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ORIGINAL ARTICLE

Effects of Expiratory Muscle Strength Training on Oropharyngeal Swallow Physiology in Persons with Obstructive Sleep Apnea (OSA): A Preliminary Study

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Effects of Expiratory Muscle Strength Training on Oropharyngeal Swallow Physiology in Persons… **Abstract**
Despite the high estimated prevalence of dysphagia in OSA, there is a paucity of evidence supporting behavioral interventions for treatment. The purpose of this study was to assess the impact of expiratory muscle strength training (EMST) on validated, standardized metrics of swallow and airway clearance capacity functions in moderate-to-severe OSA. 10 participants with OSA (mean age = 65.2 years) completed four weeks of EMST training employing a prospective single-arm, double-baseline interventional design. The Modified Barium Swallow Impairment Profile (MBSImP) Component and Composite (Oral Total [OT] and Pharyngeal Total [PT]) scores measured swallow physiology. Airway clearance capacity measures included maximum expiratory pressure (MEP) and peak cough flow (PCF). A historical normative database was used for OSA patient comparison of swallowing metrics. A total of 234 swallows were analyzed. At baseline, impairments in lingual control, oral residue and esophageal clearance were observed. However, no significant differences in the MBSImP Composite (OT/PT) scores were observed between the OSA and healthy referent group. After EMST intervention, there were no significant differences in pre- to post-intervention Composite (OT/PT) scores. However, large effect size was observed for MEP ($p < 0.001$, $d = 3.0$), and non-significant, but moderate effect size was observed in PCF ($p = 0.19$, $d = 0.44$). Study findings further quantify swallowing in moderate-to-severe OSA and provide preliminary evidence supporting the impact of EMST on airway clearance capacity.

Keywords Obstructive sleep apnea (OSA) · Swallowing · Dysphagia · Expiratory muscle strength training (EMST)

Introduction

A systematic review detailing the association of dysphagia (disordered swallowing) in obstructive sleep apnea (OSA) estimated the prevalence of dysphagia to range between 20 and 78% [1]. Dysphagia in OSA is hypothesized to occur as a consequences of neuropathic changes to the pharyngeal muscles caused by long-term intermittent hypoxic injury, low frequency vibrations from snoring and other inflammatory changes triggering oxidative stress [2]. These sensory alterations affect mechano-chemo and vibratory receptors, causing reduction in upper airway sensations in OSA [3]. The exact pathogenesis is complex, and the effects of these alterations remain unknown. However, it is postulated that these sensory alterations in the upper airway further perturb the sensorimotor function of the aerodigestive tract, affecting airway protection and swallow function [3, 4]. Untreated dysphagia can lead to serious complications, including aspiration pneumonia.

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Consequently, persons with OSA are almost three times more likely to develop pneumonia, with dysphagia and corresponding aspiration contributing to an increased risk of development [5].

An international survey reported that approximately 50% of speech-language pathologists (SLPs) provided dysphagia services for persons with OSA [6]. Yet, there are no evidence-based practice guidelines for clinicians to manage dysphagia in OSA effectively. This is likely to be attributed to several factors, including the complex and heterogenous nature of OSA and the understudied pathophysiology of dysphagia in OSA that prohibit targeted treatment regimens [1, 6].

Inadequate upper airway muscle activation in response to negative pressure during sleep is a key pathophysiological trait of OSA and may contribute to the pathogenesis of dysphagia in persons with OSA. Thus, interventions known to target upper airway muscles may yield clinically meaningful results for both sleep-disordered breathing and swallowing impairments. Emerging studies on respiratory strengthening exercises as a method to enhance pulmonary- and sleep-related outcome measures in OSA (e.g., maximum expiratory pressure [MEP] and OSA severity indices) have shown promising evidence [7]. In addition, there has been support in the literature regarding the utilization of oropharyngeal exercises and orofacial myofunctional therapy to alleviate sleep-related symptoms in patients with OSA [8, 9]. Interestingly, no study to date has explored its potential benefits for improving swallowing impairment in OSA.

