Head & Neck

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ORIGINAL ARTICLE

Expiratory Muscle Strength Training in Head and Neck Cancer Survivors With Radiation-Associated Dysphagia: Results of a Pilot Prospective Trial

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Received: 5 December 2025 | **Revised:** 19 March 2026 | **Accepted:** 31 March 2026

Keywords: aspiration | dysphagia | expiratory muscle strength training | expiratory pressure | head and neck cancer

ABSTRACT

Background: This single-arm pilot study evaluated feasibility, safety, and outcomes of expiratory muscle strength training (EMST) in head and neck cancer (HNC) with radiation-associated dysphagia (RAD).

Methods: Thirty disease-free HNC survivors (≥3 months post-radiotherapy, median 16 months) with evidence of aspiration (penetration-aspiration scale [PAS] ≥6) underwent an 8-week EMST protocol (25 repetitions, 5 days/week). Pre- and post-intervention assessments included maximum expiratory pressure (MEP), voluntary cough peak expiratory flow (PEF), video-fluoroscopy, and patient-reported outcomes.

Results: Twenty-six participants (87%) completed the trial, with high adherence (89% sessions attended; 91% repetitions completed). Adverse events occurred in 8/30 (26.7%). MEP significantly increased by 66% ($p < 0.001$); PEF showed a non-significant 8% increase ($p = 0.23$). PAS and IDDSI-Functional Diet Scale scores improved in 38% ($p < 0.05$).

Conclusion: EMST is feasible, safe, and improves expiratory and swallowing function in aspirating HNC survivors, warranting randomized trials.

1 | Introduction

Impaired airway protection is a major concern after radiotherapy (RT) for HNC (HNC). It is estimated that 10%–14% of HNC survivors treated with RT develop pneumonia within 2 years of head and neck radiotherapy [1], and lifetime risk approaches 25% after chemoradiation [2]. Pneumonia is associated with a 42% excess risk of death in cancer survivorship [2], accounting for approximately 20% of non-cancer related deaths in this population [3]. The past two decades saw great progress in both swallowing specific supportive care, proactive swallowing therapy [4–7], and swallowing optimized RT delivery to reduce risk of dysphagia and aspiration pneumonia [8, 9]. Still, the prevalence of aspiration pneumonia was unchanged

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Preliminary data from this study were presented at the 2019 Dysphagia Research Society Annual Meeting, held in San Diego, CA.

based on population level data from SEER-Medicare when comparing cohorts of patients treated 2002–2011, highlighting the need for ongoing efforts to optimize airway protection in this population [1].

Airway protection relies on coordinated functions in the aerodigestive tract and respiratory system. Troche and colleagues [10] proposed a continuum of behaviors necessary to protect the airway both during swallowing (prevention) and in response to foreign material (ejection). Expiratory muscle strength training (EMST), a pressure-threshold respiratory exercise device, was originally developed to improve pulmonary function in vocal performers and athletes [11]. Its use has since expanded to clinical populations with, or at risk for, airway protection impairment, where it has been studied and implemented as a therapeutic intervention to improve pulmonary and upper airway function. In various prospective trials, a progressive EMST program of 4–8 weeks duration has shown to improve maximum expiratory pressures (MEP), a marker of subglottic expiratory force generating capacity, by 25%–41% among healthy volunteers and neurogenic populations (PD, ALS, and CVA) with, or at risk for, aspiration [12–15]. In HNC, retrospective studies also suggest potential therapeutic benefit. A retrospective case series of 64 HNC survivors with radiation-associated aspiration (penetration-aspiration scale [16] [PAS] ≥ 6) who completed an 8-week EMST program reported an average 57% increase in MEP and improvement in Dynamic Imaging Grade of Swallowing Toxicity (DIGEST [17, 18]) swallow safety scores in 30% of participants [19]. In a subset of 23 participants from the same study, 36% with below-predicted baseline MEP normalized after training [19]. A separate prospective feasibility trial in six patients with a history of supracricoid partial laryngectomy demonstrated improved peak expiratory flow (PEF) of voluntary cough (PEF; by 21% on average) and dyspnea scores post-EMST, although no instrumental swallowing assessments were conducted [20].

It is hypothesized that the underlying mechanism for these improvements involves enhanced airway protection through the strengthening of the expiratory muscles involved in cough, as well as increased activation of the swallowing musculature in response to the progressive load imposed by the pressure threshold device over the training period [21, 22]. Transference of this exercise task to swallowing and cough is not, however, consistently found in clinical studies. For instance, four studies reported improvements after EMST in airway protection (per PAS) [23, 24] or severity of pharyngeal dysphagia (per DIGEST) on modified barium swallow (MBS) studies in PD, ALS, and HNC populations [15, 19], while two other trials failed to detect differences in measures of swallowing function [14, 25]. Impact of EMST on cough function in pathologic populations also varies in published studies, with only a few trials reporting improvements such as cough PEF rise and cough volume acceleration in reflexive coughs [14] and compression phase duration, expiratory rise time, and cough volume acceleration in voluntary coughs [23].

In light of these mixed findings, further study is warranted, particularly in HNC survivors, where post-radiotherapy aspiration is associated with reduced MEP and PEF compared to survivors with no evidence of aspiration [26]. This pilot, single-arm prospective feasibility trial was therefore conducted to examine the therapeutic potential of EMST in survivors with chronic aspiration (defined as toxicity that persists or develops beyond the acute phase of radiation-related injury [27]) after head and neck radiotherapy, assess the tolerability of formal EMST regimens in a symptomatic survivorship setting, and afford effect-size estimation for future randomized trials. Therapeutic potential was assessed to ascertain objective completion rate (feasibility endpoint), instrumental change in MEP (primary endpoint), and change in swallowing, cough, and patient-reported measures (secondary endpoints). Exploratory aims included evaluating the influence of baseline characteristics on MEP change and examining 12-month functional outcomes across study arms to inform future trial design.

2 | Materials and Methods

2.1 | Design and Participants

This single-arm pilot clinical trial (NCT02662907) evaluated the feasibility, safety, and functional change after an EMST program in disease-free HNC survivors with chronic aspiration. A nested cohort of participants meeting eligibility was consecutively recruited between 2016 and 2018 from the Swallowing Clinics in the Head and Neck Center at the University of Texas MD Anderson Cancer Center (Houston, TX, USA).

First-round eligibility included adults with a history of curative-intent RT for a new primary HNC within the past 15 years, who were referred to the Section of Speech Pathology and Audiology for swallowing evaluation and completed RT at least 3 months prior to enrollment. Exclusion criteria encompassed the following: recurrent disease; a second primary of the head and neck, central nervous system, or thoracic cavity; history of head and neck surgery (excluding diagnostic procedures, transoral surgery, or non-radical neck dissection); history of functionally limiting chronic or acute cardiac, pulmonary, or neuromuscular disease; tracheotomy or oxygen dependence at the time of the MBS; and a Mini Mental Status Exam (MMSE) [28] score < 24.

Second-round eligibility determined enrollment in the therapeutic EMST trial and included: (i) evidence of aspiration (PAS score ≥ 6) on the MBS study; and (ii) consented to participate in the trial. Those not meeting the second-round eligibility (either because they declined participation despite aspiration, or because they did not exhibit aspiration) were followed in parallel for a 12-month follow up. Within this group, some completed an independent, non-clinician–led home EMST program ("Home Program"), while others did not engage in any EMST program (Observation).

MBS appointment schedules (from routine post-RT swallow assessments) were screened for potential eligibility. For each included participant the following demographic data were collected: age at the start of treatment, time post-RT, sex, T-classification, HNC site, therapeutic combination, radiation dose, and feeding tube status. This analysis was approved by the Institutional

Review Board of The University of Texas MD Anderson Cancer Center (FWA00000363; OHRP IRB Registration IRB00000121; Submission ID: 2015–0238-MDACC). All subjects provided informed consent.

2.2 | Intervention: Expiratory Muscle Strength Training (EMST)

Participants underwent an 8-week EMST program using the EMST150 device (Aspire Products, Gainesville, Florida), calibrated weekly to 75% of each participant's current MEP. Training was conducted using a standardized 5–5–5 schedule: five sets of five breaths, 5 days per week. All training was completed while standing and using a nose clip. Participants were instructed to take a deep breath, hold the cheeks lightly with the thumb and forefingers, and blow forcefully through the device until the valve opens (hearing air rush out). Weekly in-clinic sessions were conducted with a licensed speech-language pathologist (SLP), who verified technique, monitored progress, and recalibrated devices. Participants were provided with written instructions for home practice between clinic visits. The intervention was described and delivered according to the Template for Intervention Description and Replication (TIDieR) guide [29] (Supplement).

