Hyoid Movement and Laryngeal Penetration During Sequential Swallowing

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This study examined hyoid movement during sequential swallowing and evaluated the relationship among trajectory patterns, swallowing types based on laryngeal movement and laryngeal penetration. Twelve healthy adults underwent videofluorography during sequential swallowing. Each swallow was classified into two types: opened laryngeal vestibule after swallow (i-Segmental type) and closed laryngeal vestibule after swallow (i-Continuous type). Each participant’s swallowing type was classified by the same method. We analyzed two-dimensional movements of the hyoid, and the trajectories were classified into three patterns: hyoid moved in the anterosuperior direction after the onset of swallow (pattern L); hyoid moved in the anterosuperior direction after the onset of swallow, beyond the mandibular plane (pattern X); and the hyoid was above the mandibular plane at the onset of swallow, and then it moved in the inferior direction (pattern U). Two-way ANOVA revealed that there was a significant interaction between the swallowing type and trajectory pattern, and laryngeal penetration was the highest for the combination of individual swallow of i-Continuous type and pattern L. In sequential swallowing, the existence of a penetration-prone swallowing pattern combination was an interesting phenomenon relevant to eating management for dysphagic patients; however further study in patient groups is required.

Key words: Deglutition, Sequential swallowing, Hyoid bone, Kinematics, Fluoroscopy

Introduction

Studies on swallowing liquid have mostly investigated about discrete swallow where participants were asked to hold a certain amount of liquid in their mouth and then to swallow on command. However, when we drink liquid normally, we often drink from a cup or using a straw with several successive swallows. Few studies have been conducted on this sequential swallowing of liquids.

Chi-Fishman and Sonies observed rapid sequential swallowing in healthy volunteers and reported that the larynx exhibited a “raise and partial fall pattern” during sequential swallowing in all participants [1].

Daniels and Foundas monitored sequential swallowing and reported patterns different from those of the command swallow [2]. In their study, swallowing patterns were categorized into three types based on hyolaryngeal complex movement in sequential swallowing, and the frequency of each pattern was reported. In Type 1, the laryngeal vestibule opened after each swallow (53%); in Type 2, the laryngeal vestibule remained closed (27%); and the Mixed type was a combination of Types 1 and 2 swallowing cycles in one series of sequential swallowing (20%). Dozier and colleagues classified swallowing patterns according to Daniels and Foundas’ method and reported the frequency of the Always Open group.

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(opening laryngeal vestibule after each swallow), the Always Closed group (vestibule kept closed), and the Mixed group as 67.1%, 1.4%, and 31.4%, respectively [3].

From these reports, we considered that various patterns exist in sequential swallowing.

With regard to analysis of sequential swallowing with focus on hyoid movements during swallowing, one previous study used ultrasound [4], but a thorough two-dimensional motion analysis has not been performed. Daniels and colleagues, Chi-Fishman and Sonies, and Dozier and colleagues discussed evidence of laryngeal penetration. We thus aimed at investigating laryngeal penetration and relationship with sequential swallowing types and hyoid movement.

The objective of the present study is to ascertain the relationship among the swallowing types based on Daniels and Foundas’ report, trajectories of the hyoid movement, and laryngeal penetration.

Participants

Participants were 12 healthy adult volunteers (8 males and 4 females) with no obvious history of neurological, pharyngeal, or laryngeal disorder and no problems with eating or drinking in daily living (mean age: 32 years, range: 25-64 years). The study protocol was approved by the Ethics Committee of Fujita Health University, the School of Medicine (No. 06-093) and Tokyo Medical and Dental University (No. 383). Informed consent was obtained from each participant.

