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Swallow Strength Training Exercise For Elderly: A Health Maintenance Need

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Abstract:

Background: Recent studies have shown high prevalence of oropharyngeal dysphagia associated with frailty- and age-related muscle weakness. Strength training exercises have been advocated for locomotive health maintenance in the elderly and have shown positive outcomes. As muscles involved in oropharyngeal phase of swallowing are also comprised of striated muscles, the aim of this study was to determine biomechanical effect of a novel resistance exercise program, Swallowing Against Laryngeal Restriction (SALR), on pharyngeal phase swallowing in the healthy elderly. Methods: A total of 28 volunteers (75 + 7 years; 17 females) with no complaint of dysphagia were studied using video fluoroscopy before and after 6 weeks of the swallow strength training exercise. Eighteen of these volunteers also underwent high-resolution pharyngeal manometry non-concurrent with fluoroscopy. Ten additional volunteers (81 + 6 years; 9 females) were studied by videofluoroscopy before and after 6 weeks of a sham exercise. Key Results: Swallow resistance exercise but not the sham exercise resulted in a significant increase in maximum upper esophageal sphincter opening ($P < .01$), superior and anterior laryngeal excursion ($P < .01$) as well as posterior pharyngeal wall thickness ($P < .01$). Resistance exercise but not sham exercise also resulted in a significant increase in deglutitive pharyngeal contractile integral ($P < .01$). Conclusions & Inferences: Strength training of muscles involved in the pharyngeal phase of swallowing using the swallowing against laryngeal restriction technique is feasible and significantly improves key physiologic features of the pharyngeal phase of swallowing. These findings provide the basis for consideration of developing an exercise-based swallow health maintenance program for the elderly swallow health maintenance program for the elderly.

Keywords

aging; dysphagia; elderly; exercise; swallow health maintenance; swallowing disorders

Abbreviations

ICC interclass correlation
OPD oropharyngeal dysphagia
PhCI pharyngeal contractile integral
PPW posterior pharyngeal wall
sRED Swallow Resistance Exercised Device
UES upper esophageal sphincter
UESDmax maximum deglutitive anteroposterior opening of the UES

INTRODUCTION

Oropharyngeal dysphagia (OPD) is increasingly recognized among independently living elderly[1] [2] [3] [4] [5] [6] and frail populations.[7] [8] With expected doubling in the global population age 65 and older to about 1.6 billion by year 2050,[9] the impact of OPD on population health and health care resources will be significant.

Although strength training exercises have been advocated for locomotive health maintenance in the elderly with positive outcomes,[10] [11] a similar approach for preservation of swallow function in the elderly is not currently available. The success of strength training exercises depends on adequate overload and fatigue of the target muscles during contraction.[12] In an earlier study,[13] we showed that applying resistance against anterosuperior movement of the hyolaryngeal complex during repetitive swallowing results in overload and fatigue of the pharyngeal and suprahyoid muscles evidenced by significant reduction in both pharyngeal deglutitive contractile pressure and maximum deglutitive hyolaryngeal excursion. This study,[13] however, was not designed to evaluate strengthening of the target muscles. The aim of the present study therefore was to determine the effect of our proposed strength training exercise regimen based on the technique of Swallowing Against Laryngeal Restriction (SALR) on pharyngeal phase of swallowing biomechanics, pharyngeal motor function and upper esophageal sphincter (UES) opening in the elderly. As posterior pharyngeal wall thickness measured on fluoroscopic images has been used as a surrogate for muscle loss and sarcopenia,[14] we determined this thickness before the initiation of swallow (PPW-Hold) and during swallow (PPW-Max).

METHODS

We studied a total of 38 volunteers with no complaint or history of dysphagia. Twenty-eight of these volunteers (75 ± 7 years; 17 F) were studied by videofluoroscopy (30 frame/s) during swallowing 1, 3, and 5 mL 40% W/V Barium, 3 repetitions each) before and after 6 weeks of swallow strength training exercise. Eighteen of twenty-eight volunteers also underwent pre- and postexercise high-resolution pharyngeal manometry during 5 repetitions each of dry, 5 and 10 mL water swallows non-concurrent with but on the same day as fluoroscopy. An additional 10 elderly (81 ± 6 years; 9 F) were studied by videofluoroscopy before and after 6 weeks of a sham exercise. Studies were approved by internal review board of the Human Research Protection Program at the Medical College of Wisconsin and all participants gave written informed consent.

