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Respiratory-Swallow Training in Patients with Head and Neck Cancer

Bonnie Martin-Harris, PhD, CCC-SLP[1,2,3], **David McFarland, PhD, CCC-SLP**[4], **Elizabeth G. Hill, PhD**[5], **Charlton B. Strange, MD**[6], **Kendrea L. Focht, CScD, CCC-SLP**[1,2,3], **Zhuang Wan, MS**, **Julie Blair, MA, CCC-SLP**[2,3], and **Katlyn McGrattan, MS, CCC-SLP**[1,2]

[1]Department of Otolaryngology-Head and Neck Surgery, College of Medicine, Medical University of South Carolina, Charleston, SC

[2]Evelyn Trammell Institute for Voice and Swallowing, Medical University of South Carolina, Charleston, SC

[3]Ralph H. Johnson VA Medical Center, Charleston, SC

[4]Faculties of Medicine, Université de Montréal and McGill University, Montréal, QC, Canada

[5]Department of Public Health Sciences, Medical University of South Carolina, Charleston, SC

[6]Division of Pulmonary and Critical Medicine, College of Medicine, Medical University of South Carolina, Charleston, SC

Abstract

Objective—To test a novel intervention to train swallowing to occur in the mid-to-low expiratory phase of quiet breathing to improve swallowing safety and efficiency.

Design—Safety and efficacy non-randomized clinical trial with one-month follow-up.

Setting—Head and neck cancer (HNC) ambulatory clinics.

Participants—Thirty patients with HNC and chronic dysphagia completed the intervention. Fifteen of these patients participated in a one-month follow-up visit.

Interventions—Training protocol based on hierarchy of motor skill acquisition to encourage autonomous and optimal respiratory-swallowing coordination. Visual feedback of respiratory

Correspondence to: Bonnie Martin-Harris, PhD, CCC-SLP, BRS-S, ASHA Fellow, Professor, Department of Otolaryngology-Head and Neck Surgery, Director, Evelyn Trammell Institute for Voice and Swallowing, Medical University of South Carolina, 135 Rutledge Ave, MSC 550, Charleston, SC 29425, Telephone: 843-792-7162, harrisbm@musc.edu.

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phase and volume for swallowing initiation was provided by nasal airflow and rib cage/abdomen signals.

Main Outcome Measures—Respiratory-swallow phase pattern, Modified Barium Swallow Impairment Profile™© (MBSImP) scores, Penetration Aspiration Scale (PAS) scores, M.D. Anderson Dysphagia Inventory scores

Results—Using visual feedback, patients were trained to initiate swallows during the mid-expiratory phase of quiet breathing and to continue to expire after swallowing. This optimal phase patterning increased significantly after treatment (p <0.0001). Changes in respiratory-swallowing coordination were associated with improvements in three MBSImP component scores: laryngeal vestibular closure (p = 0.0004), tongue base retraction (p <0.0001), and pharyngeal residue (p = 0.01). Significant improvements were also seen in PAS scores (p <0.0001). Relative to pre-treatment values, patients participating in one-month follow-up had increased optimal phase patterning (p <0.0001), improved laryngeal vestibular closure (p = 0.01), tongue base retraction (p = 0.003), and pharyngeal residue (p = 0.006) MBSImP scores, and improved PAS scores (p <0.0001).

Conclusions—Improvements in respiratory-swallowing coordination can be trained using a systematic protocol and respiratory phase-lung volume related biofeedback in patients with HNC and chronic dysphagia, with favorable effects on airway protection and bolus clearance.

Keywords

deglutition disorders; rehabilitation; head and neck neoplasms; respiratory aspiration; feedback; sensory

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A growing body of literature indicates the existence of a highly stable, coordinative relationship between respiration and oropharyngeal swallowing in healthy adults.[1–22] Normal swallows occur most frequently during a pause in the expiratory phase of the breathing cycle, between middle and low expiratory lung volumes at quiet breathing, with some variability due to bolus consistency and swallowing task.[1–24] This coordinative phase relationship appears to serve two related functions. First, expiratory flow surrounding swallowing may be vital to airway protection. Secondly, expiratory flow facilitates mechanical functions advantageous to swallowing, such as laryngeal elevation and closure, pharyngeal pressure generation with consequent bolus clearance, and pharyngoesophageal segment (PES) opening.[1–3,10]

