의학석사 학위논문

Influence of effortful swallowing on the temporal and kinematic variables in healthy subjects

건강한 성인에서 노력 연하 기법이 시간과 역동학적인 변수에 미치는 영향

2013년 2월

서울대학교 대학원

임상의과학과

장혜진

건강한 성인에서 노력 연하 기법이 시간과 역동학적인 변수에 미치는 영향

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February 2013

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Abstract

Influence of effortful swallowing on the temporal and kinematic variables in healthy subjects

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Introduction: We investigated the influence of the effortful swallowing maneuver on the movements of the hyoid bone, the larynx and the epiglottis in healthy subjects.

Methods: A total of 41 healthy subjects (20 men, 21 women) swallowed 10ml of diluted barium solution using two swallowing strategies; normal swallowing and effortful swallowing. The frame-by-frame movement of anatomical structures such as the hyoid bone, the larynx and the epiglottis were tracked from digitized videofluoroscopic images. Both temporal and kinematic variables were analyzed.

Results: Compared to normal swallowing strategy, effortful swallowing yielded significantly larger vertical displacement of the hyoid bone (17.48±6.07 vs. 13.88±5.48mm; $p<0.001$), vertical (26.24±8.29 vs. 23.54±6.84mm, $p=0.003$) and horizontal (8.01±2.89 vs. 6.97±2.42mm, $p=0.019$) displacement of the larynx. Maximal angle of the epiglottic rotation was larger with effortful swallowing than with normal swallowing (115.19±15.13 vs. 103.30±22.35°; $p=0.001$). In addition, total durations of hyoid vertical excursions (1.57±0.60 vs. 1.35±0.26sec; $p=0.027$), hyoid horizontal excursion (1.66±0.52 vs. 1.35±0.22sec; $p=0.001$), vertical excursion of the larynx (1.60±0.58 vs. 1.34±0.25sec; $p=0.012$) and epiglottic rotation (1.12±0.53 vs. 0.88±0.17sec; $p=0.004$) were greater in effortful swallowing maneuver than in normal swallowing

Conclusions: The effortful swallowing maneuver extended the hyoid excursion, the laryngeal excursion and the epiglottic rotation in healthy subjects. These results suggest that the effortful swallowing maneuver might have a favorable effect on airway protection.

Keywords: Dysphagia, Deglutition, Deglutition disorder, Rehabilitation, Effortful swallow

Student Number: 2011-22015

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List of Abbreviations

VFSS, Videofluoroscopic swallowing study

2-D, two-dimensional

Start-to-max, time span from the start of swallow-related motion to the moment of maximal displacement

Max-to-end, time span from the moment of maximal displacement to the moment of maximal retraction at the end of a swallow

Start-to-end, time span from the start of swallow-related motion to the moment of maximal retraction at the end of a swallow

Introduction

Various neurological or structural disorders affecting the swallowing function can cause dysphagia. Dysphagia leads to increased morbidity and mortality through dehydration, malnutrition and aspiration pneumonia, and may cause deterioration in the quality of life. Physiatrists address patients' dysphagia by means of dietary modification and swallowing therapy such as educating compensatory swallowing maneuvers, improving sensory awareness, and so on.

One of the swallowing maneuvers is effortful swallowing, which was proposed by Kahrilas (1). It was designed for patients who had reduced retraction of the tongue base toward the posterior pharyngeal wall. The patients are instructed to squeeze all the swallowing muscles as hard as they could while swallowing. Through this maneuver, the base of tongue is pressed to the posterior pharyngeal wall and the bolus is forcibly squeezed down into the esophagus. It is believed that an increased effort augments the posterior movement of the tongue base which improves the clearance of the vallecular residue (2).

Some researchers investigated into the biomechanical changes that occur during effortful swallowing in healthy subjects, with the purpose to illuminate the mechanism of improving the swallowing function. Most of them measured intraoral or pharyngeal pressure during effortful swallowing. Increases in duration and amplitude of the pharyngeal pressure during effortful swallowing have been reported (3-8), which accords with the proposed mechanism of the maneuver.

