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Original Article

Effect of expiratory muscle training on respiratory muscle fatigue in healthy adults: a randomized controlled trial

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Abstract. [Purpose] This study examined the effects of expiratory muscle training on fatigue in individual respiratory muscles. [Participants and Methods] Healthy adult males (n=31) were randomly assigned to two groups: expiratory muscle training (n=15) and normal controls (n=16). In the expiratory muscle training group, training was performed once for 15 min at 50% load of the maximum expiratory mouth pressure twice daily for 4 weeks. Respiratory muscle fatigue indicators were measured using surface electromyography as the median power frequency of each respiratory muscle at the time of measuring the maximum inspiratory mouth pressure during 20 min of inspiratory muscle loading and maximum expiratory mouth pressure. [Results] In the expiratory muscle training group, the median power frequency values of the sternocleidomastoid, rectus abdominis, and internal oblique/external oblique before expiratory muscle training significantly decreased during inspiratory muscle loading. However, no difference was observed in the median power frequency values measured before and during inspiratory muscle loading after the expiratory muscle training. In the normal controls, the median power frequency values of the sternocleidomastoid and rectus abdominis significantly decreased during inspiratory muscle loading. [Conclusion] Expiratory muscle training increased fatigue tolerance of the sternocleidomastoid, rectus abdominis, and internal and external oblique muscles in healthy individuals.
Key words: Expiratory muscle training, Respiratory muscle fatigue, Surface electromyography

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INTRODUCTION

In chronic obstructive pulmonary disease (COPD), a typical disease treated in respiratory rehabilitation, respiratory muscle fatigue is often the cause of respiratory failure[1)]. Decreased contractility associated with respiratory muscle fatigue plays a significant role in dyspnea and restriction on exercises in patients with respiratory illness[2)]. However, the importance of respiratory muscle fatigue has not been widely recognized in clinical practice[3)] and respiratory muscle fatigue is rarely evaluated[2)]. Moreover, the characteristics of respiratory muscle fatigue, including respiratory support muscles, have not been clarified. Though ventilatory muscle training has been used to treat respiratory muscle fatigue, its effects on respiratory muscle fatigue remain unclear[2, 4)].

Respiratory muscle fatigue can be measured either by measuring muscle contractility or by electromyography (EMG)[5)]. Methods for measuring muscle contractility or respiratory muscle strength should measure muscle strength during maximal inspiratory or expiratory effort of the participant, and there are methods for measuring maximum inspiratory mouth pressure (PImax) and maximum expiratory mouth pressure (PEmax). While PImax and PEmax are characterized by noninvasive

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comprehensive assessment of respiratory muscle strength, it is difficult to capture individual respiratory muscle fatigue using respiratory muscle strength alone because they reflect the maximum contractile force of the entire respiratory muscle. In EMG, both invasive using needle and wire electrodes and noninvasive methods using surface electrodes are present. Invasive methods may be used to locally extract activity of muscles located in deep layers, such as in diaphragm. While this method can derive potentials from local single muscle fibers, it is invasive and risky when evaluating respiratory muscles. Therefore, surface electromyogram (sEMG) is used as a method to extract respiratory muscle fatigue[6–8]. When the sEMG values are coupled with PImax and PEmax values, it is possible to evaluate individual muscle activities and coordination between muscles, and so this approach is effective to evaluate respiratory muscle fatigue based on individual respiratory muscle activity. Thus, sEMG and PImax/PEmax evaluations are important for the assessment of respiratory muscle fatigue; however, combination of these two methods, which is necessary for a detailed assessment of respiratory muscle fatigue, has been thus far rarely adopted.

Gross et al.[6] previously reported that the intake resistance load (hereafter, intake load) caused by 50% load pressure produced fatigue of the diaphragm, and a surface EMG revealed a decrease in frequency of the diaphragm. Roussos et al.[9] reported that the inspiratory muscle loading produced muscular fatigue and dyspnea sensation of the diaphragm and respiratory support muscles. In addition, Tsukamoto et al.[10] reported that muscle fatigue in sternocleidomastoid and rectus abdominis affected the decrease in PImax and PEmax due to inspiratory muscle loading. Furthermore, Tsukamoto et al.[11] reported on the efficacy of the expiratory muscle training (EMT) under inspiratory muscle loading in decreasing PImax and PEmax, which are involved in respiratory muscle strength, and on suppressing dyspnea. However, since the effect of EMT on muscle fatigue in individual respiratory muscles has not been clarified, this study was conducted to test it as a continuation study of our preceding studies[11].