Previous data suggest consistent, coordinative patterning may be perturbed in dysphagic patients including those with head and neck cancer (HNC).[25–33] We have shown that HNC patients who tended to initiate swallowing by interrupting the inspiratory phase of the breathing cycle had greater severity of airway invasion and swallowing impairment when contrasted with those with more stable patterning.[25] Further, patients with HNC tend to have severe swallowing impairments often refractory to current therapeutic approaches.[34–51] This led to the current work and speculation that training a more beneficial mechanical and airway protective coordinative relationship might improve swallowing impairments in these patients. Testing of HNC patients as the first study patient population has the advantage of clinical stability in the early years post treatment, thereby enabling investigators to

differentiate spontaneous recovery from the treatment effect. Since COPD is another common disease in the HNC population, the impact of COPD on swallowing function was determined.

Our primary aims were three-fold: 1) use a novel respiratory-related feedback protocol to train optimal respiratory-swallowing coordinative patterns; 2) determine the effect(s) of training on respiratory-swallowing phasing and primary swallowing outcome measures; and 3) test the stability of the training effect one-month post-treatment. We hypothesized that more optimal respiratory-swallowing coordination could be learned, sustained, and have a beneficial impact on swallowing function in chronically dysphagic patients treated for HNC. The study was designed to have a minimum of 80% power to detect a reduction of 50% in impairment comparing post- to pre-intervention rates, based on analyses accounting for the paired study design with two-sided $\alpha = 0.05$.

METHODS

Institutional Review Board Approval—The Medical University of South Carolina (MUSC) Institutional Review Board (IRB) for Human Research approved the study for enrollment at MUSC and the Ralph H. Johnson VA Medical Center (VAMC).

Patients

Adult patients aged 21 years and older were recruited during a three-year period from head and neck tumor ambulatory clinics at the academic hospital and the VAMC. Patients provided written informed consent and were >6 months post-HNC treatment. Patients underwent a pre-assessment pulmonary function test and modified barium swallow study (MBSS). Participants meeting inclusion criteria entered the intervention phase.

Patients were included if they had persistent complaints of swallowing difficulty that were resistant to traditional dysphagia therapy, Penetration-Aspiration Scale (PAS) scores ≥3 and ≤7, [53] and a sum ≥5 on the Modified Barium Swallow Impairment Profile™© (MBSImP) on the following MBSImP components: initiation of pharyngeal swallow, anterior hyoid excursion, pharyngoesophageal segment opening, tongue base retraction, and pharyngeal residue.[52] These components were selected based on previous studies and preliminary work as salient impairments in HNC patients.[25] Participants were required to tolerate at least one liquid consistency indicated by PAS score of ≤6 as observed on MBSS. If the patient received a PAS score of >6 on a particular liquid consistency (e.g., thin liquid), it was not used during the intervention as a concern for patient safety. All participants had non-optimal (non E-E) respiratory-swallow patterns on at least 60 % of swallows or had inconsistent non-optimal respiratory-swallow patterns. Patients were excluded for evidence of recurrent HNC, concomitant neurologic disease, evidence of stricture, or nasogastric feeding tube. Patients with recent aspiration pneumonia, forced expiratory volume in 1 second (FEV1) <30% predicted,[54] or impaired cognition identified on a standardized tool (Cognistat)[55,56] were excluded.

Clinician Raters and Trainers

Two expert speech-language pathologists (SLPs) (BMH and JB) conducted and interpreted the de-identified MBSSs. To use the MBSImP, the SLP must have exceeded the reliability criterion of 80% of inter-rater reliability.[76] These two SLPs had ≥90% inter- and intra-study agreement on MBSImP scoring, PAS scoring, and identification of respiratory-swallowing phase patterns based on unpublished laboratory data. For purposes of this study, each MBSS was scored using consensus scoring between BMH and JB.

Four SLPs, with 2 to 15 years of clinical experience, were trained individually by the first author (BMH) and carried out the treatment sessions. The standardized treatment methods were contained in an instruction manual, modeled by BMH and second author (DMcF). Competency was assessed during simulated practiced. The instruction manual also included detailed instructions regarding equipment set-up, how to provide feedback, and how to monitor and measure success of treatment goals. The clinicians treated at both institutions.