Other researchers collected healthy subjects' data on the movements of the anatomic structures involved in swallowing to understand the mechanism of airway protection during effortful swallowing. However, literature on this topic is sparse. Bülow et al. (9) reported that effortful swallowing showed reduced maximal hyoid and laryngeal motion, which may be a result of decreased preswallow hyoid-mandible distance that happens in effortful swallowing. On the other hand, Hind et al. (10) showed that the durations of hyoid maximum anterior excursion, laryngeal vestibular closure, and upper esophageal sphincter opening were longer, and the amplitude of the superior movement of the hyoid bone was larger in effortful swallowing, whereas the amplitude of the anterior movement of the hyoid was shorter. Thus, the kinematic effect of effortful swallowing is still a controversial question.

There were also studies that investigated the effect of effortful swallowing in patients with dysphagia. Lazarus et al. (11) showed that effortful swallowing increased pressure and duration of contact of the tongue base and the pharyngeal wall in head-and-neck cancer patients. Bülow et al. (12) revealed that effortful swallowing reduced depth of the misdirected swallows in patients with moderate to severe pharyngeal dysfunction, although it did not reduce the frequency of misdirected swallow. Other studies investigated the training effect of effortful swallowing. Felix et al. (13) proved that a 2-week swallowing therapy program, which consisted of effortful swallowing and biofeedback, increased the pharyngeal pressure in Parkinsonism patients. Park et al. (14) showed that a 4-week program of effortful swallowing, combined with motor electrical stimulation, enhanced the vertical movement of the larynx. These findings are in accord with the conventional belief in the benefit of effortful swallowing. However, the other study conducted by Bülow et al. (15) yielded the findings opposite to the ones aforementioned. They showed that the peak amplitude and the duration of intra-bolus pressure were not altered by effortful swallowing in patients with dysphagia due to cerebrovascular accidents or head-and-neck cancer. Synthetically, the effect of effortful swallowing in patients with dysphagia is a subject of ongoing debate.

To date, studies have revealed some changes in pressure of anatomical spaces, and those in durations and amplitudes of structural movements accompanying effortful swallowing. Though, findings from the analyses on the structural displacements induced by the effortful swallowing are somewhat inconclusive so far. Besides, little is known about airway protection achieved through epiglottic folding, even though there are some reports about the laryngeal closure duration.

This study has been carried out with the purpose to estimate the biomechanical changes that occur during effortful swallowing. The changes under investigation included those in amplitude and duration of the movements of the more detailed anatomical structures. Hypotheses were set that hyoid/laryngeal excursion and epiglottic rotation and their duration would increase during effortful swallowing, which play a critical role in improving airway protection.

Materials and Methods

Subjects

Forty-one healthy adults (20 males and 21 females) volunteered to participate in this study. Their mean age was 52.89±17.93 (range : 23-78). Prior to enrollment, data on their medical history were collected through questionnaire administration. Subjects were enrolled who reported neither symptoms nor signs of swallowing problems, no history of pulmonary disease, no neurologic diseases such as cerebral infarction, syncope, or transient ischemic attack. All subjects were fully informed of the potential risks and complications, and then written consents were obtained.

Procedures

Videofluoroscopic swallowing study (VFSS) was performed on the subjects seated upright. Subjects were instructed to drink 10ml of barium solution (Solutop Suspension®, Tae Joon Pharm Corp., Ltd, Seoul, Korea), diluted to 35% in weight per volume, twice; in usual manner at first, and then with effortful swallowing maneuver. Effortful swallowing maneuver was instructed as 'swallow as hard as you can'. No additional instructions about effects or mechanism of the maneuvers were given. Subjects tried dry effortful swallowing twice for practice before actually swallowing the liquid. If subject swallowed multiple times to clear the material, the first swallowing was analysed.

VFSS was conducted using a mobile fluoroscopy system (Medix 3000, Hitachi, Japan) and recorded with a digital computer frame grabber board (Pegasus HD/SD Board; Grass valley, Inc., Conflans St. Honorine, France) and image processing software (EDIUS 4.5; Grass valley, Inc., Conflans St. Honorine, France). Recorded movie clips were in high resolution (1980 x 1080 pixels) digital format and the sampling frequency was 30 frames per second. Movie clip was trimmed, leaving the slip from 0.5 seconds before the liquid head reached the lower mandibular margin to 0.5 seconds after the end of the liquid passed the upper esophageal sphincter. A 24mm-diameter coin was attached to the midline of the subject's chin to serve as a reference ruler for the radiographic magnification.

