Duration of apnea on mastication and swallowing

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To clarify the respiratory kinetics associated with swallowing, we measured and analyzed the respiratory flow rates of eight healthy adult males during masticatory swallowing, including the points at which respiratory arrest and resumption occurred. We measured nasal respiratory kinetics using a differential pressure pneumotachograph. Laryngeal movement was determined using an acceleration pickup. We tested subjects during free masticatory swallowing of 12 g and 24 g portions of cooked rice. Subjects were seated in a vertical position. Waveforms of respiratory kinetics and of laryngeal movement were simultaneously recorded on a data recorder and analyzed. The food volume was not directly proportional to the number of swallowing. The mean duration of apnea during swallowing in subjects eating 24 g of rice was longer than in those eating 12 g, although this difference was not significant. There was no significant difference in the duration of apnea between interposed swallows and terminal swallows. The respiratory pattern during masticatory swallowing was expiration-swallowing-expiration in 81.2% of the subjects. The results of this experiment suggest that swallowing volume does not influence the duration of apnea during masticatory swallowing. (J Osaka Dent Univ 2013; 47: 227-231)

Key words: Respiration; Mastication; Deglutition; Swallowing volume; Nasal respiratory kinetics

INTRODUCTION

Chewing and swallowing movements have been described using a five-stage model based on command swallowing.1 However, the command swallowing model does not describe chewing and swallowing movements under normal eating conditions. Currently, swallowing is classified into four modes: command, masticatory, pharyngeal, and consecutive swallowing.2 The swallowing mode employed while eating a standard diet is masticatory swallowing. Masticatory swallowing has been described using a process model.3 In this model, food crushed during mastication is transported to the mesopharynx, where the presence of a food bolus in the oral cavity and pharynx initiates the swallowing reflex. However, a detailed mechanism of masticatory swallowing that incorporates the effects of swallowing volume, frequency of swallowing, and the physical properties of food remains to be clarified.4-6 The frequency and other characteristics of food bolus transport to the mesopharynx during mastication (stage II transport) are also unclear.

Several studies have reported respiratory patterns, respiratory arrest, and duration of apnea during command swallowing.7-9 Similar studies of respiratory patterns and arrest during masticatory swallowing have been performed.9,10 However, the pressure, temperature, and torso circumference measurements used to evaluate respiration were influenced by the external environment in these studies, leading to variations in the data.9,11 Respiratory arrest and initiation points were also unclear in these studies. Therefore, respiratory kinetics during masticatory swallowing remain to be clarified. In this experiment, we measured and analyzed subjects' respiratory flow rates to clarify respiratory kinetics during masticatory swallowing.
MATERIALS AND METHODS

Subjects
The subjects were eight males without subjective or objective abnormalities in swallowing or respiratory functions between 23 and 29 years of age with a mean of 26 years. The methods and significance of the study were explained to the subjects before their participation, and informed consent was obtained in accordance with the Helsinki Declaration (Ethics Review Board of Osaka Dental University, Vol.100507).

Measurement of nasal respiratory kinetics
Nasal respiratory kinetics were measured using the Pneumotach System (RSS100HR ; Hansrudolph, Shawnee, KA, USA). Each subject’s nasal region was covered with a specially ordered nasal mask (RSS100 HR ; Hansrudolph). After confirming a leak-free seal, the sensor flow range was established from 0 to 160 L/min, and the nasal respiratory flow rate was determined.

Measurement of laryngeal movement
Laryngeal motion was measured as an indicator of swallowing movement. An acceleration pickup (PV-90 B, RION, Tokyo, Japan) was applied with surgical tape to the skin at the anterior incisure of the laryngeal thyroid cartilage. Simultaneously, the acceleration pickup was fixed on a resin plate of 1.5 cm × 1 cm, as described by Ohara. The waveforms obtained were amplified at a sensitivity of 0.48 millivolts per division (mv/DIV) using a charge amplifier (PV-90B ; RION).

Block diagram
Figure 1 shows a diagram of the experimental design. The waveforms of respiratory kinetics and of laryngeal movement were simultaneously recorded on a data recorder (SIR-1000i ; Sony, Tokyo, Japan), and transferred to a personal computer for analysis.

Experimental methods
Cooked rice was used as the test food at a volume of either 12 g, which is a mouthful, or 24 g. The latter volume filled the greater portion of the oral capacity at rest in most subjects. Experimental conditions were free masticatory swallowing while sitting in a vertical position. Subjects were instructed to eat freely as usual, and to signal when oral food volume reached zero, indicating completion of the trial session. Trial sessions were randomly conducted three times. We confirmed that symptoms such as choking and nausea did not occur during or after the experiment, and that respiration was stable at the time of measurement.

Analysis of number the of swallows per trial session
We measured the number of swallows per trial session. The final swallow in each session was regarded as terminal swallowing, and swallows before the terminal phase as interposed swallowing.

