Physiology & Behavior 189 (2018) 92–98

Contents lists available at ScienceDirect

Physiology & Behavior

journal homepage: www.elsevier.com/locate/physbeh

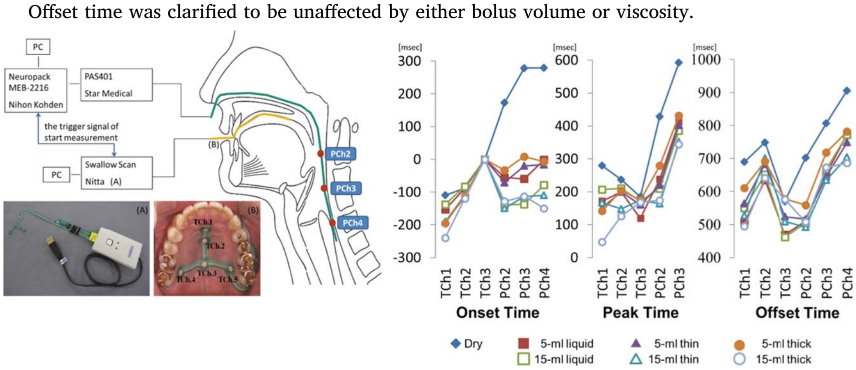
Effect of bolus volume and flow time on temporospatial coordination in oropharyngeal pressure production in healthy subjects

Jitsuro Yano[a,*], Yoichiro Aoyagi[b], Takahiro Ono[c], Kazuhiro Hori[c], Wakami Yamaguchi[d], Shigehiro Fujiwara[c], Isami Kumakura[e]

[a] *Department of Sensory Science, Faculty of Health Science and Technology, Kawasaki University of Medical Welfare, 288 Matsushima, Kurashiki, Okayama 701-0193, Japan*
[b] *Department of Rehabilitation Medicine I, School of Medicine, Fujita Health University, 1-98 Dengakugakubo, Kutsukake-cho, Toyoake, Aichi 470-1192, Japan*
[c] *Divisions of Comprehensive Prosthodontics, Niigata University Graduate School of Medical and Dental Sciences, 2-5274 Gakkocho-dori, Chuo-ku, Niigata, Niigata 951-8514, Japan*
[d] *Central Research Institute, Kawasaki Medical School, 577 Matsushima, Kurashiki, Okayama 701-0192, Japan*
[e] *Senri Rehabilitation Hospital, 4-6-1 Onoharanishi, Minoh, Osaka 562-0032, Japan*

GRAPHICAL ABSTRACT

Bolus volume affected onset time, and bolus viscosity affected onset time and peak time.
Offset time was clarified to be unaffected by either bolus volume or viscosity.



ARTICLE INFO

Keywords:
Tongue pressure
Pharyngeal pressure
Swallowing
Dysphagia
Flow time
Bolus volume

ABSTRACT

The effects of bolus volume and flow time on the sequential coordination of tongue pressure (TP) and pharyngeal pressure (PP), which are important in the biomechanics of swallowing, are unclear. In this study, we measured TP and PP simultaneously in 10 healthy adults at multiple points during dry swallowing and the swallowing of 5 ml and 15 ml of liquids with different viscosities, and investigated changes in the timing of the onset, peak, and offset of these pressures. TP was measured using a sensor sheet system with five measuring points on the hard palate, and PP was measured using a manometry catheter with four measuring points. The order and correlations of sequential events, such as onset, peak, and offset times of pressure production, at each pressure measuring point were analyzed on the synchronized waveforms. We found that the differences between the TP and PP onset times decreased when the bolus volume was larger. The change in bolus volume had very little effect on peak time or offset time. The flow time of the bolus affected the appearance of onset and peak time for both TP and PP. A time difference between TP and PP emerged as the flow time increased, with TP starting to appear before PP. This may be the first detailed analysis of pressure-flow dynamics that treats the mouth and pharynx as a single

* Corresponding author.
E-mail addresses: yano@mw.kawasaki-m.ac.jp (J. Yano), yyy@rc5.so-net.ne.jp (Y. Aoyagi), ono@dent.niigata-u.ac.jp (T. Ono), hori@dent.niigata-u.ac.jp (K. Hori), wakami@med.kawasaki-m.ac.jp (W. Yamaguchi).

https://doi.org/10.1016/j.physbeh.2018.03.006
Received 30 December 2017; Received in revised form 3 March 2018; Accepted 5 March 2018
Available online 06 March 2018

functional unit. We believe that our analysis is an important step toward extending future research to include a wider range of age groups and dysphagia patients.

1. Introduction

In the act of swallowing, the jaw, tongue, pharynx, larynx, and various other swallowing-related organs move sequentially in order within one second. Among these movements, the lingual and pharyngeal constrictor muscles play an extremely important role in bolus transport, ejecting the bolus smoothly from the mouth into the pharynx and from there into the esophagus by contracting in a precisely timed sequence to generate swallowing pressure [1–8]. In patients with dysphagia, bolus transport is impaired, leading to oral and pharyngeal residue, laryngeal penetration, and aspiration [9,10]. Larger boluses in particular have a higher risk of aspiration or laryngeal penetration [11], and substances with low flow time (liquids) flow rapidly from the mouth into the pharynx, leaving insufficient time for airway protection [12].