The movie clips were analized by a research assistant blind to this study who had had a 2-year experience in swallowing motion analysis. Predefined anatomical landmarks were marked using a motion analysis software (Ariel Performance Analysis System; Ariel Dynamics, Inc., Trabuco Canyon, CA, USA) in each frame of the movie clip; the anterior-superior margin of the hyoid bone, base and tip of the epiglottis, anterior margin of the subglottic airway column which represents the larynx. For these landmarks to get coordinates, a coordinate system was operationally defined. In it, the y-axis was defined as the straight line connecting the anterior-inferior margin of the fourth cervical vertebra (defined as the 'zero' point) to the anterior-inferior margin of the second cervical vertebra, and the x-axis as the straight line perpendicularly crossing the y-axis at the 'zero' point (Fig. 1).

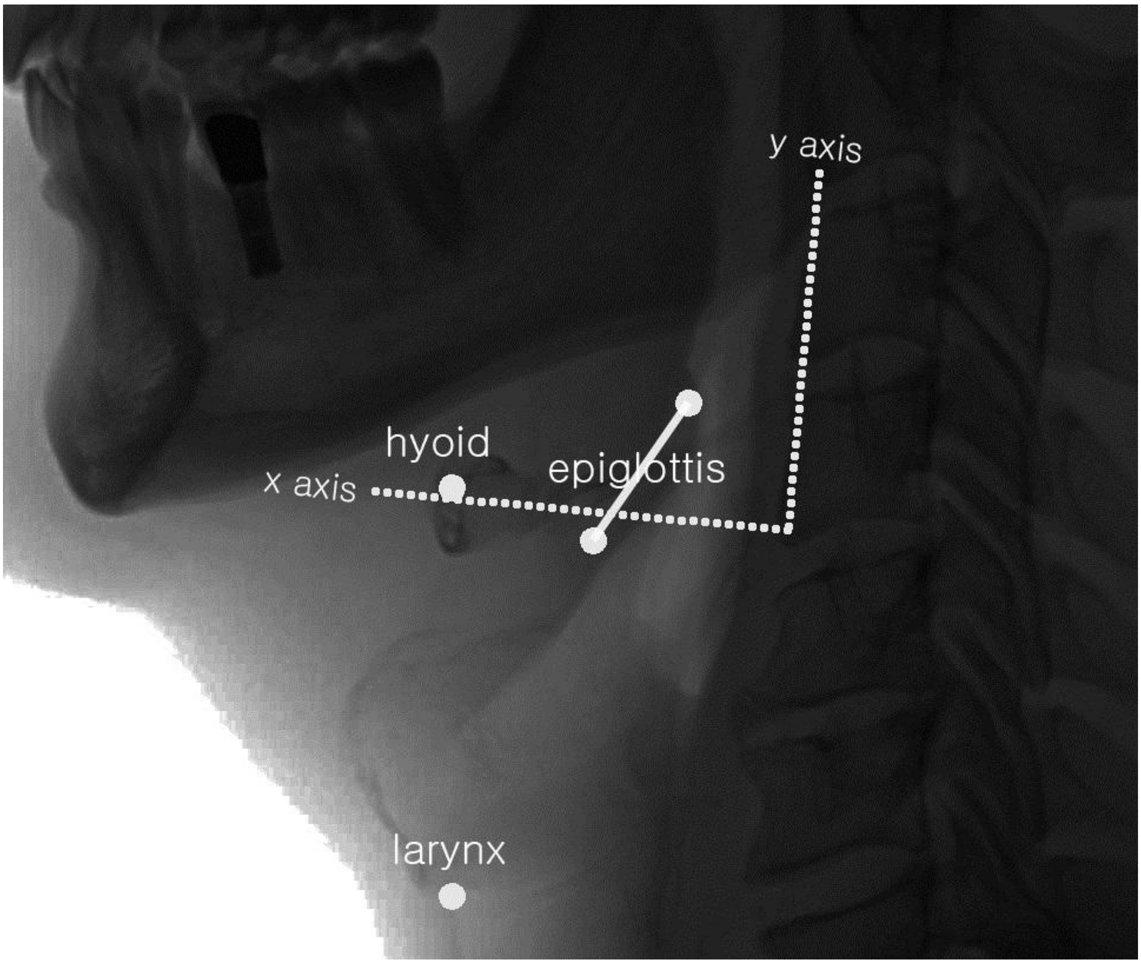

Fig. 1. Anatomical landmarks and the coordinate system. The anterior-superior margin of the hyoid bone, base and tip of the epiglottis, anterior margin of the subglottic airway column which represents the larynx, are shown

Measurements

A MATLAB (R2007a, The MathWorks, Inc., Natick, MA, USA) script was written to extract the outcome variable. The units of distance and velocity variables were converted into millimeter and meter per second, respectively, using the diameter of the coin as a reference. All measurements were made by one trained investigator who was blind to the swallowing method applied for each movie clip using MATLAB.