On the basis of our previous studies, this study hypothesizes that EMT not only increases expiratory muscle strength, but also improves fatigue tolerance of the rectus abdominis through the increase in the efficiency of contraction of the diaphragm and reduces the decrease in PImax and PEmax.

Thus, this study aimed to clarify the inhibitory effect of EMT on muscle fatigue in each respiratory muscle during inspiratory muscle loading.

PARTICIPANTS AND METHODS

This study was conducted with the approval of the International University of Health and Welfare Ethics Review Committee (approval no.16-Io-140). All participants were briefed and written informed consent was obtained. This study was conducted according to CONSORT guidelines[12].

Participants were recruited using the Tokoha University bulletin board between January and April 2017. Males aged between 20 and 40 years were included. Exclusion criteria were history of smoking, respiratory illness, neurological illness, and orthopedic illness of the neck and trunk.

Totally 31 healthy adult males were enrolled and randomly assigned to two groups: EMT group (n=15) with 4-week EMT and normal controls (NC) group (n=16) without EMT. This was a nonblinded randomized controlled trial, where participants were assigned at a 1:1 ratio using a random number table with simple randomization by the investigators.

Before the study commenced, participants from both groups underwent a baseline evaluation of the muscle activity of each respiratory muscle during PImax and PEmax measurements with inspiratory load, and of respiratory function at rest. EMT was performed using EMST150® (manufactured by Aspire Products, Cape Carteret, NC, USA). The EMT group underwent training twice daily for 15 min for 4 weeks using an expiratory muscle load of 50% of PEmax (50% PEmax)[13–15]. Their daily routines were unmodified from before the study, except for EMT. Participants recorded their EMT on the training record form. The daily routines of the NC group remained unchanged.

Participants in both groups were evaluated at 4 weeks after the study in the same manner as before the study.

Muscle fatigue was evaluated based on muscle activity of each respiratory muscle during PImax and PEmax measurements.

Muscle fatigue of each respiratory muscle was evaluated using the sEMG median power frequency (MDF) as an index of muscle fatigue. Surface electromyometers (MQ16, KISSEI COMTEC, Nagano, Japan) were used for the measurements. The measuring muscles were the right trapezius, sternocleidomastoid, pectoralis major, diaphragm, rectus abdominis, external oblique, and internal oblique. Electrodes were attached to the muscles at the midpoint between the line connecting the shoulder peak and the 7th cervical vertebra for the trapezius; the center of the abdominal muscles for the sternocleidomastoid; the upper part of the axilla pectoralis major and the 6th–7th intercostal[6] on the central line of the right clavicle for the diaphragm; 1 cm superior to the umbilicus and 2 fingerbreadths lateral to the white line for the rectus abdominis; in the 8th lateral[16] for the external oblique; and in the anterior iliac spine at 1 cm and below the line connecting the left and right anterior superior iliac spines for the internal oblique. For the electrode attachment site of the diaphragm, a sonogram diagnostic device (LOGIQ P6 Expert, GE Healthcare, Tokyo, Japan) was used to confirm the diaphragm's position. Measurements were taken with a linear probe using the B-mode method with a spatial resolution of 10 MHz and a depth of 5 cm. At the measurement site, a probe perpendicular to the 8th–9th right axillary linear intercostal space where the diaphragm position could be confirmed was scanned[17]. Electromyogram waveforms appeared after checking the diaphragm in the 6th–7th intercostal space on the right central clavian line. Regarding the electrode attachment site of the muscle to be measured, skin pretreatment was performed sufficiently, and an impedance checker (EM-570, Noraxon, Scottsdale, AZ, USA) was used to confirm that the impedance level fell below 5 kΩ. Dual electrodes (EM-272S, Noraxon) were used to standardize the distance between the electrodes to 2 cm.

