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Geniohyoid Muscle and Diaphragm Ultrasonography and Maximal Expiratory Pressure During Four Weeks of Expiratory Muscle Strength Training in Healthy Young Men: An Exploratory Pilot Study

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Abstract

Background: Expiratory muscle strength training (EMST) improves expiratory muscle strength and swallowing function, but its effects on swallowing-related muscles are not well characterized. This exploratory pilot study described changes in geniohyoid area (primary outcome) and in contraction ratio, diaphragm thickness, thickening fraction, and maximal expiratory pressure (MEP; secondary outcomes) during four-week EMST in healthy young men. Methods: Ten healthy men performed EMST with an expiratory muscle trainer targeting 75% of MEP (device maximum 80 cmH_2O; actual median load 58–68% of MEP), 25 breaths per day, five days per week for four weeks. Outcomes were assessed at baseline, two weeks, and four weeks. Results: All participants completed the program without adverse events. MEP increased from 118.3 ± 30.9 to 153.4 ± 37.0 cmH_2O ($F(2,18) = 18.10$, $p < 0.001$; mean change 35.1 cmH_2O, 95% CI 23.9 to 46.3), mainly during the first two weeks. Because the ultrasonographic assessment was unblinded and its reliability unestablished, these data, including the primary outcome, are reported descriptively; inferential analysis was limited to MEP. Conclusions: Four weeks of EMST was feasible and was accompanied by an increase in MEP, although a learning effect cannot be excluded. Controlled studies with blinded, reliability-tested ultrasonography are needed.

Keywords: expiratory muscle strength training; EMST; geniohyoid muscle; ultrasonography; diaphragm; swallowing muscles; respiratory muscle training; pilot study

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1. Introduction

Expiratory muscle strength training (EMST) is a respiratory muscle training intervention designed to improve expiratory muscle strength by providing resistance during forceful exhalation. Originally developed to enhance cough effectiveness and airway clearance, EMST has increasingly been applied in swallowing rehabilitation because of its beneficial effects on swallowing function and airway protection [1–3]. Previous studies have demonstrated that EMST improves maximal expiratory pressure (MEP), cough performance, and swallowing safety in individuals with Parkinson's disease and stroke [2–4], and systematic reviews have reported favorable effects of EMST on swallowing-related

outcomes [5,6]. Although these functional benefits are well established, the structural adaptations of swallowing-related muscles following EMST remain poorly understood.

The geniohyoid muscle is one of the primary suprahyoid muscles responsible for anterior and superior displacement of the hyoid bone during swallowing. This movement contributes to upper esophageal sphincter opening and airway protection, and atrophy of the geniohyoid muscle has been associated with aspiration in older adults [7,8]. Surface electromyographic studies have shown that the submental muscles are activated during EMST [9], and expiratory muscle weakness has been associated with altered suprahyoid muscle activity during swallowing [10], suggesting that EMST may load not only the expiratory muscles but also swallowing-related musculature. Ultrasonography enables non-invasive, repeatable, and radiation-free evaluation of geniohyoid muscle morphology, including its cross-sectional area (CSA) and contraction characteristics [11–13].

Despite accumulating evidence regarding the functional effects of EMST, structural changes in the geniohyoid muscle during EMST have rarely been examined. Pauloski and Yahnke used ultrasonography to document weekly increases in geniohyoid CSA, together with MEP, during a five-week EMST program at 75% of MEP in ten healthy adults [14]. However, that study did not assess the diaphragm, which is also recruited during EMST, or the change in geniohyoid shape during voluntary contraction. Describing these outcomes together may help in planning controlled studies of EMST in patients with dysphagia.

Therefore, this exploratory pilot study aimed to describe changes in geniohyoid area (pre-specified primary outcome) and in the geniohyoid contraction ratio, diaphragm thickness, diaphragm thickening fraction, and MEP (secondary outcomes) during a four-week EMST program in healthy young men, and to examine the feasibility of the program.

2. Results

2.1. Participant Characteristics

A total of 10 healthy male participants were enrolled, and all completed the 4-week EMST program without dropout (Figure 1). According to verbal confirmation at the weekly supervised sessions, all participants completed the program largely as prescribed, with no protocol deviations requiring exclusion; however, the exact numbers of completed sessions and breaths were not recorded. Because 75% of MEP exceeded the device maximum in 8 participants during weeks 1–2 and in 9 participants during weeks 3–4, the actual training load corresponded to a median of 68% (range 48–75%) of baseline MEP during weeks 1–2 and 58% (range 38–75%) of the reassessed MEP during weeks 3–4 (Table S1). Baseline characteristics are summarized in Table 1. The mean age was 20.2 ± 0.4 years, height 168.7 ± 4.8 cm, body weight 67.5 ± 12.9 kg, and body mass index (BMI) 23.8 ± 4.7 kg/m^2; no participant was a smoker. Adverse events were checked at the weekly supervised sessions, and none were reported during the intervention.

