Influence of Age and Bolus Size on Swallowing Function: Basic Data and Assessment Method for Care and Preventive Rehabilitation

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Objective numerical data on swallowing function are needed to aid in eating and swallowing intervention and preventive rehabilitation. Using noninvasive methods, the influences of age and differences in size of water bolus on laryngeal activity and respiratory activity were examined in healthy young and older women. Swallowing function was influenced by age and bolus size. Influence of bolus size was recognized only in duration of laryngeal movement in younger women, with no apparent influence in older women. Results for older women were thought to be related to declines in swallowing function with the physiological aging of respiratory and swallowing muscles. In the future, noninvasive methods need to be developed for evaluating function and therapeutic effects against swallowing function impairment and to provide objective numerical data for health insurers.


Interest in appetite and health has been rising in Japan in recent years. Moreover, by 2020, the older population in the world is expected to be greatly increased. As a preparatory measure to address future care requirements, care insurance for all Japanese people >40 years old was established in 2000. Care and preventive rehabilitation programs addressing physical strength, withdrawal and dementia, eating and swallowing, and nutrition have been implemented as part of the care insurance industry since 2006. Because concrete numerical data and methods have not been available to evaluate the need for preventive care or rehabilitation for eating and swallowing, such programs have not always progressed as expected.

When the swallowing reflex develops normally, laryngeal elevation occurs. Generally, laryngeal elevation is assessed from the surface as movement of the thyroid cartilage. The passage to the trachea is interrupted by laryngeal elevation, resulting in apnea for the duration of swallowing. However, swallowing functions deteriorate with age. Nerve and muscle activity decrease, and swallowing reflexes become delayed (Shaker et al., 1993). Problems with swallowing functions start to become apparent by age 70 (Furukawa, 1989). Personal factors such as age, alimentary modality and viscosity, remaining dentition (Dejaer, Pelemans, Bibau, & Ponette, 1994), and bolus size strongly influence swallowing function (Tracy et al., 1989). Frequency of falls has been shown to correlate with swallowing and respiratory functions (Nilsson, Ekberg, Olsson, & Hindfelt, 1994). Reviews dealing with swallowing function in healthy older people have made numerous general remarks, but very little concrete numerical data obtained using more objective methods have been presented.
This study used noninvasive methods of examining swallowing function (Higashijima & Koga, 2002) to review the influence of cervical position and bolus volume on laryngeal movement, sound associated with swallowing, and deglutition apnea during voluntary swallowing in normal adults. Moreover, I have previously used this method to evaluate interrelated function between swallowing and respiration in Parkinson’s disease (Higashijima, 2005) and multiple cerebral infarction (Higashijima, 2008).

One aim of this study was to obtain concrete numerical data for swallowing function for use in selecting and judging the efficacy of care and preventive rehabilitation programs. A second aim was to obtain waveform information in addition to raw numerical data to obtain objectivity in similar applications.

Method

Participants

Participants included healthy female 2nd-year students at Kawasaki University of Medical Welfare and the healthy wives of patients in Kawasaki Medical College Hospital. The study protocol was explained verbally to all participants, and written documentation was provided. Informed consent was then obtained from 23 healthy younger women (mean age ± standard deviation, 20.9 ± 0.3 years; range, 20–21 years) and 23 healthy older women (69.9 ± 4.0 years; range, 65–78 years). Participants reported no history of swallowing disorders associated with respiratory or neuromuscular disease. Moreover, all participants completed a questionnaire of 35 questions regarding eating and swallowing, and no problems were identified from the results. This study was limited to women to eliminate differences in pharyngeal capacity because of sex.

Apparatus

Participants were familiarized with the experiment protocol, after which three sensors (AD Instruments, Bella Vista, New South Wales, Australia) were attached. Participants were then instructed to sit on a chair with an extendable backrest (Figure 1), with the cervical angle maintained at a constant 20° flexion. An MLT1132 respiration pickup sensor (sensitivity: 4.5 ± 1 mV/mm; AD Instruments) was placed on the xiphoid process of the participant’s sternum to monitor respiratory movements of the chest wall. An MLT1010 transducer (frequency response: 2.5 to 5000 Hz) was attached at the thyroid cartilage to record back-and-forth movement of the thyroid cartilage during swallowing. An MLT415 thermistor respiration pickup sensor (operating range: 0° C to 50° C; AD Instruments) was placed in the left nasal cavity of each participant to monitor nasal airflow and temperature differences between inspired and expired air. These three sensors were used to identify organic movement changes and movement persistence but not amplitude.

