting the oral cavity via the oral vestibule so as not to inhibit natural swallowing. Because of its “reversible” structure, the cable of the sensor sheet could be placed on either side of the participant, depending on the state of dentition. After attachment of sensor sheet, a calibration was performed. There was a small hollow in the cable of the sensor sheet. The negative pressure was given to the hollow using a vacuum pump, then any pressure within the range of measurement could be given by the atmospheric pressure. In the present study, we applied about 10 kPa for calibration. The range of measurement of the sensor sheet was almost 0–40 kPa.

To record the timing of larynx movement with swallowing, a microphone (JM0116, Ono Sokki, Kanagawa, Japan) was attached at the inferior border of the cricoids and swallowing sounds were recorded.

2.3. Food sample

The liquid (5 ml of water) and six gel samples prepared using two types of gelling agent (SAN SUPPORT® G-1014 and KELCOGEL®; San-Ei Gen F.F.I., Inc., Osaka, Japan) were used as test samples. SAN