Surface EMG measurements were obtained by dipole derivation to measure the maximum intraoral pressure (PImax, PEmax) and record each respiratory muscle activity with an EMG device. A digital video camera (HANDYCAM HDR-CX560, SONY, Tokyo, Japan) was connected to the EMG device by an AD converter (ADVANCEDDV ADVC-55, CANOPUS, Tokyo, Japan), and video recording was performed when the task was performed in a time-synchronized state. The sampling frequency was 1,500 Hz, and muscle activity started when the maximum resting amplitude of measured muscle activity was exceeded. In addition, when ECG waveforms were mixed into the EMG, the QRS component of the ECG was removed to minimize the effect[18)], and the muscle radioform between the QRS and QRS components was used for analysis[19)]. The myoradioforms were processed using a 20–350 Hz bandpass filter and a data integration analysis program (Kineanalyzer Ver4, KISSEI COMTEC). Electromyogram frequency analysis used MDF with Fast Fourier Transform as an indicator of muscle fatigue.

Respiratory muscle strength was measured by connecting a spirometer (Autospiro AS-507, Minato Medical Science Co., Ltd., Osaka, Japan) to a respiratory muscle gauge unit (Respiratory Musculometer ASS, Minato Medical Science Co., Ltd). The measurement was taken with the participant in the seated position wearing a nose clip and holding a respiratory muscle meter in the left hand. Measurement of inspiratory muscle strength was performed using the Black and Hyatt methods[20)], and the maximum inhalation and exhalation were measured three times each, with the maximum values being PImax and PEmax. The measurements were taken using methods and instruments in accordance with the standard method published in the American Thoracic Society (ATS)/European Respiratory Society (ERS) statement[21)].

For respiratory function, a spirometer (Autospiro AS-507, Minato Medical Science Co., Ltd.) was used to measure forced vital capacity (FVC), percentage FVC (%FVC), forced expiratory volume in one sec (FEV1.0), percentage FEV in one sec (FEV1.0%), and peak expiratory flow (PEF) three times each, and the maximum value of each was adopted. Respiratory function was evaluated in accordance with the ATS standard method[14)].

The procedure for evaluating inspiratory muscle loading and each respiratory muscle fatigue was based on a previous study[10)]. First, the PImax and PEmax of the participants was measured before the inspiratory muscle loading. The pressure at 50% of the PImax (50% PImax) measured before the inspiratory muscle loading was used as the inspiratory muscle load pressure. Threshold IMT® (Respironics New Jersey Inc., Parsippany, NJ, USA) or POWERbreathe PLUS® (POWERbreathe International Ltd., Southam, Warwickshire, UK) were used as the inspiratory muscle loading instruments. The participants underwent 2 min of inspiratory muscle loading, followed by 1 min of rest, which was taken as 1 set. The participants repeated this process for 10 sets, and the total time of inspiratory muscle loading was 20 min. Breathing during the inspiratory muscle loading was 15 times per min and the inhalation and exhalation times were 2 sec each. During each 1-min rest, PImax and PEmax were measured and muscle activity of each respiratory muscle was recorded simultaneously. After the end of the inspiratory muscle loading, PImax and PEmax were measured. Muscle activity in each respiratory muscle was measured every 5 min.

For statistical analysis, a paired t-test was used to compare respiratory muscle strength and respiratory function before and after the study for both groups. Comparisons of respiratory muscle strength and respiratory function before and after the study period between the groups were verified using an unpaired t-test. The interaction between PImax and PEmax and each respiratory muscle MDF over time during the inspiratory muscle loading in both groups was tested by two-way repeated measures analysis of variance (group and measurement timing). Additionally, we used one-way repeated measures analysis of variance that factored in the measurement time of each group, and a multiple comparison test was performed by the Bonferroni method if the main effect was observed. The statistical analysis software JSTAT version 13.0 was used and the significance level was $p<0.05$.

RESULTS

Figure 1 shows the flow diagram of this study[11)]. None of the participants dropped out during the study period and were all included in the analysis.

Table 1 shows the characteristics, respiratory function, and respiratory muscle strength of the participants before and after the study for both groups[11)]. The PEmax and PEF values after the study were significantly higher in the EMT group compared to the PEmax and PEF values before the study ($p<0.01$ and $p<0.05$). No other significant differences were observed for either group before and after the study. PEmax value after the study period of the EMT group was significantly higher than that of the NC group ($p<0.01$). There were no significant differences in other respiratory functions and respiratory muscle strength between the EMT and NC groups before and after the study period.