2.3 | Outcome Measures

2.3.1 | Expiratory Function Testing

Two objective measures of expiratory function were taken at the time of enrollment (pre-EMST) and at the end of therapy (post-EMST, i.e., immediately after the 8-week training period with an allowable window of 2 weeks): (1) MEP, and (2) voluntary cough PEF. MEP was measured using a digital manometer (Micro Respiratory Pressure Meter, CareFusion, Yorba Linda, California). Participants were instructed to inhale to total lung capacity ("Fill your lungs as much as possible"), seal the lips fully around a flanged mouthpiece, and exhale forcefully ("Blow out as fast and as hard as you can"). Expiratory tests were completed while standing using a nose clip. MEP was calculated as the maximum of three trials within 10% variance. Voluntary cough PEF was measured using the digital Mini Wright Peak Flow Meter (KW-Med Inc., Antioch, Illinois). Patients were instructed to inhale to total lung capacity and to "Cough hard like there is something stuck in the throat" while standing. PEF was calculated as the maximum of three trials within 10% variance. Additionally, MEP was measured at each weekly clinic visit to recalibrate the EMST device.

2.3.2 | Intervention Feasibility, Safety, and Adherence

Program completion rate was derived by counting the number of patients who withdrew (i.e., dropped out of therapy) before completing the 8-week program; 80% completion was a priori specified as the benchmark for feasibility. Medical records and therapy notes were reviewed for adverse events. Adherence was self-reported using a standard form retrieved at each weekly clinic visit. Full adherence was defined as completing > 900 breaths of the prescribed 1000 breaths through the training (25 breaths per day, 125 breaths per week).

2.3.3 | Swallow Functional Outcomes

Standardized MBS assessment was performed pre- and post-intervention using a validated protocol [17] recorded at 30 frames/s in the lateral and anterior–posterior planes. Bolus trials included 2 trials each of thin liquid barium (5 mL, 10 mL, and cup sip), Varibar pudding (1 tsp. presentation), and ¼ cracker coated in Varibar pudding (Bracco Diagnostics Inc.). Each study was graded by a blinded, trained laboratory rater using PAS [16], DIGEST [18], and the Modified Barium Swallow Impairment Profile (MBSImP) [30]. The PAS is an 8-point ordinal scale that evaluates the depth airway invasion and the patient's response (0 = no airway entry, 8 = silent aspiration). The maximum PAS score across all bolus trials was used for analysis. DIGESTv2 is a validated tool to grade the severity of pharyngeal dysphagia based on degree and pattern of penetration/aspiration (according to PAS, Safety grade) and pharyngeal bolus clearance (Efficiency grade) during an MBS study. The overall DIGEST grade is derived by a combination of Safety and Efficiency grade, with an overall grade of pharyngeal dysphagia from 0 (no pharyngeal dysphagia) to 4 (life threatening) [18]. The MBSImP is a validated, standardized tool for evaluating the physiologic components of an oropharyngeal swallow during an MBS study. It includes 17 components, each scored on an ordinal scale with higher scores indicating greater impairment. In this analysis, we analyzed the Pharyngeal Total Score, that is, the sum of components 7–16, which ranges from 0 to 29 [30].

Additional swallow outcomes included clinician-rated functional status and patient-reported measures. Functional status measures included the Performance Status Scale for Head and Neck Patients (PSS-HN) [31], which evaluates functional ability across three subscales (normalcy of diet, eating in public, and intelligibility of speech) via semi-structured interview, and the International Dysphagia Diet Standardization Initiative Functional Diet Scale (IDDSI-FDS) [32], which classifies food texture and liquid thickness on an eight-level scale (0–7).

Patient-reported outcomes included the MD Anderson Dysphagia Inventory (MDADI) [33] and MD Anderson Symptom Inventory for Head and Neck Cancer (MDASI-HN) [34]. The MDADI is a validated 20-item questionnaire assessing the impact of dysphagia on the quality of life across global, physical, emotional, and functional domains. The composite score (mean of physical, emotional, and functional subscales) ranges from 20 to 100, whereas domain scores range from 20 to 100, with higher scores indicating better dysphagia-related quality of life. The MDASI-HN is a validated measure of symptom burden in patients with HNC, capturing both general cancer-related and HNC-specific symptoms. Each symptom is rated from 0 ("not present") to 10 ("as bad as you can imagine"). Three summary scores were derived: the MDASI-HN Total Symptom score (sum of 22 general+HN symptoms); MDASI-HN Symptom score (sum of 9 HN-specific symptoms); and MDASI Interference score (sum of 6 items reflecting how symptoms interfere with daily

life), with higher scores indicating greater symptom severity/interference. All outcome measures were administered at baseline pre-therapy and following completion of the 8-week EMST intervention.

2.3.4 | 12-Months Follow Up

All participants (those who completed the trial and those in the observation groups) underwent a follow-up evaluation 12 months after enrollment. At this time, PSS-HN, MDADI, and MDASI-HN were re-assessed, and feeding tube status and pneumonia history were documented per chart review. Self-reported 12-month pneumonia history was also surveyed using two adapted items from the National Health and Nutrition Examination Survey [35] ("*In the past 12 months, has a doctor or other health professional told you that you had pneumonia*?" and "In the past 12 months, has a doctor or other health professional told you that you were hospitalized for pneumonia?").

2.4 | Statistical Plan

Baseline demographic and clinical characteristics were summarized using descriptive statistics. Continuous variables were expressed as means and standard deviations (SD) or medians and interquartile ranges (IQR) depending on distribution; categorical variables were summarized as frequencies and percentages.

The primary endpoint was change in MEPs following the 8-week EMST intervention. Secondary outcomes included changes in PEF, PAS scores, DIGEST grades, MBSImP scores, and patient-reported and clinician-rated functional measures (MDADI, MDASI-HN, PSS-HN, IDDSI-FDS, and feeding tube status). Pre- and post-intervention values were compared using paired *t*-tests or Wilcoxon signed-rank tests according to the distribution of differences. Ordinal outcomes were analyzed using the sign test or McNemar's test for paired proportions. Effect sizes were calculated for all analyses. For group-based comparisons, Cohen's *d* was computed to quantify the magnitude of treatment effects. For correlation-based analyses (and/or nonparametric tests), effect sizes were expressed as *r*. For the feasibility endpoint, the intervention was considered feasible if ≥ 80% of enrolled participants completed the post-treatment evaluation.

Subgroup analyses stratified outcomes by pre-EMST MEP (poor vs. adequate; cut-offs: 81 cmH_2O for females, 109 cmH_2O for males [36]), time since RT (to distinguish early vs. late survivorship, < 2 vs. ≥ 2 years), age (< 62 vs. ≥ 62 years old [37–39]), and pre-EMST BMI (< 25 vs. ≥ 25). Within-group pre- to post-EMST differences were evaluated using paired *t*-tests or Wilcoxon signed-rank tests, as appropriate; between-group comparisons of change scores used independent *t*-tests, Fisher's exact, or Mann–Whitney tests as appropriate.

Exploratory uni- and multi-variable linear models further explored predictors of post-treatment MEP gains, adjusting for relevant clinical covariates defined a priori per study protocol (NCT02662907), including pre-EMST MEPs, pre-EMST DIGEST Safety grade, RT dose, concurrent CT, time since RT, age, sex, smoking status, and pre-EMST BMI.

Additional exploratory analyses reported 12-month outcomes for all study arms (EMST Trial, Home Program, and Observation, including aspirators and non-aspirators) and in pairwise comparisons (EMST Trial vs. Home Program, aspirators; EMST Trial vs. Observation, aspirators) using Fisher's exact, or Kruskal–Wallis tests as appropriate. Uni- and variable regression models evaluated arm allocation as a predictor of functional and clinical outcomes, adjusting for baseline aspiration status. All tests were two-sided with $\alpha = 0.05$. Analyses were performed using StataNow/SE 18.5 (1985–2023 StataCorp LLC) and R version 4.4.1 (The R Foundation for Statistical Computing).