Altering the consistency of food and adjusting bolus volume and flow time is generally practiced in the clinical care of dysphagia patients [1,13–15]. Adjusting the properties of foods and liquids may make swallowing safer and easier [16].

A number of studies have also reported the effect of bolus volume and flow time on swallowing function in healthy individuals [1,11,17–24]. The evaluation methods used in those studies have included ultrasound [18], videofluorography (VF) [1,11,20], electromyography [17,19,21,23], computed tomography (CT) [24], and swallowing sound [22]. However, none of those methods are capable of evaluating the pressure-flow dynamics that occur as the bolus passes through the intraluminal space from the mouth to the esophagus, including the pressure of the tongue against the palate (tongue pressure, TP) and the force exerted by the constriction of the pharyngeal muscles (pharyngeal pressure, PP), as well as the timing with which these appear and the timing of the relaxation of the upper esophageal sphincter (UES).

Conventionally, intra-oral pressure and PP have been measured using different individual devices. Intra-oral pressure has been measured with an air-filled bulb placed inside the mouth [25,26]. Hori et al. [3] developed an extremely thin sensor sheet capable of measuring the contact pressure of the tongue at multiple points on the palate (i.e., TP), and showed the anterior-to-posterior order of the generation of this pressure in the mouth and its pressure gradient in healthy individuals. Pharyngeal pressure has been well reported, including analyses of maximum PP, the time for which PP is maintained, and UES relaxation time [27–29]. Recently, more studies have been using high-resolution manometry (HRM) to investigate PP, and it can be seen from the topography obtained using HRM that pressure is disseminated from the upper pharynx to the esophagus [30,31].

Studies have found that there is a certain amount of coordination between the timing of the appearance of TP and the movement of the hyoid bone and larynx [32], and it is probable that there is also some coordination between the generation of TP and PP. In a previous study, we produced simultaneous records using a TP sensor sheet to measure TP and manometry to measure PP, and discovered that TP and PP are sequentially coordinated during saliva swallowing in healthy individuals [33]. The onset and peak of TP appear before those of PP, with the onset of PP time-locked to the peak of TP, and this association is particularly strong with the onset of TP in the midline posterior region. If these pressure-flow dynamics are adjusted according to bolus volume and flow time, taking this into account could enable food preparation to be tailored more closely to the individual function of dysphagia patients.

In this study, we therefore investigated the effect of bolus volume and flow time on the temporospatial coordination of oropharyngeal pressure production in healthy adults, using a system for the simultaneous measurement of TP and PP.

2. Materials and methods

2.1. Subjects

Ten healthy subjects (3 men and 7 women; age range, 21–27 years; mean age, 22.1 ± 2.1 years) without disturbances of mastication and deglutition, abnormalities in the number or position of teeth except for the third molar, history of orthodontic treatment and temporomandibular disorders, and abnormality in occlusion were included in this study.

As for the subject number in the current study, we used the sample size software G*Power (v 3.1.9.2, Franz Faul, University of Kiel, Kiel, Germany) to calculate. We calculated the sample size as nine after setting the power (1-Beta) 0.80, Alpha 0.05, effect size 0.40, number of measurements 5. Written, informed consent was obtained from each subject after explaining the aim and methodology of the study. This study received approval by the ethics committee of Kawasaki University of Medical Welfare.

2.2. Experimental setting

2.2.1. Volume and flow time of bolus

Subjects were first asked to sit on a chair with their head vertical to the floor. They were then asked to swallow either saliva or a bolus with different volume and flow time according to the examiner's instructions, with the TP sensor sheet on the hard palate and the manometry catheter through the pharynx. The boluses consisted of six different types: 5 ml and 15 ml of liquid, thin liquid (1.0%w/v), and thick liquid (2.5%w/v). The viscosities of the thin and thick liquids were adjusted using a starch-baced thickening agent (Toromeiku-SP, Meji, Tokyo, Japan). The thin and thick liquids were obtained by adding 2.5 g of thickening agent to 250 ml and 100 ml mineral water. A subject swallowed either saliva or each bolus five times, for a total of 35 swallows. The order of task completion was randomized by block condition for each subject. Block condition was 5 task of 7 block per task.

The viscosities of the liquid, thin liquid, and thick liquid were measured using the line spread test (LST) [34,35] on a different day. The LST was performed using a flat plate with concentric circles and six axes showing the radius of each circle. A cylinder with a diameter of 30 mm, filled with 20 ml of liquid, was placed on the center of the circles. The cylinder was lifted and the liquid was allowed to spread for 30 s. The flow limits of the liquid along the six axes were read and averaged. This test was performed three times to obtain the average. The average LST values for the liquid, thin liquid, and thick liquid were 43.9 ± 1.4 mm, 41.0 ± 0.6 mm, and 31.1 ± 0.4 mm, respectively. These viscosities are commonly used in swallowing examinations. The thin liquid and thick liquid are equivalent in flow time to the mildly thick and extremely thick liquids described in the Japanese Dysphagia Diet 2013 established by the Dysphagia Diet Committee of the Japanese Society of Dysphagia Rehabilitation [35].

2.2.2. Settings of measurement devices

Tongue and pharyngeal pressures were recorded synchronously during swallowing. To synchronize data, the trigger signal to start measurement from a Swallow Scan tactile sensor system (Nitta, Osaka, Japan) was sent to an electrode junction box (Neuropack MEB-2216,