1. Spatial Variables

The vertical, horizontal and two-dimensional (2-D) maximal displacements of the hyoid and the larynx during the swallowing were calculated from the coordinates of resting and maximal points. Lower value of pre- and post-swallowing point was set as the resting point.

And maximal angle of the epiglottic rotation was measured, defining the initial epiglottic angle as 0°.

2. Temporal Variables

The durations of the vertical and the horizontal hyoid excursions, the laryngeal elevation and the epiglottic rotation were measured, based on the following definitions (16).

Start-to-max: time span from the start of swallow-related motion to the moment of maximal displacement.

Max-to-end: time span from the moment of maximal displacement to the moment of maximal retraction at the end of a swallow.

Start-to-end: time span from the start of swallow-related motion to the moment of maximal retraction at the end of a swallow.

‘Horizontal’ and ‘vertical’ refers to ‘x-axis’ and ‘y-axis’ respectively, in the coordinate system described earlier.

Statistical Analysis

Paired *t* tests were run to compare variables between normal and effortful swallowing. All statistical analyses were done using SPSS 18.0 (SPSS Inc., Chicago, IL). P values less than 0.05 were concluded significant.

Results

Spatial Analysis

Table 1 displays, by swallowing method, mean ± standard deviations of the maximal displacements of the hyoid and the larynx, in each dimension (vertical, horizontal and 2-D), along with the maximal angle of the epiglottic rotation. Effortful swallowing showed larger maximal displacements of the hyoid, vertically and 2-dimensionally, compared to those in normal swallowing. Maximal displacements of the larynx in all directions were larger in effortful swallowing than those in normal swallowing. The epiglottis rotated to a greater angle in effortful swallowing.

Table 1. Maximal displacements of the hyoid, the larynx, and the maximal angle of the epiglottic rotation

	Normal swallowing (Mean ± SD)	Effortful swallowing (Mean ± SD)	*p*-value
Maximal displacement of hyoid (mm)			
Vertical	13.88±5.48	17.48±6.07	0.000**
Horizontal	11.96±2.66	12.77±2.91	0.097
2-dimensional	16.23±4.92	18.04±6.32	0.015*
Maximal displacement of larynx (mm)			
Vertical	23.54±6.84	26.24±8.29	0.003**
Horizontal	6.97±2.42	8.01±2.89	0.019*
2-dimensional	23.85±7.05	26.08±9.24	0.022*
Maximal angle of epiglottic rotation (°)	103.30±22.35	115.19±15.13	0.001**

* $p<0.05$; ** $p<0.01$

Temporal Analysis

Table 2 displays the temporal statistics. Mean ± standard deviations of the durations in vertical and horizontal excursions of the hyoid, and those in vertical excursion of the larynx were shown along with those in the epiglottic rotation, by swallowing methods. In case of the vertical excursions of the hyoid and the larynx, the max-to-end and the start-to-end durations were longer in effortful swallowing compared to those in normal swallowing. For hyoid horizontal excursion, the start-to-max and the start-to-end durations were longer in effortful swallowing. The max-to-end and the start-to-end durations of the epiglottic rotation were longer in effortful swallowing.