Swallow strength training exercise device

To overload the swallowing muscles, we used the technique of swallowing against laryngeal restriction. To induce laryngeal restriction, we used a device constructed in our laboratory providing resistance to the anterosuperior excursion of the hyolaryngeal complex. As shown in Figure , this device consists of a cotton fabric strap affixed with VELCRO (Velcro USA, Manchester, NH) at both ends for customize fitting of the device when the strap is wrapped around the neck. A concave flexible plastic disk is affixed to the middle of the strap assembly serving as a support structure for an inflatable polyethylene bag that applies an external force to the laryngeal cartilage to resist anterior and superior deglutitive laryngeal movement. The inflatable bag is connected via a flexible catheter to a hand pump and pressure gauge (Welch-Allyn, 4341 State Street Road, Skaneateles Falls, NY, 13153-0220). A known external pressure may be applied to the thyroid by partially inflating the bag to a specific pressure reading on the gauge. The soft and compliant bag conforms to the surface of the skin cradling the irregular laryngeal geometry while applying a resistive force to anterosuperior deglutitive distraction of the hyolaryngeal complex.

Videofluoroscopic recording

We used digital videofluoroscopy recorded in the sagittal view at 90 keV, using a 9-in. image intensifier and appropriate collimation. We recorded fluoroscopic movies of 1, 3, and 5- mL thin liquid barium swallows each repeated 3 times. Fluoroscopic images were centered on the pharyngoesophageal junction to clearly visualize the pharynx, UES, proximal esophagus, larynx, and hyoid bone. Images were digitally stored for subsequent stop-action kinematic video analysis.

Pharyngeal high-resolution manometry/Pharyngeal contractile integral

Studies were performed in a seated, upright position. Pharyngeal and proximal esophageal pressures were recorded using a high-resolution manometric catheter positioned transnasally to traverse the pharynx, UES, and proximal esophagus. The manometric probe and its associated computerized recording and analysis system (ManoScan and ManoView Systems; Given Imaging, Duluth, GA) stores pressure data from 36 pressure sensors (1 cm sensor spacing), displays the manometric information in topographic or line graph formats, and provides postacquisition analytic tools for parameterization of temporal and spatial pressure data. We used the pharyngeal contractile integral (a feature of the ManoScan measurement software) that overcomes the known inherent recording site-specific variability[15] [16] as a measure of pharyngeal contractility. Subjects were verbally cued to perform, in randomized fashion, 5 swallows each of dry as well as 5 and 10 mL water slowly injected in the oral cavity by a syringe and swallowed as a single bolus. There was a 20-second interval between swallows wherein the subject refrained from swallowing.

STUDY GROUPS

Swallow resistance exercise group

After the device was strapped around the neck overlying the laryngeal cartilage, externally applied pressure was induced by adding air to the device bag and maintained at the desired pressure by means of the pressure gauge included in the device. Volunteers were asked to always follow a thrice-daily exercise regimen. During the first 2 weeks, the exercise regimen consisted of 30 saliva swallows at 15 seconds' interval against minimal resistance of 20 mm Hg applied by pharyngeal exerciser. The external resistance was increased at the end of 2 weeks from 20 to 30 mmHg and subsequently from 30 to 40 mmHg in the last 2 weeks.

Sham exercise group

In this group, device was placed around the neck overlying loosely the laryngeal cartilage. No external pressure was applied during exercise. These volunteers were asked to perform repetitive tongue protrusion for 5 times at 30 second interval. This was repeated 3 times a day for 6 weeks.

Weekly telephone interviews were conducted to assess progress in both study groups. After 6 weeks, each subject underwent follow-up fluoroscopic and manometric studies accordingly with the same test swallows as the pre-exercise studies.