Radiographic Evaluation of Respiratory-Swallow Phase Pattern, Swallowing Function, and Airway Invasion

Pre- and post-intervention MBSSs were conducted in a routine fluoroscopy suite with a radiologist present. The patients were seated upright and positioned in the lateral viewing plane. The visualization field included the lips anteriorly, nasal cavity superiorly, cervical spinal column posteriorly, and the pharyngoesophageal segment (PES) inferiorly.[21,57–60] Nasal airflow was captured using a standard, 7-foot nasal cannula connected to the Swallow Signals Lab™, a peripheral device for use with the KayPENTAX™ Digital Swallowing Workstation (DSW) (Model 7100, Lincoln Park, NJ).[a] Movements of the rib cage (RC) and abdomen (ABD) were recorded using respiratory inductance plethysmography (RIP) (Inductotrace System, Ambulatory Monitoring, Inc.).[b] All data were synchronized and recorded using the acquisition hardware and software of the DSW Swallow Signals Lab™ at a sampling rate of 250 Hz for the respiratory and nasal airflow signals and 30 frames/sec for the videofluoroscopic images.

The MBSImP, a standardized, reliable and valid approach for the assessment and interpretation of the MBSS, was used to provide measures of swallowing physiology pre- and post-treatment.[c]52 For the purposes of this current study, the MBSImP protocol was abbreviated. Specifically, only liquid swallows were included because many of the patient volunteers could not meet safety/inclusion criteria on consistencies that went beyond thick liquid consistencies, and solid consistencies would provide a safety risk to most of the head and neck cancer participants. Swallow tasks were performed sequentially rather than in random order because some patients had difficulty with thicker liquid consistencies (PAS ≥6). Thin liquid, nectar-thick liquid, and (thin) honey-thick liquids (Varibar® oropharyngeal contrast, Bracco Diagnostics, Inc.)[d] were presented in the following order: 5-mL via teaspoon, 15-mL via measured medicine cup, and cup sip via self-presentation for patient

[a]KayPentax Digital Swallowing Workstation; KayPENTAX, 3 Paragon Dr, Montvale, NJ 07645.
[b]Inductotrace; Ambulatory Monitoring, Inc., 731 Saw Mill River Rd, Ardsley, NY 10502.
[c]Northern Speech Services, Inc., 325 Meecher Road, Gaylord, Michigan 49735.
[d]Varibar Thin, Nectar, Honey and Pudding; Bracco Diagnostics, Inc, 107 College Rd E, Princeton, NJ 08540.

preferred volume intake from a 3-ounce plastic cup. Two trials of each volume and consistency were presented for a maximum of 18 trials. The second trial for a given volume and consistency combination was not presented if the patient aspirated without expectoration on that specific volume/consistency.

Because a solid bolus was not tested, MBSImP component 3 (bolus preparation/mastication) was not included for scoring. Further, the anterior-posterior (A-P) view was not examined in this study in an attempt to minimize radiation exposure and MBSImP components 13 (pharyngeal contraction) and 17 (esophageal clearance) examined in A-P view were not relevant to the study hypotheses. Elimination of these 3 components left a total of 14 MBSImP components included in the study protocol for analysis.

During the MBSS, patients were not provided with specific verbal instructions about the nature or timing of their swallow or breathing pattern relative to swallowing. Rather, they were instructed to swallow the liquid in their usual manner. Patients were asked to maintain a neutral posture during the drinking tasks, since earlier work has indicated that alteration of posture from the upright position may affect respiratory-swallow phasing.

VAMC patients returned for one-month follow-up MBSS to explore any detraining. During the post-intervention and one-month follow-up MBSSs, patients were not provided any instructions or verbal feedback regarding their respiratory-swallow phase pattern that they mastered during the intervention phase of this study (i.e., initiation of the swallow during mid-expiration around mid- to low lung volume and following the swallowing with a brief expiration).

Interventions

Visually guided feedback—Simple graphic illustrations of nasal airflow, RC, and AB movements were created to provide hard copy illustrations of appropriate respiratory-swallowing patterning. Figure 1 provides an example illustration of a signal used to demonstrate the initiation of the pharyngeal swallow during expiration at mid- and low-lung volume. These same illustrations were then displayed on a computer screen and eventually replaced with nasal airflow and respiratory movements recorded from each patient.

