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The Speed of the Hyoid Excursion in Normal Swallowing

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Purpose: To examine the speed of hyolaryngeal excursion in different age and gender groups during normal swallowing.

Methods: Temporal and biomechanical measurements of hyolaryngeal excursion were calculated using videofluoroscopic swallowing examinations (VFSEs) of 37 healthy individuals. Statistical comparisons were made by two-way repeated analysis of variance (ANOVA) with between subject variables being age and gender, and within subject variable being bolus volume (5 mL and 10 mL thin liquids). Significance level was set as $p<0.025$.

Results: The speed of hyoid excursion in older populations was significantly slower than in younger ones. There was no gender or bolus volume difference or interaction in the speed of hyoid excursion.

Conclusions: Slower hyoid excursion may put older populations at higher risk for aspiration in case of illness or accident. The preventive approach is essential.

Keywords: Hyoid, Speed, Age, Swallowing

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INTRODUCTION

Swallowing is a necessary bodily function that moves a bolus from the mouth to the esophagus. A sequence of certain physiological events must occur in order to optimize the quality and safety of the swallow [1]. One of the important physiological events in the pharyngeal phase of a swallow is marked by the movement of the hyoid bone. This is also known as hyoid excursion. In normal young adults, the hyoid begins this excursion before or during the time the bolus passes the ramus of the mandible [2]. The hyoid bone is moved upward (superiorly) and forward (anteriorly) by suprahyoid muscles. The contraction of these muscles in turn pulls on the larynx and the upper esophageal sphincter (UES) [3]. Hyoid excursion inhibits tonic contraction of the musculature of the cricopharyngeal sphincter. Although upward and forward movement of the hyoid occurs in healthy swallowers, there have been noted differences in various demographics. In aging, Kim and McCullough [4] observed significant differences in the amount of forward movement of the hyoid bone, with younger subjects having greater displacement. Younger subjects also exhibited greater vertical displacement, although the displacement was not statistically significant. As people age, their forward hyoid displacement reduces although their upward displacement remains relatively the same [4]. The dangers of reduced forward displacement include a smaller opening of the UES, which may in turn cause the bolus to remain in the pharynx because it is unable to pass into the esophagus, which could increase the risk of aspiration after the swallow. Researchers have identified that with age, many individuals naturally compensate for the reduction of the UES opening. As the bolus moves through the pharyngeal passage more slowly, it allows the UES to stay open longer and to increase the number of times an individual swallows with each bolus [5,6]. Both of these compensatory methods help alleviate the need for a wider UES opening in older populations. Also, although not statistically significant, females tended to have higher means for both forward and upward displacement [4]. Studies have also shown that the volume of the bolus affects the extent of hyoid excursion.

Previous studies on hyoid excursion show great variability in the distance traveled by the hyoid and larynx during the normal swallow [7]. Because this distance can differ from person to person for reasons including but not limited to age, gender, and bolus volume, it is important to consider the speed of hyoid excursion to see if the range is more consistent. The knowledge of hyoid excursion speed is important in order for clinicians to recommend the appropriate intervention or exercise regimen for their populations with swallowing difficulties. So far, there have been limited studies measuring and exploring what can be considered the normal speed of the hyoid excursion in terms of age and gender. This study aimed to find speed of the hyoid excursion during the normal healthy swallow. The collected data in this study will provide clinicians with normative figures to compare to their patients.

METHODS

Subjects

This study submitted for analysis the swallows of 40 normal subjects using videotapes of videofluoroscopic swallowing examinations (VFSEs). However, three subjects were excluded due to the poor visibility of hyoid bone. The subjects were divided into two separate age groups. Twenty subjects between the ages of 21 and 51 years (mean = 30) made up the younger subject group, and seventeen subjects between the ages of 70 and 87 years (mean = 77) made up the older subject group. Children were excluded in this investigation. Children have different swallowing mechanism related to structural and physiologic development. The younger subject group consisted of ten females and ten males. The older subject group consisted of nine females and eight males. Each subject passed a comprehensive questionnaire, a cranial nerve examination, and an oral motor/structural examination in order to participate in the study. All subjects with any neurological or structural abnormality affecting the head and neck were excluded from the study. All participants provided informed consent form, and the study design was approved by the Internal Review Board at Ohio University (#07E108). Each subject swallowed two 5 mL and two 10 mL thin liquid boluses, for a total of 148 swallows analyzed for this study.