Previous data supports improved swallowing function after EMST in non-OSA conditions [10–12]. Specifically, improvements in suprahyoid musculature contraction, hyoid displacement, and pharyngoesophageal segment opening with subsequent reductions in airway invasion and pharyngeal residue [12]. Such swallow impairments have also been commonly reported in individuals with OSA [1]. Therefore, the study aimed to explore the impact of EMST on oropharyngeal swallowing physiology and airway clearance capacity in persons with OSA. It was hypothesized that individuals with OSA would demonstrate impaired swallowing physiology compared to an age-matched historic normative database [13]. Further, we hypothesized improvements in swallow function, including hyolaryngeal excursion, tongue base retraction and pharyngeal residue measures (MBSImP Components 8, 9, 15, and 16), and airway clearance capacity measures (MEPs and peak cough flow) after the EMST intervention. Lastly, we explored responsiveness of EMST to patient-reported swallowing- and reflux-related measures using the Eating Assessment Tool-10 (EAT-10) [14] and Reflux Symptom Index (RSI) [15]. It was hypothesized that OSA participants would show improvement in dysphagia and reflux symptoms following EMST.

Methods

This study was a prospective single-arm, double-baseline interventional design approved by the Institutional Review Board (21-237). The participants were recruited through advertisement via a University-wide mass email system and referred from the University Hospital's sleep clinic. Each participant completed informed consent prior to the procedures and was conveniently recruited from local sleep clinics within the Mobile region of Alabama. The inclusion criteria were compliant with strict safety standards set forth by the Institutions Radiation Safety Committee and included: (1) $\geq$ 40 years; (2) moderate-to-severe OSA (Apnea-Hypopnea Index > 15); and (3) presented with adequate lip seal. Exclusion criteria were: (1) neurological conditions, such as stroke, etc.; (2) head and neck cancer (HNC); (3) anterior neck surgery; (4) cognitive impairment (Mini-Mental Status Examination score < 26 [16]; (5) confirmed or suspected pregnancy; (6) current smoker; (7) alcohol consumption > 2 drinks/day; (8) illicit drug use; (9) severe chronic lung disease, (e.g., GOLD stages 3 and 4); (10) barium allergy; (11) family history of HNC; or (12) previous participation in research study with exposure to radiation within 5 years.

Data Collection Procedures

Each participant completed a total of three data collection visits, including two baseline visits (Baseline 1 and Baseline 2) and one post-intervention visit. Participants also completed four weekly clinic visits during the intervention period to calibrate the EMST150™ device and set a new threshold for weekly training (i.e., 75% of [MEP]). Design and data collection procedures are illustrated in Fig. 1.

Baseline 1 Procedures

A baseline clinical questionnaire was administered to obtain relevant medical, surgical, and social history. Further, the Modified Malampatti Classification [17] was completed to quantify hypopharyngeal obstruction. Patient-reported outcome measures (PROs) for swallowing and reflux were ascertained by employing the EAT-10 [14] and RSI [15], respectively. Two measures of airway clearance capacity were also performed: MEP and peak cough flow (PCF). Baseline MEP values were obtained using a commercially available digital pressure manometer (MicroRPM, Micro Direct). The measurement was obtained by instructing the participants to "inhale as deeply as possible and then exhale as hard and forcefully as possible. The mean MEP was calculated across these five trials to determine the threshold with adequate rest periods of 1 minute between trials.