Based on a well-established hierarchy of motor skill acquisition,[63–65] the training protocol was divided into three learning modules for a total of 21 goals (outlined in Table 1): 1) *Identification*; 2) *Acquisition* (performance); and 3) *Mastery*. For each goal within the Identification and Acquisition modules, a minimum of 8 out of 10 trials were required for the goal to be met. A minimum of 9 out of 10 trials was required during the Mastery. If the patient did not meet the goal, reinstruction was provided.

The purpose of the *Identification* module was to enable patients to identify quiet breathing respiratory phases and volumes, the characteristic respiratory pause that occurs to accommodate swallowing, and optimal and non-optimal respiratory-swallow patterns. Patients progressed from printed illustrations to viewing a computer screen that displayed their own respiratory signals. Patients were trained to identify swallows (indicated by the respiratory pause) and respiratory-swallowing patterns and volumes by pointing to the

targets on the printed illustrations and then on the computer screen. Although all three respiratory signals were presented, patients were trained to focus on the RC signal for visually guided feedback during the *Identification* and *Acquisition* modules. The RC signal was chosen because it is highly predicative of quiet breathing lung volume and because it has been the target respiratory kinematic in our previous assessments of respiratory-swallowing coordination in adult humans.

The purpose of the *Acquisition* module was for the patient to produce the optimal respiratory-swallow pattern during self-initiated (self-administered) liquid swallows via cup deemed appropriate according to patient eligibility criteria (i.e., PAS of ≥ 6 on the pre-treatment MBSS). Patients progressed to a series of self-initiated swallows during which swallows, the respiratory flow and RC/ABD signals were displayed and recorded using the DSW. Patients were instructed to produce a swallow during the expiratory phase of respiration around mid to low quiet breathing lung volumes and conclude the swallow with a brief expiration (E-E pattern). The clinician reviewed and calculated the patient's accuracy online, and provided immediate feedback. The training continued until the patient achieved 80% accuracy using the E-E pattern at mid-to-low lung volume.

The purpose of the *Mastery* module was to ensure demonstration of proficiency in producing the E-E pattern across all appropriate liquid consistencies without visual or verbal feedback on 90% of the trials.

The patients participated in twice-weekly one-hour sessions for to achieve mastery of the optimal respiratory-swallow phase patterning. All patients were able to complete the intervention within 4 weeks (range of 4 to 8 sessions). Patients were not instructed to practice the content of their training outside of training sessions, because the effect of home practice was not part of the study aims nor was it possible to accurately or consistently monitor patient compliance.

Quality-of-life Measures

Each patient completed the M.D. Anderson Dysphagia Inventory (MDADI) pre- and post-intervention. The MDADI is a self-administered questionnaire designed to evaluate the impact of dysphagia on the quality-of-life of patients with HNC.[66]

Spirometry

Spirometry was performed by American Thoracic Society standards with a minimum of three maneuvers taking best FEV1 and FVC into standardized interpretation (Hankinson reference). Obstructed participants were characterized into Global Initiative for Obstructive Lung Disease (GOLD) spirometric groups on the basis of % predicted FEV1.[54]

Statistical Analysis

Contingency tables of study time period (pre-intervention, post-intervention, and 1 month follow-up) by ordinal MBSImP component scores or PAS values yielded sparse table cells due to small expected rates of high scores in this patient population. To mitigate resulting analysis issues, MBSImP component scores and PAS values were treated as binary