Lateral view fluoroscopic video recordings were analyzed for the following measures:

1. The maximum width of the UES opening as defined by the line between the anterior and posterior walls of the pharyngoesophageal segment at its narrowest area during maximum opening
2. Anterior and superior hyoid movement defined as the maximum deglutitive excursion of the anteroinferior corner of the body of the hyoid from its resting position, wherein the excursion is measured relative to directions perpendicular (anterior) and parallel (superior) to the cervical spine
3. Anterior and superior laryngeal movement defined as the maximum deglutitive excursion of the anterior superior portion of the subglottic air column from its resting position
4. Pharyngeal contraction integral as described below
5. Posterior pharyngeal wall thickness was characterized by 2 metrics. The width of unconstricted pharyngeal wall with bolus held in the oral cavity prior to swallow ("PPW-Hold") and at the point of maximum pharyngeal constriction ("PPW-Max"). For each measure, a vertical line was first drawn along the most anterior aspect of C2 and C3. The horizontal thickness measurement was made by extending a straight line from the anterior edge of the pharyngeal wall to the vertical line at the midpoint of C3.

All videofluoroscopic data were analyzed by 2 raters. One rater (DA) was not blinded to the study groups as he participated in all recruitment, data acquisition, analysis of the experimental data and assignment of subjects to exercise or sham groups. Due to this first-hand involvement in all aspects of the study, blinding him to participant group was logistically untenable. The second rater (MK) received study data for analysis unaware of the status of the participant. Both raters had considerable experience and training in videofluoroscopic image analysis. One of the authors/raters (MK) has been doing videofluoroscopic analysis of swallowing biomechanics for 30 years. The other rater was trained to perform videofluoroscopic analysis by the senior author (RS) who has similar longstanding experience and publications in the field.

Pharyngeal contractile integral

High-resolution manometry was analyzed for pharyngeal contractile integral (PhCI), a parameter derived from the ManoView analysis software. The PhCI was characterized by circumscribing a space-time box in the topographic ManoView display to surround the pharyngeal deglutitive pressure recording with the upper margin of the box at the most proximal probe sensor before deglutition and the distal margin of the box at the predetermined upper margin of the UES high-pressure zone at the time of return of the high-pressure zone to its resting manometric profile.[15] [16]

Statistical analysis

Statistical analysis was performed using paired t test and repeated measures analysis of variance. Data are presented as mean ± standard error of the mean unless stated otherwise. Each study parameter was tested using repeated measures analysis of variance to model both the effects of bolus volume and exercise performance. To further detect which volumes were driving the effects of exercise on swallowing biomechanics, post hoc, pair-wise t testing was performed wherein the probability of making a type I error was corrected using Tukey's correction. The alpha threshold was chosen to be $P < .05$.

Interobserver reproducibility

The significant increases in the swallowing metrics documented by the first observer were confirmed independently by a second observer. Interobserver reproducibility was tested using intraclass correlation (ICC) analysis. There were minimal interobserver differences in the magnitude of measured parameters, but these differences did not reach statistical significance.

RESULTS

All subjects tolerated the experiment well and completed the study without any untoward event.

Effect of swallow resistance exercise on maximum deglutitive UES opening

Comparison between maximum deglutitive anteroposterior opening of the UES during 1, 3, and 5 mL swallows at enrollment and completion of the 6-week study showed significant increase for all tested swallowed volumes ($P < .01$) that are shown in Figure . In addition, the significant volume effect in the maximum UES opening at enrollment was preserved after 6 weeks of exercise (Figure , $P < .01$).

Effect of swallow resistance exercise on deglutitive hyolaryngeal excursions

Deglutitive laryngeal excursions which play a pivotal role in displacement of the airway away from the path of the swallowed bolus and UES opening increased significantly following the 6 weeks of exercise for all tested volumes (Figure , $P < .05$). Effect of exercise regimen on anterior hyoid bone excursion reached statistical significance for 3 and 5 mL for anterior ($P < .03$) but not superior excursion.