Table 2 shows the changes in PImax and PEmax over time during the inspiratory muscle loading before and after the study for both groups[11)]. There was a significant interaction between groups and time of measurement for PImax and PEmax in the EMT group ($p<0.01$ for both); however, no interaction was seen in the NC group. Before the study, the values of PImax and PEmax in the EMT group decreased significantly during and after the inspiratory muscle loading compared to before the inspiratory muscle loading ($p<0.01$), whereas the values of PImax and PEmax after the study did not differ during and after the inspiratory muscle loading compared to before the inspiratory muscle loading. The values of PImax and PEmax before and after the study period in the NC group significantly reduced during and after inspiratory muscle loading compared to the values before inspiratory muscle loading ($p<0.01$).

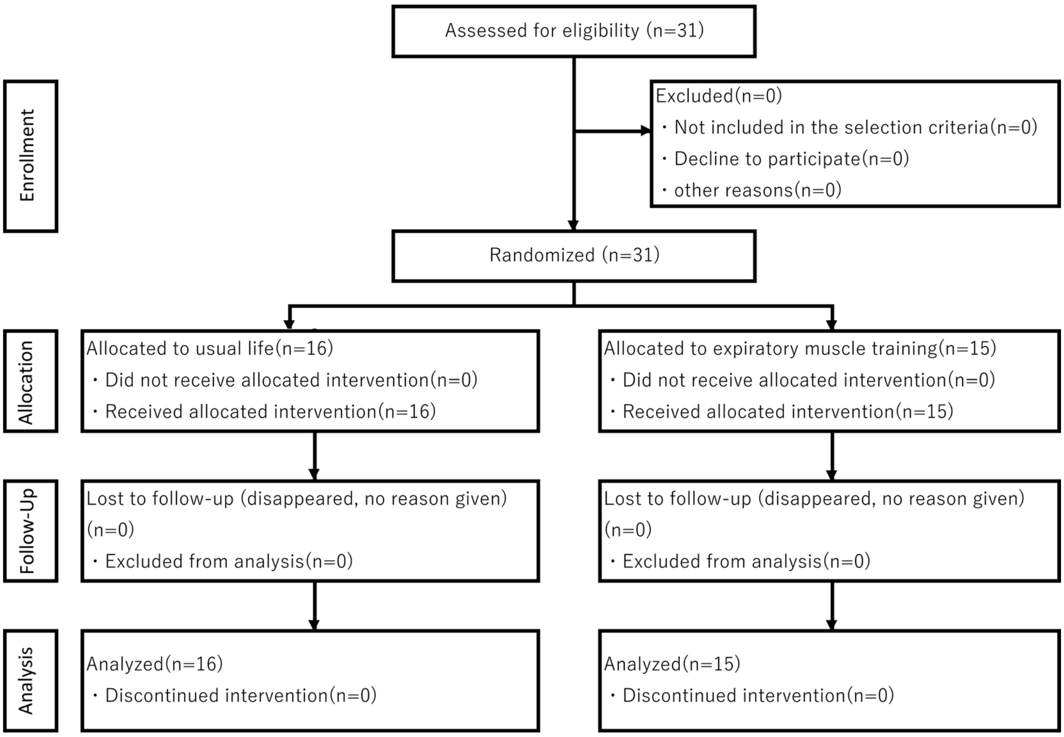

Fig. 1. The CONSORT flow diagram.

Table 1. Effects of expiratory muscle training on participant characteristics, respiratory function, respiratory muscle strength