variables.[67] Specifically, MBSImP component scores were dichotomized as not impaired (score = 0) versus impaired (score = 1+), with the exception of lip closure, oral residue, tongue base retraction, and pharyngeal residue for which a score of 2+ was considered impaired. For these four components, a score of 1 is considered normal and is maintained in the MBSImP assessment tool to assist scorers in distinguishing normal from abnormal findings. PAS scores were dichotomized as not impaired (score = 1 or 2) versus impaired (score = 3+).[68] Respiratory-swallow phase score was also treated as a binary variable (optimal vs. non-optimal phase patterns). If a swallow task (bolus viscosity and volume combination) was not presented to a patient for safety concerns, the patient's corresponding task-specific MBSImP component scores, PAS scores, and respiratory-swallow phase scores were recorded as the most severe value. Overall component and PAS impairment rates, and non-optimal respiratory-swallow phase rates were calculated as the proportion of impaired (non-optimal) swallows across all tasks, with each subject contributing a maximum of 18 measures (9 tasks × 2 replicates per task) to a given estimate. Task-specific rates were also calculated, in which case subjects contributed at most two measures to each estimate. Measures obtained from the same subject are correlated and corresponding data analysis methods should account for the subsequent lack of independence. Accordingly, comparisons between impairment rates and non-optimal respiratory-swallow pattern rates were performed using Rao-Scott Chi-square tests.[69] MDADI scores were summarized using means and standard deviations, and comparisons performed using paired t-tests. Because we were interested in the association between chronic obstructive pulmonary disease (COPD) presence and the ability to learn optimal respiratory-swallow phase pattern, we used Rao-Scott chi-square tests to compare pre- and post-intervention non-optimal respiratory-swallow pattern rates separately for subjects with and without COPD, where COPD is defined as FEV_1 less than 70% of FVC.[54] Insufficient numbers of severely obstructed individuals were included to define if COPD severity impacted outcomes. Statistical analyses were performed using SAS version 9.3 (Cary, NC: SAS Institute, Inc.).[e]

Results

Thirty patients completed the intervention (mean age ± SD = 61 ± 11 years). All patients were greater than 12 months post-cancer treatment, averaging 3.4 years (range of 1.1 to 13.0 years). None of the patients required supplemental oxygen during the day. Demographic and clinical characteristics are provided in Table 2. COPD was characterized by an FEV1/FVC ratio <0.7 and was present in 11 (37%) patients.[41]

The post-intervention MBSS was conducted a median of 4.5 days (range = 0 to 21 days) after the last training session. The time from post-intervention MBSS to one-month follow-up for the 15 VAMC patients was a median of 30 days (range = 22 to 57 days).

Optimal Respiratory Swallow Phase Training

All study patients (n = 30) met mastery criteria for optimal (E-E) respiratory-swallow phase pattern within 8 sessions. There was a significant increase in optimal respiratory-swallow

[e]SAS Institute, Inc., 100 SAS Campus Drive, Cary, NC 27513-2414.

patterns comparing pre- to post-intervention rates (43% vs. 86%, $p < 0.0001$) (Table 3). End of training and one-month post-intervention proportions were not significantly different ($p = 0.95$) (Table 4). Optimal respiratory-swallow phase pattern rates significantly increased across all bolus viscosities and volumes (Table 5).

Patients with and without COPD both experienced significant reductions in non-optimal rates of respiratory-swallow phase patterns. Specifically, COPD patients' pre-intervention rate was 56% compared with an 18% post-intervention rate, a reduction of 38% ($p = 0.0003$). Patients without COPD experienced a slightly greater reduction from 57% to 12%, a decrease of 45% ($p < 0.0001$).

Swallowing Physiology

Overall impairment rates for the 14 MBSImP component scores are provided in Table 3. Results indicate significant reductions in impairment for laryngeal vestibular closure ($p = 0.0004$), tongue base retraction ($p < 0.0001$), and pharyngeal residue ($p = 0.01$).

Airway Invasion

The proportion of pre-intervention PAS scores ≥3 decreased (improved) significantly post-intervention ($p < 0.0001$) (Table 3). This improvement was maintained, with no significant difference in the proportion of PAS scores ≥3 at one-month follow-up relative to post-intervention ($p = 0.84$) (Table 4).

MDADI

Pre-intervention MDADI scores significantly improved from an average of 60.4 to 65.3 post-intervention ($p = 0.003$) (Table 3).

Discussion

Respiratory-Swallow Phasing Can Be Trained

This study is the first to our knowledge to train optimal respiratory-swallow phase patterning in dysphagic patients. Our primary finding is that an optimal respiratory-swallow phase pattern can be trained, in at least this patient population, with our data supporting a positive effect on swallowing physiology and airway protection. We found rapid acceptance and acquisition of the training with improved airway protection and pharyngeal clearance.