Table 2. Duration of the hyoid excursion, the laryngeal elevation and the epiglottic rotation

	Duration (seconds)		
	Normal swallowing (Mean ± SD)	Effortful swallowing (Mean ± SD)	*p*-value
Hyoid vertical excursion			
Start-to-max	0.62±0.22	0.64±0.25	0.736
Max-to-end	0.73±0.21	0.94±0.53	0.019*
Start-to-end	1.35±0.26	1.57±0.60	0.027*
Hyoid horizontal excursion			
Start-to-max	0.65±0.17	0.81±0.31	0.005**
Max-to-end	0.70±0.19	0.85±0.51	0.075
Start-to-end	1.35±0.22	1.66±0.52	0.001**
Laryngeal vertical excursion			
Start-to-max	0.67±0.18	0.68±0.21	0.898
Max-to-end	0.67±0.16	0.93±0.53	0.005**
Start-to-end	1.34±0.25	1.60±0.58	0.012*
Epiglottic rotation			
Start-to-max	0.51±0.16	0.56±0.23	0.231
Max-to-end	0.37±0.11	0.56±0.37	0.002**
Start-to-end	0.88±0.17	1.12±0.53	0.004**

Start-to-max indicates the duration from initiation to maximal point. Max-to-end indicates the duration from maximal point to termination. Start-to-end indicates the duration from initiation to termination.

* $p<0.05$; ** $p<0.01$

Discussion

This study was the quantitative motion analysis of VFSS in healthy subjects conducted with the aim to estimate the biomechanical changes that occur during effortful swallowing. Differences were found in the biomechanical characteristics of the hyoid, the larynx and the epiglottis between effortful swallowing and normal swallowing. The maximal displacements of both the hyoid bone and the larynx, and the maximal angle of epiglottic rotation were larger in effortful swallowing compared to those in normal swallowing. The durations in the vertical and horizontal excursions of the hyoid, those in the vertical excursion of the larynx, and those in the epiglottic rotation were longer in effortful swallowing.

Bülow et al. (9) produced the findings opposite to those obtained from the spatial analysis in this study. They reported reduced maximal hyoid movement and maximal laryngeal elevation in effortful swallowing, when starting point was defined as immediately prior to swallowing. They discussed that such results were due to the early elevation of the hyoid and the larynx in the preswallow phase. Hind et al. (10) set the postswallow resting position as the reference point and analysed the hyoid movement. They concluded that the maximum superior excursion of the hyoid increases and the maximum anterior excursion of the hyoid decreases. In this study, the lower value of pre- and post- swallowing was set as the benchmark to find out that hyoid vertical excursion increases and the horizontal excursion did not reveal any significant changes, which coincides with the report by Hind et al. (10). This study is the only one that measured laryngeal excursion after eliminating the possibility of preswallow laryngeal elevation. With effortful swallowing maneuver, the laryngeal excursion increased vertically, horizontally and 2-dimensionally.

Hind et al. (10) reported that pharyngeal response duration, which means total duration of hyoid excursion, was significantly longer in effortful swallowing. Similar results were made in this study. It disclosed that total duration of the hyoid's vertical and horizontal excursions are lengthened. The increased duration of laryngeal elevation in effortful swallowing was also found in this study. A noticeable point is that the total durations of the hyoid and the laryngeal elevation increased while the time taken to reach the maximal point did not show significant change. In other word, the hyoid/larynx elevations did not slacken and kept an elevated state for a longer period, which can be interpreted as a favorable effect from the view point of better airway protection.

We did not measure laryngeal vestibular closure duration, whereas Hind et al. (10) did. However, we measured the epiglottic rotation duration instead, which turned out to be larger with effortful swallowing. Similar to the hyoid/larynx elevation, the latency to reach the maximal angle did not change. Thus, the duration that the epiglottis covers the laryngeal entrance was lengthened without affecting the promptness with which the maximal point was reached.

The results of our study revealed some discernible similarities compared with those of previous kinematic studies on Mendelsohn maneuver. Firstly, this study showed that the duration of the hyolarnygeal excursion turned out to be longer with effortful swallowing. Elongated duration is also a major characteristic found in Mendelsohn maneuver which was devised to treat cricopharyngeal dysfunction by way of widening the upper esophageal opening by volitionally prolonging the superoanterior displacement of the larynx in midswallow (1). Instruction for effortful swallowing was 'swallow hard as you can'. A subject might know that he/she is making an effortful swallowing endeavor by feeling his/her own sensory input of squeezing effort into the oropharynx. In other words, effortful swallowing might require more sensory and additional cortical involvement than normal swallowing might. The prolongation of hyolaryngeal excursion might be explained as a subsidiary effect made by the 'effort'. Swallowing and cough are similar in the aspect that they both are mainly reflexive body reactions. Lasserson et al. (17) found that muscle activation is longer in volitionally performed cough compared to that in purely reflexive cough. The same effect might apply to swallowing, which can explain the increased duration of the hyolaryngeal excursion in effortful swallowing and Mendelsohn maneuver. Secondly, increased hyoid displacement is one of the main findings in effortful swallowing in this study, which is also known to be a notable biomechanical change shown in Mendelsohn maneuver (1, 18).