Procedure

The current study was limited to the assessment of swallowing function during the oral and pharyngeal phases, excluding chewing function during the preparatory phase. Participants were required to swallow a water bolus. The procedure was performed in a room at a constant temperature of 23 °C and involved injection of 10 mL of water at 10 °C into the oral cavity of each participant. Participants were instructed to keep this liquid in the mouth until a red lamp signal (trigger) was seen. After receiving an explanation of the study protocol, the participant took a pretest swallow of water. When the chart recorder (MLT1132 respiration pickup sensor) indicated the end of an expiratory phase of respiratory movement, the trigger was shown to the participant to completely swallow the water bolus. Resumption of a respiratory movement wave on the chart recorder was confirmed after the trigger passed. A chart recorder was then used for recording until the two-wave respiratory movement was over, after which the first reading was obtained. A new signal to swallow 10 mL of water was then given when the participant again reached the end of the expiratory phase. After receiving the explanation of the study protocol, the participant took a pretest swallow of water. Swallowing of a 10-mL bolus was then performed three times. After resting for 15 min, the procedure was repeated for three swallows of a 20-mL water bolus.

Data Analysis

Data were recorded during the procedure using both a chart recorder and a digital audiotape recorder (sampling rate =
100 mm/s). These data were read by a computer using a Power Lab data analysis system (AD Instruments) and analyzed using Chart version 4.0 software (AD Instruments). During 10- and 20-mL water bolus swallowing, four parameters were compared between age groups and bolus sizes (Figure 2): duration from trigger to start of thyroid cartilage movement (laryngeal movement latency), duration of thyroid cartilage movement (duration of laryngeal movement), duration from trigger to end of air ventilation (apnea latency), and duration of apnea. Analysis of the four parameters was performed using the Mann–Whitney U test. Data analysis for participants of the same age was performed using the t test. Analysis of patterns of laryngeal movement was performed using Fisher’s exact probability test. Level of statistical significance was set at \( p < .01 \), unless otherwise noted.

Results

Differences in Age

Significant differences were observed in laryngeal movement latency, duration of laryngeal movement, and apnea latency between healthy younger and older women with the 10-mL water bolus (\( p < .01 \); Figure 3). Significant differences were recognized in laryngeal movement latency and apnea latency between healthy younger and older women with the 20-mL water bolus (\( p < .01 \); Figure 4).

Differences in Bolus Size

Significant differences were recognized in duration of laryngeal movement between 10 and 20 mL for healthy younger women (\( p < .01 \)). However, no significant differences were recognized between the four parameters for 10 and 20 mL among healthy older women (Table 1).

Wave Pattern of Laryngeal Movement

Patterns of laryngeal movement were analyzed between water bolus sizes of 10 mL and 20 mL. Analysis of laryngeal movement pattern used the second swallowing waveform. The laryngeal movement wave created was classified into single-wave, two-wave, or multiple-wave patterns (Figure 5).

Significant differences in laryngeal movement patterns were recognized between young and older women for single-
Figure 3. Four parameter differences between older and younger women on 10 mL of water.

**p < .01.

Figure 4. Four parameter differences between older and younger women on 20 mL of water.

**p < .01.
and multiple-wave patterns and between single- and two-wave patterns for the 10-mL water bolus ($p < .01$).

**Discussion**

Swallowing function was influenced by both age and bolus size. Influences of age were recognized in laryngeal movement latency, apnea latency, and duration of laryngeal movement (at 10 mL). In addition, influence of age was seen in laryngeal movement latency and apnea latency (at 20 mL). Influence of bolus size was recognized only in duration of laryngeal movement for younger women; it was not recognized in all older women. Moreover, laryngeal movement patterns were documented in young and older women for the 10-mL bolus but not for the 20-mL bolus.

Leopold and Kagel (1983) reported that the swallowing process can be divided into five stages, of which the first is the oral stage. In a physiological sense, the oral stage of swallowing involves a voluntary first half and a reflexive second half. Significant differences in laryngeal movement latency and apnea latency appear to represent influences on the voluntary movement part of the oral stage. As suggested by Logemann (1998), this could be because the bolus consisted of nonviscous water. Dodds et al. (1989) reported that when participants were instructed to hold food in the mouth and swallow on a signal, some participants held food at the bottom of the oral cavity (dipper type), whereas others held food on the tongue (tipper type). In the current study, participants were instructed to hold water in the mouth and swallow on a signal. Differences in laryngeal movement latency may result simply from participants’ holding the water bolus in different positions. In particular, laryngeal movement latency and apnea latency were shorter in older women than in younger women. This was attributed to older women holding the water bolus nearer to the pharynx. Moreover, as a major reason for significant differences, older people may