3 | Results

3.1 | Trial Participants

Of 302 screened participants meeting the first-round eligibility criteria, 175 (58%) consented to be included in the analysis and screened for second-round eligibility. Among these, 113 were non-aspirators and 62 had evidence of aspiration on MBS. Of these 62, 30 consented to participate in the trial, while 32 did not. Overall, 30 participants enrolled in the trial, of whom 26 completed the 8-week intervention; the remaining 145 were followed in parallel (Home program and Observation arms, Figure 1).

Among trial participants, mean age was 63.6 (SD = 9.4) years and 93.0% (28/30) were male. Most patients (21/30, 70.0%) had a history of multimodality cancer treatment (chemoradiation therapy [CRT]) and all but two were treated for oropharyngeal primary tumors. The median time since completion of cancer treatment was 16 months (IQR: 27.8, range: 3–175). Table 1 summarizes clinical and demographic characteristics of the study population.

3.2 | EMST Protocol Feasibility, Adherence, and Safety

The trial completion rate was 87% (26/30, Table 2). Attrition was due to surgery, change in insurance, requesting to withdraw, and loss to follow-up. Completers attended a median of 8 (IQR = 2) sessions and non-completers a median of 3.5 (IQR = 2.5). On average, non-completers trended toward a younger age ($p = 0.06$), but no other difference was observed in demographics, clinical characteristics, or time since RT. EMST exercise adherence was high among completing participants with 186/208 (89%) therapy sessions attended, and self-reported home exercise completion totaling 23 620/26000 prescribed repetitions (91%). Adverse events were reported in 27% of participants; all but one were deemed unrelated to EMST per the institutional data and safety monitoring Board. The single "possibly related" event ($n = 1$) involved dehydration-related vertigo after feeding tube removal with left ear pain (Grade 1). One event was deemed "unlikely related" ($n = 1$), consisting of headache with intermittent dizziness/vision loss (Grade 2). The remaining participants ($n = 6$) experienced events deemed "unlikely related", including congestion,

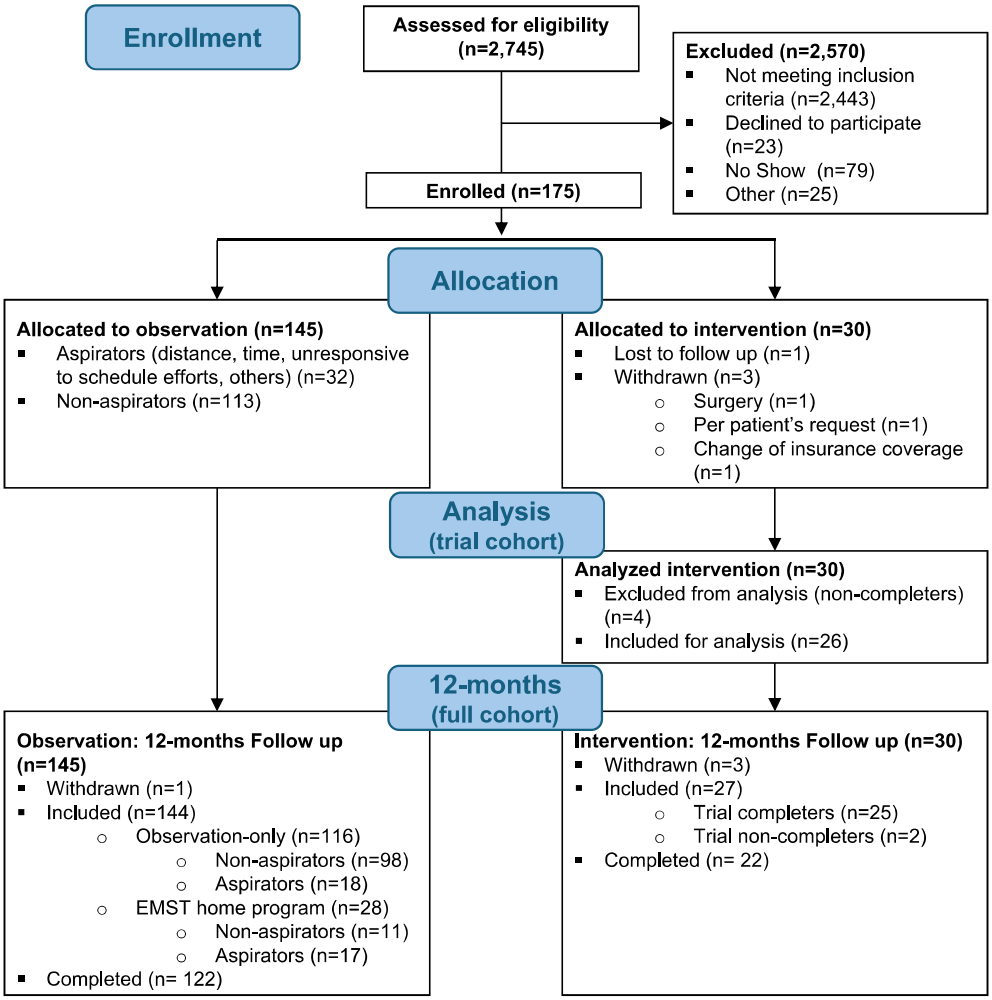

FIGURE 1 | CONSORT diagram. [Color figure can be viewed at wileyonlinelibrary.com]

lung infection, hypotension, radionecrosis-related pain, dysphonia, and aspiration-related hospitalization (Grades 1–4).

3.3 | Expiratory Function Outcomes

Among the 26 individuals who completed the 8-week EMST program, MEP significantly increased by an average of 66%, from 100.0 ± 40.3 cmH_2O at baseline to 167.0 ± 48.7 cmH_2O post-intervention ($p < 0.001$, $d = 1.64$) (Figure 2A). Voluntary PEF increased by 8% on average, from 369.4 ± 120.8 L/min to 399.6 ± 102.8 L/min, but this change was not statistically significant ($p = 0.24$, $d = 0.23$) (Figure 2B).

3.4 | Swallow Functional Outcomes

MBS-derived metrics are shown Figure 3, with detailed data in Table S1. Significant pre-post improvements were observed in PAS scores ($p = 0.003$, $r = -0.85$), with 10 participants (38.5%) showing improved scores (Figure 3A). Most improvements involved reductions by two or more PAS scores (Figure 4A). Individual changes in PAS scores in relation to DIGEST Safety scores are visualized in Figure S1. Most individuals showed either no change in both PAS and safety (9/26, 34.6%) or improved PAS with stable safety (5/26, 19.2%). Smaller proportions showed concurrent improvement (4/26, 15.4%) or other less frequent patterns (each ≤ 15%, Figure S1). Clinician-rated diet level by IDDSI-FDS also significantly improved ($p = 0.002$, $r = 0.99$; Figure 3E). Ten participants (38.5%) demonstrated better scores, including one participant who progressed from NPO to IDDSI-FDS level 4, and others who improved by 1–3 levels (Figure 4B). The IDDSI-liquid levels also improved significantly ($p = 0.03$, $r = -0.75$), with 5/6 improvements involving a change from level 2 to level 0 (Figure 4C). DIGEST (Figure 3B), MBSImP (Figure 3C), MDADI (Figure 3d) and MDASI (Figure 3F) did not show statistically significant changes.

3.5 | Subgroup Analysis

Significant MEP improvements were observed in both the adequate (Δ = 51.5 cm H_2O, 95% CI −27.8 to 75.3; $n = 11$) and inadequate (Δ = 76.5 cm H_2O, 95% CI −53.6 to 99.5; $n = 15$) baseline MEP groups, with no significant difference in response between them ($p = 0.12$). Similar findings were seen across subgroups based on time since RT, age, and BMI (Table S2). Participants < 2 years post-RT ($n = 18$) showed significant gains in PAS (44.5% improved; $p = 0.01$) and IDDSI-FDS scores (38.9% improved; $p = 0.01$), while those ≥ 2 years post-RT showed significant

TABLE 1 | Sample characteristics.