Effect of swallow resistance exercise on pharyngeal contractile integral

Eighteen of twenty-eight participants underwent pharyngeal high-resolution manometry in addition to their fluoroscopic studies. As seen in Figure , there was significant increase in average pharyngeal contractile integral after 6 weeks of exercise compared to pre-exercise values ($P < .05$).[17]

The effect size for each measured parameter calculated using Cohen's d is shown in the Table .[17]

Table 1. Effect sizes for measured parameters

Effect size	Max anterior hyoid	Max superior hyoid	Max anterior larynx	Max superior larynx	Max UES diameter		PhCI

Exercise							
1 mL	0.39	0.29	0.70	0.35	0.38	Dry	0.11
3 mL	0.41	0.22	0.51	0.37	0.46	5 mL	0.31
5 mL	0.46	0.32	0.58	0.35	0.42	10 mL	0.40
Sham							
1 mL	0.20	−0.09	−0.17	−0.19	0.03		
3 mL	−0.14	−0.06	−0.39	−0.10	−0.16		
5 mL	−0.21	−0.06	−0.53	−0.12	−0.15		

Note: Negative effect sizes denote instances where pre-exercise average values exceeded postexercise values.

In addition, similar to the entire group, the maximum UES opening, anterior as well as superior laryngeal excursion in these eighteen manometrically studied volunteers showed significant increase after 6 weeks of exercise for all tested volumes. Comparison of the measured parameters before and after the exercise regimen in the eighteen manometrically studied volunteers is shown Table .

Table 2. Comparison of the measured parameters before and after the exercise regimen in the eighteen manometrically studied volunteers

Mean ± SEM	Max anterior hyoid	Max superior hyoid	Max anterior larynx	Max superior larynx	Max UES diameter
Pre					
1 mL	0.98 ± 0.14	1.05 ± 0.18	0.83 ± 0.16	2.59 ± 0.26	0.86 ± 0.10
3 mL	1.02 ± 0.14	1.04 ± 0.23	0.93 ± 0.14	2.50 ± 0.31	1.10 ± 0.12
5 mL	1.04 ± 0.17	1.10 ± 0.26	0.89 ± 0.17	2.58 ± 0.26	1.22 ± 0.13
Post					
1 mL	1.22 ± 0.16 (0.004)	1.19 ± 0.26 (0.21)	1.17 ± 0.13 (0.001)	2.88 ± 0.36 (0.12)	0.94 ± 0.10 (0.001)
3 mL	1.17 ± 0.17 (0.19)	1.26 ± 0.26 (0.24)	1.11 ± 0.14 (0.014)	2.97 ± 0.27 (0.008)	1.21 ± 0.13 (0.008)
5 mL	1.19 ± 0.15 (0.17)	1.24 ± 0.30 (0.47)	1.15 ± 0.16 (0.009)	2.88 ± 0.36 (0.12)	1.36 ± 0.13 (0.0005)

Values in parentheses represent the P-value for corrected, paired t test comparison of the pre- vs postexercise values.

Effect of swallow resistance exercise on posterior pharyngeal wall thickness

We determined posterior pharyngeal wall thickness before the initiation of swallow (PPW-Hold) and during swallow (PPW-Max). Comparison of posterior pharyngeal wall thickness showed that 6 weeks of exercise was associated with significant increase in both measures for all tested volumes (Figure , $P < .01$).

Effect of sham exercise on pharyngeal phase biomechanics, UES opening and posterior ...

Comparison of the pre- and postexercise volunteers showed that 6 weeks of sham exercise did not result in any significant increase in any of the measured parameters.

Inter-rater concordance

There was excellent agreement between the 2 independent raters for all metrics. The ICC values ranged from 0.91 to 0.99 with anterior laryngeal excursion pre-exercise values having the lowest levels of agreement across the 3 volumes (ICC=0.91).

DISCUSSION

In this study, we determined the effect of a novel swallow resistance exercise technique described previously[13] on pharyngeal phase swallowing physiology in the elderly. Study findings indicate that 3 times daily sets of 30 swallows for 6 weeks while wearing a Swallow Resistance Exercised Device (sRED) which applies progressive resistive load to anterosuperior laryngeal movement significantly increases the maximum deglutitive UES anteroposterior opening diameter, pharyngeal contractile integral, posterior pharyngeal wall thickness as well as superior and anterior movement of the larynx. We chose the current exercise regimen empirically based on other swallow exercises used in practice.[18] [19] [20] [21] Whether the number of daily repetitions or the duration of exercise can be modified while maintaining its efficacy awaits further studies.