Methods

Videofluorography (VF) was performed to observe sequential swallowing in lateral projection. Each participant was asked to sit comfortably without immobilizing the head. A cup containing 200 ml of 50% w/v liquid barium and a straw (0.6 cm diameter; commonly used in Japan) was given to each participant, who was instructed to “sip several times without pausing between swallows and continuously holding the straw between the lips”. No instruction was given about the speed and volume of swallowing in order to evaluate normal behavior. Videofluorography was performed using a fluoroscopy unit (PBW-30A, Toshiba, Japan) and recorded using a digital video recorder (WVD9000, Sony, Japan) and a 1/100 second video timer (VTG-33, For-A, Japan) at a rate of 30 frames/second. Video images were replayed in slow motion using video editing software (iMovie, Apple Inc., USA).

To limit radiation exposure, one trial of sequential swallowing was completed for each subject. The last swallow of each sequential swallow was not included in the analyses. A total of 71 swallows of the 12 participants were analyzed. In one participant, the first swallow of sequential swallowing was eliminated because of a technical issue related to data recording.

Swallowing types and individual swallowing types in sequential swallowing

Based on Daniels’ method, each individual swallow during sequential swallowing was classified into two types: opened laryngeal vestibule with an upright epiglottis after swallow (i-Segmental type) and closed laryngeal vestibule with an inverted epiglottis after swallow (i-Continuous type).

In addition, swallowing type of each participant was also classified into the following three types: Segmental type (all swallows were i-Segmental type), Continuous type (all swallows were i-Continuous type), and Mixed type (a combination of i-Segmental type and i-Continuous types).

The presence of laryngeal penetration was also investigated by using VF images [5]. The Penetration-Aspiration scale (P-A scale) was used to score airway invasion for each swallow [6]. The P-A scale is an 8-point indicator. The score is determined from the depth of bolus invasion into the airway, clearance of bolus, and response to the airway invasion.

Two-dimensional motion analysis of the hyoid

Two-dimensional movement of the hyoid during sequential swallowing was analyzed using lateral VF images. Move-tr/2D (Library, Japan) was used for motion analysis. While using the posterior nasal spine (PNS) as a reference point, the X-axis was defined as the line connecting the PNS and anterior nasal spine (ANS). The Y-axis was defined as the line perpendicular to the X-axis passing through the PNS. Based on these axes, the hyoid was identified at its anteroinferior point, and its position was converted into two-dimensional coordinates (Figure 1). The XY coordinates of the PNS (reference point) were set as 0. Along the X-axis, the anterior side had positive values, and along the Y-axis, the superior side had positive values. Furthermore, we ascertained the positional relationship between the hyoid and the mandibular plane (the plane that comes into contact with the mandibular margin and passes through the menton (Me)) during sequential swallowing. If two lines were observed at the lower mandibular border, we created an intermediate line and used it as
Data analysis

To assess the relationships between swallowing types and hyoid trajectory patterns, chi-square analyses was completed (SPSS 11.0.1J, SPSS Japan Inc., Japan). The relationships among individual swallowing types, hyoid trajectory patterns, and laryngeal penetration were examined using a two-way analysis of variance (ANOVA). Tests of simple effects were performed to explore interactions and were followed by post hoc analyses of differences (Bonferroni test).

Results

The number of individual swallows per sequential swallowing ranged from 5 to 9 (mean: 6.9 ± 1.3). The last swallow of each sequential swallowing was excluded because the larynx returned to its rest position, and all swallows were classified i-Segmental type. For the sequential swallowing trial, the radiation exposure time ranged from 9 to 17 seconds (mean: 12.4±3.1) and the mean estimated exposure dose was about 670µSv [7].

Classification of swallowing types

Table 1 summarizes sequential swallowing types of each participant. For sequential swallowing types in the twelve participants, six showed the Segmental type, five demonstrated the Continuous type, and one showed the Mixed type.

In the Mixed type, the participant showed four i-Continuous type and three i-Segmental type swallows during the sequential swallow.