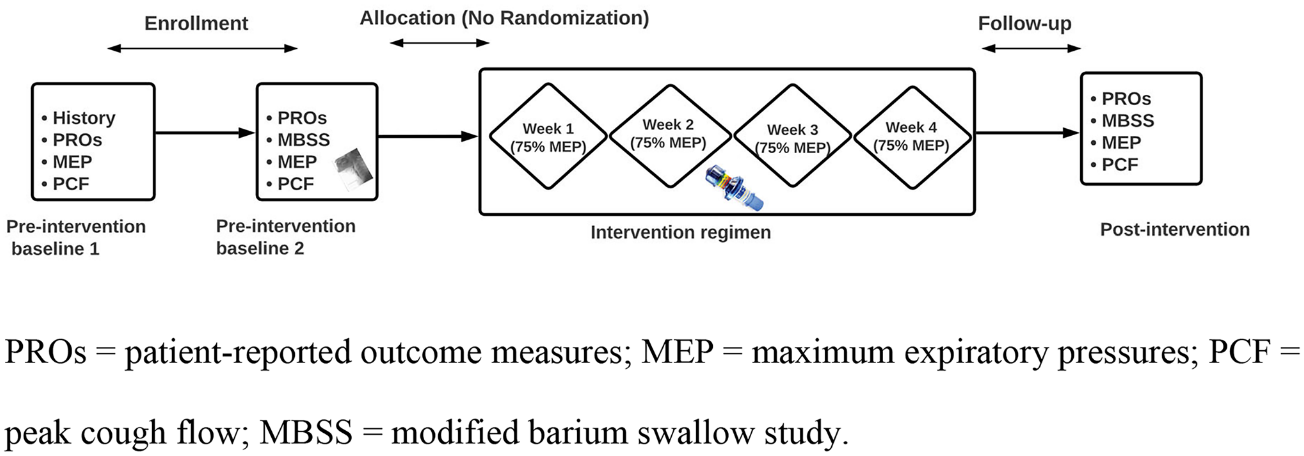

Fig. 1 Swallow safety measures at baseline visit 2 and post-intervention

Voluntary cough strength was obtained via peak cough flow (PCF) across three trials measured with ComPAS and Pneumotrac software system (Morgan Scientific Inc.), with the participants instructed to "cough hard as if something is stuck in your throat." The highest scores were used to report PCF based on the American Thoracic Society guidelines and consistency with published literature [18].

Baseline 2 Procedures

A replication of Baseline 1 procedures was applied at this measurement visit to account for selection-maturation effects. In addition, participants also completed a modified barium swallow study (MBSS). The standardized Modified Barium Swallow Impairment Profile (MBSImP™) [19, 20] protocol was followed using commercially available barium contrast (Varibar®, Bracco Diagnostics, Inc.). Continuous fluoroscopy (GE OEC C-arm) was used, and digital recording of swallow images was collected at 30 frames per second (TIMS 2000 SP & TDRS, TIMS Medical).

EMST Intervention

Within a 1-week period of the Baseline 2 visit, all eligible participants completed a four-week EMST intervention using the EMST150™ device (Aspire Products), a handheld, one-way, spring-loaded valve trainer. The EMST device was set to 75% of the participant's MEP, ascertained during the second baseline visit. During training, the participants were instructed to take a deep, forceful breath and then place the device's mouthpiece inside their mouth behind their teeth with their lips closed tightly. They were also instructed to forcefully blow into the device [21]. A single session consisted of 25 targeted forceful exhalations, performed in five sets of five repetitions, with a one-minute rest period between sets. At the start of each intervention week, participants returned for in-person recalibration of the device and were assigned a revised target to complete their first day of weekly training. They completed the remaining four days of weekly training via telehealth sessions with the first author (AB). Participants completed and returned a weekly tracking sheet with detailed instructions to maintain fidelity and monitor treatment adherence for each of the four weeks of EMST. The weekly tracking sheet al.so included a measure of perceived exertion (Modified Borg Scale) [22] completed by the participant for each day of exercise during the intervention period.

Post-intervention Procedures

The post-intervention visit was scheduled within one week of EMST completion. At this visit, participants completed all study procedures from the second baseline visit (i.e., EAT-10, RSI, MEP, PCF, and MBSS).

Data Analysis

The validated, standardized MBSImP scoring protocol was used to interpret the MBSS [19, 20]. The Overall Impression (OI), which represents the highest score across swallow tasks (as appropriate), was obtained for each of the 17 physiologic components assessed. Further, Composite Oral Total (OT) and Pharyngeal Total (PT) scores were also summed according to published scoring guidelines [19, 20]. Composite (OT/PT) scores of 55 age-matched healthy controls were derived from a historical database of 195 healthy adults [13]. Components of swallow physiology were considered "impaired" if the scores were greater than the median scores of the healthy cohort [13]. To measure swallow safety, the nine swallows observed in the lateral viewing plane were evaluated using the standardized and validated Penetration-Aspiration Scale (PAS) [23].

Statistical Analysis

All analyses were conducted using Statistical Package for the Social Sciences (SPSS), version 28.0. Descriptive statistics were calculated for all variables of interest. The probability of alpha (α) = 0.05 and two-tailed testing were used to ascertain statistical significance. Independent t-tests were used to compare Composite (OT/PT) scores between persons with OSA to the healthy, non-dysphagic cohort [13]. In addition, to determine the impact of EMST on swallowing physiology and airway clearance capacity in individuals with OSA, paired sample t-tests used to compute gain scores (i.e., differences between pre-and post-intervention MBSImP OT/PT scores, MEPs and PCF). The proportion of intervention "responders" was defined by the Reliable Change Index (RCI) for MBSImP PT for any pharyngeal component mean score change of > 0.54 [24]. Nonparametric Wilcoxon signed-rank tests were also used to compare pre- and post-intervention EAT-10 and RSI scores as normality assumptions were unmet.