	EMT n=15		NC n=16	
	Before the study	After the study	Before the study	After the study
Male sex, n (%)	15 (100)	–	16 (100)	–
Age, years	27.3 ± 2.4	–	26.7 ± 5.1	–
Height, cm	173.2 ± 5.0	–	170.5 ± 5.4	–
Body weight, kg	64.8 ± 7.4	64.5 ± 7.3	67.0 ± 7.0	66.6 ± 6.9
Body mass index, kg/m^2	21.5 ± 1.5	21.5 ± 1.8	23.1 ± 2.1	22.9 ± 2.1
Respiratory function				
FVC, L	4.5 ± 0.5	4.6 ± 0.6	4.4 ± 0.4	4.4 ± 0.4
%FVC, %	106.3 ± 10.7	107.3 ± 11.6	104.5 ± 9.8	104.6 ± 10.3
$FEV_{1.0}$, L	4.0 ± 0.4	4.0 ± 0.4	3.8 ± 0.4	3.8 ± 0.4
$FEV_{1.0\%}$, %	88.2 ± 5.9	87.8 ± 6.2	87.1 ± 4.2	86.7 ± 3.7
PEF, L/s	9.5 ± 1.1	10.2 ± 1.1*	9.8 ± 1.1	9.6 ± 0.9
Respiratory muscle strength				
PImax, cmH_2O	118.8 ± 16.8	127.1 ± 19.7	108.4 ± 17.3	112.1 ± 22.1
PEmax, cmH_2O	108.0 ± 23.7	130.1 ± 28.6**##	98.1 ± 14.8	95.3 ± 14.5

Mean ± standard deviation.
Pre/post comparison within each group, *$p<0.05$, **$p<0.01$, Pre/post comparison between 2 groups, #$p<0.05$, ##$p<0.01$.
EMT: expiratory muscle training group; NC: normal control group; FVC: forced vital capacity; %FVC: percentage forced vital capacity; $FEV_{1.0}$: forced expiratory volume in one second; $FEV_{1.0\%}$: forced expiratory volume % in one second; PEF: peak expiratory flow; PImax: maximum inspiratory mouth pressure; PEmax: maximum expiratory mouth pressure.

Table 2. Chronological changes in PImax and PEmax (50%PImax load)

	EMT n=15				NC n=16			
	PImax		PEmax		PImax		PEmax	
	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study
Pre-load	118.8 ± 16.8	127.1 ± 19.7	108.0 ± 23.7	130.1 ± 28.6	108.4 ± 17.3	112.1 ± 22.1	98.1 ± 14.8	95.3 ± 14.5
2 min	109.0 ± 16.0*	125.4 ± 20.9	98.2 ± 22.8*	125.7 ± 24.0	99.5 ± 18.3	104.5 ± 20.7	87.3 ± 14.3*	93.8 ± 17.4
4 min	110.3 ± 13.5	127.3 ± 21.2	98.0 ± 24.4*	125.2 ± 29.8	100.7 ± 18.0	104.2 ± 22.1	85.6 ± 16.2**	89.9 ± 16.1
6 min	111.1 ± 16.3	128.7 ± 21.9	93.6 ± 24.1**	122.0 ± 31.5	97.2 ± 15.8	100.7 ± 19.7*	88.1 ± 14.7*	89.5 ± 14.1
8 min	107.7 ± 16.1**	127.3 ± 23.6	93.9 ± 24.7**	125.4 ± 38.2	98.5 ± 15.4	105.3 ± 17.3	90.9 ± 14.4	89.1 ± 17.2
10 min	109.3 ± 13.9	125.1 ± 23.1	92.9 ± 25.0**	125.8 ± 32.5	102.0 ± 15.6	102.6 ± 17.8	88.2 ± 12.8*	92.2 ± 16.9
12 min	104.5 ± 13.1**	124.0 ± 23.3	91.6 ± 26.2**	121.0 ± 28.4	97.9 ± 13.8	103.3 ± 16.6	85.9 ± 13.9**	88.2 ± 16.5
14 min	98.8 ± 16.5**	124.5 ± 23.4	87.6 ± 26.3**	126.1 ± 35.4	101.9 ± 15.8	99.2 ± 19.5**	85.7 ± 15.1**	83.5 ± 12.9**
16 min	104.3 ± 17.4**	124.5 ± 23.4	89.9 ± 24.5**	127.0 ± 29.1	96.7 ± 15.3	98.6 ± 19.0**	83.3 ± 14.8**	86.8 ± 14.9
18 min	105.2 ± 16.2**	124.9 ± 23.9	89.4 ± 23.6**	124.7 ± 34.2	96.1 ± 18.0*	97.2 ± 15.6**	81.8 ± 17.0**	84.9 ± 16.6*
20 min	102.2 ± 16.5**	126.3 ± 16.9	86.0 ± 22.9**	127.5 ± 34.0	95.4 ± 19.4*	96.7 ± 17.8**	81.3 ± 17.7**	82.0 ± 15.6**
5 min rest	109.3 ± 13.9	122.1 ± 19.5	96.0 ± 22.0**	124.1 ± 34.2	103.1 ± 17.4	100.4 ± 19.8*	86.4 ± 14.8**	86.1 ± 14.9
10 min rest	114.8 ± 12.7††	126.3 ± 20.3	97.1 ± 24.5**††	120.9 ± 29.4	106.3 ± 17.3	98.9 ± 21.8**	88.6 ± 14.4	88.9 ± 11.7
15 min rest	115.8 ± 16.4††	125.8 ± 18.3	97.6 ± 21.3**††	120.6 ± 30.8	103.8 ± 15.7	104.1 ± 20.0	90.8 ± 15.4	92.8 ± 13.2†
20 min rest	116.0 ± 16.4††	122.5 ± 17.3	100.0 ± 23.7††	122.0 ± 30.9	101.1 ± 16.8	105.7 ± 18.0	93.7 ± 13.5††	95.8 ± 17.3††
25 min rest	114.9 ± 15.1††	121.9 ± 18.9	99.9 ± 21.9††	119.2 ± 32.0	107.2 ± 16.6	103.6 ± 21.8	91.4 ± 13.8†	91.1 ± 16.7
30 min rest	121.2 ± 16.9††	123.2 ± 19.4	101.5 ± 22.9††	121.3 ± 31.0	108.3 ± 17.5†	108.1 ± 19.3†	93.1 ± 12.4††	93.3 ± 15.4†