Videofluoroscopic swallowing exam (VFSE)

The VFSE data in this study were originally collected for a previous study [8]. Using a mobile, C-arm x-ray (OEC Diasonics, model 7600) system, the subjects' swallows were filmed while they were sitting in an upright position in a stretcher chair. Videos were recorded onto a Panasonic Super VHS PV-S7670 Pro Line Multiplex videocassette recorder. The fluoroscopic tube was placed on the side of the subject to capture an image of the subject that included the lips on one side of the frame to the back of the neck on the other, and the nasopharynx superiorly to just below the UES area inferiorly. The two 5 mL and two 10 mL thin liquid boluses were a 50/50 mixture of E-Z-HD Barium Sulfate Powder for Suspension and the viscosity of the boluses were carefully controlled through constant temperature and periodic rechecks with a Brookfield viscometer. VFSE data with 30 frames per second and 100 msec timer were digitized for the analysis using Adobe Premiere Pro C3.

Procedures of maximum hyoid excursion distance

To obtain the speed of hyolaryngeal excursion, two biomechanical measurements (maximal vertical and anterior displacement of hyoid bone) were completed from two picture frames of VFSE: one showing the resting position of hyoid bone and the other showing the maximum displacement of the hyoid bone during the swallow (Figure 1). The biomechanical measurements in this study were collected prior to this study in the Swallowing Research Laboratory at Ohio University [4]. The following calculation was then completed for each:

$$\text{Maximum Hyoid Excursion Distance} = \sqrt{(\text{Maximum anterior displacement}^2)+(\text{maximum vertical displacement}^2)}$$

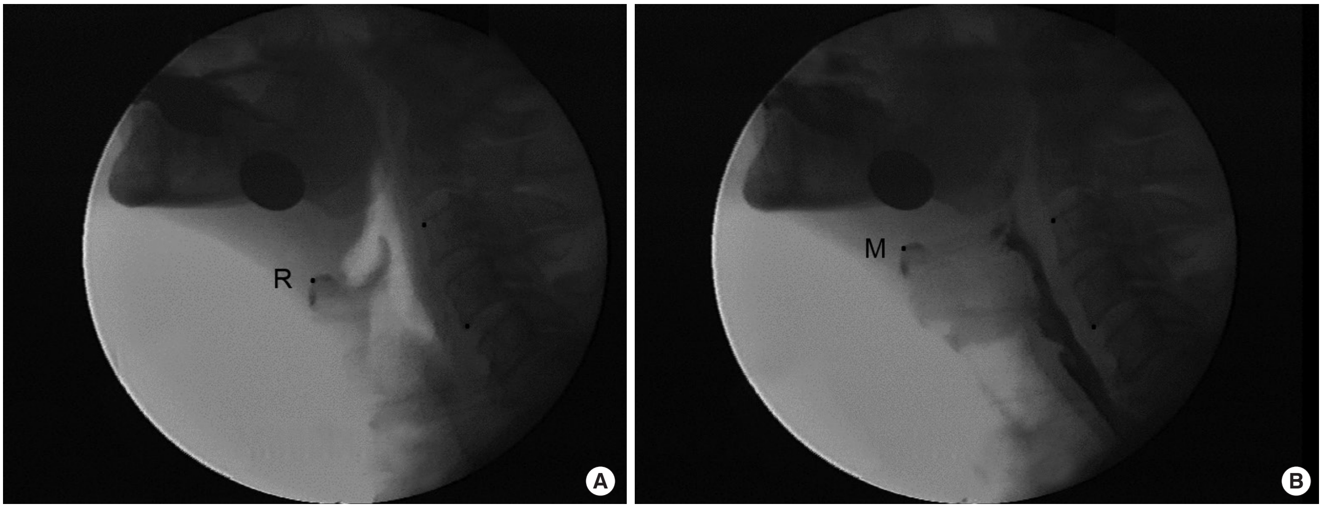

Figure 1. Hyoid excursion during the swallow: (A) Rest frame of hyoid bone (R). (B) Maximum displacement frame of hyoid bone (M).