This study has several shortcomings. Subjects were distributed over a wide range of age, because this study intended to investigate into the biomechanical characteristics in general population. However, swallowing can differ according to age. Especially, in the enderly, preswallow gesture of the tongue base and hyoid can occur, the duration of the hyoid motion can increases and the latency of laryngeal elevation might be elongated (19). Age variety in the sample made it out of reach to unearth the distinctive characteristics of effortful swallowing for each age group. The sample size was too small to produe statistically significant conclusions to the hypotheses made across the age groups regarding to a few factors. Another liability is the lack of monitoring measure to confirm whether the subject performed effortful swallowing correctly. This study is based on the presumption that the subject will perform effortful swallowing in the right way with a plain instruction and a little bit of practice. Incorrect effortful swallowing my have obscured the biomechanical changes induced by different swallowing maneuvers. Despite such difficulties, some meaningful changes could have been identified. A more elaborate study with a larger sample size would elicit a deeper insight into the biomechanical change caused by effortful swallowing.

Put together, effortful swallowing increases amplitude and duration of hyolaryngeal complex excursion and epiglottic rotation. These changes would contribute to improved airway protection. Effortful swallowing has usually been recommended to patients with an impaired tongue base retraction and the subsequent vallecular residue. However, the results from this study imply that effortful swallowing can be helpful to patients who suffer from misdirected swallowing due to reduced hyolaryngeal excursion and epiglottic rotation.

To date, literature about effortful swallowing in dyphagia patients have been mostly case series studies. A further biomechanical study with a larger sample of dysphagia patients is recommended in order to confirm the actual effect and to expand the eligibility of effortful swallowing maneuver.

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초록

건강한 성인에서 노력 연하 기법이 시간과 역동학적인 변수에 미치는 영향

장혜진

임상의과학과

서울대학교 대학원

서론: 우리는 건강한 성인을 대상으로 노력연하가 설골과 후두, 후두덮개의 움직임에 미치는 영향에 대해서 알아보았다.

방법: 건강한 성인 41명(남자 20명, 여자 21명)이 연구 대상으로 모집되었고 대상자들은 10ml의 바륨 용액을 한번은 평상시대로 삼켰고 또 한번은 노력 연하 기법을 사용해서 삼켰다. 디지털화된 비디오투시영상에서 설골과 후두, 후두덮개와 같은 해부학적 구조물의 위치를 프레임마다 찍어서 움직임을 분석하였다. 이를 바탕으로 시간적, 역동학적 변수들을 추출하였다.

결과: 보통 삼킬 때에 비해서 노력 연하기법을 사용하여 삼켰을 때, 설골의 수직 상방(17.48±6.07 vs. 13.88±5.48mm; $p<0.001$) 움직임과 후두의 수직 상방(26.24±8.29 vs. 23.54±6.84mm, $p=0.003$), 수평 전방(8.01±2.89 vs. 6.97±2.42mm, $p=0.019$) 움직임이 증가하였다. 그리고 설골과 후두 움직임의 최대 속도도 증가하였다. 후두덮개 회전 각도도 노력 연하에서 보통 연하보다

켰다(115.19±15.13 vs. 103.30±22.35°; p=0.001). 또한, 설골의 수직 상방(1.57±0.60 vs. 1.35±0.26sec; p=0.027), 수평 전방(1.66±0.52 vs. 1.35±0.22sec; p=0.001) 움직임, 후두의 수직 상방(1.60±0.58 vs. 1.34±0.25sec; p=0.012) 움직임, 후두덮개 회전(1.12±0.53 vs. 0.88±0.17sec; p=0.004)의 지속 시간도 더 길었다.

결론: 노력 연하 기법은 그냥 삼킬 때와 비교하여 설골, 후두의 움직임과 후두덮개의 회전을 증대시킨다. 이러한 변화는 노력 연하 기법이 기도 보호에 긍정적으로 작용할 것으로 생각된다.

주요어: 연하곤란, 삼킴 장애, 재활, 노력 연하

학번: 2011-22015