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ORIGINAL ARTICLE

Effects of Effortful Swallowing Exercise with Progressive Anterior Tongue Press Using Iowa Oral Performance Instrument (IOPI) on the Strength of Swallowing-Related Muscles in the Elderly: A Preliminary Study

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Abstract

The purpose of this study was to confirm the effect of effortful swallowing (ES) exercise programs applied to increase the swallowing-related muscle strength in the elderly. In this study, 20 healthy elderly people (76.65 ± 5.87 years; 10 women and 10 men) participated and exercised for 7 weeks. The experimental group performed ES exercise combined with external resistance using Iowa Oral Performance Instrument (IOPI), and the control group performed pure ES without external resistance. The exercises were performed for 20 min a day, 2 days a week for 7 weeks in both groups. ES was repeated 60 times in weeks 1 and 2, 80 times in week 3 and 4, and 120 times in weeks 5–7. In the experimental group, the isometric and swallowing tongue pressures at week 8 were significantly improved compared to baseline. At week 8, the anterior and swallowing tongue pressures and anterior tongue endurance were significantly higher than those of the control group. In the control group, no significant change in tongue pressure-related variables was observed after 7 weeks of exercise. ES exercise combined with IOPI resistance for 7 weeks tended to increase the suprahyoid muscle activation level without statistical significance. For clinical application of this exercise protocol, further studies including more elderly people and patients with dysphagia are required.

Keywords Deglutition · Deglutition disorders · Electromyography · Exercise · Tongue

Introduction

Effortful swallow (ES) was designed to better remove boluses from the epiglottic vallecula by increasing the posterior movement of the tongue base during pharyngeal swallow [1]. This phenomenon is produced by the participant's voluntary efforts during swallowing. Hiss and Huckabee proposed to apply ES as a rehabilitation technique for patients with dysphagia with weak pharyngeal contractility [2]. They noted that repeated ESs cause the pharyngeal muscles to contract more strongly, which increases overall strength over time. Regarding the principles of exercise, ES has excellent specificity [3]. Specificity is an exercise principle that is most effective when the training task is similar to the end goal of the exercise. Burkhead et al. suggested that swallowing would be the best training task if the purpose of the exercise is to improve swallowing function [4].

The results of previous studies applying pure ES exercise with no external resistance are as follows: First, two studies including healthy young adults have been performed. Clark and Shelton confirmed the effectiveness of the three methods of ES exercise (ES in isolation, ES with maximum-effort tongue elevation, and high effort sips followed by ES) conducted for 4 weeks [5]. Participants performed three sets of ten repetitions of assigned exercise daily for 4 weeks at home. According to self-reports of the number of exercise sessions, participants performed the exercise at least 5 days/week. After 4 weeks of exercise, tongue pressure during ES was significantly improved in all groups. However, there was no difference in exercise effects according to the exercise methods. Park et al. compared the effects of isometric tongue exercise using Iowa

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Oral Performance Instrument (IOPI), ES exercise, and ES exercise in chin tuck posture [6]. The participants performed the exercise for 30 min a day, 3 days a week, for a total of 4 weeks. After 4 weeks of exercise, the isometric tongue pressure improved significantly in all groups, and there was no difference in exercise effects between groups. Second, two studies including the elderly have been performed. Park and Kim conducted home-based ES exercise for participants aged ≥ 56 years (mean age, 73 years) 30 times a day, 3 days a week, for a total of 4 weeks [7]. After 4 weeks of exercise, the isometric anterior tongue pressure was significantly improved; however, the suprahyoid muscle activation level did not significantly change. Oh et al. conducted an ES exercise for participants aged ≥ 65 years, 20 min a day, 2 days a week, for a total of 7 weeks [8]. In their study, the repetition of exercises was increased progressively. The results of the 7-week ES exercise showed unexpectedly no significant improvement in suprahyoid muscle activation, isometric or swallowing tongue pressure, or tongue endurance. Limited studies have applied pure ES exercise to the elderly, and even the two aforementioned published studies have shown conflicting results. Therefore, studies on the effects of pure ES exercise applied to the elderly are difficult to draw clear conclusions.

The researchers noted the limitations of ES as an exercise program. Slovarp et al. reported that the suprahyoid muscle activation level varied significantly among people during ES performance [3]. This indicates that the performance level may be inconsistent in patients with dysphagia performing ES. They also pointed out limitations in terms of resistive load and gradual resistance provision. In addition, ES is difficult to be performed by patients with severe dysphagia because it requires repeated swallowing by participants for exercise [3]. According to Kim et al., ES exercise is limited in that exercise intensity cannot be quantified [9].