Reliability

Randomly selected swallows (20%) were re-examined to determine inter- and intra-rater reliability for MBSImP™ and PAS measures within four weeks by two experienced SLPs, including the first author (AB). In cases of conflict, a consensus rating was established by the senior author (KLG). Reliability was determined using ordinal kappa for MBSImP™ Component OI and PAS scores. Intraclass correlations [ICC (2,1)] were used for continuous MBSImP™ Composite (OT/PT) scores.

Results

Participants

Eleven eligible participants were initially enrolled in the study, although one dropped out after completing the baseline assessments due to complications after having the COVID-19 virus. Therefore, 10 participants completed the study (Table 1). All participants were a Functional Oral Intake Scale (FOIS) level 7 (eating a regular diet with no diet restriction) at baseline [25]. Each participant completed Baseline 2 within 12–14 days of the Baseline 1 visit, followed by four weeks of respiratory muscle strength training. A total of 200 treatment sessions were conducted, and the adherence rate for the OSA group was 100%.

Table 1 Mean (SD) demographic and clinical characteristics at baseline unless otherwise reported

	M (SD)	95 % CI
Age (years)	65.2 (6.6)	60.4, 69.9
Sex		
Male *n* (%)	5 (50.0%)	
Female *n* (%)	5 (50.0%)	
Race		
White	9 (90.0%)	
Black	1 (10.0%)	
BMI (kg/m^2)	34.95 (5.8)	30.4, 39.4
Smoking history *n* (%)	6 (66.6%)	
Years of OSA	9.1 (4.0)	6.0, 12.2
AHI	40.1 (26.0)	21.5, 58.7
OSA Severity		
Moderate *n* (%)	5 (50.0%)	
Severe *n* (%)	5 (50.0%)	
CPAP usage (hours)	6.8 (1.7)	5.5, 8.0
Modified Mallampati classification		
Type II *n* (%)	1 (9.0%)	
Type III *n* (%)	1 (9.0%)	
Type IV *n* (%)	9 (81.8%)	

BMI Body Mass Index, *AHI* apnea-hypopnea index, *CPAP* continuous positive airway pressure

Baseline Assessment 1

Descriptives are presented in Table 2. Three participants (27.2%) had abnormal EAT-10 scores (scores ≥ 3). Two participants (20%) had abnormal RSI scores (scores ≥ 13). The median MEP was 91.3 (range: 77–118.8 cmH20), indicating values were within normative limits [26]. The median PCF for the OSA group was 9.4 (range: 4.6–11.4 L/sec), also demonstrating normal values [27].

Baseline Assessment 2

No significant differences in EAT-10 scores were observed between baseline visits for EAT-10 and RSI scores (Table 2). Although the median MEP scores were slightly higher than the first baseline assessment, the difference was not statistically significant ($p = .19$) and was consistent with normal referent values [26]. The median PCF was slightly lower than the first baseline assessment, although still within normal limits (Table 2) [27].

Swallowing Physiology and Safety

A total of 240 boluses were collected across two visits. Six swallows were excluded from the analysis due to failure to follow instructions for the sequential swallow task (i.e., performed discrete swallows). Thus, a total of 234 swallow trials were analyzed.

Reliability

Inter-rater reliability was good (κ = 0.89, $p < 0.001$) and intra-rater reliability was excellent (κ = 1, $p < 0.001$) for MBSImP Composite scores. Intra-rater reliability for PAS scores indicated perfect agreement (k = 1).