Two-dimensional motion analysis of hyoid movement

From the findings of our preliminary study (unpublished), we classified the patterns of trajectories of the hyoid bone as follows: hyoid moved in the anterosuperior direction after the onset of swallow with no movement beyond the mandibular plane (pattern L) (Figure 2); hyoid moved in the anterosuperior direction after...
Figure 2: Trajectory of hyoid movement; Type L
The trajectory of the hyoid from swallowing reflex triggering to the start of the next reflex during one swallow of sequential swallowing is shown. The white circle indicates the location of the hyoid at swallow onset, and the black circle indicates the onset of the next swallow. The line indicates the mandibular plane at swallow onset (defined as the start of rapid motion of the hyoid).

Figure 3: Trajectory of hyoid movement; Type X
The trajectory of the hyoid from swallowing reflex triggering to the start of the next reflex during one swallow of sequential swallowing is shown. The white circle indicates the location of the hyoid at the time of swallow onset, and the black circle indicates the onset of the next swallow. The line indicates the mandibular plane at swallow onset.

Figure 4: Trajectory of hyoid movement; Type U
The trajectory of the hyoid from swallowing reflex triggering to the start of the next reflex during one swallow of sequential swallowing is shown. The white circle indicates the location of the hyoid at swallow onset, and the black circle indicates the onset of the next swallow. The line indicates the mandibular plane at swallow onset.

Table 1. Subjects and swallowing types

<table>
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Hyoid movement during sequential swallowing

the onset of swallow beyond the mandibular plane (pattern X) (Figure 3); and the hyoid was above the mandibular plane at the onset of swallow, and then it moved in the inferior direction rather than the superior direction (pattern U) (Figure 4). In the present study, individual swallows classified into three types based on the same method.

For individual swallows, the relationship between swallowing type and trajectory pattern was examined (Table 2). Swallowing type was significantly related to trajectory pattern ($\chi^2(2, N=70)=14.106$, $p=0.001$). The hyoid trajectory of the first swallow of sequential swallowing was pattern U in one participant and pattern X or L in the other participants. In the i-Segmental type, pattern L and X trajectories were common and in the i-Continuous type, pattern L and U trajectories were common. In other words, in the i-Segmental type, pattern U trajectory occurred less, and in the i-Continuous type, pattern X trajectory occurred less.

In the Mixed type, the laryngeal vestibule opened after the second and third swallows, but it remained closed for the other swallows. In terms of the trajectory of the hyoid (Figure 5), when the laryngeal vestibule was open between swallows, the hyoid was markedly lowered, and when laryngeal closure and elevation were maintained, the hyoid remained elevated and downward displacement was small. The trajectory pattern was a mixture of patterns X and U.

Laryngeal penetration

Laryngeal penetration was seen during some of the swallows in the present study (Figure 6). The frequency of the laryngeal penetration in each individual swallow was evaluated (Figure 7). Of seventy swallows, fourteen penetrated and all received the P-A scale score of 2 (entry of the bolus into the larynx with clearing).

A two-way ANOVA, which included swallowing type and trajectory pattern as between-subjects factor, was conducted on laryngeal penetration. ANOVA revealed that there was no significant main effect for swallowing type but a significant main effect for trajectory pattern.
[F(2,64) = 5.47, P = 0.006] and a significant interaction between swallowing type and trajectory pattern [F(2,64) = 4.33, P = 0.017].

To further explore the nature of the interaction, simple-effect follow up tests were performed to compare trajectory pattern separately for each swallowing type, and swallowing types for each trajectory pattern.

The results of these analyses indicated that for pattern L, significantly more frequent laryngeal penetration occurred in the i-Continuous type than in the i-Segmental type (P < 0.001). For patterns X and U there were no significant differences between i-Continuous and i-Segmental types.

Subsequent post hoc testing revealed that in the i-Continuous type the laryngeal penetration occurred significantly more in pattern L than in patterns X and U (pattern L vs. X; P = 0.004, pattern L vs. U; P < 0.001).

In the i-Segmental type, there were no significant differences among swallowing patterns.

Discussion

Swallowing types

Daniels and the colleagues reported that the 36 of 38 healthy adults showed the same swallowing pattern in two trials [8]. The swallowing type had small variations in individual. Thus we decided that it was sufficient to evaluate one trial of sequential swallowing in previous study.