To overcome these limitations, ES and neuromuscular electrical stimulation (NMES) have been applied simultaneously [9–12]. NMES applied as external resistance during ES was performed targeting the infrahyoid muscles rather than the typical attachment sites (suprahyoid muscles). The effect of ES exercise applied with NMES to the infrahyoid muscle as resistance significantly increased the superior and anterior excursions of the hyoid bone and larynx. Additionally, the degree of airway aspiration decreased; and overall pharyngeal function improved [10–12]. However, NMES strengthens the weakened oropharyngeal muscles and is typically used as an adjunct treatment to recover swallowing function [13]. It serves to retrain functional muscle contraction patterns by stimulating nerves and the motor end plate [14]. Because of these mechanisms included in NMES, the effects of ES combined with NMES were mixed with the effects of NMES alone, hindering confirmation of the effects of pure ES.

Clark and Shelton suggested that IOPI biofeedback could be used to provide gradual external resistance to ES performance [5]. Of the three types of ES exercises they used to confirm the exercise effect of ES, exercises 1 (ES in isolation) and 2 (ES with maximum-effort tongue elevation) could not control target resistance. Therefore, they recommended providing biofeedback using IOPI in a later study [5]. IOPI has been widely used to measure and increase tongue strength and has the advantage of providing systematic resistance by objectively measuring tongue strength. Park and Kim also suggested that studies on the effects of load, volume, and intensity of the exercise are necessary to obtain maximum benefit from ES exercise [7]. Therefore, in this study, to overcome the limitations of ES exercise, which could not easily provide systematic resistance, IOPI, which could objectively provide systematic external resistance, was used as a biofeedback for ES exercise. The purpose of this study was to compare the effect of ES exercise with progressive resistance using IOPI according to the recommendations of Clark and Shelton [5] with that of pure ES exercise without external resistance. The study hypothesis was that ES exercise combined with progressive external resistance using IOPI will show a significantly higher strengthening effect on swallowing-related muscles compared to pure ES exercise.

Materials and Methods

Participants

This study included twenty volunteers (mean age, 76.65 ± 5.87 years; range 67–90 years) without a reported history of speech or swallowing deficit and who could perform the ES exercise (Table 1). Recruitment was conducted through announcements in one community welfare center. This was a preliminary study conducted to confirm the direction of the study before the main study. Therefore, in this study, a total of 20 participants were recruited; ten in the experimental group and ten in the control group. No

Table 1 General characteristics of the participants of the study

	Experimental group (n = 10)	Control group (n = 10)	p-value
	Mean ± SD	Mean ± SD	
Age (years)	75.0 ± 4.85	78.3 ± 6.57	0.217
Sex			1.000
Male	5	5	
Female	5	5	

participant reported any drug use that could affect swallowing or neurological function or having engaged in any type of swallowing-related strength training for at least 1 year before enrollment in this study. Swallowing disorder was confirmed through an interview with researchers. Participants who repeatedly coughed during the baseline examination conducted in this study were finally excluded from the study.

Experimental Procedures

The procedures were in accordance with the ethical standards of the committee on human experimentation at the institution at which the work was conducted. Before beginning the study, all participants received a thorough explanation of the purpose, risks, and procedures, and provided written informed consent. This study was approved by our Institutional Review Board.

This study was carried out in the following order:

(1) Baseline measurement (activation of the suprahyoid muscle during typical and effortful swallowing measured using surface electromyography [sEMG] and isometric and swallowing tongue pressures and tongue endurance measured using a tongue pressure measurement system),
(2) Exercise allocation (experimental and control groups),
(3) Seven-week exercise program (10 min/session, 2 sessions/day, 2 days/week for a total of 7 weeks),
(4) Re-evaluation at week 8 (suprahyoid muscle sEMG and tongue pressure-related variables).

Measurements at baseline and week 8 were conducted in the same place, at the same time, and by the same examiner.

Electrophysiological Evaluation

Before starting sEMG measurements, the skin under the chin where the suprahyoid muscles are located was wiped with an alcohol pad and dried for at least 1 min. Participants sat in a sturdy chair with back and armrests, and both feet were placed on the floor. sEMG measurements were conducted using TeleMyo-DTS (Noraxon, Inc., Scottsdale, AZ, USA) and analyzed using MyoResearch 1.07 XP software (Noraxon Inc., Scottsdale, AZ, USA). The sEMG signals were amplified, band-pass filtered (10 and 500 Hz), and notch filtered (60 Hz) before being digitally recorded at 1000 Hz and processed into the root mean square. To record the activation of the suprahyoid muscle complex (mylohyoid, geniohyoid, and anterior digastric muscles), wireless sEMG electrodes were placed at a distance of 1 cm on the skin on both sides of the midline under the chin [15].