Baseline Swallow Physiology

Although the OSA group had higher OT scores, no significant difference was observed between the OSA group (M = 6.4, SD = 1.6) and the healthy referent group (M = 5.5, SD = 2.5) [13], t (67) = 1.49, $p = .14$, $d = 0.53$. Similarly, there was not a significant difference between PT scores between the OSA (M = 7.1, SD = 1.3) and healthy age-matched referent (M = 6.0, SD = 2.4), t (67) = 8, $p = 1$, $d = 0.1$. The OSA group demonstrated impairments in various physiological components compared to the healthy cohort. For example, 30% of participants ($n = 3$) demonstrated impairment in Tongue Control during Bolus Hold (Component 2), with frequent loss of half of the bolus into the pharynx before pharyngeal swallow onset. Majority of OSA participants (80%; $n = 8$) presented with Oral Residue (Component 5), with residue observed primarily on the oral tongue. Almost half of the OSA participants (40%; $n = 4$) demonstrated impaired Esophageal Clearance (Component 17), ranging in severity from mild collection to complete or no clearance. Descriptive PAS scores across swallow tasks are detailed in Table 4.

Impact of EMST on Swallowing Physiology and Safety

No statistically significant differences were observed between pre- and post-intervention MBSImP Composite OT and PT scores, t (9) = 0.0, $p = 1.0$, $d = 0.0$ and t (9) = 1.67, $p = 0.13$, $d = 0.53$, respectively (Table 3. There were no intervention responders for improvement in MBSImP OT scores (i.e., > 2 × SD from sample group mean). For MBSImP PT scores, five treatment responders were identified, with a mean score change of > 0.54 [24]. Out of the treatment responders, four participants specifically demonstrated gain changes for Tongue Base Retraction (Component 15). Although the frequency of PAS occurring within the safe range was higher post-intervention, the difference was not statistically significant, $p = 0.45$ (Table 4).

Table 2 Baseline descriptive for patient-reported outcome measure for swallowing, reflux, and, airway clearance measures

Variable	Baseline 1			Baseline 2			p
	M (SD)	95 % CI	Range	M (SD)	95 % CI	Range	
EAT-10	2.9 (4.7)	(− 0.4, 6.2)	0–15	1.8 (2.5)	(− 0.4, 3.6)	0-8	0.67
RSI	7.4 (7.1)	(2.3, 12.4)	0–23	6.8 (8.7)	(.5, 13.0)	1–29	0.70
MEP cmH2O	94.5 (14.5)	(84.1, 104.9)	77–118.8	100.2 (15.7)	(88.7, 111.2)	79.6-120.6	0.19
PCF (L/sec)	8.7 (2.4)	(7.1, 10.4)	4.6-11.4	8.5 (2.3)	(6.8, 10.1)	4.2-12.3	0.55

EAT-10 eating assessment tool, *RSI* reflux symptom index, *MEP* maximum expiratory pressure, *PCF* peak cough flow

Table 3 MBSImP composite scores for baseline visit 2 and post-intervention

Composite scores	Baseline			Post-intervention		
	M (SD)	95% CI	Range	M (SD)	95% CI	Range
Oral total	6.4 (1.6)	(5.2, 7.6)	4–9	6.4 (1.8)	(5.0, 7.7)	4–9
Pharyngeal total	6.8 (1.6)	(5.6, 7.9)	4–9	5.8 (1.8)	(4.5, 7.1)	3–9

Table 4 Swallow safety measures at baseline visit 2 and post-intervention

PAS	Baseline (N = 100[a]) % (n)	Post-Intervention (N = 104[b]) % (n)
1	95.0% (95)	98.1 (102)
2	1.0 % (1)	0% (0)
3	5.0% (5)	1.9% (2)

[a] = 8 missing; [b] = 4 missing

Impact of EMST on Airway Clearance Capacity

There was a large significant difference between the post-intervention assessment and second baseline assessment for MEPs, t (9) = *9.5*, $p < .001$, $d = 3.0$, with a gain score of M (SD) = 39.9 (13.1), 95% CI 30.5–49.3 (Fig. 2). There was no significant difference for PCF, t (9) = *1.3*, $p = .2$, $d = 0.44$ (Fig. 2). However, a moderate effect in gain score was observed of M (SD) = 0.3 (0.69), 95% CI −0.2, 0.8.

Impact of EMST on PROs

Although EAT-10 total scores were lower post-intervention, there was no statistically significant difference compared to baseline, $Z = -0.32$, $p = 0.74$, $r = -0.32$ (Fig. 3). Similarly, there was no statistically significant difference for post-intervention RSI scores, $Z = -1.0$, $p = 0.31$, $r = -0.56$. (Fig. 3). The median Modified Borg Scale was 2 (easy) and ranged from 1 to 6 (no exertion to moderate exertion) throughout the intervention period.