We suspect that expiratory phasing of swallows may impart airway protective benefits particularly in disordered swallowing where function is compromised. These benefits might include preventing aspiration of food and liquid prior to, during, and after critical periods of bolus transport and clearance. Further, the vocal folds are partially adducted during the expiratory phase of the breathing cycle[2,3] and together with continued diaphragm activity[69] act to "brake" the passive recoil of the lungs/thorax returning the respiratory system to its resting volume. This medialization may facilitate their adduction during the respiratory inhibition that occurs during swallowing.[2,3] Swallowing in mid-to-low expiratory quiet breathing lung volumes also means that the diaphragm is returning to a relaxed uncontracted

position and thus the traction of the larynx is minimized potentially facilitating laryngeal elevation for swallowing.

The changes in respiratory-swallowing coordination were associated with significant improvements in swallowing physiology as measured by the MBSImP. More specifically, tongue base retraction lead to improved pharyngeal residue scores (i.e., bolus pharyngeal clearance). These data suggests that more appropriate phase patterning may impart other physiological advantages extending to the upper airway and oropharyngeal cavity. The data from the one-month post-treatment MBSS suggests treatment effects were maintained.

Although MDADI swallowing specific quality-of-life mean scores significantly increased post-intervention (approximate 5 point increase, $p = 0.003$), this did not reach the threshold for clinical significance (10-point change).[70]

Study Limitations

There were limitations to this study. The small study patient sample was heterogeneous, including various cancer locations, cancer treatments, and comorbidity of COPD. Further, too few individuals with severe COPD were available to study the impact of COPD severity on outcomes. Next, only half of the patient sample was followed up one-month post-intervention. Results of one-month follow-up, therefore, should be interpreted with caution. Lastly, the patients had received prior swallowing treatment, although all had plateaued and continued to experience swallowing difficulty. Despite these limitations, we demonstrated that improvements in respiratory-swallowing coordination could be trained using a systematic protocol in patients with HNC and chronic dysphagia. Future work will include a larger sample size in an attempt to control for potential confounding variables, such as previous dysphagia treatment, tumor location and cancer treatment, with all patients available for follow-up.

Conclusions

This study demonstrated that patients with HNC and chronic dysphagia could be trained to produce an optimal respiratory-swallow phase pattern after completion of a structured phase training protocol. Favorable effects on airway protection and bolus clearance were also observed, with carry-over effects evident at one-month follow-up. This successful feasibility and efficacy study will lead to future research on respiratory swallowing training that includes a planned randomized clinical trial of respiratory-swallow phase training alone and in combination with other traditional, evidenced based methods of swallowing therapy. We intend to expand the therapeutic procedure to two patient groups that have indications of respiratory-swallow impairments, particularly those who will benefit from improvements in the physiologic targets shown to improve in this study (e.g., COPD and stroke).[71–75]

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List of Abbreviations

A-P	anterior-posterior view
ABD	abdomen
COPD	chronic obstructive pulmonary disease
E-E	expiratory-swallow-expiratory
FEV1	forced expiratory volume in 1 second
HNC	head and neck cancer
MBSS	modified barium swallow study
MBSImP	Modified Barium Swallow Impairment Profile
MDADI	M.D. Anderson Dysphagia Inventory
PAS	Penetration-Aspiration Scale
PES	pharyngoesophageal sphincter
RC	ribcage
RIP	respiratory-inductance plethysmography
SLP	speech-language pathologist
VAMC	Veterans Affairs Medical Center

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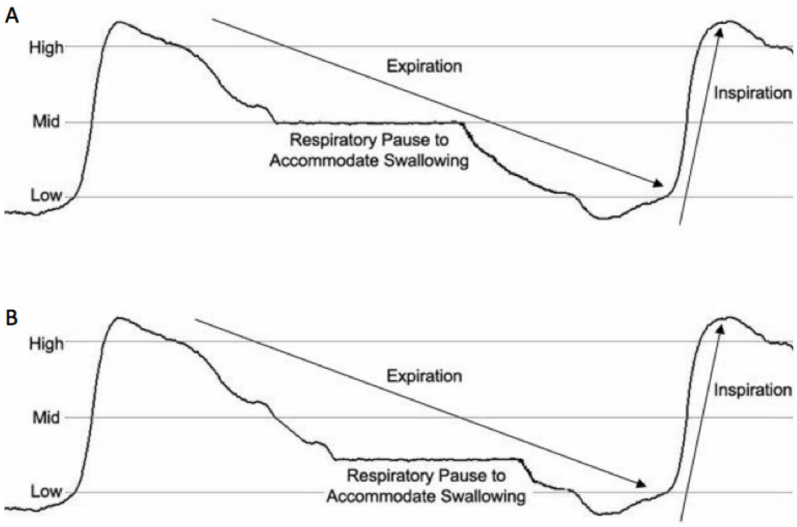

Fig 1.