The isometric reference voluntary contraction (RVC) was used to normalize the EMG data. RVC was used instead of maximum voluntary contraction to decrease the risk of injury. To measure RVC, the participants lay down on a mat and rested for 1 min. When the sEMG signal stabilized, the participants raised their heads and looked at the tip of their feet for 5 s. At this time, the shoulder was prevented from lifting from the floor. This was a modification of the isometric portion of the Shaker exercise [16]. The first (1 s) and last (1 s) sections of the entire 5-s interval of suprahyoid muscle activation were excluded from the RVC analysis. Therefore, only the middle 3 s of the entire 5 s of RVC was used for analysis [17]. Measurements were preceded by a familiarization session to exclude the effects of the learning curve and improve the reliability of measurements. The measurements were then repeated 5 times, with a 30-s rest period between the trials. During the typical swallowing test, the examiner used a disposable 3-mL syringe to put water in the participants' mouth. Participants held 3 mL of water in their mouth and swallowed it comfortably, as directed by the examiner. During the effortful swallowing test, 3 mL of water put in the participants' mouth was swallowed according to the following instructions from the examiner: "As you swallow, push really hard with your tongue" [18]. The typical swallowing and ES tests were performed five times each, and the average value of the five trials was used for analysis. The onset and offset signals representing the effort applied by the participant for each task were identified, and signals between the onset and offset signals were analyzed to obtain the peak values (peak amplitude) for each participant. For each participant, the mean value of sEMG signals was expressed as the percentage of RVC (%RVC) [17].

Tongue Pressure Measurements

IOPI (IOPI Pro system 2.3; IOPI Medical, Redmond, WA, USA) was used to measure tongue pressure. Tongue endurances of the anterior and posterior tongue portions were measured only once, and the remaining variables were measured five times. A 30-s break was provided between measurements. The highest value (kPa) was used for analysis of the maximum isometric tongue pressure in the anterior and posterior tongue portions [19]. Typical swallow and ES pressures were measured five times, and the mean values were used for analysis. Anterior and posterior tongue endurances were measured only once.

Maximum Anterior Tongue Isometric Pressure Maximum anterior tongue strength was assessed with the tongue bulb positioned longitudinally along the hard palate just posterior to the alveolar ridge [19]. Participants were asked to press the bulb as hard as possible toward the hard palate with the tongue tip for 3 s with the mouth lightly closed.

Maximum Posterior Tongue Isometric Pressure Maximum posterior tongue strength was assessed with the tongue bulb positioned longitudinally along the hard palate, with the distal end of the bulb at the posterior border of the hard palate [19]. After placing the bulb in the correct position, the connecting tube was painted with a permanent marker to the point where it met the front teeth to place the bulb in the same position at every measurement. Participants were asked to press the bulb as hard as possible toward the hard palate with the posterior tongue portion for 3 s with the mouth lightly closed.

Typical Swallowing Tongue Pressure The bulb was positioned at the anterior tongue pressure measurement site. The examiner used a disposable 3-mL syringe to put water in the participants' mouth. Participants held 3 mL of water in their mouth and swallowed it comfortably, as directed by the examiner [20].

Effortful Swallowing Tongue Pressure The bulb was positioned at the anterior tongue pressure measurement site. The examiner used a disposable 3-mL syringe to put water in the participants' mouth. Participants held 3 mL of water in their mouth and swallowed it as hard as possible, as directed by the examiner [21].

Anterior Tongue Endurance The bulb was positioned at the anterior tongue pressure measurement site. When measuring endurance, the target pressure was set to 50% of the maximum tongue pressure obtained by each participant. After sufficiently educating the participants on how to measure endurance, they were instructed to maintain the target value for as long as possible. When the participants' tongue pressure reached the target value, the green light on the top of the built-in LED of the device turned on, and the time measurement was started. While measuring tongue endurance, participants could monitor changes in tongue pressure on the LED window. The end criterion for endurance measurement was to deviate from the green light (indicating the target value) for more than 2 s [22]. Endurance was measured only once [23]. In this study, changes in endurance before (baseline) and after exercise (week 8) were measured using absolute endurance according to Clark's recommendation [24]. Therefore, endurance at the absolute force level used at baseline was measured at week 8.