Discussion

This pilot study explored the impact of EMST on persons with OSA using standardized and validated metrics to quantify oropharyngeal swallow physiology and airway clearance capacity. We found that when compared to healthy controls, the OSA group demonstrated higher OT and PT scores, but these differences failed to reach statistical significance. After EMST, there were no significant differences in OT and PT scores compared to baseline scores. However, significant gains were observed in MEPs, an important airway clearance capacity metric. In addition, this study established that a resistance respiratory training program set to 75% of maximum MEPs was safely tolerated in this cohort, with no adverse effects as measured by a self-perceived exertion scale. One notable observation was that OSA Participant 4 had a higher reported perceived exertion (maximum score of 5 indicating "moderate" exertion) compared with other participants; their surgical history revealed a previous coronary

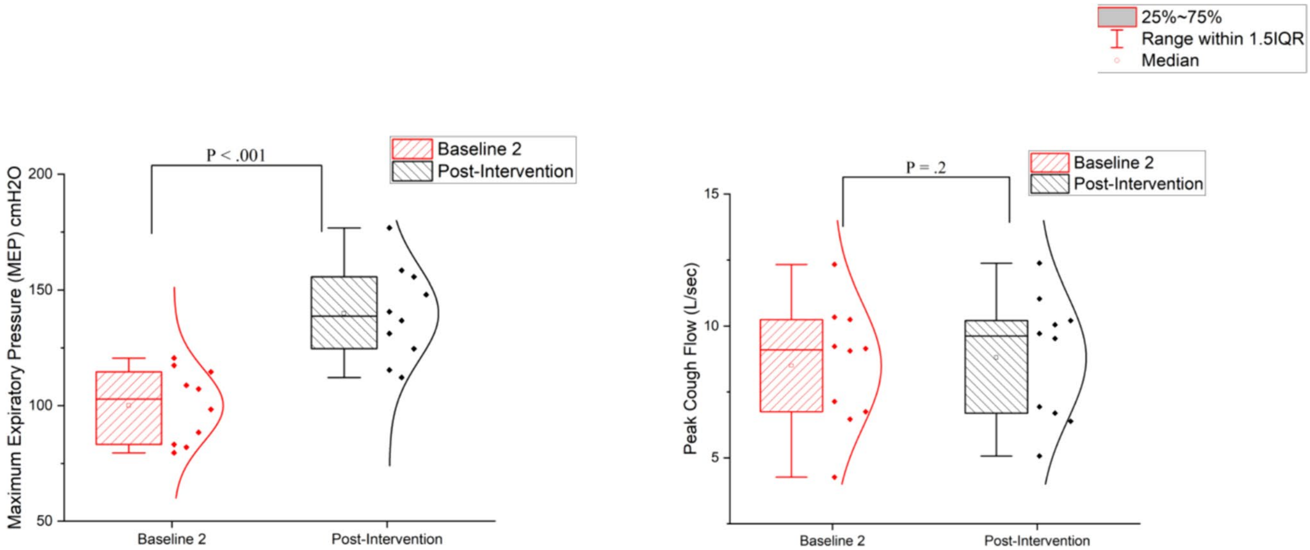

Fig. 2 OSA group comparison of MEP and PCF across baseline visit 2 and post-intervention visit