The results of the present study have 2 important clinical ramifications. Firstly and easily surmised, is its potential application to patients with pharyngeal dysphagia and secondly, although less obvious but equally important from public health perspective is its potential usefulness as a preventative measure to reduce deterioration of swallowing function in the elderly. This latter topic to our knowledge has not been previously explored but considering the strengthening effect of the proposed exercise and its ease of performance, it can be envisioned that it could potentially offer a viable approach for a swallow health maintenance program in the elderly population.

With the rapid growth of the aging population, it is not surprising that dysphagia is increasingly recognized as a significant healthcare issue that is associated with significant cost and morbidity. The prevalence of dysphagia is expected to increase further given the demographic trends in the United States. For example, it is predicted that 10 000 more Americans will join the ranks of senior citizens each day for the next 18 years because of the aging Baby Boomer population. It is thought that by 2030, 1 of 5 residents in the United States will be of age 65 or older. [22]

While most of the diseases leading to oropharyngeal dysphagia are increasingly prevalent with advancing age, the physiologic changes of aging by themselves are also linked to the risk of dysphagia.[23] [24]

Several studies have documented that a reduced mass and function of muscles involved in swallowing contribute to dysphagia due to aging. The volume of the geniohyoid muscle has been reported to significantly decrease in older compared to younger subjects and furthermore this value was significantly reduced in aspirators compared to non-aspirators among otherwise healthy older subjects.[25] Another study showed the significant association of tongue strength with aspiration status in older individuals.[26] The posterior pharyngeal wall in older adults is found to be thinner and not constrict to the same extent in older subjects compared with younger individuals.[14]

Prior studies[27] [28] have shown that deglutitive UES opening diameter is also susceptible to the effect of aging with significant clinical consequences, such as postswallow residue and aspiration. Although several factors contribute to UES opening,[29] [30] the anterior distraction of the hyo-laryngo-cricoid-complex induced by the contraction of suprahyoid muscles constitutes the main factor. Weakness of suprahyoid muscles in the elderly seems to drive the effect of age on the UES opening diameter.[31] Strengthening the suprahyoid muscles has been shown to increase the UES diameter in the elderly and dysphagic patients,[18] [19] [20] [21] reduce the hypopharyngeal intrabolus pressure[21] and residue and remedy postdeglutitive aspiration.[19] [20]

The economic impact of swallowing disorders in older persons has not been studied in detail. Nevertheless, emerging data suggest a significant burden on patients, society and health care resources. Dysphagia can lengthen the hospital stay and increase costs. In 1 study, the cost related to stroke patients with oropharyngeal dysphagia was $4510 more per patient than for those without dysphagia. In addition, patients with dysphagia were more likely to be discharged to nursing homes and had longer hospital stays than patients without dysphagia even after controlling for age, comorbidities, ethnicity, and proportion of time alive.[32]

Apart from the cost of home and hospital care and rehabilitation, oropharyngeal dysphagia can be associated with other societal costs such as loss of productivity, as well as adding to “social burden” through affecting eating practices, mealtime regimes, fear of choking, altered diets, slow eating and drinking, fatigue, and embarrassment of eating in public, need for preparation of special diets with its associated financial burden and stress.[33] Preventing or postponing the development of oropharyngeal dysphagia due to non-disease-related causes, such as advanced age and frailty by institution of preventative exercises, can potentially help maintain quality of life, reduce the economic impact and societal/social burden of the disease and merits further investigations.

There are several limitations to this study. While a sham group was evaluated for whom the sham exercise had no relationship to swallowing, per se, there was no swallowing control group to test that the changes we report are not simply an artifact of practicing swallowing for 6 weeks. However, our strategy is predicated on fatigue of the muscles shown in prior studies. We have also tested unloaded but repeated (30 times) swallowing. We did not find evidence of fatigue. Although we agree with the usefulness of unloaded repeated swallows for future studies, the above indication may be useful. The sham group was also not monitored for increased swallow frequency due to the sham exercise activity. Furthermore, the study groups in our experiment were not balanced. The issue of detraining goes beyond the scope of the present study; thus, future studies will address the durability of the result and guide the development of exercise regimen intensity, frequency and duration needed to maintain strength and biomechanical benefits. This is especially important in the elderly and sedentary who may be more susceptible to detraining as compared to healthy young individuals.[34] [35] [36] [37] However, what the present study clearly demonstrated is that the age effect on the swallowing muscles can be improved/reversed by the proposed exercise. Like any other strength training exercises in healthy individuals, preserving the effect requires maintenance of the exercise regimen. A further limitation of this study relates to the subjective method for evaluating compliance of the participants (ie, use of telephone contact). Although participants were interviewed by telephone weekly, there was no metric or descriptive data gathered to objectively gauge compliance. The telephone interviews consisted of queries regarding the participant’s operation of the exercise device and addressing any concerns or comments from the participants. At some point in each interview, each participant was asked to describe in their own words how the exercise regime was being performed. This allowed the interviewer to reinforce appropriate execution of the exercise regime or to correct inappropriate actions by the participants.