	Cohort ($n=175$)	Therapy arm ($n=30$)	Completed trial ($n=26$)	Non-completers ($n=4$)
Age, mean (SD)	61.69 (9.03)	63.6 (9.4)	64.9 (9.3)	55.6 (5.9)
Sex, male *n* (%)	159 (90%)	28 (93.3%)	24 (92.3%)	4 (100%)
Time post-RT, months median (IQR) [Range]	11.8 (18.2) [3.0, 175.5]	16.0 (27.8) [3.2, 175.5]	16.0 (27.8) [3.2, 175.5]	15.9 (45.1) [3.9, 77.0]
Time post-RT, binary				
<2 years	138 (78.9%)	21 (70.0%)	18 (69.2%)	3 (75.0%)
≥2 years	37 (21.1%)	9 (30.0%)	8 (30.8%)	1 (25.0%)
BMI				
<25	68 (38.9%)	17 (56.7%)	15 (57.7%)	2 (50.0%)
≥25	107 (61.1%)	13 (43.3%)	11 (42.3%)	2 (50.0%)
T-classification				
0	6 (3%)			
1	34 (19%)	3 (10.0%)	3 (11.5%)	1 (25.0%)
2	59 (34%)	12 (40.0%)	11 (42.3%)	2 (50.0%)
3	34 (19%)	6 (20.0%)	4 (15.4%)	1 (25.0%)
4	40 (23%)	8 (26.7%)	7 (26.9%)	
Unknown	2 (1%)	1 (3.3%)	1 (3.8%)	
HNC site				
Oropharynx	153 (87%)	27 (90%)	23 (88.46%)	4 (100.0%)
Hypopharynx	4 (2%)	1 (3%)	1 (4%)	
Larynx	12 (7%)	2 (7%)	2 (3.85%)	
Unknown primary	1 (0.57%)			
Therapeutic combo				
CRT	127 (73%)	21 (70.0%)	17 (65.4%)	4 (100.0%)
RT	5 (3%)	1 (3.3%)	1 (3.8%)	
Induction + RT/CRT	34 (19.43)	8 (26.7%)	8 (30.8%)	
Surgery + PORT/POCRT	9 (5%)			
Surgery				
Neck only	21 (12%)	1 (3.3%)	1 (3.8%)	
Primary only	4 (2%)			
Primary + neck	6 (3%)			
None	144 (82%)	29 (96.7%)	25 (96.2%)	4 (100.0%)
Radiation dose, Gy, median (IQR) [range]	69 (2.54) [50, 72]	70 (0) [66, 72]	70 (0) [66, 72]	70 (0) [70, 70]

Abbreviations: BMI, body mass index; CRT, chemoradiotherapy; HNC, head and neck cancer; PO[C]RT, post-operative [C]RT; RT, radiotherapy.

improvements in feeding tube status (12.5% improved; $p=0.04$) and MBSImP Pharyngeal score ($\Delta=-1.9$, 95% CI −3.2 to −0.5). However, no between-group differences in change were statistically significant. Among participants ≥62 years old ($n=17$), PAS (35.3% improved; $p=0.03$), IDDSI-FDS (35.3% improved; $p=0.03$), and MBSImP scores improved significantly ($\Delta=-1.4$, 95% CI −2.8 to −0.1), with a significant between-group difference in MBSImP change compared to younger participants (Δ between groups = 2.2, 95% CI 0.0 to 4.3; $p=0.02$). In those with BMI ≥25 ($n=11$), PEF increased significantly ($\Delta=89.2$ L/

TABLE 2 | EMST treatment summary.

	Therapy arm ($n=30$)	Completed trial ($n=26$)	Non-completers ($n=4$)
Sessions attended, *n* (%)			
1	1 (3.3%)		1 (25.0%)
2			
3	1 (3.3%)		1 (25.0%)
4	4 (13.3%)	3 (11.5%)	1 (25.0%)
5	1 (3.3%)		1 (25.0%)
6	4 (13.3%)	4 (15.4%)	
7	2 (6.7%)	2 (7.7%)	
8	17 (56.7%)	17 (65.4%)	
Sessions attended, median (IQR)	8 (2)	8 (2)	3.5 (2.5)
Training days, median (IQR) [Range]	40 (9) [1, 40]	40 (3) [8, 40]	9 (13) [1, 25]
Adherence to 75% resistance load, *n* (%)	27 (90.0%)	23 (88.5%)	4 (100.0%)
Adherence percent[a], median (IQR) [range]	100 (22.5) [2.5, 100]	100 (7.5) [12, 100]	22.5 (32.5) [2.5, 62.5]
Adverse events, *n* (%)			
No	22 (73.3%)	20 (76.9%)	3 (75.0%)
Yes	8 (26.7%)	6 (23.1%)	1 (25.0%)
AE attribution, *n* (%)			
Not related	6 (20.0%)	5 (19.2%)	1 (25.0%)
Unlikely related[b]	1 (3.3%)	1 (3.8%)	
Possibly related[b]	1 (3.3%)		
AE grade, *n* (%)			
Grade 1	1 (3.3%)	2 (7.7%)	
Grade 2	5 (16.7%)		
Grade 3	1 (3.3%)		
Grade 4	1 (16.7%)	4 (15.4%)	1 (25.0%)

Abbreviation: AE, adverse events.
[a]% breaths completed through the training of the prescribed 1000.
[b]The one possibly related case was grade 1, and the unlikely related was a grade 2.

min, 95% CI 15.8 to 162.6; $p=0.02$), with a significant between-group difference compared to those with lower BMI (Δ between groups = −102.2, 95% CI −201.3 to −3.0; $p=0.04$) (Table S2).

3.6 | Exploratory Analysis: Predictor of MEP Change

Exploratory univariate and multivariable regression analyses explored predictors of change in MEP following the intervention (Table S3). In the univariate models, no variable was significantly associated with MEP change ($p>0.05$). The multivariable linear model, which included pre-specified variables (baseline MEP, baseline DIGEST safety score, radiation dose, concurrent chemoradiotherapy, years since radiotherapy completion, age, sex, smoking history, and baseline BMI), was not statistically significant (adjusted $R^2=0.23$, $p=0.16$).

3.7 | Exploratory Analysis: 12-Months Follow-Up

At 12-month follow-up (Table S4), pneumonia occurred in 7.2% of the overall cohort (9/125), with rates varying by study arm: 14.3% in the EMST Trial group (3/21), 21.1% in the Home Program group (4/19), 9.1% among aspirators in the Observation group (1/11), and 1.4% among non-aspirators in the Observation group (1/74). Feeding tube dependence was observed in 7.9% of participants (10/126), with the highest prevalence in the Observation-aspirating subgroup (18.2%) and lowest in Observations, non-aspirating (2.7%). Compared to aspirators in the Home

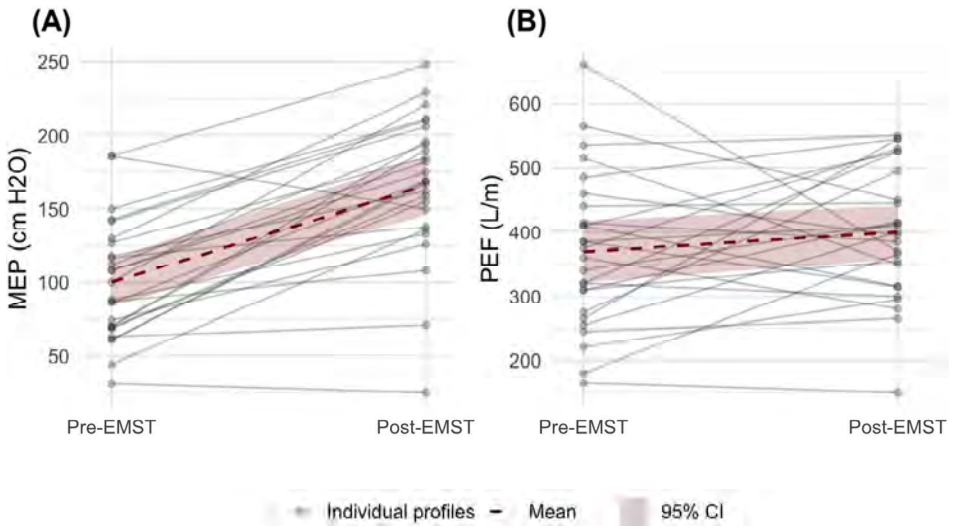

FIGURE 2 | Individual- and group-level respiratory outcomes changes pre- and post-8 weeks of EMST ($n = 26$ trial completers). Panel A: MEP mean change showed 66% improvement ($p < 0.001$); Panel B: Mean PEF change showed 8% improvement ($p = 0.24$). MEP, maximum expiratory pressure; PEF, peak expiratory flow. [Color figure can be viewed at wileyonlinelibrary.com]