Posterior Tongue Endurance The bulb was positioned at the posterior tongue pressure measurement site. All measurement aspects other than bulb location were the same as the anterior tongue endurance measurement.

The sequence of tests performed at baseline and week 8 were the same for all participants. Shaker isometric exercise (sEMG RVC) was performed first; the typical swallowing test was performed next; and subsequently, the ES test was performed, followed by measurements of the anterior and posterior tongue strength, typical and effortful swallowing pressures, and anterior and posterior tongue endurances in that order. Between the anterior and posterior tongue endurance measurements, a 2-min rest period was provided to recover from muscle fatigue.

ES Exercises

Twenty participants recruited for the study were randomized into two groups with equal male and female sex ratios (stratified randomization). Randomization was performed using Microsoft Excel 2016. Exercises were performed simultaneously in the same place for 7 weeks in both groups. Exercises in the experimental and control groups were conducted in different time schedules. The exercise comprised a total of two sessions with 10 min/session. After one session was over, the participants took a 2-min break to recover from fatigue. Both groups exercised sitting on a sturdy chair with a backrest. The electronic timer sounded an alarm every 20 s, and the participants effortfully swallowed their saliva according to the sound.

Control Group (ES Exercise Only) ES exercise was administered as a group exercise program. According to the alarm sound of the electronic timer, the experimenter instructed the participants as follows: "Swallow very hard while squeezing the tongue in an upward-backward motion toward the soft palate" [25]. If swallowing was difficult because of repeated swallowing, participants dampened their mouth with some water and tried to swallow again. Every 20 s, research assistants checked with the eyes and hands whether or not the participants were doing their best to exercise and provided verbal feedback if necessary. Participants rested for 2 min after exercising for 10 min and exercised again for 10 min (a total of 22 min). Therefore, 60 swallows were performed across two sessions. In this study, the repetition number of the exercise was progressively increased over time by referring to the method of a previous study [8]. This was a method to increase exercise intensity of strength training [4]. At the beginning of the exercise program (weeks 1 and 2), ES was performed every 20 s (a total of 60 swallows). As the program progressed, participants implemented more ESs within the same period. ES was performed every 15 s in weeks 3 and 4 (a total of 80 swallows) and every 10 s from weeks 5 to 7 (a total of 120 swallows) [8].

Experimental Group (ES Exercise with External Resistance) For the experimental group, all protocols proceeded identically with the control group except for providing external resistance by IOPI during ES exercise execution. Participants placed the IOPI bulb at the anterior tongue pressure measurement position, set 80% of the maximum pressure as the target value and performed the ES exercise together. The intensity of the exercise was at 60% of the maximum anterior tongue pressure in week 1 and 80% of the maximum pressure in weeks 2–7 [26]. The target value of tongue pressure was re-measured and applied on day 1 of each week. The research assistant sat next to the participant to check whether or not the tongue pressure reached the target value with the eyes and provided verbal feedback. Participant who did not reach the target during ES implementation were encouraged to perform ES again without delay.

In this study, all exercises were conducted in in-person sessions and not administered independently at home to reduce the variation of individual participation in self-exercise.

Statistical Analysis

All data were analyzed with SPSS (version 25.0) for Windows (SPSS Inc., Chicago, IL, USA). Among variables, typical swallowing pressure and anterior and posterior tongue endurances were used for analysis after logarithmic conversion. Data are expressed as mean ± standard deviation. Descriptive statistics and tests for normality (Shapiro-Wilks test) were performed for all outcome variables. All variables were found to be normally distributed, and independent *t*-tests were conducted to check for significant differences among all dependent variables in the two groups at baseline. Wilcoxon signed-rank tests were performed to confirm whether or not the dependent variable in each group was significantly improved from the baseline. One-way analysis of covariance was conducted to determine a statistically significant difference between experimental and control groups in the swallowing-related muscle strength at week 8 after controlling for baseline strength differences.

To confirm the inter-rater reliability of data extraction from collected sEMG data, all baseline data were analyzed separately by two evaluators. A two-way mixed effects model of the intra-class correlation coefficient (ICC) was used. ICCs (3,1) were 0.980 (Shaker isometric exercise, 95% confidence interval [CI] 0.970–0.986), 0.988 (typical swallow, 95% CI 0.982–0.992), 0.995 (ES, 95% CI 0.993–0.997), respectively. The reliability of sEMG analysis confirmed in this study was more than 0.9, indicating excellent reliability [27]. The significance level was set at $p < 0.05$.