Table 1. Baseline characteristics of the study participants.

Variable	Mean ± SD
Age (years)	20.2 ± 0.4
Height (cm)	168.7 ± 4.8
Weight (kg)	67.5 ± 12.9
BMI (kg/m^2)	23.8 ± 4.7

Data are presented as mean ± standard deviation (SD).

2.2. Preliminary Ultrasonographic Observations: Geniohyoid Muscle

The ultrasonographic values are presented descriptively in Table 2. The mean longitudinal area of the geniohyoid muscle was 1.58 ± 0.12 cm^2 at baseline, 1.60 ± 0.12 cm^2 at 2 weeks,

and 1.62 ± 0.12 cm^2 at 4 weeks, and the transverse CSA was 1.30 ± 0.08 cm^2, 1.32 ± 0.08 cm^2, and 1.33 ± 0.08 cm^2, respectively. The mean contraction ratio was 21.2 ± 1.5%, 24.0 ± 1.4%, and 27.3 ± 1.8%.

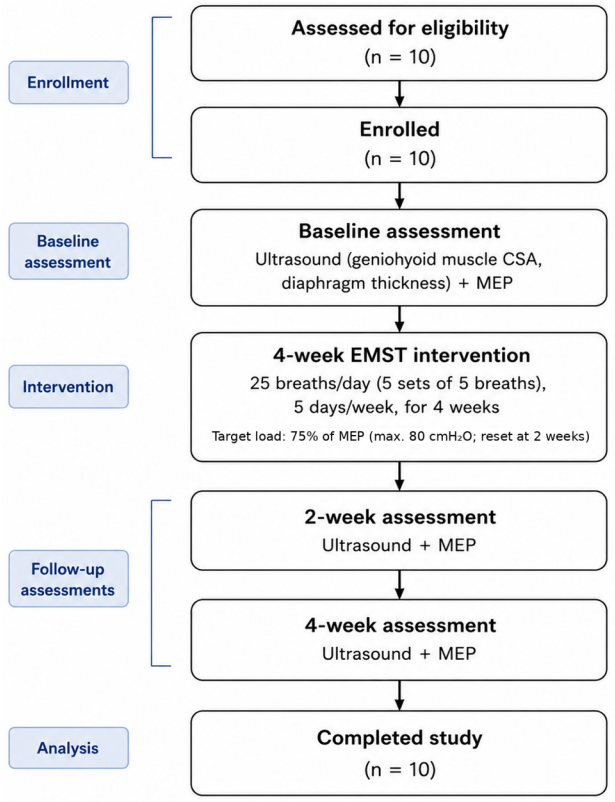


Figure 1. Flow diagram of participant recruitment, intervention, and outcome assessments. Abbreviations: CSA, cross-sectional area; EMST, expiratory muscle strength training; MEP, maximal expiratory pressure.

Table 2. Preliminary ultrasonographic observations (descriptive).

Variable	Pre	2 Weeks	4 Weeks
Longitudinal area (cm^2)	1.58 ± 0.12	1.60 ± 0.12	1.62 ± 0.12
Transverse CSA (cm^2)	1.30 ± 0.08	1.32 ± 0.08	1.33 ± 0.08
Contraction ratio (%)	21.2 ± 1.5	24.0 ± 1.4	27.3 ± 1.8
Diaphragm thickness, end-expiration (mm)	1.78 ± 0.10	1.80 ± 0.10	1.82 ± 0.11
Diaphragm thickness, end-inspiration (mm)	2.53 ± 0.18	2.62 ± 0.18	2.74 ± 0.19
Thickening fraction (%)	42.7 ± 3.6	45.3 ± 3.4	50.7 ± 3.2

Data are presented as mean ± standard deviation (SD). The assessment was unblinded and measurement reliability was not assessed; therefore, no statistical tests were performed. Longitudinal area is the area of the muscle in the midsagittal longitudinal image, and transverse CSA is the area in the transverse image. Abbreviation: CSA, cross-sectional area.

2.3. Preliminary Ultrasonographic Observations: Diaphragm

Diaphragm thickness at end-inspiration was 2.53 ± 0.18 mm, 2.62 ± 0.18 mm, and 2.74 ± 0.19 mm at baseline, 2 weeks, and 4 weeks, and thickness at end-expiration was 1.78 ± 0.10 mm, 1.80 ± 0.10 mm, and 1.82 ± 0.11 mm, respectively (Table 2). The thickening fraction was 42.7 ± 3.6%, 45.3 ± 3.3%, and 50.7 ± 3.2%. These values are presented without statistical testing for the reasons described in Section 4.7.