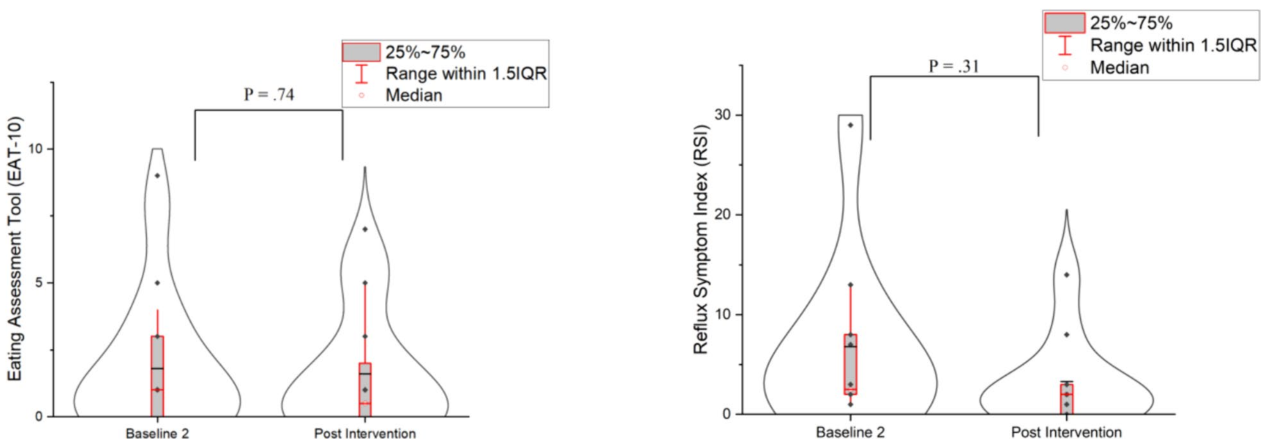

Fig. 3 OSA group comparison of EAT-10 and RSI scores across baseline visit 2 and post-intervention

artery bypass graft that may have influenced the perceived exertion. Future studies should ascertain comorbid conditions when determining the resistance threshold.

Baseline Swallow Physiology

Although the 10 study participants were observed to have higher average MBSImP Composite (OT/PT) scores compared to the 55 healthy controls, these comparisons were not statistically significant. However, the presence or absence of OSA in the historical database is unknown as this information was not included in their clinical history to determine eligibility. Considering the high prevalence of OSA in the community [28], the absence of OSA in the normative cohort cannot be ruled out. Further, CPAP use is considered the gold standard of care for OSA. Literature supports that CPAP may mitigate the sensorimotor aberrations caused by snoring as it allows the airway to remain patent and prevents traumatic forces to the airway caused by snoring and, in fact, may also improve swallowing function [29]. This may have been an influential factor in demonstrating decreased swallow impairments in this cohort. Although the individuals in the current study received CPAP treatment, evidence indicates that patient refusal of CPAP use reaches almost 50% [30]. Specifically, the physiologic components observed to be altered in the OSA group included Tongue Control during Bolus Hold (Component 2), Oral Residue (Component 5), and Esophageal Clearance (upright position) (Component 17). These deficits may be due to neuropathic changes causing injury to genioglossus and pharyngeal dilatory muscles, as well as altered respiratory pressure changes during sleep that are often the pathophysiological traits of OSA [31].

Tongue has a significant role in providing sensory inputs to initiate a pharyngeal swallow and producing adequate pressure for bolus transfer [32]. The deficits in Component 2, which involves tongue control, and Component 5, concerning oral residue, indicate a reduced ability to generate and coordinate lingual pressure, posing a risk factor for dysphagia. These functional impairments also suggest potential for evaluating new treatments for obstructive sleep apnea (OSA). However, for MBSImP Component 17 OI score, presbyesophagus causing esophageal dysmotility cannot be completely ruled out since there is a reported higher prevalence of esophageal dysmotility and chronic higher nocturnal reflux in OSA that may contribute to prolonged esophageal clearance and retrograde flow observed in the current study [33].

Impact of EMST on Swallow Physiology and Safety

After four weeks of EMST training, no significant differences were found in MBSImP OT and PT scores. The lack of significant findings could be attributed to multiple factors. The small sample size ($N=10$) can increase the potential for false negatives and increase the likelihood of under-identification of true findings. Moreover, treatment dosage may have influenced results as EMST was provided for five days over the 4-week intervention period. While the exact dose and intensity for all dysphagia interventions (including EMST) remains elusive [34], a more extended period of intervention may have been needed to promote significant physiologic change.