Unit: cmH_2O (Mean ± standard deviation).
Comparison with pre-load, *$p<0.05$, **$p<0.01$; Comparison with +20 min load and rest, $^{\dagger}p<0.05$, $^{\dagger\dagger}p<0.01$.
EMT: expiratory muscle training group; NC: normal control group; PImax: maximum inspiratory mouth pressure; PEmax: maximum expiratory mouth pressure.

Tables 3, 4 show the changes in each respiratory muscle MDF in both groups over time. Neither group showed any interaction before and after the study. In the EMT group, we found a significant difference in sternocleidomastoid at PImax between preload and 2, 10 to 14, 18 and 20 min after the inspiratory muscle loading and 5 to 25 min after resting compared to before the study ($p<0.05$) (Table 3). In PEmax (Table 3), rectus abdominis showed a significant difference between before the inspiratory muscle loading and 10 min, and 18 min after the loading. For the external oblique there was a significant difference between before the inspiratory muscle loading and 2 min, and 4 min after loading. Internal oblique showed a significant difference between before the inspiratory muscle loading and 5 min, 20 min, and 30 min after resting ($p<0.05$). After the study in the EMT group, no difference was observed in the time course of each respiratory muscle MDF.

In the NC group, before the study, we found significant differences in the sternocleidomastoid at PImax between before starting the inspiratory muscle loading and after 16 min and 20 min during the loading, and after 15 min and 30 min of resting (Table 4). For PEmax (Table 4) of the rectus abdominis, we found significant differences between before starting the inspiratory muscle loading, after 2 min and 20 min during the loading, and after 15 min and 25 min of resting ($p<0.05$). After the study in the NC group, we found significant differences in the sternocleidomastoid at PImax between before starting the inspiratory muscle loading and after 16 min and 20 min during the loading. For PEmax of the rectus abdominis, we found significant differences between before starting the inspiratory muscle loading and after 2 min, 4 min and from after 8 min to after 12 min during the loading; and from after 16 min to after 30 min of resting ($p<0.05$).

The MDF values for the trapezius, pectoralis major, and diaphragm showed no significant decrease after the study in both groups.

DISCUSSION

The purpose of this study was to examine the effect of 4-week EMT on muscle fatigue in individual respiratory muscles during inspiratory muscle loading. This was reported as an ongoing study of Tsukamoto et al[11]. The study was continued because the effect of EMT on muscle fatigue in individual respiratory muscles could not be validated by evaluating PImax and PEmax alone. Additionally, the evaluation of each respiratory muscle was performed using a surface electromyogram because all MDFs of each respiratory muscle during the inspiratory muscle loading before and after the study had to be shown over time.