2.4. Changes in Maximal Expiratory Pressure

MEP increased from 118 ± 30.9 cmH_2O at baseline to 139 ± 30.1 cmH_2O at 2 weeks and 153 ± 37.0 cmH_2O at 4 weeks (repeated-measures ANOVA, $F(2,18) = 18.10$, $p < 0.001$; Table 3, Figure 2). The mean change from baseline was 21.0 cmH_2O (95% CI 7.1 to 34.9) at 2 weeks and 35.1 cmH_2O (95% CI 23.9 to 46.3) at 4 weeks. Post hoc analyses showed significant increases from baseline to week 2 ($p = 0.015$) and from baseline to week 4 ($p = 0.0002$), whereas the change from week 2 to week 4 (14.1 cmH_2O, 95% CI −0.4 to 28.6) was not statistically significant ($p = 0.055$). MEP was higher at 4 weeks than at baseline in all participants, although three participants showed a lower value at one time point than at the preceding one.

Table 3. Changes in maximal expiratory pressure during the 4-week expiratory muscle strength training program.

Variable	Pre	2 Weeks	4 Weeks	*p* Value
MEP (cmH_2O)	118 ± 30.9 [a]	139 ± 30.1 [b]	153 ± 37.0 [b]	<0.001

Data are presented as mean ± standard deviation (SD). Comparisons among baseline, 2-week, and 4-week measurements were performed using one-way repeated-measures analysis of variance ($F(2,18) = 18.10$, $p < 0.001$; Mauchly's test of sphericity, $p = 0.70$), followed by paired *t*-tests with Holm correction. Different superscript letters indicate significant differences between time points ($p < 0.05$); time points sharing a letter did not differ significantly. Post hoc pairwise comparisons: baseline vs. 2 weeks, $p = 0.015$; baseline vs. 4 weeks, $p = 0.0002$; 2 weeks vs. 4 weeks, $p = 0.055$. Abbreviation: MEP, maximal expiratory pressure.

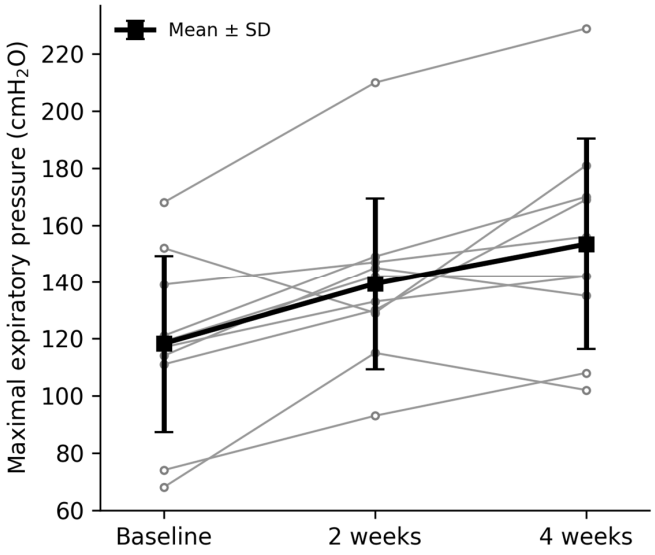


Figure 2. Individual and mean changes in maximal expiratory pressure during the 4-week expiratory muscle strength training program. Thin gray lines represent individual participants ($n = 10$); the bold black line and squares indicate the mean, and error bars indicate standard deviation (SD). Open circles indicate individual values.

3. Discussion

This pilot study showed that a four-week EMST program was feasible in healthy young men, with all participants completing the program without adverse events, and that MEP increased by approximately 35 cmH_2O (approximately 30%) from baseline to four weeks. Most of this increase occurred within the first two weeks. Because the reliability of the ultrasonographic measurements was not established, the ultrasonographic outcomes, including the pre-specified primary outcome of geniohyoid area, are discussed only as preliminary observations.

The magnitude of the MEP increase is comparable to that reported in previous EMST studies [2,3,14], although our values, recorded as instantaneous peak pressures, are not directly comparable with plateau-based values obtained by standard manometry [15]. Early strength gains after resistance training are largely attributed to neural adaptations [16], which may explain the rapid increase during the first two weeks. However, MEP is an effort-dependent maximal maneuver, and in the absence of a control group, a learning effect from repeated testing cannot be separated from the training effect. Notably, because of the device maximum of 80 cmH_2O, most participants trained below the targeted 75% of MEP, particularly after the load was readjusted at two weeks; this may partly explain why MEP did not increase significantly between two and four weeks. Future studies in healthy adults should use a device with a higher load range.