Initiation of the pharyngeal swallow during expiration at mid volume (A) and mid-to-low volume (B). The swallow occurs as respiration ceases (respiratory pause).

Table 1

Description of goals for each training module

Module	Goal Description	Criteria Level (%)
Identification	Identification of target respiratory phase (expiration) (Goal 1) and swallow event (Goal 2) using simulated tracings.	80
	Identification of target respiratory phase (expiration) (Goal 3) and swallow event (Goal 4) using visually guided feedback provided by respiratory movements during self-swallowing.	80
	Identification of target respiratory phase (expiration) and swallow event during swallowing at high, mid, and low lung volumes relative to a tidal volume cycle using simulated tracings (Goal 5) and using visually guided feedback during self-swallowing (Goal 6).	80
Acquisition	Swallow initiation at target phase (expiration) using visually guided feedback for thin (Goal 7), nectar-thickened (Goal 8), and honey-thickened (Goal 9) liquids during self-swallowing.	80
	Swallow initiation at target phase (expiration) without visually guided feedback for thin (Goal 10), nectar-thickened (Goal 11), and honey-thickened (Goal 12) liquids during self-swallowing.	80
	Target phase (expiration) after completion of a swallow event using visually guided feedback for thin (Goal 13), nectar-thickened (Goal 14), and honey-thickened (Goal 15) liquids during self-swallowing.	80
	Target phase (expiration) after completion of a swallow event without visually guided feedback for thin (Goal 16), nectar-thickened (Goal 17), and honey-thickened (Goal 18) liquids during self-swallowing.	80
Mastery	Swallow initiation at target phase around mid-to-low lung volume followed by target phase (expiration) after completion of the swallow without visually guided feedback for thin (Goal 19), nectar-thickened (Goal 20), and honey-thickened (Goal 21) liquids during self-swallowing.	90

NOTE. Visually guided feedback provided to the patient using rib cage tracing on the Kay Digital Swallow Station.

Table 2

Study patient demographics and clinical characteristics

Variable	Academic Hospital (N=15)	VAMC (N=15)	Total (N=30)
Age (years)			
Mean ± SD	58 ± 13	64 ± 9	61 ± 11
Range	22 – 78	39 – 74	22 – 78
Gender			
Male	12 (80)	14 (93)	26 (87)
Female	3 (20)	1 (7)	4 (13)
Race/Ethnicity			
Non-Hispanic white	13 (87)	13 (87)	26 (87)
Non-Hispanic black	2 (13)	2 (13)	4 (13)
Tumor Location			
Oral cavity	1 (7)	2 (13)	3 (10)
Oropharynx	10 (67)	4 (27)	14 (46)
Nasopharynx	1 (7)	2 (13)	3 (10)
Larynx/Hypopharynx	2 (13)	4 (27)	6 (20)
Pharynx	1 (7)	2 (13)	3 (10)
Unknown/Not reported	0 (0)	1 (7)	1 (3)
T Stage			
1	1 (7)	3 (20)	4 (13)
2	8 (53)	4 (27)	12 (40)
3	3 (20)	2 (13)	5 (17)
4	2 (13)	0 (0)	2 (7)
Unknown/Not reported	1 (7)	6 (40)	7 (23)
Cancer Treatment			
Surgery alone	0 (0)	6 (40)	6 (20)
Radiation alone	0 (0)	1 (7)	1 (3)
Chemotherapy and Radiation	3 (20)	4 (27)	7 (23)
Surgery and Radiation	1 (7)	1 (7)	2 (7)
Surgery, Chemotherapy and Radiation	11 (73)	2 (13)	13 (43)
Unknown/Not reported	0 (0)	1 (7)	1 (3)
Lung Function			
Normal	12 (80)	5 (33)	17 (57)
Restrictive	0 (0)	2 (13)	2 (7)
Mild Obstructive	0 (0)	1 (7)	1 (3)
Moderate Obstructive	3 (20)	6 (40)	9 (30)
Severe Obstructive	0 (0)	1 (7)	1 (3)