Procedures for duration measurement of hyoid excursion

Duration of hyoid excursion was then measured for each swallow from the hyoid's position at rest until its maximum point of excursion. Each swallow was examined multiple times in real time and frame-by-frame in slow motion. The resting position frame was determined as the frame before the hyoid begins moving in any forward or upward motion. The maximum frame was determined as the last frame where the hyoid reached maximum forward or upward motion (Figure 1). Adobe Premiere Pro C3, a video editing software, was used to determine each frame, which is represented in seconds, and that time was recorded into an Excel sheet. After determining the time of the resting position frame of the hyoid bone and the time of the maximum position frame of the hyoid bone, the following equation was used to determine the time that elapses between the two positions:

Duration of maximum hyoid excursion = Time of maximum position - time of resting position

A formula for hyoid excursion speed was then utilized as follows:

$$\text{Hyoid Excursion Speed} = \frac{\text{Maximum displacement of the hyoid (cm)}}{\text{Duration of maximum hyoid excursion (sec)}}$$

Statistical analysis

Age and gender differences were analyzed for the speed of hyoid excursion during oropharyngeal swallowing. For the dependent variable, the statistical comparison was completed using a two-way analysis of variance (ANOVA) for repeated measures with volume of bolus as the within-subject variable, and age and gender as between subject variables. Wilkin's Lambda was used to determine the significance ($p < 0.025$).

RESULTS

Reliability

Designated swallows of 8 randomly selected participants (32 swallows, 22%) were re-analyzed for inter-judge reliability by a second independent judge. The second judge was a graduate student and has undergone training on temporal measurements using Adobe Pro C3. Pearson correlation coefficients were calculated to determine the relationship between the first and second measurements. The r values obtained were 0.86 ($p < 0.01$), indicating a significant correlation. The primary investigator re-analyzed the same 8 participants (32 swallows, 22%) a second time, for intra-judge reliability. The r values obtained were 0.92 ($p < 0.01$), indicating a significant correlation between the first and second set of measurements.

None of the subjects in this study displayed signs of dysphagia or aspiration during the VFSEs. All of the swallows exhibited normal tongue base retraction, epiglottic inversion and seal, and UES opening.

Age

The mean and 95% confidence interval for the speed of hy-

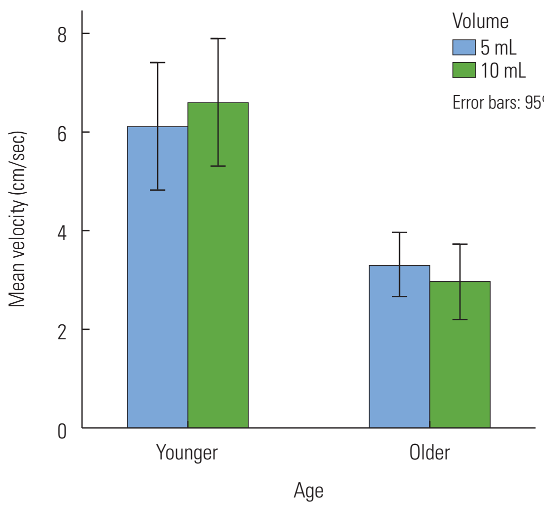

Figure 2. Mean speed of hyolaryngeal excursion values and 95% confidence interval for the two bolus volumes among younger and older subjects.