The ultrasonographic observations should be interpreted with particular caution. Although the mean values of geniohyoid area, contraction ratio, diaphragm thickness, and thickening fraction were higher at four weeks than at baseline, the absolute differences in geniohyoid area (0.03–0.04 cm^2) and end-expiratory diaphragm thickness (0.04 mm) were small relative to the expected measurement error of manual ultrasonographic tracing [17]. In addition, the examiner was aware of the time point, and measurement reliability was not assessed. Early increases in muscle size during resistance training may also reflect muscle swelling rather than hypertrophy [18,19], and end-inspiratory diaphragm thickness and thickening fraction depend on inspiratory effort and lung volume [20,21], which were not controlled. Therefore, these data cannot be used to infer morphological adaptation.

Pauloski and Yahnke reported increases in geniohyoid CSA during EMST in healthy adults [14], submental muscle activity increases during EMST [9], and inspiratory muscle training has been shown to increase diaphragm thickness [22]. Whether EMST produces measurable changes in the geniohyoid muscle [7,8] and diaphragm should be examined in studies designed for that purpose.

This pilot study identifies the requirements for such studies: storage of all ultrasonographic images, blinded measurement in random order, assessment of reliability and measurement error, objective recording of training adherence, standardization of respiratory conditions, and a control group. With these safeguards, ultrasonography may complement MEP in evaluating responses to EMST [11,13], including in patients with Parkinson's disease, stroke, or sarcopenia [2,4,12].

Beyond healthy individuals, this ultrasonographic approach may be applicable to neuromuscular disorders in which bulbar and respiratory muscle weakness coexist. In amyotrophic lateral sclerosis (ALS), EMST has been shown to be well tolerated and to increase MEP and hyoid displacement during swallowing [23], and respiratory strength training has been evaluated in a sham-controlled trial [24]; serial diaphragm ultrasonography has been associated with the timing of non-invasive ventilation and survival [25]. Diaphragm ultrasonography has also been used to characterize diaphragm involvement in late-onset Pompe disease [26], and muscle ultrasonography can reveal selective muscle involvement in spinal muscular atrophy (SMA) [27]. In these populations, combined assessment of the geniohyoid muscle and diaphragm could help monitor disease progression and responses to respiratory or swallowing interventions, provided that its reliability is established [17]. Other potential uses include monitoring of swallowing-related muscles in older adults with sarcopenic dysphagia [11] and in patients recovering from critical illness.

This study has several limitations. First, the sample was small and limited to young healthy men. Second, the absence of a control group precludes separating training effects from learning effects. Third, the training load was limited by the device maximum and was lower than the targeted 75% of MEP in most participants. Fourth, training adherence was confirmed only verbally, and the numbers of completed sessions and breaths were not

recorded. Fifth, MEP was recorded as the instantaneous peak pressure with a portable device whose agreement with a laboratory pressure manometer has not been established; therefore, the absolute MEP values should be interpreted as within-participant changes measured with the same device. Finally, swallowing function was not assessed.

In summary, four weeks of EMST was feasible and was accompanied by an increase in MEP in healthy young men, whereas the ultrasonographic data remain preliminary.

4. Materials and Methods

4.1. Study Design

This pilot study employed a single-arm before-and-after design. Outcome measurements were performed at baseline (Pre), after 2 weeks, and after completion of the 4-week intervention (Figure 1). The study was conducted from May to June 2026. The protocol was approved by the Institutional Review Board of Gifu University of Health Science (Approval No. 2026-8; approved on 26 May 2026) and conducted in accordance with the Declaration of Helsinki [28]. The study was not registered in a clinical trial registry. Written informed consent was obtained from all participants before enrollment.

4.2. Participants

Ten healthy male university students were recruited at Gifu University of Health Science through announcements on campus. Only men were included to reduce sex-related variability in muscle size in this small pilot sample. Eligible participants were aged 18 years or older and had no history of respiratory disease, neuromuscular disease, dysphagia, or orthopedic disorders affecting respiratory function. Individuals with current smoking habits, acute illness, or contraindications to forceful expiratory exercise were excluded. Three participants reported regular exercise habits, and none had previous experience with respiratory muscle training. Because this was a pilot study, the sample size was determined by feasibility rather than by a formal power calculation [29]. With 10 participants, a two-sided α of 0.05, and a power of 0.80, the minimum detectable within-participant effect size for a paired comparison was $d_z = 1.00$.