Results

Submental Muscle Activation Level

Table 2 presents the changes in sEMG peak amplitudes from the submental suprahyoid muscles (%RVC) during typical and effortful swallowing. At baseline, there was no significant difference between the groups in typical or effortful swallowing. After 7 weeks of training, suprahyoid muscle activation levels during typical or effortful swallowing were not significantly changed compared to baseline in both groups ($p > 0.05$; Table 2). Further, there was no significant difference in suprahyoid muscle activation levels during typical or effortful swallowing between the experimental and control groups at week 8 [$F(1,17) = 1.277$, $p = 0.274$, $\eta^2 = 0.70$; $F(1,17) = 0.023$, $p = 0.881$, $\eta^2 = 0.001$, respectively].

Lingual Strength

Table 3 presents the changes in isometric tongue pressure in the anterior and posterior tongue portions. At baseline, there was no significant difference between the groups in anterior or posterior tongue pressure. In the experimental group, anterior and posterior tongue pressures increased significantly from baseline to week 8 ($p = 0.007$ and 0.035, respectively), but there was no significant change in the control group ($p = 0.445$ and 0.858, respectively). At week 8, the anterior tongue pressure of the experimental group was significantly higher than that of the control group [$F(1,17) = 5.560$, $p = 0.031$, $\eta^2 = 0.246$], but no significant difference was observed in the posterior tongue pressure between the groups [$F(1,17) = 2{,}753$, $p = 0.115$, $\eta^2 = 0.139$].

Table 2 Training effects of 7-week ES exercise on suprahyoid muscle activation (% RVC) during swallowing

	Experimental sEMG peak value Mean ± SD	*p*-value (Baseline vs. WK 8)	Control sEMG peak value Mean ± SD	*p*-value (Baseline vs. WK 8)	*p*-value (Experimental group vs. Control group)
TS (Baseline)	120.6 ± 64.09		201.1 ± 126.86		0.090
TS (8 WK)	118.4 ± 55.53	0.445	191.8 ± 90.37	0.721	0.274
ES (Baseline)	223.3 ± 108.74		295.7 ± 179.95		0.291
ES (8 WK)	242.0 ± 120.18	0.241	278.2 ± 133.95	0.959	0.881

TS typical swallowing, *ES* effortful swallowing, *SD* standard deviation, *RVC* reference voluntary contraction, *sEMG* surface electromyography, *WK* week

Table 3 Training effects of 7-week ES exercise on isometric tongue pressures

	Experimental group		Control group		p-value
	Mean ± SD (kPa)	p-value (Baseline vs. WK 8)	Mean ± SD (kPa)	p-value (Baseline vs. WK 8)	(Experimental group vs. Control group)
ATP (Baseline)	49.9 ± 9.28		44.5 ± 13.35		0.308
ATP (8 WK)	58.7 ± 10.66	0.007*	46.2 ± 13.69	0.445	0.031**
PTP (Baseline)	49.2 ± 7.90		42.7 ± 10.81		0.142
PTP (8 WK)	53.4 ± 7.75	0.035*	43.5 ± 10.87	0.858	0.115

ES effortful swallowing, *SD* standard deviation, *ATP* anterior tongue pressure, *PTP* posterior tongue pressure, *WK* week

*Significant difference versus baseline ($p < 0.05$)

**Significant difference between treatment arms ($p < 0.05$)

Tongue Pressure During Swallowing

Table 4 presents the changes in tongue pressure during swallowing. At baseline, there was no significant difference between the groups in typical or effortful swallowing pressure. In the experimental group, typical and effortful swallowing pressures increased significantly from baseline to week 8 ($p = 0.013$ and 0.007, respectively), but there were no significant changes in the control group ($p = 0.202$ and 0.445, respectively). At week 8, both typical and effortful swallowing pressures in the experimental group were significantly higher than that of the control group [$F(1,17) = 4.823$, $p = 0.042$, $\eta^2 = 0.221$; $F(1,17) = 13.894$, $p = 0.002$, $\eta^2 = 0.450$, respectively].

Lingual Endurance

Table 5 presents the changes in anterior and posterior tongue endurances. At baseline, there was no significant difference between the groups in anterior or posterior tongue endurance. After 7 weeks of training, anterior and posterior tongue endurances did not significantly change compared to baseline in either group ($p > 0.05$). However, at week 8, anterior tongue endurance of the experimental group was significantly longer than that of the control group [$F(1,17) = 5.621$, $p = 0.030$, $\eta^2 = 0.248$]. No significant difference was observed in the posterior tongue endurance between the groups at week 8 [$F(1,17) = 0.139$, $p = 0.714$, $\eta^2 = 0.008$].