Daniels and Foundas [2] reported that the swallowing pattern where the laryngeal vestibule opened after each swallow was most common at 53%. This agrees with the results of this study, where the same pattern, which we called the Segmental type, was the most common, accounting for 6 of the 12 participants (50%).

Chi-Fishman and Sonies [1] observed rapid sequential swallowing and reported a “raise and partial fall pattern” in all cases. They observed that the laryngeal vestibule remained closed during sequential swallowing, but in 3 of the 10 participants, a slit in the laryngeal vestibule was observed during laryngeal lowering. In that report.
swallowing types were not defined and classified clearly, and as a result, data could not be compared directory with our data. However, the results of this study resembled those of Daniels and Foundas’ study. The present study and Daniels’ study evaluated normal swallow behavior, while chi-Fishman study evaluated swallows when subjects were asked to rapidly swallow sequentially.

**Hyoid trajectory**

Three distinct trajectory patterns were identified: patterns U, X, and L. Ligament and muscle attachments suspend the larynx in the neck between the hyoid bone and sternum. Thus, vertical and anterior movement of hyoid is involved in laryngeal movement [9, 10]. It has been suggested that the vertical displacement of the hyoid is associated with the closure of the laryngeal vestibule. [11] To investigate relation to three swallowing types based on laryngeal movement and laryngeal penetration, the hyoid trajectory was classified by the location of the onset of swallow and vertical displacement during swallowing.

The pattern U was different from other patterns depending on the location of the hyoid at the onset of swallow. During swallowing, the hyoid generally moves in the anterosuperior direction, and its movement converges in the direction of the chin. Therefore, when the hyoid was above the mandibular plane at the beginning, it moved in the inferior direction rather than the superior direction after the onset of swallow, but when the hyoid was below the mandibular plane, it moved in a mostly superior direction after the onset of swallow. As far as hyoid movement in the X-axis direction was concerned, this increased after the onset of swallow in all cases, and there was no phase change. Swallowing reflex patterns did not change, and the differences in the vertical location of the hyoid immediately before the onset of swallow seemed solely responsible for the trajectory differences.

Hyoid excursion is generated by the contraction of the suprathyroid muscles, i.e., the geniohyoid, mylohyoid, digastric, and stylohyoid muscles. The geniohyoid and mylohyoid muscles are involved in anterior movement [9]. In pattern U swallows, the hyoid had already moved to elevated position because of sustained muscle activity of suprathyroid muscles before the onset of swallow. Geniohyoid and mylohyoid muscles started their maximum activation after the onset of swallow, and hyoid elevation was continued. For patterns L and X, the suprathyroid muscles started to contract after the onset of swallow and hyoid moved in the anterosuperior direction. The vertical displacement of hyoid of pattern X was greater than that of pattern L.

Hyoid pattern U was observed in only one swallow in i-Segmental type swallows. In the i-Continuous type swallows, pattern X swallows were few (4 of 33 swallows). Although a slight trend was observed, a combination of swallowing type and trajectory pattern was not firmly established. Thus, varying combinations of laryngeal movement and hyoid movement were observed.

Many studies have been conducted on hyoid movements during swallowing. With regard to videofluorography, Ekberg observed hyoid movements in healthy adults during command swallow of liquids and reported two patterns: a two-step pattern (n = 40) where the hyoid moved in the posterosuperior direction and then in the anterior direction, and a one-step pattern (n = 10) where the hyoid moved in the anterosuperior direction [9]. The elevation of the hyoid in relation to bolus passage occurred later in subjects with the one-step pattern than in subjects with the two-step pattern.

In the present study, as easily understandable for the trajectories of Figures 2-6, all swallows were of the one-step pattern. However, the leading edge of the bolus seemed to be in a more distal portion of pharynx at the onset of swallow during sequential swallowing (data not shown), as has been revealed by past investigations [2]. It is likely that the hyoid had to move the shortest way to clear the bolus quickly.