The exercise regimen tested in the present study resulted in improvement in several of the age-related deteriorations including a significant increase in: (i) contractile function of the suprahyoid muscles evidenced by the increase in deglutitive anterior excursion of the larynx and hyoid bone, (ii) maximum anteroposterior diameter of the UES, (iii) contractility of the pharyngeal muscles evidenced by significant increase in their deglutitive contractile integral and (iv) thickness of posterior pharyngeal wall. This multifaceted effect offers a unique opportunity to simultaneously address the weaknesses of several key components of the swallowing apparatus.

In summary, strength training of pharyngeal phase of swallowing muscles using the technique of swallowing against laryngeal restriction safely improves key physiologic features of the pharyngeal phase of swallowing. In addition to the potential usefulness of this exercise in dysphagic patients, these findings provide the opportunity for consideration of instituting an exercise-based swallow health maintenance program for the elderly.

CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

Notes

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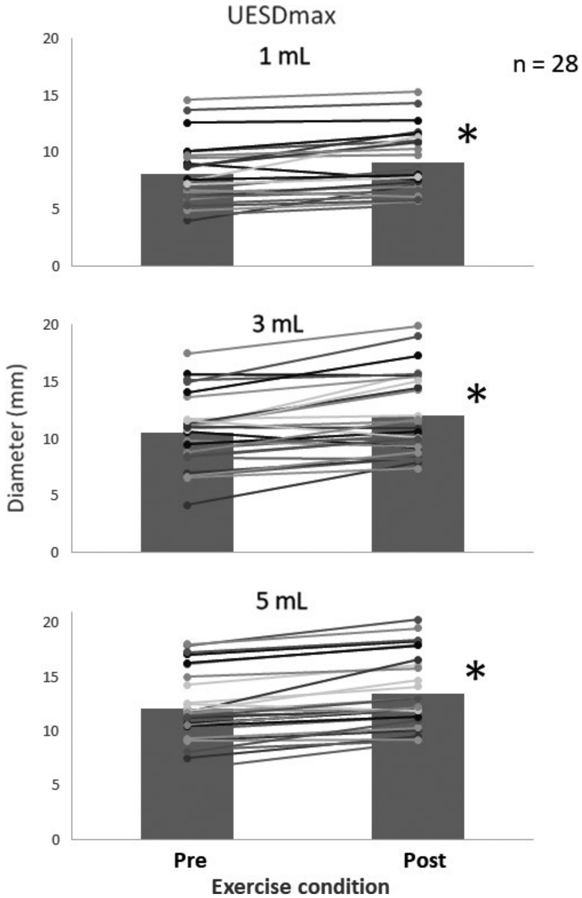
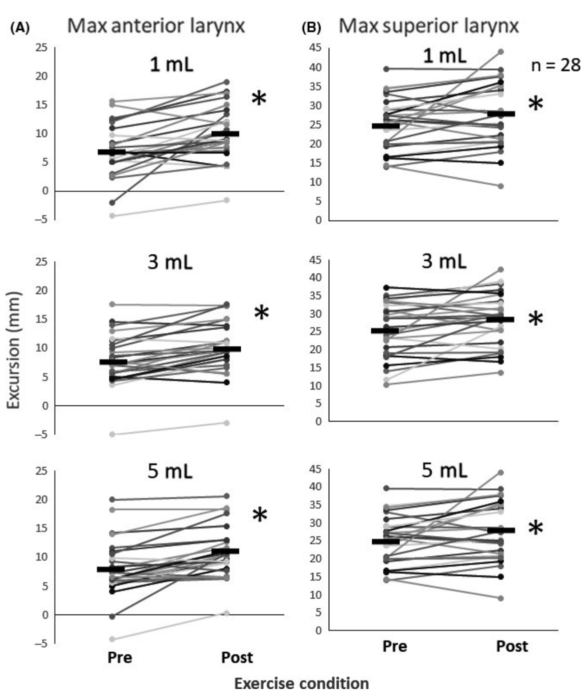
Figures