4.3. Expiratory Muscle Strength Training

Participants performed EMST using the POWERbreathe EX1-Medic (POWERbreathe International Ltd., Southam, UK), a handheld expiratory muscle trainer that applies resistance during exhalation (adjustable load 10–80 cmH_2O), in combination with the POWERbreathe Smart Adaptor (POWERbreathe International Ltd., Warwickshire, UK) (Figure S1), which was used to measure MEP (Section 4.6). Both devices were used according to the manufacturer's instructions without modification. The target training intensity was 75% of each participant's baseline MEP, based on previous EMST protocols [2,3]; when the target exceeded the device maximum, the load was set at the maximum level (80 cmH_2O). Participants performed 25 expiratory efforts per day, divided into five sets of five breaths, five days per week, for four consecutive weeks, with a 30–60 s rest between sets. Each effort was performed in a seated position from maximal inspiration against the prescribed expiratory resistance. MEP was reassessed after two weeks, and the load was readjusted to 75% of the updated MEP within the device range. Training was supervised in person once a week, when technique and resistance settings were checked; on the other days, participants trained independently. Completion of training was confirmed verbally at the weekly sessions; although the companion mobile application can store session data on each participant's smartphone, these data were neither requested from participants nor collected by the investigators.

4.4. Ultrasonographic Assessment of the Geniohyoid Muscle

Ultrasonographic images were obtained using a SONIMAGE HS2 Pro system (Konica Minolta, Tokyo, Japan) with an L18-4 linear-array transducer, with the same preset depth and gain at all visits. Participants lay supine without a pillow, with the head and neck in a neutral position (no flexion, extension, or rotation), the mouth closed, and the tongue at rest on the floor of the mouth. For the longitudinal image, the transducer was placed submentally in the midsagittal plane, parallel to the long axis of the geniohyoid muscle, so that the mental spine of the mandible and the hyoid bone were visible in the same image (Figure 3A). The transverse image was obtained by rotating the transducer 90° at the midpoint between the mandible and the hyoid bone (Figure 3B). The area traced in the longitudinal image (longitudinal area) is the area of the muscle in the midsagittal plane rather than a true cross-section perpendicular to the muscle fibers, whereas the area traced in the transverse image (transverse CSA) approximates the anatomical cross-section of the left and right geniohyoid muscles. The transducer was applied with minimal pressure, and outlines were traced manually using the built-in measurement function of the ultrasound system. To calculate the contraction ratio, longitudinal images were also acquired during maximal voluntary contraction of the suprahyoid muscles, elicited by pressing the tongue against the hard palate with maximal effort for approximately 3 s after one practice trial; the frame showing the largest muscle area was selected (Figure 3C). The contraction ratio was calculated as (area during contraction − area at rest)/area at rest × 100. Each measurement was obtained three times with the transducer removed and repositioned between acquisitions, and the mean value was used for analysis. All ultrasonographic measurements were performed by a single physical therapist with more than 20 years of clinical experience who was aware of the assessment time point. Measurement reliability was not assessed.

4.5. Ultrasonographic Assessment of Diaphragm Thickness

Diaphragm thickness was measured with the same system and transducer at the zone of apposition of the right hemidiaphragm in the supine position, with the transducer placed perpendicular to the chest wall in the eighth or ninth intercostal space between the anterior and mid-axillary lines [30]. The same intercostal space was used at every visit. During quiet breathing, end-inspiration and end-expiration were identified on B-mode cine loops as the frames with the greatest and smallest thickness; tidal volume and respiratory rate were not monitored. Diaphragm thickness was defined as the perpendicular distance between the pleural and peritoneal lines (Figure 3D), and thickening fraction was calculated as (end-inspiratory thickness − end-expiratory thickness)/end-expiratory thickness × 100 [20]. Measurements were obtained from three breathing cycles at each time point, and the mean value was used for analysis. Ultrasonographic assessments were performed at least 24 h after the last training session.

4.6. Maximal Expiratory Pressure

MEP was measured using the POWERbreathe Smart Adaptor as a standalone device with the Strength Test Plug inserted (i.e., detached from the training device), as specified by the manufacturer, with reference to the ATS/ERS recommendations [15] and previous EMST studies [2,3]. Participants were seated, wore a nose clip, and performed maximal expiratory efforts from total lung capacity through the mouthpiece with the cheeks supported. Three trials were performed at each time point with 1 min of rest between trials, and the highest value was used for analysis; no additional repeatability criterion was applied. The value recorded was the instantaneous peak pressure displayed by the companion application (ActiBreathe, version 1.4.6; POWERbreathe International Ltd., Southam, UK), rather than the pressure sustained over 1 s recommended by the ATS/ERS statement [15]. To our

knowledge, the pressure measurement of the Smart Adaptor has not been validated against a laboratory manometer, and the manufacturer does not report its measurement accuracy; the same device was used for all participants and time points.