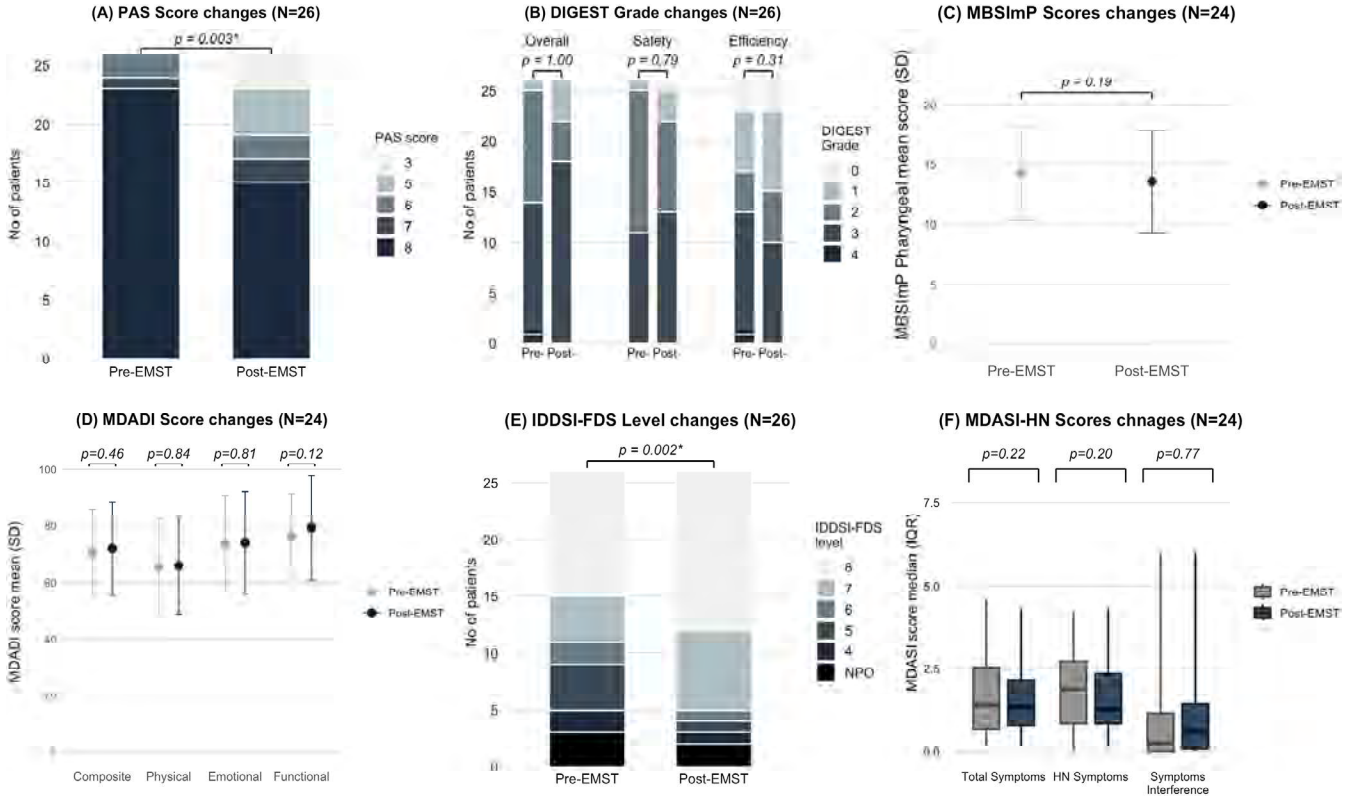

FIGURE 3 | Changes in swallowing outcomes before and after 8 weeks of EMST among trial completers ($n = 26$). PAS (A), DIGEST (B), MBSImP Pharyngeal (C), MDADI (D), IDDSI-FDS (E) and MDASI-HN (Panel F). PAS and IDDSI-FDS showed significant change post-EMST ($p > 0.05$). DIGEST, dynamic imaging grade of swallowing toxicity; IDDSI-FDS, international dysphagia diet standardization initiative functional diet scale; MBSImP, modified barium swallow impairment profile; MDADI, MD anderson dysphagia inventory; MDASI-HN, MD anderson symptom inventory for head and neck cancer; NPO, Nihil per os (Nothing by mouth); PAS, penetration-aspiration scale.

Program group, EMST Trial participants had significantly better MDADI composite and emotional scores ($p < 0.05$), with trends toward higher MDADI physical ($p = 0.063$, Table S4). Compared to aspirators in the Observation group, EMST Trial participants had significantly lower MDASI interference scores (1.28 vs. 0.80; $p = 0.032$), with no other significant differences observed between the groups (Table S4).

In multivariable linear analysis adjusting for baseline aspiration status (Table S5), EMST trial participants had significantly better swallowing-related outcomes than the Home Program group, including higher MDADI composite ($\beta = -16.8$, $p = 0.002$), emotional ($\beta = -18.1$, $p = 0.001$), physical ($\beta = -13.0$, $p = 0.031$), and functional scores ($\beta = -15.0$, $p = 0.009$), as well as lower MDASI-HN symptom ($\beta = 1.46$,

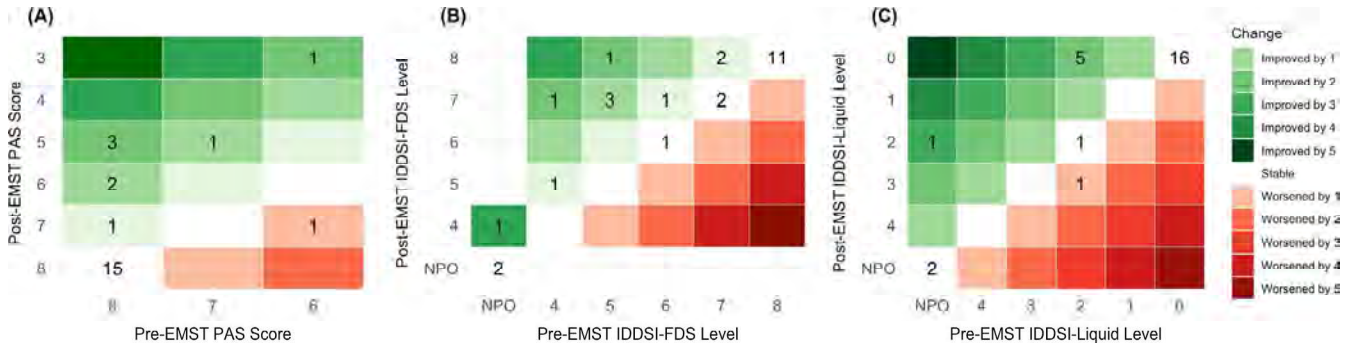

FIGURE 4 | Changes in PAS scores (A), IDDSI-FDS (B), and IDDSI-liquids (C) levels before and after 8 weeks EMST among trial completers. Each cell shows the *number of patients* who experienced an improvement, no change, or worsening in their scores between timepoints ($p > 0.05$). IDDSI-FDS, international dysphagia diet standardization initiative functional diet scale; PAS, penetration-aspiration scale. [Color figure can be viewed at wileyonlinelibrary.com]

$p = 0.011$) and interference scores ($\beta = 1.28$, $p = 0.041$). Compared to the Observation group (both aspirators and non-aspirators), EMST participants had significantly lower MDADI emotional ($\beta = -11.9$, $p = 0.030$) and MDASI interference scores ($\beta = 2.29$, $p < 0.001$).

4 | Discussion

EMST is a rehabilitative program that has been tested for outcomes related to respiratory muscle strength, cough, swallow, and voice function in healthy young adults, elderly individuals, and patients with progressive neurodegenerative disease [40], with growing use in HNC survivors [19, 41, 42]. In this pilot trial, our findings showed that the 8-week EMST program was feasible, associated with improved MEPs, penetration-aspiration, and diet range, but failed to establish improvement in cough and perceived swallow function.