In this study, EMT of 50% PEmax for 4 weeks significantly increased PEmax and suppressed muscle fatigue during inspiratory muscle loading in both inhaled (PImax) and exhaled muscles. Additionally, EMT on the muscle fatigue of each

Table 3. Chronological changes in respiratory muscle MDF during PImax, PEmax measurement under inspiratory resistance load (EMT group)

	EMT PImax								EMT PEmax					
	Trapezius		Sternocleidomastoid		Pectoralis major		Diaphragm		Rectus abdominis		External oblique		Internal oblique	
	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study
Pre-load	64.3 ± 9.4	69.7 ± 15.9	93.0 ± 26.1	84.9 ± 19.5	77.3 ± 23.4	76.9 ± 16.7	72.2 ± 12.5	73.0 ± 9.5	79.6 ± 15.5	79.4 ± 19.3	73.8 ± 21.2	67.5 ± 12.7	108.9 ± 41.4	111.5 ± 30.1
2 min	59.2 ± 8.7	64.5 ± 16.9	74.8 ± 24.2**	86.9 ± 24.6	70.4 ± 26.1	74.0 ± 20.2	67.7 ± 13.1	75.5 ± 14.6	69.7 ± 15.8	72.4 ± 20.8	59.7 ± 19.5**	64.2 ± 13.9	94.7 ± 41.2	109.1 ± 30.2
4 min	60.2 ± 12.8	70.4 ± 22.6	84.7 ± 21.7	82.6 ± 17.5	71.5 ± 22.1	68.6 ± 18.7	70.8 ± 13.2	68.4 ± 14.8	71.4 ± 13.7	76.5 ± 17.7	62.7 ± 18.5*	67.8 ± 11.1	102.4 ± 48.4	108.7 ± 33.0
6 min	58.1 ± 12.3	63.7 ± 16.3	84.3 ± 27.9	83.1 ± 17.0	73.3 ± 24.3	72.9 ± 20.2	71.1 ± 9.3	72.5 ± 14.8	75.0 ± 14.9	75.6 ± 18.0	68.0 ± 23.3	67.5 ± 12.0	99.2 ± 44.0	108.5 ± 25.1
8 min	57.4 ± 14.5	69.1 ± 21.9	85.1 ± 24.6	82.8 ± 17.1	71.1 ± 26.2	72.5 ± 20.4	68.0 ± 12.9	72.5 ± 13.7	71.7 ± 14.8	73.4 ± 16.4	67.3 ± 25.1	70.2 ± 15.2	99.4 ± 43.3	109.9 ± 30.0
10 min	59.6 ± 15.4	66.7 ± 24.8	80.1 ± 21.5**	82.6 ± 20.4	75.1 ± 26.1	70.8 ± 15.7	67.4 ± 10.0	71.7 ± 11.8	66.0 ± 9.8*	72.1 ± 18.3	65.2 ± 24.5	65.6 ± 11.6	94.9 ± 35.0	111.1 ± 30.7
12 min	55.3 ± 11.1	64.2 ± 19.1	80.1 ± 20.1**	81.7 ± 19.2	76.5 ± 27.9	73.9 ± 18.7	67.4 ± 12.8	75.4 ± 12.3	73.9 ± 14.3	72.8 ± 24.8	65.3 ± 18.8	65.0 ± 14.1	97.9 ± 43.3	104.8 ± 36.0
14 min	62.2 ± 14.3	67.7 ± 24.2	80.5 ± 22.1**	85.7 ± 20.1	72.8 ± 23.1	73.3 ± 17.8	69.2 ± 13.6	79.4 ± 15.1	73.4 ± 16.2	73.0 ± 18.3	66.0 ± 16.2	64.2 ± 12.0	98.6 ± 44.1	107.4 ± 33.2
16 min	63.9 ± 13.3	69.3 ± 22.4	84.0 ± 20.0	83.6 ± 19.1	72.3 ± 22.0	68.8 ± 16.0	67.4 ± 11.7	70.4 ± 8.5	72.1 ± 14.6	75.3 ± 17.7	70.3 ± 26.6	63.6 ± 10.3	101.3 ± 42.3	108.2 ± 33.2
