Coordination of Laryngeal Movements and Orofacial Muscle Activities in Swallowing

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Abstract: The purpose of the present study was to investigate the coordination between the muscle activities of the masticatory, facial and suprahyoid muscles, and the action of the oral, pharyngeal and laryngeal organs in healthy subjects during chewing and swallowing barium bread. Videofluorography (VF) and electromyography (EMG) were recorded while subjects took in, masticated and swallowed the barium bread.

The following results were obtained: in the pharyngeal stage of swallowing, a monophasic wave was observed during laryngeal movement. The reproducibility was confirmed in the relationship between the laryngeal movement wave and bolus position when swallowing. The duration of muscle activity in the masticatory muscles, orbicular oris muscle and suprahyoid muscle during swallowing was significantly longer than in chewing. In the temporal relationship between laryngeal movement and muscle activities, the temporal and masseter muscles began the activities before the onset of the monophasic laryngeal movement, whereas the digastric and mylohyoid muscles were activated almost simultaneously or slightly after onset.
I. Introduction

Swallowing consists of a series of complex movements of related organs and its purpose is to transport food in the form of a bolus from the oral cavity to the stomach. Swallowing movements were categorized into three stages, i.e., oral (stage I), pharyngeal (stage II) and esophageal (stage III) stages. Pharyngeal and esophageal stages are induced by reflex, and are controlled mainly by the swallowing center in the brain stem. These sequential movements are accomplished by rapid and precisely coordinated activities of the swallowing-related muscles, such as the perioral muscle, temporal, masseter, tongue, palatal, hyoid, pharyngeal and laryngeal muscles (see Miller 1999 for review).

The larynx is an important organ for swallowing. Its forward and upward movement induces the epiglottis to cover the larynx, and thus prevent the airway from aspiration. The movement also shortens the distance between the pharynx and esophagus, and extends the space of the entrance for the esophagus. Previous studies have focused on the laryngeal movement during swallowing, however, to our knowledge no precise report is available in which the coordination between the activities of swallowing-related muscles and the actual movements of swallowing-related organs is observed during the act of chewing and swallowing.

Such precise records are desirable in the clinical situation to establish the type of examination and diagnosis for patients with difficulty in swallowing (i.e., dysphagia).

Accordingly this study investigated the coordination between the muscle activities of the masticatory muscles, orbicular oris muscle and suprahyoid muscles and the actual movements of the oral, pharyngeal and laryngeal organs during chewing and swallowing barium bread by EMG and VF recordings.

II. Materials and Methods

1. Subjects and test foods

The subjects examined were three male staff members (mean age 31.6 yrs) in our department who were examined in advance to ensure that there were no problems regarding mastication and swallowing.

As a test food, we prepared bread opaque radiographically with barium for VF observation following the method for Inaki et al. The barium bread was given at 10 g per each trial, in accordance with Yoshida's method. These observations were carried out after an explanation of the purpose of the study was given to the subjects, and their consent obtained.

2. Recording apparatus and methods

1) Electromyography and VF recording

Each subject was required to sit on a chair in the X-ray room of our university hospital so that the Frankfort plane was parallel to the floor, insofar as possible. Each subject was then given 10 g of barium bread at each trial and directed to masticate it freely for 5 trials. VF recordings were made from food intake into the oral cavity to the termination of swallowing.

EMGs were recorded from the bilateral temporal and masseter muscles, the unilateral orbicular oris muscle, anterior belly of the digastric muscle and the mylohyoid muscle. Bipolar surface silver-chloride electrodes (8 mm diameter, at 16 mm interelectrode distance) were fixed to the skin over muscles after confirming muscle direction by palpation.

Laryngeal movements were recorded on videotape using a CCD camera set at the left side of the subject, so that the laryngeal movements were macroscopically observed during chewing and swallowing.

In cooperation with the department of dental roentgenology at our university, X-ray videotape recordings were carried out simultaneously, in which the image was converted into a video signal by fluorescent amplification tube (image intensifier). Images were recorded on computer memory and monitored on a screen (Fig. 1).

2) Laryngeal movement wave and the system for observation

![Block diagram of the present system](image-url)
Laryngeal movements were recorded as electrical wave change using a laboratory made sensor constructed of conductive rubber (10×90mm). Electrical resistance of the sensor changes with its expansion following laryngeal movement.

The VF image, CCD camera image, EMGs and laryngeal movement described above were displayed simultaneously on a monitor, divided into 3 parts using a video formatter (Nihon Kohden, VY-302B) and frame synchronizer (Nihon Kohden, FS-400). The VF and CCD images were synchronized with EMG and laryngeal movements at the right end of the recording in actual time sequence (Fig. 2).

3. Statistical parameters and analysis
   1) Reproducibility
      In the pharyngeal stage of swallowing, the reproducibility of the relationship between the laryngeal movement wave, the laryngeal closure and the bolus passage was discussed.

   2) Burst durations of the muscles during chewing and swallowing
      Burst durations of the temporal, masseter, orbicular oris, digastric and mylohyoid muscles were measured on the computer screen (Fig. 3). Mean duration of each muscle per subject was then obtained from ten continuous chewing cycles; at the time stable muscle activities were recorded.