This study aligns and extends previous evidence. MEP gains (66%) were comparable to those in our prior retrospective series (57%) [19], and similar to those observed in neurogenic dysphagia populations [15, 24] and post-irradiated nasopharyngeal carcinoma survivors (41%) [43]. Together, these findings support the relevance of EMST for enhancing expiratory strength in HNC survivors. Importantly, MEP gains were observed across subgroups regardless of baseline MEP, time since RT, age, or BMI, suggesting that individual baseline characteristics may not be strong determinants of training response in this cohort. While improvements in swallowing safety were seen in roughly 30%–40% of participants in our retrospective series and the current trial, the present trial detected improvement in PAS but not DIGEST Safety gains, unlike the retrospective series. The divergence may represent fundamental differences in the scales themselves, where PAS captures swallow safety on worst individual boluses, whereas DIGEST Safety provides a more global assessment across trials, making it more representative of overall functional safety but potentially less sensitive to subtle, bolus-level changes. Additionally, differences in study populations likely contributed: the earlier cohort was much further post-RT (average 8 years) with severe dysphagia (74% with baseline DIGEST Safety grade 3), whereas the current cohort was mostly earlier post-RT (< 2 years) and had milder impairments (57% DIGEST Safety grades 1–2). These differences suggest that EMST may offer more sizable safety-related functional benefit in more chronic, severe cases, though our subgroup analysis by time since RT was not powered to confirm this.

Importantly, this trial showed significant improvements in PAS scores, with 38% of participants transitioning from silent aspiration to less severe events with voluntary airway defense. This pattern of improvement aligns with hypothesized EMST mechanisms (enhanced cough strength [11] and load-dependent submental or pharyngeal muscle recruitment [21, 44]) which may aid airway defense even if bolus clearance or efficiency remains unchanged. Similar PAS improvements have been reported inconsistently in the literature, with some studies demonstrating significant changes post-EMST in HNC [43] and neurogenic populations [23, 24, 45–47], while others report only non-significant trends in PAS [14, 15, 48]. These findings suggest that while EMST may not eliminate aspiration, it could offer functional compensatory benefit, particularly in improving swallow–respiratory coordination and mitigating the most severe forms of airway invasion.

Dietary outcomes reflected these functional gains. After EMST, 38% of patients demonstrated improved diet range (per IDDSI-FDS), most commonly progressing from nectar thick to thin liquids with the strategy of supraglottic swallow or throat clear/re-swallow. These improvements thus reflect again enhanced airway protection strategies and more effective airway protection with thin (rather than complete elimination of aspiration), which is consistent with the lack of significant change in DIGEST Safety scores. Although short-term patient-reported outcomes (MDADI, MDASI) exhibited only small, non-significant gains, our 12-month follow-up data support a delayed, yet meaningful benefit. EMST participants in the trial who participated in guided MEP-calibrated SLP-led training over 8 weeks demonstrated better swallowing-related quality of life and lower symptom burden than those with aspiration in the Home Program EMST and Observation groups. These findings suggest that more intensive clinician-directed EMST may produce gradual, sustained improvements in function and quality of life, potentially as patients adapt to new compensatory strategies and experience the sustained impact of improved airway protection. It is unclear if this relates to better adherence or more precise loading of the EMST therapy in the clinician-guided model.

Adherence in this trial was higher than typically reported in behavioral swallowing interventions [49], and comparable to rates observed in previous EMST programs [15]. While the trial met its feasibility endpoint—with over 80% of participants completing the intervention—the four dropouts (who completed therapy for 1–4 weeks) suggest that while most participants could sustain the 8-week regimen, some may find the duration burdensome. Understanding whether gains plateau earlier could help optimize program length and improve retention. Previous EMST protocols have typically implemented 4–5 weeks of EMST. Future research should explore the optimal dosing and identify whether and when gains plateau, as observed in other populations [50–52]. Understanding this trajectory in HNC survivors may be critical to inform therapy personalization and maximize both engagement and therapeutic benefit.

Limitations of this study include the absence of a random control group, limiting causal inference regarding treatment effects. While efforts were made to include a heterogeneous HNC cohort, the majority of participants had oropharyngeal cancer treated with definitive radiotherapy ± chemotherapy, potentially limiting generalizability to other tumor sites or treatment pathways (e.g., primary surgery, non OPC). The exploratory analysis of predictors of MEP change was pre-specified but limited by small sample size and multiple predictors; given the non-significant model, these findings should be interpreted cautiously. Nonetheless, to our knowledge, this pilot trial represents the 1st-in-humans prospective demonstration of pragmatic feasibility of EMST in a symptomatic post-RT survivorship setting, and shows a pre- to post-therapy improvement for future prospective trials.

5 | Conclusion

In this prospective trial, EMST was feasible, well-tolerated, and associated with improved maximum expiratory pressure, diet range, and reduced severity of aspiration in HNC survivors with RAD. While improvements were not observed across all physiologic domains, the shift from silent aspiration to milder, more penetration-aspiration defended events in 40% may reflect meaningful functional gains. These findings support the potential role of EMST as a targeted intervention for select patients with impaired airway protection after HN RT and warrant further evaluation in controlled trials.

Author Contributions

In accordance with the Contributor Roles Taxonomy (CRediT, https://credit.niso.org/), the contributing authors have designated responsibilities and individual author attribution. The corresponding author (Katherine A. Hutcheson) assumes responsibility for role assignment, and all contributors have been given the opportunity to review and confirm assigned roles. Beatrice Manduchi: data curation, formal analysis, interpretation, writing – original draft. Carla L. Warneke: data curation, formal analysis. Martha Portwood Barrow, George A. Eapen, Emily K. Plowman, Clifton D. Fuller, Stephen Y. Lai: conceptualization, methodology, writing – review and editing. Katherine A. Hutcheson: conceptualization, funding acquisition, writing – original draft, review and editing, supervision.

Acknowledgments

We thank the clinicians in the Section of Speech Pathology and Audiology at MD Anderson for their dedication to patient care and participation in data collection. We also gratefully acknowledge Alicia Wang, Jhankruti Zaveri Desai, Alicia Wang, Suting Louisa Bibiana, Cecilia Felix-Lusterman, and Marissa Ramos to the research conduct and data management for this study as well as Sheila Buoy, and Ariana Sahli for their valuable assistance and contributions.

Funding

This work was accomplished with support of the MD Anderson Institutional Research Grant Program Survivorship Seed Monies Award. BM is supported by the UTHealth Houston Innovation for Cancer Prevention Research Training Program Postdoctoral Fellowship (Cancer Prevention and Research Institute of Texas grant #RP210042). The content is solely the responsibility of the authors and does not necessarily reflect the official views of the National Institutes of Health or the Cancer Prevention Research Institute.

Disclosure

In accordance with EQUATOR Network (Enhancing the QUAlity and Transparency of health Research) guidance, we have utilized the CONSORT checklist (extension Pilot and Feasibility Trials).

Conflicts of Interest

The authors declare that there are no conflicts of interest related to this work. Clifton D. Fuller receives unrelated royalties from the University of Texas System from Kallisio Inc.; unrelated grants from U.S. National Institutes of Health, and Elekta AB; and unrelated travel/honoraria/registration from: the National Institutes of Health, Elekta AB, Siemens Healthineers/Varian Medical systems, Philips Medical Systems, GE Healthcare.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

References

1. K. A. Hutcheson, Z. Nurgalieva, H. Zhao, et al., "Two-Year Prevalence of Dysphagia and Related Outcomes in Head and Neck Cancer Survivors: An Updated SEER-Medicare Analysis," *Head & Neck* 41, no. 2 (2019): 479–487, https://doi.org/10.1002/hed.25412.

2. B. Xu, I. J. Boero, L. Hwang, et al., "Aspiration Pneumonia After Concurrent Chemoradiotherapy for Head and Neck Cancer," *Cancer* 121, no. 8 (2015): 1303–1311, https://doi.org/10.1002/cncr.29207.

3. M. M. Szczesniak, J. Maclean, T. Zhang, P. H. Graham, and I. J. Cook, "Persistent Dysphagia After Head and Neck Radiotherapy: A Common and Under-Reported Complication With Significant Effect on Non-Cancer-Related Mortality," *Clinical Oncology* 26, no. 11 (2014): 697–703, https://doi.org/10.1016/j.clon.2014.08.009.

4. G. S. Ajmani, C. C. Nocon, B. E. Brockstein, A. B. Kelly, J. Allison, and M. K. Bhayani, "Association of a Proactive Swallowing Rehabilitation Program With Feeding Tube Placement in Patients Treated for Pharyngeal Cancer," *JAMA Otolaryngology. Head & Neck Surgery* 144, no. 6 (2018): 483–488, https://doi.org/10.1001/jamaoto.2018.0278.

5. M. Baudelet, F. Duprez, L. van den Steen, et al., "Increasing Adherence to Prophylactic Swallowing Exercises During Head and Neck Radiotherapy: The Multicenter, Randomized Controlled PRESTO-Trial," *Dysphagia* 38, no. 3 (2023): 886–895, https://doi.org/10.1007/s00455-022-10513-6.