With regard to two-dimensional analysis of hyoid movements, Jacob and colleagues [10], Dodds and colleagues [12], Cook and colleagues [13], and Dantas and colleagues [14] observed hyoid movements during command swallow, and Ishida and colleagues [15] observed hyoid movements during swallowing of chewed solids and liquids. All these authors reported that the volume of the bolus affected the amount of hyoid movement. As discussed in these reports, two-dimensional motion analysis by videofluorography has been used occasionally to ascertain the changes in hyoid movements due to changes in swallowing conditions.

**Ultrasonography** has been used instead of videofluorography in the analysis of hyoid movements in sequential swallowing of liquids. Chi-Fishman and Sonies performed ultrasonography to ascertain hyoid movements during discrete and sequential swallowing of liquids [4] and reported that the maximum displacement of the hyoid from the starting point of swallowing and the length of trajectory per swallow were significantly
shorter in sequential swallows than in discrete swallows. Furthermore, in sequential swallowing, there were different modes of hyoid trajectory: the hyoid was repositioned close to the starting point of swallowing after each swallow, or the hyoid was not repositioned during sequential swallowing. Although the definition of hyoid movement patterns was different, three trajectory patterns were identified in the present study.

Laryngeal penetration

With regard to laryngeal penetration during discrete swallow, Robbins and colleagues evaluated the usability of the P-A scale to distinguish normal swallows in healthy adults aged between 21 and 84 years with 3ml liquid boluses. They reported that 55 of 285 swallows (19.3%) received scores of 2 or 3, and an 83-year-old man aspirated (a score of 7) [16]. Daggett and colleagues examined the frequency of penetration in 98 normal subjects aged between 20 and 94 years. Of 206 swallows, 22 (10.7%) received a score of 2 on 3ml liquid bolus, and 22 of 154 swallows (14.3%) received a score of 2 on cup swallow [17].

Daniels and colleagues evaluated the presence of laryngeal penetration using the P-A scale [8]. In the young group (25-35 years), 25 of 399 swallows (7%) received scores of 2 or 3; for the old group (60-86 years), 68 of 249 swallows (27%) received scores of 2-5; and aspiration occurred in one swallow (a score of 7). More, laryngeal penetration occurred with hyolaryngeal complex lowering as well as with continued hyolaryngeal complex elevation. The younger subjects demonstrated a slightly greater likelihood of penetration with hyolaryngeal complex elevation compared with a lowered hyolaryngeal complex. Dozier and colleagues reported that 4% subjects (N = 70, 21-93 years) received a P-A scale score of 2 [3]. Chi-Fishman & Sonies reported that laryngeal penetration occurred in 3 of 10 subjects [1]. Other reports in the literature suggest that the penetration rate does not differ significantly between discrete swallow and sequential swallow.

In the present study, 14 of 70 swallows (20%) had penetration, a P-A scale score of 2. The frequency of penetration was similar to those in studies on discrete swallow.

However, we found an interesting relationship; the ANOVA revealed that there was a significant interaction between swallowing type and trajectory pattern. The frequency of laryngeal penetration was the highest in a combination of i-Continuous type and pattern L.

Laryngeal penetration depends on the timing of laryngeal closure during swallowing. In other words, after a bolus enters the pharynx, a relative delay in laryngeal closure increases the probability of laryngeal penetration. No penetration was seen for pattern U, because the hyoid and larynx are already sufficiently elevated at the onset of swallow. However, in the sequence of i-Continuous type and pattern L, when continuous hyoid and laryngeal elevation were required, it was not actually sufficient; thus, laryngeal closure might also have been insufficient, increasing the possibility of laryngeal penetration.

Laryngeal penetration must be avoided to protect the airway. In the present study, patients with swallowing disorders were not examined, but since the frequency of laryngeal penetration varied among the swallowing types and trajectory patterns, it would be clinically useful to assess such differences and classify larynx and hyoid movement pattern in sequential swallowing.

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