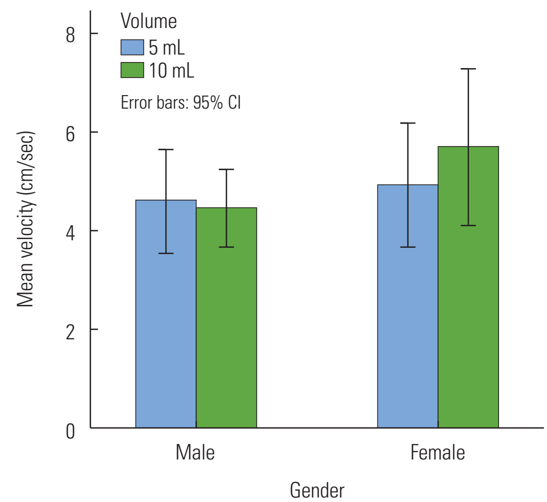

Figure 3. Mean speed of hyolaryngeal excursion values and 95% confidence interval for the two bolus volumes among male and female subjects

olaryngeal excursion values for the two bolus volumes among younger and older subjects are displayed in Figure 2. The mean speed of hyolaryngeal excursion did differ significantly between younger and older subjects ($F[1, 140]=33.39$, $p<0.01$). The younger subjects demonstrated a mean speed of 6.08 cm/s (SD=4.08) for 5 mL boluses and a mean speed of 6.56 cm/s (SD=4.06) for 10 mL boluses. The older subjects demonstrated a mean speed of 3.36 cm/s (SD=2.02) for 5 mL boluses and a mean speed of 3.02 cm/s (SD=1.92) for 10 mL boluses. This suggests that age does have a significant effect on the speed of hyolaryngeal excursion.

Gender

The mean and 95% confidence interval for the speed of hyolaryngeal excursion values for two bolus volumes among males and females are displayed in Figure 3. The mean speed of hyolaryngeal excursion did not differ significantly between male and female subjects ($F[1, 140]=2.34$, $p=0.13$). The male subjects demonstrated a mean speed of 4.58 cm/s (SD=3.17) for 5 mL boluses and a mean speed of 4.40 cm/s (SD=2.30) for 10 mL boluses. The female subjects demonstrated a mean speed of 4.92 cm/s (SD=3.82) for 5 mL boluses and a mean speed of 5.65 cm/s (SD=4.67) for 10 mL boluses. There was no volume difference in the speed of hyolaryngeal excursion. In addition, there was no interaction among age, gender and volume.

DISCUSSION

Based on our analysis of data, age has a significant effect on the speed of hyolaryngeal excursion. Gender differences were visually and numerically apparent, but results were not statistically significant. The results of this study along with the clinical implications of the effects are discussed below.

Age

The results of this study revealed that older subjects had significantly slower hyolaryngeal excursions than younger subjects. This finding is consistent with other temporal measurements of swallowing by Robbins, Hamilton, Lof, and Kempster [5]. They reported increased stage transition duration, pharyngeal transition duration, duration of UES opening, and total swallowing duration with aging. Similarly, Logemann, Pauloski, Rademaker, and Kahrilas [9] reported differences in older women's swallowing durations compared to younger women's. Although only the difference in UES opening duration was significant, pharyngeal delay duration, base of tongue contact to pharyngeal wall duration, and laryngeal closure duration increased in older women. Tracy et al. [10] reported the longest laryngeal closure durations in middle-aged and older subjects, as well.

The slower hyolaryngeal excursion and longer swallowing durations in older subjects may be attributed to an overall slowing of nervous system activities [11]. It is possible for less acute lingual sensation to result in increased time for neural processing along with weakened oral control [5,10,12]. Age-related changes in central and peripheral nervous system may affect neurons in the sensory components of the cranial nerves and decreases in the number of taste buds and changes in other senses, such as smell, influence taste perception changes. These alterations in the aging neural mechanism may account for slower hyolaryngeal excursion.