   3) Temporal relationship between laryngeal movements and muscle activities during swallowing
      To set a reference in time, beginning points of the sudden elevation of the laryngeal movements was defined (Fig. 4). The muscular action time was measured as the time lag
The beginning of sudden laryngeal elevation was set as the zero point for action time measurement. When a muscle acted in advance of the beginning point of laryngeal elevation, the value measured was considered negative (−), and was considered positive (+) when a muscle acted after the beginning point.

a: duration of the muscle activity in chewing  
b: duration of the muscle activity in swallowing  
c: the beginning point of muscle activity at beginning of laryngeal elevation between action commencement and the beginning point of laryngeal elevation. When a muscle acted in advance of the beginning point of laryngeal elevation, the value measured was considered negative (−), and was considered positive (+) when a muscle acted after the beginning point (Fig. 3).

Differences in each parameter were evaluated by Mann-Whitney test.

### III. Results

1. Reproducibility

A clear monophasic wave was observed in the laryngeal movements in the pharyngeal stage of swallowing. The monophasic wave in the laryngeal movements always coincided with the laryngeal closure accompanied with the bolus passage (Fig. 4). This was true in all subjects tested.

2. Burst durations of the muscles during chewing and swallowing

The burst duration of muscle activity in the masticatory muscles, orbicular oris muscle and suprahyoid muscle in swallowing was significantly longer than in chewing (Table 1).

3. Temporal relationship between laryngeal movements and muscle activities during swallowing

At jaw closure i.e., temporal and masseter muscles began their activities before the onset of the monophasic laryngeal elevation associated with laryngeal closure, whereas the
suprahyoid muscles i.e., anterior belly of the digastric muscle and hyoid muscle began activities almost simultaneously or slightly after the onset of the monophasic laryngeal movement. The mean latency of the orbicular oris muscle indicated that it began its activity before the onset of the laryngeal monophasic movement; however, there were large differences among the subjects. (Table 2).

IV. Discussion

The pharyngeal stage is a natural reflex that is accomplished within 1 second. In this short time, many organs must work in a certain time sequence, such as the anterior sealing of lips, velopharyngeal closure, glossopharyngeal junction opening, laryngeal closure, bolus propulsion, upper esophageal sphincter opening, and pharyngeal clearance. Therefore, VF examination has been employed in previous studies as the most popular method. However, there have been no reports discussing the coordination between the muscle activities of the masticatory muscles, orbicular oris muscle and suprahyoid muscles and the actual movements of the oral, pharyngeal and laryngeal organs while chewing and swallowing food by EMG and VF recordings.

Test food volume was based on Yoshida’s method. If the test food volume is excessive, the subject cannot swallow it all at once, but divides it into several boluses before swallowing them. Hence, the best volume for one swallow ranges from 5 to 10 g.

We began the swallowing observation at the point of foods taken into the oral cavity because, in advance of the oral stage, the food is recognized and identified by the visual and
olfactory senses, past experience and memory (advanced stage), and the food taken in is masticated and its properties examined (preparatory stage)\(^{13}\).

The reason for using EMG in this observation was as follows: it is kinephysiologically adequate to analyse swallowing from the aspect of muscular action, not bolus passing states, since there are no differences in temporal relationship between muscular actions by bolus volume. Orbicular oris muscle was measured by EMG for comparison with abnormal and infant swallowing, for future studies. The thyrohyoid muscle is most strongly linked to laryngeal elevation, but the extent of this connection could not be determined; therefore, suprahyoid muscle interaction with the thyrohyoid muscle was selected for measurement.

The laryngeal elevation mechanism involves contraction of the suprahyoid muscles, causing hyoid bone elevation, and then contraction of the thyrohyoid muscle, one of the infrahyoid muscles. The suprahyoid muscles were activated from the beginning to the end of swallowing, their actions requiring fixing of the jaw. The temporal and masseter muscles, i.e., the jaw closing muscles, therefore, were forced to act in advance of the suprahyoid muscles\(^{3,14}\).

In the present study, the burst duration of the masticatory, orbicular oris and suprahyoid muscles during swallowing was significantly longer than in chewing. Similarly, due to the temporal relationship between laryngeal movement and muscle activity, the temporal and masseter muscle began their activities before the onset of the monophasic laryngeal movement, whereas the anterior belly of the digastric muscle and mylohyoid muscle began activities almost simultaneously or slightly after the onset of the monophasic laryngeal movement. The mean action time of the orbicular oris muscle was also evaluated as being negative. However, it was not actually determined that this muscle acted in advance of the beginning of laryngeal elevation, because there were large individual and trial differences.

V. Conclusion

The activities of the masticatory muscles, orbicular oris muscle and suprahyoid muscles in chewing and swallowing in subjects with normal swallowing were investigated using Videofluorography (VF), EMG and laryngeal movement waves.

The results obtained were as follows:

1. In the pharyngeal stage of swallowing, a clear monophasic wave was observed in the laryngeal movements. Reproducibility was confirmed in the relationship between the laryngeal movement wave and bolus position in swallowing.
2. The burst duration of muscle activity in the masticatory muscles, orbicular oris muscle and suprahyoid muscles in swallowing was significantly longer than in chewing.
3. The temporal and masseter muscles began their activities before the onset of monophasic laryngeal elevation, whereas the anterior belly of the digastric muscle and mylohyoid muscle began activities almost simultaneously or slightly after the onset of the monophasic laryngeal movement.

In conclusion, simultaneous observation of VF, EMG and laryngeal movement waves suggests that bolus transportation and swallowing can be examined by analysing the relationship between muscular actions from chewing to swallowing and laryngeal movements.

References