Discussion

The purpose of this study was to investigate the effects of ES exercises conducted for 7 weeks on swallowing-related muscle strength in healthy elderly people. Particularly, we compared the exercise effect of ES with progressive resistance using IOPI and pure ES without external resistance.

In the experimental group, including progressive resistance using IOPI, isometric anterior and posterior tongue pressures and typical and effortful swallowing pressures were significantly improved compared to baseline. Furthermore, isometric anterior tongue pressure and typical and effortful swallowing pressures of the experimental group

Table 4 Training effects of 7-week ES exercise on swallowing tongue pressures

	Experimental group		Control group		p-value
	Mean ± SD (kPa)	p-value (Baseline vs. WK 8)	Mean ± SD (kPa)	p-value (Baseline vs. WK 8)	(Experimental group vs. Control group)
TSP (Baseline)[#]	3.17 ± 0.34		3.14 ± 0.45		0.901
TSP (8 WK)[#]	3.57 ± 0.23	0.013*	3.29 ± 0.36	0.202	0.042**
ESP (Baseline)	35.68 ± 9.23		37.58 ± 12.75		0.707
ESP (8 WK)	49.65 ± 7.33	0.007*	39.54 ± 14.91	0.445	0.002**

ES effortful swallowing, *SD* standard deviation, *TSP* typical swallowing pressure, *ESP* effortful swallowing pressure, *WK* week

*Significant difference versus baseline ($p < 0.05$)

**Significant difference between treatment arms ($p < 0.05$)

[#]Logarithmically transformed data

Table 5 Training effects of 7-week ES exercise on tongue endurances (logarithmically transformed data)

	Experimental group		Control group		*p*-value
	Mean ± SD (kPa)	*p*-value (Baseline vs. WK 8)	Mean ± SD (kPa)	*p*-value (Baseline vs. WK 8)	(Experimental group vs. Control group)
ATE (Baseline)	2.49 ± 0.74		2.68 ± 1.14		0.676
ATE (8 WK)	3.38 ± 1.34	0.059	2.39 ± 1.07	0.241	0.030**
PTE (Baseline)	2.45 ± 0.89		2.38 ± 1.39		0.902
PTE (8 WK)	2.71 ± 0.61	0.553	2.83 ± 1.50	0.333	0.714

ES effortful swallowing, *SD* standard deviation, *ATE* anterior tongue endurance, *PTE* posterior tongue endurance, *WK* week

*Significant difference versus baseline ($p < 0.05$)

**Significant difference between treatment arms ($p < 0.05$)

at week 8 were significantly higher compared to the control group after controlling for baseline strength differences ($p < 0.05$).

The activation level of the suprahyoid muscle during effortful swallowing showed an increasing trend compared to baseline in the experimental group, but there was no statistically significant difference compared to baseline or the control group. This was an unexpected result, but similar results were found in Park and Kim's study [7]. They did not use external resistors as in this study, but they used a protocol of making participants place their tongue behind their upper teeth and push them as hard as possible for 3 s before swallowing. This action was similar to the action of participants pressing the IOPI bulb with their tongue when performing ES in our study (experimental group). After 4 weeks of exercise, participants' isometric anterior tongue pressure was significantly improved from baseline, but the suprahyoid muscle activation level was not changed [7]. These findings of those two studies including healthy older adults suggest that the strengthening effect of ES is more focused on the tongue than the suprahyoid muscle. This may also mean that ES exercise intensity may not be sufficiently high to induce muscle strengthening of the suprahyoid muscle. Originally, ES was designed to improve the posterior movement of the posterior tongue during pharyngeal swallow. Molfenter et al. reported that the immediate effect of ES on the elderly population was the greater amount of residues in the pyriform sinus after swallowing compared to typical swallowing [28]. Nativ-Zeltzer et al. also found that when the elderly performed ES, the UES relaxation pressure was significantly higher than when they performed typical swallowing. These studies, which identified immediate effects of ES, suggest that the effects other than increased posterior tongue movement may not be good as expected. The suprahyoid muscle also contributes to the generation of tongue pressure inherent in ES performance [18, 29], but the strengthening effect of the suprahyoid muscle from the repetitive implementation of ES is unlikely to be significant. Therefore, if the goal of the treatment is to strengthen the suprahyoid muscle rather than to promote posterior tongue retraction, which is the original purpose of ES, applying other exercises targeting the suprahyoid muscle itself, such as the Shaker exercise, may be more efficient [16].