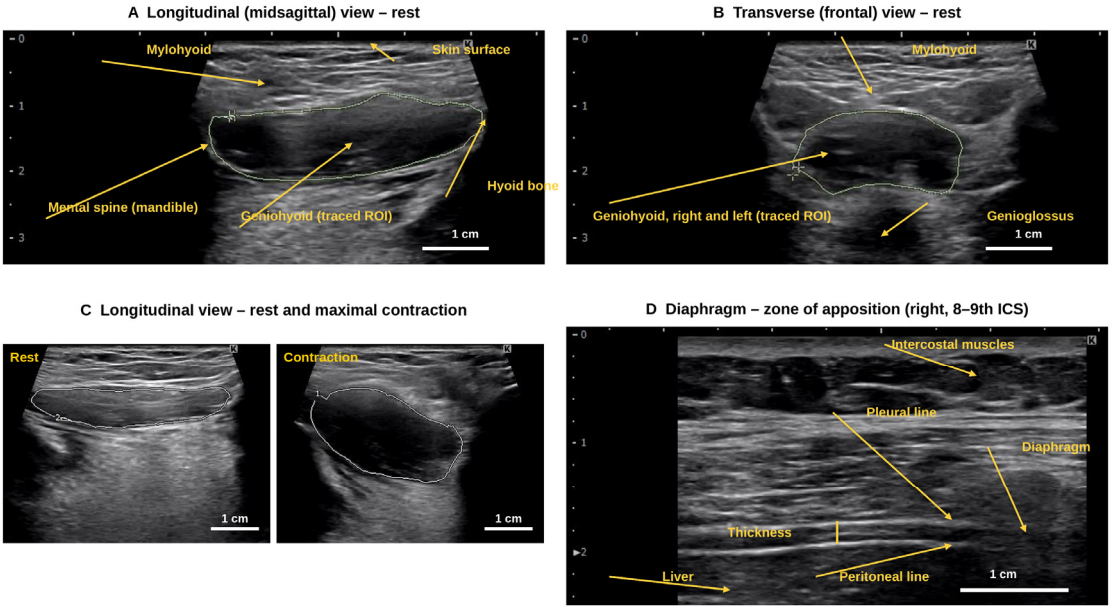


Figure 3. Representative ultrasonographic images of the geniohyoid muscle and diaphragm. (**A**) Longitudinal (midsagittal) image of the geniohyoid muscle at rest, between the mental spine of the mandible and the hyoid bone. (**B**) Transverse (frontal) image of the geniohyoid muscle at rest. The traced region of interest (ROI) is shown in (**A**,**B**). (**C**) Longitudinal images of the geniohyoid muscle at rest and during maximal voluntary contraction, showing the traced outlines used to obtain the areas for the contraction ratio. Because the tracing images from the study visits were not retained, these images were acquired afterwards from a healthy volunteer using the same equipment and procedure. (**D**) Measurement of diaphragm thickness at the zone of apposition, defined as the perpendicular distance between the pleural line and the peritoneal line. Scale bars, 1 cm. The cross-shaped markers and the numbers 1 and 2 are caliper and trace labels displayed by the ultrasound system. Abbreviations: ROI, region of interest; ICS, intercostal space.

4.7. Statistical Analysis

For MEP, normality was confirmed using the Shapiro–Wilk test, and changes over time were analyzed using one-way repeated-measures analysis of variance (ANOVA) with Mauchly's test of sphericity, followed by paired *t*-tests with Holm correction. Mean changes are presented with 95% confidence intervals (CIs). Data are presented as mean ± standard deviation (SD). The pre-specified primary outcome was geniohyoid area (longitudinal area and transverse CSA), and the secondary outcomes were the geniohyoid contraction ratio, diaphragm thickness, diaphragm thickening fraction, and MEP. However, because the assessment was unblinded, measurement reliability was not established, and the observed changes were small relative to the expected measurement error, all ultrasonographic outcomes, including the primary outcome, are presented descriptively, without statistical testing, as preliminary observations, and inferential analysis was applied only to MEP. All analyses were conducted using R software (version 4.5.2; R Foundation for Statistical Computing, Vienna, Austria). Statistical significance was set at $p < 0.05$.

5. Conclusions

A four-week EMST program targeting 75% of MEP was feasible in healthy young men and was accompanied by an increase in MEP, mainly during the first two weeks. The

ultrasonographic observations of the geniohyoid muscle and diaphragm were preliminary and cannot be interpreted as evidence of morphological adaptation. Controlled studies with blinded and reliability-tested ultrasonographic assessment are needed before applying this approach to patients with dysphagia.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/muscles5040082/s1, Table S1: Target and actual training loads for each participant; Figure S1: Expiratory muscle strength training device used in this study.

Author Contributions: Conceptualization, S.W.; methodology, S.W. and T.S.; software, S.W.; validation, S.W., T.K., T.I. and T.S.; formal analysis, S.W.; investigation, R.H., H.M., I.Y., R.Y. and M.Y.; resources, S.W., T.K., T.I. and T.S.; data curation, R.H., H.M., I.Y., R.Y. and M.Y.; writing—original draft preparation, S.W.; writing—review and editing, S.W., T.K., T.I. and T.S.; visualization, S.W.; supervision, T.K., T.I. and T.S.; project administration, S.W. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of Gifu University of Health Science (Approval No. 2026-8).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available from the corresponding author upon reasonable request. The data are not publicly available because they contain information that could compromise the privacy of the study participants.