![Table 1. Four Parameter Times Between Older and Younger Women With Differing Bolus Sizes](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>10-mL Bolus M ± SD (s)</th>
<th>20-mL Bolus M ± SD (s)</th>
<th>10-mL Bolus M ± SD (s)</th>
<th>20-mL Bolus M ± SD (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laryngeal movement latency</td>
<td>0.20 ± 0.15</td>
<td>0.15 ± 0.11</td>
<td>0.32 ± 0.15</td>
<td>0.43 ± 0.38</td>
</tr>
<tr>
<td>Duration of laryngeal movement</td>
<td>2.49 ± 0.56</td>
<td>2.53 ± 0.60</td>
<td>1.77 ± 0.67</td>
<td>2.49 ± 0.73*</td>
</tr>
<tr>
<td>Apnea latency</td>
<td>0.37 ± 0.22</td>
<td>0.35 ± 0.16</td>
<td>0.69 ± 0.30</td>
<td>0.65 ± 0.42</td>
</tr>
<tr>
<td>Duration of apnea</td>
<td>1.21 ± 0.29</td>
<td>1.59 ± 0.35</td>
<td>1.39 ± 0.56</td>
<td>1.80 ± 0.61</td>
</tr>
</tbody>
</table>

*Note. M = mean; SD = standard deviation.*

*p < .01.

![Figure 5. Modality and number of participants displaying a laryngeal movement pattern.](image)
display considerable weakness of the oral muscles and degradation of sensory nerve conduction compared with young people because of physiological aging (Yamada, 2001).

Duration of laryngeal movement differed significantly between ages at 10 mL, but no difference between ages was seen at 20 mL. Also, the influence of bolus size was recognized only in the duration of laryngeal movement in younger women. Nilsson et al. (1994) examined sucking water with a straw between young and elderly men. Elderly men were able to swallow only a small quantity because of degradation of suction pressure, and segmentation swallowing was recognized, in which laryngeal movement occurs multiple times during apnea. Nilsson et al. (1994) and Logemann (1998) found in numerous studies that segmentation swallowing occurs with weakness of the muscles of laryngeal elevation because of physiological aging. Moreover, older people perform swallowing in cooperation with cessation of breathing and display problems in reserve capacity (Logemann, 1998). The current results resemble those of Nilsson et al. (1994) and Logemann (1998). Two-wave and multiple-wave laryngeal movement patterns were documented in older women in this study, and two-wave and multiple-wave patterns were more marked for the 20-mL than for the 10-mL bolus. Older women in this study thus appeared to practice segmentation swallowing while cooperating with the breath cycle method to compensate for weakness of the muscles of laryngeal elevation caused by physiological aging. However, duration of laryngeal movement and laryngeal movement pattern for the 20-mL water bolus did not differ significantly between young and older women. Saito, Baba, and Suzuki (1996) noted that the swallow volume for Japanese is limited to approximately 15 mL of liquid. Because our study used a bolus exceeding this volume, significant differences may not have been apparent for duration of laryngeal movement or laryngeal movement pattern.

Effects of bolus size were recognized only in the duration of laryngeal movement in younger women, with no effects in older women. This was attributed to the bolus size of swallowing being appropriate for younger women, whereas changes in the swallowing function of older women were suggested.

Duration of apnea displayed no significant differences with age or bolus size. Duration of apnea in healthy people is approximately 1 s. The lack of significant differences in this study may be attributable to the fact that a halt in ventilation of approximately 2 s is normal for healthy people. In addition, Umezaki (2001) stated that duration of apnea is adjusted from the central pattern generator. Sumi (1982) stated that reverberating circuits are formed between the central pattern generator and the reticular formation and cerebrum, and diverse information is processed and relayed to the cerebrum, resulting in activation.

In summary, swallowing function is influenced by both age and bolus size. Influences of age were recognized in laryngeal movement latency, apnea latency, and duration of laryngeal movement (at 10 mL). In addition, influences of age were seen in laryngeal movement latency and apnea latency (at 20 mL). Influence of bolus size was recognized only in the duration of laryngeal movement in younger women but not recognized at all in older men. Moreover, laryngeal movement patterns were documented in younger and older women for the 10-mL but not for the 20-mL bolus. Results were attributed to bolus size being appropriate for younger women but exceeding the suggested swallowing function in older women at 20 mL. In particular, results for older women with swallowing and respiratory coordination problems and decline of functions were considered related to the effects of physiological aging on swallowing.

Preventive care or rehabilitation is often belatedly applied after risks and symptoms of swallowing function impediments develop. In mass health examinations of patients >40 years old, a simple system needs to be developed for early diagnosis and evaluation of potential problems using noninvasive methods and a simple questionnaire regarding eating and swallowing and respiratory function tests. When problems with swallowing function are discovered, occupational therapists from the insurance industry perform a detailed evaluation and provide early treatment correspondence. In the future, I aim to use noninvasive methods to evaluate the therapeutic effects of treatments for impaired swallowing function as objective numerical data for the care insurance industry. ▲

References