The experimental group in this study placed the IOPI bulb longitudinally along the hard palate just posterior to the alveolar ridge during the ES exercise and performed the exercise for 20 min. After 7 weeks of exercise, isometric anterior tongue pressure was significantly improved from baseline, and the pressure at week 8 was significantly higher compared to the control group. Isometric posterior tongue pressure in the experimental group was significantly improved after the 7-week exercise but did not show a significant difference compared to the control group. Yano et al. found that after 8 weeks of anterior tongue strengthening exercise in young adults, both anterior and posterior tongue pressures improved significantly compared to baseline [30]. Van den Steen et al. also showed similar results including the elderly [31]. The anterior and posterior tongue pressures were significantly improved from baseline in both groups trained with the IOPI bulb in the anterior or posterior tongue portions. However, after 8 weeks of exercise, anterior tongue pressure was significantly higher in the group with the bulb in the anterior placement than in the group with the bulb in the posterior tongue portion [31]. This shows partial specificity and, as confirmed in our study, that the degree of anterior and posterior tongue strength improvements may be different depending on the bulb location during ES exercise combined with IOPI training. Therefore, depending on the strength status of the participant, considering the location of the IOPI bulb may be necessary.

In the control group, participants performed the ES exercise with progressively increasing number of repetitions over 7 weeks but without any significant improvement in any variable compared to baseline. This is consistent with the results of a previous study conducted using the same protocol [8], and similar results were found in a study in which the swallowing maneuver without systematic external resistance was applied as an exercise program [32]. As some researchers have mentioned, pure ES exercise has difficulty in providing gradual resistance [3, 9]. In our study, to solve the problem of providing gradual resistance of ES exercise, we tried to increase the intensity of exercise by increasing the repetition frequency, as recommended by Burkhead et al. [4]. However, these studies confirmed that only increasing the number of repetitions of exercise without external resistance could not affect the muscle strength improvement of the swallowing-related muscles. Moreover, the cause of the problem could be found in the ES method implemented in the control group. In this study, the researcher and research assistant checked the ES performance of the control group. The participants' laryngeal movement and degree of effort during swallowing were checked with the eyes, and laryngeal movement was palpated with the hand. To induce muscle changes through exercise performance, the system must be pushed such that the participant exceeds the level of activity normally performed [4, 33]. However, there is no way to objectively determine how much of the muscle strength the participant is using during exercise with only the eyes and hands of the clinician. To strengthen the target muscles through long-term exercise, it is essential to increase resistance progressively as the participant's strength increases [4]. According to these results confirmed in our study, external resistance seems absolutely necessary to apply ES exercise as an effective strength training for the elderly population. As another way to provide objective resistance when performing ES exercise, Slovarp et al. recommended using suprahyoid muscle sEMG biofeedback [3]. This method also seems to increase the effectiveness of the ES exercise, and further studies should check its effectiveness.

In terms of endurance, anterior or posterior tongue endurance did not show significant improvement compared to baseline in either group. However, at week 8, the anterior tongue endurance of the experimental group was found to be significantly higher than that of the control group ($p < 0.05$). In this study, we measured absolute endurance instead of relative endurance to investigate the effect of progressive ES on tongue endurance [24]. This was because, through long-term strength training, improved strength may result in disadvantages due to the increased target value when measuring tongue endurances. There was no significant difference in anterior or posterior tongue endurance between the experimental and control groups at baseline. In measuring endurance by applying the target value of endurance measurement used at baseline to the experimental and control groups at week 8, there was a significant difference between the groups ($p < 0.05$). The increase in absolute tongue endurance after the long-term swallowing-related muscle strength training program identified in our study was also confirmed in a previous study [21]. This result suggests that ES exercise with external progressive resistance using IOPI could positively affect tongue endurance.

In this study, participants' tongue endurance was measured at two general placements: anterior and posterior tongue portions. After 7 weeks of exercise program, anterior tongue endurance was significantly higher in the experimental group than in the control group, but posterior tongue endurance was not different between the groups. This phenomenon has not been identified in previous studies, so they should be confirmed through additional studies. However, if the cause of the aforementioned phenomenon is estimated based on the test protocol used in this study, the break time between two endurance measurements may be too short. In this study, anterior tongue endurance was measured once, followed by rest for 2 min, and posterior tongue endurance was measured next. The 2-min break between endurance measurements was to recover from fatigue accumulated in the previous anterior tongue endurance test. The anterior tongue endurance at week 8 of all participants in this study ranged from 3 to 230 s. Clinically, some participants who did not show any particular difficulties with previous tests (sEMG tests or isometric or swallowing tongue pressure measurement) reported that they were very tired when measuring endurances. The experimental group showed significantly higher anterior tongue endurance than the control group after 7 weeks of exercise. This suggests that the amount of fatigue accumulated during anterior tongue endurance measurements could be significantly higher than at baseline. Endurance measured without fully recovering from fatigue may be difficult to guarantee objectivity in terms of reliability. Therefore, in future studies, it would be better to provide more time for continuous endurance measurements to fully recover from the fatigue accumulated in previous measurements.