In addition, weaker muscular strength and reserve may contribute to slower hyolaryngeal excursion. Muscular reserve is defined as the difference between the extent of movement necessary to accomplish a desired functional result and the actual extent of movement used to accomplish the desired functional result [13]. Logemann et al. [14] suggests the reduced range of movements in subjects with reduced reserve results in less safe and less efficient swallows. Robbins et al. [15] discussed the tongue's critical role in the swallowing process as the force that propels the bolus through the oropharynx. The submental muscles, which execute hyolaryngeal excursion, would experience loss of muscular reserve through aging and put the older populations at a higher risk for dysphagia.

Gender

The results of the current study for the effects of gender on hyolaryngeal excursion speed revealed no significant difference between males and females. Although not statistically significant, this study on the speed of hyolaryngeal excursion did find that younger participants and female participants exhibited higher mean velocities for 10 mL boluses when compared to their 5 mL bolus swallows. Older participants and male participants exhibited higher mean velocities for 5 mL boluses than their 10 mL bolus swallows. These results may be different or consistent if larger bolus sizes were compared. With larger boluses, statistically significant differences may emerge, as gender differences increased from 5 mL to 10 mL boluses [16]. Logically, these findings may also be attributed to the smaller size of the female head and neck anatomy [17].

It is possible that analysis of more swallows would provide a statistically significant difference. Regardless, such differences should be considered when collecting normative data and making comparisons to individuals with reported dysphagia. Gender differences have been reported in other temporal measurements of swallowing. Logemann et al. [14] reported earlier laryngeal closure on 1 mL boluses for women compared to men and longer UES opening duration in women. Robbins et al. [5] reported longer durations of UES openings in women, as well. It is necessary to have more research on gender difference on swallowing physiology based on bolus size.

Intervention and prevention in the older populations

Aging causes decreased muscular reserve and strength in addition to slower neuromuscular activities. Older subjects with reduced strength in tongue and submental muscles may show slower hyoid excursion. Slower hyoid excursion may place individuals at the risk of dysphagia in case of illness or accident. We should not, however, assume that changes in hyolaryngeal excursion speed place healthy older populations at any risk. Dysphagia monitoring and screening in older individuals should occur when overall physical health is compromised for whatever reason [14].

Whereas these older individuals currently do not have swallowing disorders, they may have age-related changes in swallowing that cause them to be more vulnerable to swallowing disorders. It is important to develop screening tools and preventive exercise programs for older individuals. Lingual exercises or repeated effortful swallows may prove beneficial as preventative or rehabilitative strategies for older subjects with slower hyoid excursion. Robbins et al. [15] reported higher swallowing pressures for older subjects participating in an 8-week lingual exercise program. This study suggested that muscle weakness may be reversed with exercise. Increased muscle strength as a result of lingual exercises will improve swallowing processes in older populations and may help prevent some of the loss of muscular reserve and strength which is related to slower hyoid excursion with aging.

Effortful swallows should also be considered. Hind, Nicosia, Roecker, Carnes, and Robbins [17] reported that the airway is protected for a longer amount of time during effortful swallows compared to non-effortful swallows, therefore decreasing the risk of the bolus being aspirated. It has also been reported that increased superior movement of the hyoid occurs during effortful swallows, indicating heightened laryngeal elevation and increased airway seal [18]. The overall need to establish a preventive exercise program for aging individuals remains unclear, but reduced muscular and neural reserves make these strategies potentially useful with additional research.

Limitations and future studies

The current study consisted of only 37 subjects, which is a small number. It is important for future studies to incorporate a larger number of subjects when collecting data in attempt to replicate the results of the current study. Moreover, only one bolus consistency was used and differences in bolus size were minimal (5 mL and 10 mL). Different bolus consistencies and larger volume differences should be investigated in future studies. The swallows in this study were previously recorded and some clips could not be used due to poor quality. Lastly, only normal swallows were investigated in this study. Future investigations will be conducted to investigate the swallows of subjects who are post-stroke and may or may not be aspirating. The velocities of the post-stroke subjects' swallows who are exhibiting aspiration may be expected to be slower than those of their non-aspirating counterparts, along with normal older counterparts.

CONFLICT OF INTEREST

The author has no conflict of interests.

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