6. T. H. Li, W. H. Tseng, H. L. Chiu, et al., "Proactive Swallowing Rehabilitation in Patients With Recurrent Oral Cancer Receiving

Salvage Treatment: Long-Term Swallowing-Related Outcomes," *Dysphagia* 38, no. 3 (2023): 954–964, https://doi.org/10.1007/s00455-022-10521-6.

7. R. Martino, M. I. Fitch, C. D. Fuller, et al., "The PRO-ACTIVE Trial Protocol: A Randomized Study Comparing the Effectiveness of PROphylACTic Swallow InterVEntion for Patients Receiving Radiotherapy for Head and Neck Cancer," *BMC Cancer* 21, no. 1 (2021): 1100, https://doi.org/10.1186/s12885-021-08826-0.

8. C. Nutting, L. Finneran, J. Roe, et al., "Dysphagia-Optimised Intensity-Modulated Radiotherapy Versus Standard Intensity-Modulated Radiotherapy in Patients With Head and Neck Cancer (DARS): A Phase 3, Multicentre, Randomised, Controlled Trial," *Lancet Oncology* 24, no. 8 (2023): 868–880, https://doi.org/10.1016/S1470-2045(23)00265-6.

9. H. P. van der Laan, A. Gawryszuk, M. E. M. C. Christianen, et al., "Swallowing-Sparing Intensity-Modulated Radiotherapy for Head and Neck Cancer Patients: Treatment Planning Optimization and Clinical Introduction," *Radiotherapy and Oncology* 107, no. 3 (2013): 282–287, https://doi.org/10.1016/j.radonc.2013.05.004.

10. M. S. Troche, A. E. Brandimore, J. Godoy, and K. W. Hegland, "A Framework for Understanding Shared Substrates of Airway Protection," *Journal of Applied Oral Science* 22, no. 4 (2014): 251–260, https://doi.org/10.1590/1678-775720140132.

11. C. Sapienza, M. Troche, T. Pitts, and P. Davenport, "Respiratory Strength Training: Concept and Intervention Outcomes," *Seminars in Speech and Language* 32, no. 1 (2011): 21–30, https://doi.org/10.1055/s-0031-1271972.

12. S. Anand, N. El-Bashiti, and C. Sapienza, "Effect of Training Frequency on Maximum Expiratory Pressure," *American Journal of Speech-Language Pathology* 21, no. 4 (2012): 380–386, https://doi.org/10.1044/1058-0360(2012/11-0048).

13. S. Baker, P. Davenport, and C. Sapienza, "Examination of Strength Training and Detraining Effects in Expiratory Muscles," *Journal of Speech, Language, and Hearing Research* 48, no. 6 (2005): 1325–1333, https://doi.org/10.1044/1092-4388(2005/092).

14. K. W. Hegland, P. W. Davenport, A. E. Brandimore, F. F. Singletary, and M. S. Troche, "Rehabilitation of Swallowing and Cough Functions Following Stroke: An Expiratory Muscle Strength Training Trial," *Archives of Physical Medicine and Rehabilitation* 97, no. 8 (2016): 1345–1351, https://doi.org/10.1016/j.apmr.2016.03.027.

15. E. K. Plowman, L. Tabor-Gray, K. M. Rosado, et al., "Impact of Expiratory Strength Training in Amyotrophic Lateral Sclerosis: Results of a Randomized, Sham-Controlled Trial," *Muscle & Nerve* 59, no. 1 (2019): 40–46, https://doi.org/10.1002/mus.26292.

16. J. C. Rosenbek, J. A. Robbins, E. B. Roecker, J. L. Coyle, and J. L. Wood, "A penetration-aspiration scale," *Dysphagia* 11, no. 2 (1996): 93–98, https://doi.org/10.1007/BF00417897.

17. K. A. Hutcheson, M. P. Barrow, D. A. Barringer, et al., "Dynamic Imaging Grade of Swallowing Toxicity (DIGEST): Scale Development and Validation," *Cancer* 123, no. 1 (2017): 62–70, https://doi.org/10.1002/cncr.30283.

18. K. A. Hutcheson, C. E. A. Barbon, C. P. Alvarez, and C. L. Warneke, "Refining Measurement of Swallowing Safety in the Dynamic Imaging Grade of Swallowing Toxicity (DIGEST) Criteria: Validation of DIGEST Version 2," *Cancer* 128, no. 7 (2022): 1458–1466, https://doi.org/10.1002/cncr.34079.

19. K. A. Hutcheson, M. P. Barrow, E. K. Plowman, et al., "Expiratory Muscle Strength Training for Radiation-Associated Aspiration After Head and Neck Cancer: A Case Series," *Laryngoscope* 128, no. 5 (2018): 1044–1051, https://doi.org/10.1002/lary.26845.

20. A. D. Palmer, R. K. Bolognone, S. Thomsen, D. Britton, J. Schindler, and D. J. Graville, "The Safety and Efficacy of Expiratory Muscle Strength Training for Rehabilitation After Supracricoid Partial Laryngectomy: A Pilot Investigation," *Annals of Otology, Rhinology, and Laryngology* 128, no. 3 (2019): 169–176, https://doi.org/10.1177/0003489418812901.

21. K. A. Hutcheson, M. J. Hammer, S. P. Rosen, C. A. Jones, and T. M. McCulloch, "Expiratory Muscle Strength Training Evaluated With Simultaneous High-Resolution Manometry and Electromyography," *Laryngoscope* 127, no. 4 (2017): 797–804, https://doi.org/10.1002/lary.26397.

22. R. Mancopes, S. Smaoui, and C. M. Steele, "Effects of Expiratory Muscle Strength Training on Videofluoroscopic Measures of Swallowing: A Systematic Review," *American Journal of Speech-Language Pathology* 29, no. 1 (2020): 335–356, https://doi.org/10.1044/2019_AJSLP-19-00107.

23. T. Pitts, D. Bolser, J. Rosenbek, M. Troche, M. S. Okun, and C. Sapienza, "Impact of Expiratory Muscle Strength Training on Voluntary Cough and Swallow Function in Parkinson Disease," *Chest* 135, no. 5 (2009): 1301–1308, https://doi.org/10.1378/chest.08-1389.

24. M. S. Troche, M. S. Okun, J. C. Rosenbek, et al., "Aspiration and Swallowing in Parkinson Disease and Rehabilitation With EMST: A Randomized Trial," *Neurology* 75, no. 21 (2010): 1912–1919, https://doi.org/10.1212/WNL.0b013e3181fef115.

25. E. K. Plowman, S. A. Watts, L. Tabor, et al., "Impact of Expiratory Strength Training in Amyotrophic Lateral Sclerosis," *Muscle & Nerve* 54, no. 1 (2016): 48–53, https://doi.org/10.1002/mus.24990.

26. K. A. Hutcheson, M. P. Barrow, C. L. Warneke, et al., "Cough Strength and Expiratory Force in Aspirating and Nonaspirating Postradiation Head and Neck Cancer Survivors," *Laryngoscope* 128, no. 7 (2018): 1615–1621, https://doi.org/10.1002/lary.26986.

27. S. N. King, N. E. Dunlap, P. A. Tennant, and T. Pitts, "Pathophysiology of Radiation-Induced Dysphagia in Head and Neck Cancer," *Dysphagia* 31, no. 3 (2016): 339–351, https://doi.org/10.1007/s00455-016-9710-1.

28. M. F. Folstein, S. E. Folstein, and P. R. McHugh, ""Mini-Mental State". A Practical Method for Grading the Cognitive State of Patients for the Clinician," *Journal of Psychiatric Research* 12, no. 3 (1975): 189–198, https://doi.org/10.1016/0022-3956(75)90026-6.

29. T. C. Hoffmann, P. P. Glasziou, I. Boutron, et al., "Better Reporting of Interventions: Template for Intervention Description and Replication (TIDieR) Checklist and Guide," *BMJ* 348 (2014): g1687, https://doi.org/10.1136/bmj.g1687.

30. B. Martin-Harris, M. B. Brodsky, Y. Michel, et al., "MBS Measurement Tool for Swallow Impairment–MBSImp: Establishing a Standard," *Dysphagia* 23, no. 4 (2008): 392–405, https://doi.org/10.1007/s00455-008-9185-9.