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Conflicts of Interest: The authors declare no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

EMST	Expiratory muscle strength training
CSA	Cross-sectional area
MEP	Maximal expiratory pressure
ROI	Region of interest
SD	Standard deviation

References

1. Sapienza, C.; Troche, M.; Pitts, T.; Davenport, P. Respiratory strength training: Concept and intervention outcomes. *Semin. Speech Lang.* **2011**, *32*, 21–30. [CrossRef]
2. Troche, M.S.; Okun, M.S.; Rosenbek, J.C.; Musson, N.; Fernandez, H.H.; Rodriguez, R.; Romrell, J.; Pitts, T.; Wheeler-Hegland, K.M.; Sapienza, C.M. Aspiration and swallowing in Parkinson disease and rehabilitation with EMST: A randomized trial. *Neurology* **2010**, *75*, 1912–1919. [CrossRef]
3. Pitts, T.; Bolser, D.; Rosenbek, J.; Troche, M.; Okun, M.S.; Sapienza, C. Impact of expiratory muscle strength training on voluntary cough and swallow function in Parkinson disease. *Chest* **2009**, *135*, 1301–1308. [CrossRef]
4. Park, J.S.; Oh, D.H.; Chang, M.Y.; Kim, K.M. Effects of expiratory muscle strength training on oropharyngeal dysphagia in subacute stroke patients: A randomised controlled trial. *J. Oral Rehabil.* **2016**, *43*, 364–372. [CrossRef]
5. Ashford, J.; McCabe, D.; Wheeler-Hegland, K.; Frymark, T.; Mullen, R.; Musson, N.; Schooling, T.; Hammond, C.S. Evidence-based systematic review: Oropharyngeal dysphagia behavioral treatments. Part III—Impact of dysphagia treatments on populations with neurological disorders. *J. Rehabil. Res. Dev.* **2009**, *46*, 195–204.
6. Mancopes, R.; Smaoui, S.; Steele, C.M. Effects of expiratory muscle strength training on videofluoroscopic measures of swallowing: A systematic review. *Am. J. Speech Lang. Pathol.* **2020**, *29*, 335–356. [CrossRef]
7. Pearson, W.G., Jr.; Hindson, D.F.; Langmore, S.E.; Zumwalt, A.C. Evaluating swallowing muscles essential for hyolaryngeal elevation by using muscle functional magnetic resonance imaging. *Int. J. Radiat. Oncol. Biol. Phys.* **2013**, *85*, 735–740. [CrossRef]