NOTE. Frequency and percent are presented unless otherwise specified. Some percentages may not total 100 due to rounding. Lung function determined by GOLD criteria.[54]

Table 3

Pre- and post-intervention rates (respiratory-swallow phase, PAS, and MBSImP), and average MDADI scores

Outcome Measure	Pre-intervention	Post-intervention	*p*-value
Optimal respiratory-swallow phase	43.0	86.0	<0.0001
PAS ≥3	78.0	38.3	<0.0001
Lip closure ≥2	5.7	9.3	0.17
Tongue control during bolus hold	58.7	53.8	0.14
Bolus transport/lingual motion	37.3	50.2	0.07
Oral residue ≥2	77.3	76.4	0.80
Initiation of pharyngeal swallow	90.4	90.8	0.87
Soft palate elevation	19.8	31.0	0.03
Laryngeal elevation	76.6	70.8	0.43
Anterior hyoid excursion	94.7	90.5	0.10
Epiglottic movement	71.9	68.3	0.31
Laryngeal vestibular closure	78.2	55.5	0.0004
Pharyngeal stripping wave	59.3	67.6	0.27
Pharyngoesophageal segment opening	80.6	80.5	0.99
Tongue base retraction ≥2	96.0	88.6	<0.0001
Pharyngeal residue ≥2	96.1	88.4	0.01
MDADI (mean ± SD)	60.4 ± 14.8	65.3 ± 16.7	0.003

NOTE. Percent presented unless otherwise specified. MBSImP component score ≥1 unless otherwise specified.

Table 4

Pre-intervention, post-intervention, and one-month follow-up rates (respiratory-swallow phase, PAS, and MBSImP), and average MDADI scores for VAMC patients only (N = 15)

Outcome Measure	Pre-intervention	Post-intervention	1-month follow-up	*p*-value Pre vs. 1 mo	*p*-value Post vs. 1 mo
Optimal respiratory-swallow phase	49.1	88.4	88.1	<0.0001	0.95
PAS ≥3	74.8	41.0	42.2	<0.0001	0.84
Lip closure ≥2	3.9	8.5	2.8	0.56	0.03
Tongue control during bolus hold	55.5	55.6	59.2	0.52	0.47
Bolus transport/lingual motion	40.5	56.8	41.5	0.92	0.25
Oral residue ≥2	77.2	78.3	71.1	0.16	0.05
Initiation of pharyngeal swallow	91.0	89.5	91.1	0.95	0.70
Soft palate elevation	14.3	27.3	15.6	0.82	0.14
Laryngeal elevation	70.3	71.5	63.3	0.49	0.36
Anterior hyoid excursion	92.9	92.9	93.3	0.91	0.42
Epiglottic movement	63.9	59.9	55.6	0.07	0.33
Laryngeal vestibular closure	79.7	62.2	62.2	0.01	>0.99
Pharyngeal stripping wave	48.5	62.8	60.7	0.36	0.86
Pharyngoesophageal segment opening	76.7	77.1	70.0	0.51	0.29
Tongue base retraction ≥2	93.9	82.4	80.7	0.003	0.81
Pharyngeal residue ≥2	95.9	81.6	83.0	0.006	0.75
MDADI (mean ± SD)	63.3 ± 13.1	68.9 ± 17.1	74.1 ± 17.7	0.0014	0.12

NOTE. Percent presented unless otherwise specified. MBSImP component score ≥1 unless otherwise specified.

Table 5

Optimal swallow pattern rates by bolus viscosity and volume for all study patients

Viscosity	Volume	Pre-intervention	Post-intervention	*p*-value
Thin liquid	5ml	53.3	93.3	<0.0001
	15ml	18.6	78.3	<0.0001
	Cup sip	27.1	86.7	<0.0001
Nectar	5ml	51.7	90.0	0.0001
	15ml	43.1	80.0	0.0009
	Cup sip	41.7	89.7	<0.0001
Honey	5ml	50.0	84.7	0.0013
	15ml	53.4	86.4	0.0018
	Cup sip	48.3	84.5	0.001