31. M. A. List, L. L. D'Antonio, D. F. Cella, et al., "The Performance Status Scale for Head and Neck Cancer Patients and the Functional Assessment of Cancer Therapy-Head and Neck Scale. A Study of Utility and Validity," *Cancer* 77, no. 11 (1996): 2294–2301, https://doi.org/10.1002/(SICI)1097-0142(19960601)77:11%3C2294::AID-CNCR17%3E3.0.CO;2-S.

32. C. M. Steele, A. M. Namasivayam-MacDonald, B. T. Guida, et al., "Creation and Initial Validation of the International Dysphagia Diet Standardisation Initiative Functional Diet Scale," *Archives of Physical Medicine and Rehabilitation* 99, no. 5 (2018): 934–944, https://doi.org/10.1016/j.apmr.2018.01.012.

33. A. Y. Chen, R. Frankowski, J. Bishop-Leone, et al., "The Development and Validation of a Dysphagia-Specific Quality-Of-Life Questionnaire for Patients With Head and Neck Cancer: The M. D. Anderson Dysphagia Inventory," *Archives of Otolaryngology – Head & Neck Surgery* 127, no. 7 (2001): 870–876.

34. D. I. Rosenthal, T. R. Mendoza, M. S. Chambers, et al., "Measuring Head and Neck Cancer Symptom Burden: The Development and Validation of the M. D. Anderson Symptom Inventory, Head and Neck Module," *Head & Neck* 29, no. 10 (2007): 923–931, https://doi.org/10.1002/hed.20602.

35. CDC, "National Health and Nutrition Examination Survey. National Health and Nutrition Examination Survey," 2025, accessed March 11, 2026, https://www.cdc.gov/nchs/nhanes-participants/index.html.

36. A. Lista-Paz, D. Langer, M. Barral-Fernández, et al., "Maximal Respiratory Pressure Reference Equations in Healthy Adults and Cut-Off Points for Defining Respiratory Muscle Weakness," *Archivos de Bronconeumología* 59, no. 12 (2023): 813–820, https://doi.org/10.1016/j.arbres.2023.08.016.

37. C. C. Yang, Y. C. Su, Y. W. Lin, C. I. Huang, and C. C. Lee, "Differential Impact of Age on Survival in Head and Neck Cancer According to Classic Cox Regression and Decision Tree Analysis," *Clinical Otolaryngology* 44, no. 3 (2019): 244–253, https://doi.org/10.1111/coa.13274.

38. B. J. Cline, M. C. Simpson, M. Gropler, et al., "Change in Age at Diagnosis of Oropharyngeal Cancer in the United States, 1975-2016," *Cancers* 12, no. 11 (2020): 3191, https://doi.org/10.3390/cancers12113191.

39. A. Thompson-Harvey, M. Yetukuri, A. R. Hansen, et al., "Rising Incidence of Late-Stage Head and Neck Cancer in the United States," *Cancer* 126, no. 5 (2020): 1090–1101, https://doi.org/10.1002/cncr.32583.

40. H. Laciuga, P. Davenport, and C. Sapienza, "The Acute Effects of a Single Session of Expiratory Muscle Strength Training on Blood Pressure, Heart Rate, and Oxygen Saturation in Healthy Adults," *Frontiers in Physiology* 3 (2012): 48, https://doi.org/10.3389/fphys.2012.00048.

41. Singapore General Hospital, "The Effects of Expiratory Muscle Strength Training (EMST) on Airway Protection and Swallowing in Chronic Dysphagia After Radiation Therapy," clinicaltrials.gov; 2020, accessed July 28, 2025, https://clinicaltrials.gov/study/NCT03620084.

42. Ohio State University Comprehensive Cancer Center, "The Impact of Expiratory Muscle Strength Training on Bulbar Function and Well Being of Individuals With Head and Neck Cancer," clinicaltrials.gov; 2019, accessed July 28, 2025, https://clinicaltrials.gov/study/NCT03175289.

43. S. W. Cheng, K. H. V. Leung, K. C. J. Mok, et al., "Improvement in Swallowing Function in Patients With Previous Irradiation for Nasopharyngeal Carcinoma by Expiratory Muscle Strength Training," *Dysphagia* 39, no. 1 (2024): 129–139, https://doi.org/10.1007/s00455-023-10600-2.

44. K. M. Wheeler-Hegland, J. C. Rosenbek, and C. M. Sapienza, "Submental sEMG and Hyoid Movement During Mendelsohn Maneuver, Effortful Swallow, and Expiratory Muscle Strength Training," *Journal of Speech, Language, and Hearing Research* 51, no. 5 (2008): 1072–1087, https://doi.org/10.1044/1092-4388(2008/07-0016).

45. J. H. Moon, J. H. Jung, Y. S. Won, H. Y. Cho, and K. Cho, "Effects of Expiratory Muscle Strength Training on Swallowing Function in Acute Stroke Patients With Dysphagia," *Journal of Physical Therapy Science* 29, no. 4 (2017): 609–612, https://doi.org/10.1589/jpts.29.609.

46. J. S. Park, D. H. Oh, M. Y. Chang, and K. M. Kim, "Effects of Expiratory Muscle Strength Training on Oropharyngeal Dysphagia in Subacute Stroke Patients: A Randomised Controlled Trial," *Journal of Oral Rehabilitation* 43, no. 5 (2016): 364–372, https://doi.org/10.1111/joor.12382.

47. M. J. Eom, M. Y. Chang, D. H. Oh, H. D. Kim, N. M. Han, and J. S. Park, "Effects of Resistance Expiratory Muscle Strength Training in Elderly Patients With Dysphagic Stroke," *NeuroRehabilitation* 41, no. 4 (2017): 747–752, https://doi.org/10.3233/NRE-172192.

48. E. P. Silverman, S. Miller, Y. Zhang, B. Hoffman-Ruddy, J. Yeager, and J. J. Daly, "Effects of Expiratory Muscle Strength Training on Maximal Respiratory Pressure and Swallow-Related Quality of Life in Individuals With Multiple Sclerosis," *Multiple Sclerosis Journal-Experimental, Translational and Clinical* 3, no. 2 (2017): 2055217317710829, https://doi.org/10.1177/2055217317710829.

49. B. N. Krekeler, C. K. Broadfoot, S. Johnson, N. P. Connor, and N. Rogus-Pulia, "Patient Adherence to Dysphagia Recommendations: A Systematic Review," *Dysphagia* 33, no. 2 (2018): 173–184, https://doi.org/10.1007/s00455-017-9852-9.

50. M. A. Belsky, S. Shelly, S. D. Rothenberger, et al., "Phonation Resistance Training Exercises (PhoRTE) With and Without Expiratory Muscle Strength Training (EMST) for Patients With Presbyphonia: A Noninferiority Randomized Clinical Trial," *Journal of Voice* 37, no. 3 (2023): 398–409, https://doi.org/10.1016/j.jvoice.2021.02.015.

51. J. Allen, R. Astin, C. Smith, D. Banks, and C. Turner, "Expiratory Muscle Strength Training Improves Measures of Pressure Generation and Cough Strength in a Patient With Myotonic Dystrophy Type 1," *Neuromuscular Disorders* 30, no. 9 (2020): 750–755, https://doi.org/10.1016/j.nmd.2020.07.003.

52. A. F. Saleem, C. M. Sapienza, and M. S. Okun, "Respiratory Muscle Strength Training: Treatment and Response Duration in a Patient With Early Idiopathic Parkinson's Disease," *NeuroRehabilitation* 20, no. 4 (2005): 323–333.

Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Supplementary Information S1. Table S1:** Functional outcomes pre- and post-8 weeks of EMST ($n = 26$ completed trial). **Figure S1:** Individual changes in PAS scores and DIGEST Safety grades before and after 8-weeks EMST among trial completers. Each cell shows the *PAS score* and corresponding DIGEST Safety grade per patient. The legend reports patterns of improvement (↑), no change (=), or worsening (↓) in PAS and Safety grade across timepoints. **Table S2:** Functional outcomes pre- and post-8 weeks of EMST by subgroups. **Table S3:** Univariate and multivariable regression models for change in MEP. **Table S4:** Functional outcomes at 12-months follow up by arm allocation. **Table S5:** Functional outcomes at 12-month follow-up: regression analysis by arm allocation (EMST reference, adjusted for aspiration—VIF < 5). **Supplementary Information S2.** TiDieR checklist.