8. Feng, X.; Todd, T.; Lintzenich, C.R.; Ding, J.; Carr, J.J.; Ge, Y.; Browne, J.D.; Kritchevsky, S.B.; Butler, S.G. Aging-related geniohyoid muscle atrophy is related to aspiration status in healthy older adults. *J. Gerontol. A Biol. Sci. Med. Sci.* **2013**, *68*, 853–860. [CrossRef]
9. Wheeler-Hegland, K.M.; Rosenbek, J.C.; Sapienza, C.M. Submental sEMG and hyoid movement during Mendelsohn maneuver, effortful swallow, and expiratory muscle strength training. *J. Speech Lang. Hear. Res.* **2008**, *51*, 1072–1087. [CrossRef]
10. Liaw, M.Y.; Lin, M.C.; Leong, C.P.; Wang, L.Y.; Pong, Y.P.; Yang, T.H.; Huang, Y.C. Electromyographic study assessing swallowing function in subacute stroke patients with respiratory muscle weakness. *Medicine* **2021**, *100*, e27780. [CrossRef]
11. Ogawa, N.; Mori, T.; Fujishima, I.; Wakabayashi, H.; Itoda, M.; Kunieda, K.; Shigematsu, T.; Nishioka, S.; Tohara, H.; Yamada, M.; et al. Ultrasonography to measure swallowing muscle mass and quality in older patients with sarcopenic dysphagia. *J. Am. Med. Dir. Assoc.* **2018**, *19*, 516–522. [CrossRef]
12. Erdem, Ş.; Sahin, U.K. Ultrasonographic assessment of geniohyoid muscle morphometry and elasticity in older adults: Associations with sarcopenia risk and swallowing dysfunction. *Musculoskelet. Care* **2026**, *24*, e70194. [CrossRef]
13. Alyanak, B.; Dede, B.T.; Bağcıer, F.; Akaltun, M.S. Ultrasonographic evaluation of the swallowing function: Expanding clinical applications and current evidence. *J. Diagn. Med. Sonogr.* **2026**, *42*, 139–148. [CrossRef]
14. Pauloski, B.R.; Yahnke, K.M. Using ultrasound to document the effects of expiratory muscle strength training (EMST) on the geniohyoid muscle. *Dysphagia* **2022**, *37*, 788–799. [CrossRef]
15. American Thoracic Society/European Respiratory Society. ATS/ERS Statement on respiratory muscle testing. *Am. J. Respir. Crit. Care Med.* **2002**, *166*, 518–624. [CrossRef]
16. Sale, D.G. Neural adaptation to resistance training. *Med. Sci. Sports Exerc.* **1988**, *20*, S135–S145. [CrossRef]
17. Pillen, S.; van Alfen, N. Skeletal muscle ultrasound. *Neurol. Res.* **2011**, *33*, 1016–1024. [CrossRef]
18. Seynnes, O.R.; de Boer, M.; Narici, M.V. Early skeletal muscle hypertrophy and architectural changes in response to high-intensity resistance training. *J. Appl. Physiol.* **2007**, *102*, 368–373. [CrossRef]
19. Damas, F.; Phillips, S.M.; Libardi, C.A.; Vechin, F.C.; Lixandrão, M.E.; Jannig, P.R.; Costa, L.A.R.; Bacurau, A.V.; Snijders, T.; Parise, G.; et al. Resistance training-induced changes in integrated myofibrillar protein synthesis are related to hypertrophy only after attenuation of muscle damage. *J. Physiol.* **2016**, *594*, 5209–5222. [CrossRef]
20. Umbrello, M.; Formenti, P. Ultrasonographic assessment of diaphragm function in critically ill subjects. *Respir. Care* **2016**, *61*, 542–555. [CrossRef]
21. Zambon, M.; Greco, M.; Bocchino, S.; Cabrini, L.; Beccaria, P.F.; Zangrillo, A. Assessment of diaphragmatic dysfunction in the critically ill patient with ultrasound: A systematic review. *Intensive Care Med.* **2017**, *43*, 29–38. [CrossRef]
22. Enright, S.J.; Unnithan, V.B.; Heward, C.; Withnall, L.; Davies, D.H. Effect of high-intensity inspiratory muscle training on lung volumes, diaphragm thickness, and exercise capacity in subjects who are healthy. *Phys. Ther.* **2006**, *86*, 345–354. [CrossRef]
23. Plowman, E.K.; Watts, S.A.; Tabor, L.; Robison, R.; Gaziano, J.; Domer, A.S.; Richter, J.; Vu, T.; Gooch, C. Impact of expiratory strength training in amyotrophic lateral sclerosis. *Muscle Nerve* **2016**, *54*, 48–53. [CrossRef]
24. Plowman, E.K.; Gray, L.T.; Chapin, J.; Anderson, A.; Vasilopoulos, T.; Gooch, C.; Vu, T.; Wymer, J.P. Respiratory strength training in amyotrophic lateral sclerosis: A double-blind, randomized, multicenter, sham-controlled trial. *Neurology* **2023**, *100*, e1634–e1642. [CrossRef]
25. Fantini, R.; Tonelli, R.; Castaniere, I.; Tabbì, L.; Pellegrino, M.R.; Cerri, S.; Livrieri, F.; Giaroni, F.; Monelli, M.; Ruggieri, V.; et al. Serial ultrasound assessment of diaphragmatic function and clinical outcome in patients with amyotrophic lateral sclerosis. *BMC Pulm. Med.* **2019**, *19*, 160. [CrossRef]
26. Meng, P.; Ogna, A.; Fayssoil, A. M mode ultrasound and tissue Doppler imaging to assess diaphragm feature in late onset Pompe disease. *Neurol. Int.* **2020**, *12*, 55–58. [CrossRef]
27. Nakamura, R.; Kitamura, A.; Tsukamoto, T.; Otowa, Y.; Okamoto, N.; Ogawa, N.; Yamakawa, I.; Kim, H.; Sanada, M.; Urushitani, M. Spinal muscular atrophy type 3 showing a specific pattern of selective vulnerability on muscle ultrasound. *Intern. Med.* **2021**, *60*, 1935–1939. [CrossRef]
28. World Medical Association. World Medical Association Declaration of Helsinki: Ethical principles for medical research involving human participants. *JAMA* **2025**, *333*, 71–74. [CrossRef]
29. Julious, S.A. Sample size of 12 per group rule of thumb for a pilot study. *Pharm. Stat.* **2005**, *4*, 287–291. [CrossRef]
30. Boon, A.J.; Harper, C.J.; Ghahfarokhi, L.S.; Strommen, J.A.; Watson, J.C.; Sorenson, E.J. Two-dimensional ultrasound imaging of the diaphragm: Quantitative values in normal subjects. *Muscle Nerve* **2013**, *47*, 884–889. [CrossRef]

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