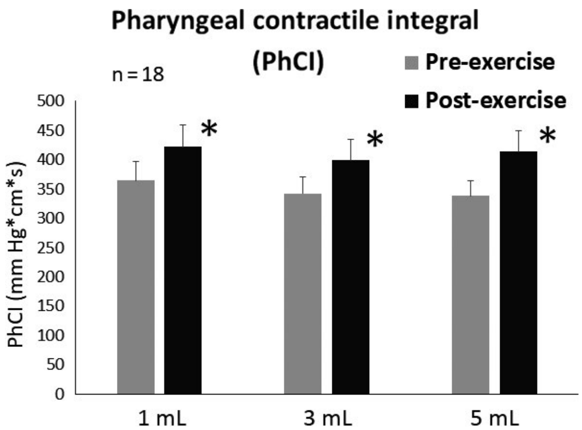
F I G U R E 1 Swallow Resistance Exercise Device (sRED) consists of an inflatable bag housed in a rigid shell. The concave surface of the inflated bag rests on the thyroid cartilage and conforms to the surface of the larynx, restricting the anterosuperior excursion of the hyolaryngeal complex



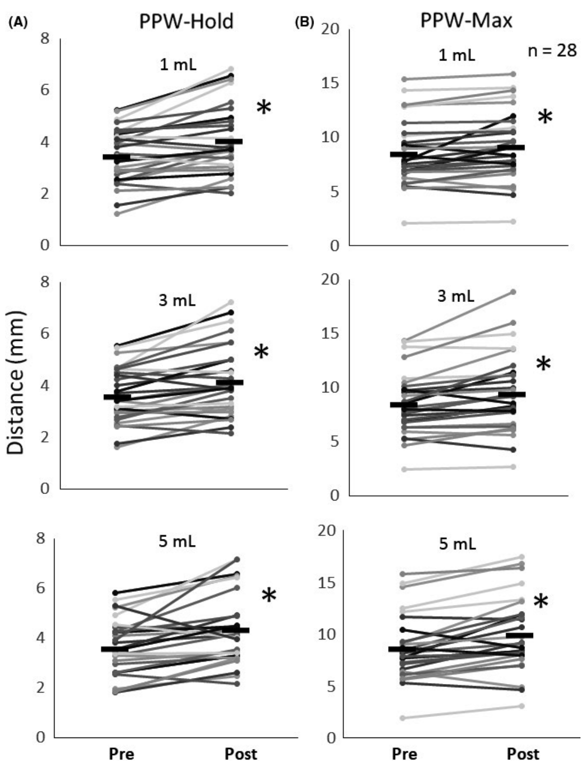
F I G U R E 2 Comparison between maximum deglutitive anteroposterior opening of the UES (UESDmax) during 1, 3, and 5 mL swallows at enrollment and completion of the 6-wk study. Significant volume effect in UESDmax at enrollment persisted and remained significant after 6 wk of exercise (P < .01)



F I G U R E 3 Deglutitive laryngeal excursions increased significantly following the 6 wk of exercise for all tested volumes (*P < .05). Individual subject average data are shown as connected scattergrams and group average is shown as a horizontal line



F I G U R E 4 For the eighteen subjects who had both manometry and fluoroscopic studies, there was significant increase in average pharyngeal contractile integral after 6 wk of exercise compared to pre-exercise values (*P < .05). Bars represent mean values and error bars represent standard error



F I G U R E 5 Posterior pharyngeal wall (PPW) thickness before the initiation of swallow (PPW-Hold) and during swallow (PPW-Max) measurements showed 6 wk of exercise was associated with significant increase in both measures for all tested volumes (*P < .01). Connected dots represent individual mean values before and after the exercise period. Group means are shown as horizontal lines