Analysis of nasal respiratory kinetics during masticatory swallowing
A representative respiratory locus and laryngeal movement waveform during rice mastication and swallowing is shown in Fig. 2. Using the respiratory flow rate, we measured the duration in seconds of apnea during swallowing as the interval between swallowing-related nasal respiratory arrest and nasal respiratory resumption. Statistical analyses were performed using Excel Statistics 2008 software Version 1.12 (SSRI, Tokyo, Japan). The number of swallows and the duration of apnea during swallowing were compared using the t-test.
RESULTS

Number of swallows during masticatory swallowing

The data on the number of swallows during masticatory swallowing are shown in Fig. 3 and Table 1. The mean number of swallows during masticatory swallowing of 12 g and 24 g of test food was 2.5 and 4.3, respectively, which represented a significant difference (p < 0.01). In all subjects, the number of swallows increased with increasing food volume. However, subjects A and E showed similar numbers of swallows for both portions in some trial sessions.

Duration of apnea during masticatory swallowing of the 12 g and 24 g portions

Data on the duration of apnea while swallowing the 12 g and 24 g portions are shown in Fig. 4 and Table 2. Overall, the mean duration of apnea while swallowing the 12 g and 24 g portions was 0.78 and 0.81 seconds, respectively. There was no significant difference between these values. In five of the eight subjects (subjects A to E), the duration of apnea during swallowing increased with increased food volume. In three of these, the difference was significant. In the other three subjects (Subjects F, G, and H), the duration of apnea while swallowing the 12 g portions was greater than for the 24 g portions.
Duration of apnea during interposed swallowing and terminal swallowing
The data on the duration of apnea during interposed swallowing and terminal swallowing are shown in Fig. 5. The duration of apnea was 0.80 seconds, regardless of the type of swallowing. There was no significant difference between the two.

DISCUSSION
Measurement devices
Temperature sensors, pressure sensors, and plethysmographs have been used to measure respiratory kinetics during swallowing. However, in these studies temperature, pressure, and torso circumference were influenced by many factors, such as low sensor sensitivity, leading to variations in the data. The Pneumotach System, a differential pressure air flow meter, measures the differential pressure related to air currents passing the pneumotachograph and converts measurements to flow rates. Environmental fluctuations, such as temperature or gas composition, do not influence measurements and there are no problems with sensor sensitivity. This system facilitates the recognition of respiratory arrest and the accurate measurement of short (1 second or less) intervals of apnea during swallowing. In masticatory swallowing, the swallows during mastication are serially measured. The Pneumotach System, which is not influenced by environmental changes, may be useful for such measurement.

Interposed swallowing and terminal swallowing
Because interposed swallowing occurs during the semi-automatic movement of rhytmical mastication, it may start more reflexively than terminal swallowing. By contrast, terminal swallowing may initiate more voluntarily, because a food bolus retained in the oral cavity is transported to the pharynx. Therefore, the mode of swallowing may differ between interposed and terminal swallowing. There may also be differences in respiratory kinetics during interposed versus terminal swallowing. In this experiment, swallowing during trial sessions was classified into two types, interposed and terminal swallowing, and the results were compared.

Number of swallows and swallowing volume during masticatory swallowing
During masticatory swallowing, food is crushed through mastication, and swallowed in several portions by division of the food bolus. This pattern differs from command swallowing, in which a designated volume of food or liquid is swallowed at once. In this experiment, the number of swallows increased with increasing test food volume. However, when the food volume was doubled, the number of swallows did not double. The number of swallows was similar for the 12 g and 24 g portions in some trial sessions. During masticatory swallowing, swallowing volume is not always similar within a trial session because the swallowing volume during interposed swallowing is significantly greater than during terminal swallowing. In addition, saliva volume and the size of the post-mastication food bolus influence swallowing volume. Therefore, the test food volume was not directly proportional to the number of swallows, which may explain why the number of swallows was similar for the 12 g and 24 g portions in some trial sessions.

Relationship between test food volume and duration of apnea during swallowing
In the case of command swallowing, the duration of apnea increases with increased swallowing volume. However, in this experiment, there was no volume-related increase in the duration of apnea. Differences in swallowing volume may explain this finding. Even when the same volume of food is ingested, a portion of the test food is transported to the pharynx (stage II transport) before the onset of swallowing. The volume of the food bolus remaining in the oral cavity immediately before swallowing is variable. The frequency of stage II transport varies among individuals and with the physical properties of the food.

Duration of apnea during interposed swallowing and terminal swallowing
The swallowing volume during interposed swallowing is larger than during terminal swallowing. In command swallowing, the duration of apnea increases with increased swallowing volume. We therefore predicted that in masticatory swallowing the duration
of apnea during interposed swallows might be longer than during terminal swallows. However, the duration of apnea during both interposed and terminal swallows in this experiment was 0.80 seconds, with no significant difference.

Nasopharyngeal closure occurs before glottic occlusion during swallowing.19,20 Our measurements of respiratory arrest during swallowing are based on nasopharyngeal closure and not glottic occlusion. Okada13 compared the duration of nasopharyngeal closure during interposed and terminal swallowing using contrast-enhanced radiography, and reported no significant difference in the duration of apnea between interposed and terminal swallowing (0.61 and 0.54 seconds, respectively). In our experiment we likewise found no difference in the duration of apnea between interposed and terminal swallowing, though the swallowing volume differed. This finding suggests that the duration of apnea during masticatory swallowing is not influenced by swallowing volume because of semi-automatic movement and rhythmical mastication, and that the duration depends on differences in the degree of involuntary and voluntary movement during interposed versus terminal swallowing.

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REFERENCES