In this study, ES exercise conducted for 7 weeks without progressive resistance showed an increasing trend in isometric and swallowing tongue pressures, and posterior tongue endurance but without statistical significance. However, ES exercise with progressive resistance using IOPI significantly improved all variables related to tongue pressure and showed a significantly higher strength improvement compared to the control group. This means that IOPI can fulfill its role as a means of providing effective progressive resistance in performing ES exercise as a long-term exercise program. In the past, NMES applied to the infrahyoid muscle was mainly used to provide resistance externally when performing ES exercise. However, it has the disadvantage of difficulty confirming the effect of pure ES because the effects of NMES itself are mixed with the effect of ES [28]. In addition, in individuals who are clinically sensitive to pain when applying NMES [34], it is difficult to provide an appropriate level of stimulation. Generally, pain receptors are located on the surface rather than the muscles to be stimulated, so in the case of NMES which typically uses surface electrodes, pain can be caused by increasing current [35]. However, the provision of progressive resistance using IOPI used in this study can be practiced by all participants who can voluntarily perform ES exercise without any difficulty.

This study has some limitations. First, this was a preliminary study on the feasibility and effectiveness of the method of providing progressive resistance using IOPI for ES exercise. To confirm this, 20 healthy elderly people were studied. To clarify the effectiveness of the method used in this study, further studies involving more participants should be conducted. Additionally, this study was conducted in healthy elderly people without swallowing problems. To apply the results to patients with dysphagia, patient groups should also be included in the study. Second, in this study, to confirm the effect of exercises that was conducted for 7 weeks, muscle physiological changes were tracked instead of swallowing functional changes. Therefore, future studies need to be conducted using videofluorosopic swallowing study or fiberoptic endoscopic evaluation of swallowing. Third, there was some difference in the way the two groups exercised. In both groups, the researchers conducted the program in a group therapy method, and research assistants confirmed whether or not the participants were performing well. However, in the experimental group, the research assistant provided verbal feedback after the participant attempted ES by checking the IOPI LED window with the eyes. In the control group, the research assistant checked whether or not the participant performed well with the eyes and hands. In the case of pure ES, there is no way to check a participant's performance except by relying on palpation by the clinician when the participant's larynx rises [36]. Therefore, due to the nature of ES, which depends on the degree of effort exerted by the participant when swallowing, the effect of exercise may vary depending on the participant if there is no device capable of externally monitoring the participant's performance level. The difference in the method of providing feedback when performing these exercises between two groups may have influenced the research results. Therefore, in future studies, it is necessary to compare the effects after consistently adjusting the method of feedback provided to the two groups. Finally, in this study, IOPI was used to provide systematic resistance when performing ES. The isometric tongue exercise using IOPI improved the tongue pressure and swallowing function in several studies [37]. Although the previous method of using IOPI was different from that of our study, general IOPI exercises reduced the amount of residue in the pharynx and the degree of airway aspiration in the pharyngeal phase of swallowing, and increased the pharyngeal response duration [38]. Therefore, it is difficult to conclude that the exercise effect confirmed through our study is the pure effect of ES exercise, excluding the effect of IOPI itself. To more clearly confirm the effect of ES exercise, comparing the effect of ES exercise using IOPI biofeedback and pure IOPI exercise would be necessary.

Conclusions

In this study, we compared the effects of two methods of ES exercise in elderly people over 65 years of age. In the experimental group that provided progressive external resistance using IOPI during ES exercise, tongue pressure-related variables markedly improved. However, in the control group that provided no external resistance during ES, the strength of the swallowing-related muscles did not change. For the clinical application of this exercise protocol, further studies including more people and patients with dysphagia are required.

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Compliance with Ethical Standards

Conflict of interest The author declares that there are no competing interests.

Ethical Approval and Consent to Participate All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committees and the 1964 Helsinki declaration and its later amendments or comparable ethical standards. All the participants provided informed consent to participate in this study. The protocol was approved by the ethics committee of Institutional Review Board of Cheongju University (1041107-202004-HR-009-01).

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