Despite the lack of a statistical improvement in Composite scores, trend analysis, and reliability change index identified five treatment responders in the OSA cohort. Improvements were noted specifically in Tongue Base Retraction (Component 15). Yanagisawa et al. [35] observed morphological changes in healthy adults after EMST training; specifically, they used magnetic resonance imaging to reveal a reduction in the area size of the genioglossus and suprahyoid muscles. Evidence supports an enlarged tongue volume in OSA patients [36, 37]. Thus, it is plausible that EMST may have altered tongue morphology with subsequent improvement in tongue function. Since the tongue plays a pivotal role in preventing airway collapse, there has been increased attention on the role of genioglossus in maintaining airway patency [38]. For example, hypoglossal nerve stimulation has been an emerging choice of surgical treatment for alleviating symptoms and severity of OSA. The underlying premise is that stimulation of the genioglossus will assist the tongue in remaining in an anterior position, preventing upper airway collapse. Unfortunately, the eligibility criteria precludes many individuals from being surgical candidates [39]. Further, pharmacological therapies targeting the genioglossus have shown promising results in animal models and humans [40]. Hence, the current finding of improved tongue base retraction is an important highlight suggesting a potential transference effect and may have clinical implications for targeted physiology to improve airway patency in OSA. Although we acknowledge that the hyoglossus and styloglossus primarily control tongue base retraction [41], future studies can utilize EMG to understand the mechanistic influence on additional lingual muscles and their role in airway patency.

Lastly, these current study findings are in congruence with a meta-analysis by Mancopes and colleagues that suggested that ordinal measures (i.e., MBSImP measures) may not be sensitive to detect physiological changes because of statistical challenges and utilization of parametric statistics with a limited sample size [42]. Therefore, studies assessing biomechanical analysis may be a better approach to further assess the impact of EMST on swallow physiology.

Impact of EMST on Airway Clearance Capacity

Study findings revealed that the OSA group had baseline MEPs within normative limits and slightly higher compared to other clinical populations, such as stroke, amyotrophic lateral sclerosis, and Parkinson's disease [43–45]. A significant increase in MEPs with a large effect size was observed after four weeks of EMST treatment. These findings are consistent with other studies, including both healthy and patient populations [10, 46]. This is not surprising since EMST specifically challenges expiratory musculature using a one-way loaded spring valve device that provides resistance during exhalation. Baseline MEPs were within normative limits, and gain scores observed were comparable to healthy adults, albeit higher than neurogenic disorders [43, 45]. Higher expiratory pressures may serve as an airway defense mechanism to protect the airway from airway invasion and any adverse pulmonary complications. The non-significant gains in PCF values were consistent with previous reports in conditions such as stroke [10] and may have resulted from the small sample size. However, the gain in PCF post-EMST demonstrated a moderate effect size. Previous studies suggest that the physiological relationship between improved MEPs and peak cough airflow strength contributes to a strong airway defense mechanism [47, 48]. Hence, these results are consistent with the literature suggesting that although the post-intervention PCF was not significant, there may be an association between increased post-intervention MEPs and voluntary cough airflow. Future studies with adequate power are needed to further evaluate these findings.

Limitations

This study is not without limitations. First, the current study includes a small convenient sample ($N=10$), which increases the risk of type II error. The OSA population was also limited to moderate-to-severe groups. Although the current study employed a double baseline design to prevent selection-maturation effects, a repeated baseline instrumental assessment could not be performed due to the University's Radiation Safety Committee restrictions. Further, the absence of a control group makes the true effects of EMST unclear. In addition, this cohort lacked swallow safety concerns (i.e., majority of Penetration-Aspiration Scale scores were 1–2 at baseline). Further, the optimal dosage of EMST targeting swallow physiology remains uncovered. Future studies should employ a more rigorous study design that is sufficiently powered and with varied dosages to determine the effectiveness of EMST in improving oropharyngeal swallowing physiology, biomechanics, and airway clearance capacity measures. Future studies should consider endotyping of OSA as this may influence treatment responsiveness, which would help inform clinical decision-making regarding patient-centered and physiological-based treatment based on those personalized factors.

Conclusion

This first proof of concept study assessed the effect of EMST on swallow physiology and airway clearance capacity in OSA. The findings from the current can also caution against clinicians consuming research and researchers conducting swallow-related investigations without considering the potential influence(s) of OSA. Lastly, this study established the safety and strong tolerance of OSA participants to the EMST intervention approach at 75% of a 1 repetition maximum, without any perceived exertion.

Author Contributions AB was responsible for partial conceptualization, data collection, analyses, drafting, editing, finalizing the manuscript and procuring funding; GC was responsible for statistical support and editing the manuscript draft, WB and BB were responsible for editing manuscript draft and providing scientific expertise; and KLG was responsible for conceptualization, overseeing the study procedures, providing infrastructure for the study, editing, finalizing manuscript draft and securing funding for the study.

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Data Availability The data underlying in this article will be shared with request to the corresponding author.

Declarations

Conflict of interest The author(s) declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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