18 min	63.3 ± 12.8	67.2 ± 20.2	78.1 ± 20.4**	81.7 ± 18.7	78.3 ± 26.9	72.1 ± 19.0	69.0 ± 9.9	70.6 ± 15.3	65.8 ± 11.3*	73.5 ± 15.7	67.8 ± 21.6	66.5 ± 10.5	96.4 ± 44.0	105.9 ± 35.4
20 min	59.0 ± 13.9	66.0 ± 24.1	81.6 ± 19.3*	82.6 ± 17.5	73.6 ± 23.1	73.7 ± 19.7	65.1 ± 13.1	77.9 ± 14.2	68.4 ± 14.4	74.2 ± 18.7	66.9 ± 17.7	67.7 ± 12.2	96.6 ± 35.2	110.5 ± 34.3
5 min rest	59.6 ± 15.3	68.4 ± 21.2	81.6 ± 17.2*	85.3 ± 18.0	73.6 ± 22.6	74.7 ± 20.5	66.4 ± 13.3	73.2 ± 13.8	73.3 ± 13.7	72.1 ± 20.8	67.9 ± 24.2	67.8 ± 12.1	90.3 ± 39.0**	109.9 ± 33.8
10 min rest	60.8 ± 11.6	65.8 ± 20.9	77.5 ± 18.0**	77.5 ± 15.8	69.9 ± 21.5	71.4 ± 15.7	65.7 ± 15.4	71.9 ± 8.5	71.2 ± 15.7	72.8 ± 22.1	67.0 ± 21.0	63.9 ± 12.7	96.4 ± 45.0	108.8 ± 29.7
15 min rest	59.1 ± 15.1	66.4 ± 10.4	80.9 ± 24.8**	86.4 ± 20.6	73.1 ± 21.7	71.8 ± 15.9	70.5 ± 15.6	68.7 ± 11.0	68.7 ± 14.5	72.2 ± 17.3	66.1 ± 20.5	73.3 ± 22.7	93.8 ± 37.6	110.0 ± 33.4
20 min rest	60.2 ± 10.6	66.4 ± 11.3	79.0 ± 19.5**	80.2 ± 13.9	72.3 ± 24.0	69.0 ± 8.4	69.4 ± 18.7	69.6 ± 11.9	74.1 ± 19.9	74.3 ± 20.3	66.2 ± 25.4	69.9 ± 18.8	90.5 ± 40.9**	107.9 ± 34.2
25 min rest	55.4 ± 14.6	66.1 ± 12.8	77.6 ± 21.9**	79.0 ± 11.5	72.3 ± 23.1	69.1 ± 16.3	70.1 ± 15.1	71.6 ± 12.2	76.7 ± 14.9	73.2 ± 19.7	65.1 ± 19.9	66.4 ± 12.0	102.0 ± 44.9	113.6 ± 39.5
30 min rest	60.9 ± 15.7	65.9 ± 11.0	83.3 ± 23.5	80.2 ± 11.5	70.4 ± 23.8	68.9 ± 16.4	65.8 ± 14.6	76.4 ± 16.5	74.9 ± 18.5	76.4 ± 15.5	66.0 ± 19.7	65.2 ± 10.4	92.5 ± 42.8*	109.7 ± 31.4

Unit: Hz (Mean ± standard deviation); n=15.
Comparison with pre-load, *$p<0.05$, **$p<0.01$; Comparison with +20 min load and rest, $^{\dagger}p<0.05$, $^{\dagger\dagger}p<0.01$.
MDF: median power frequency; EMT: expiratory muscle training group; PImax: maximum inspiratory mouth pressure; PEmax: maximum expiratory mouth pressure.

Table 4. Chronological changes in respiratory muscle MDF during PImax, PEmax measurement under inspiratory resistance load (NC group)

	NC PImax								NC PEmax					
	Trapezius		Sternocleidomastoid		Pectoralis major		Diaphragm		Rectus abdominis		External oblique		Internal oblique	
	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study	Before the study	After the study
Pre-load	65.8 ± 11.8	68.2 ± 24.0	81.0 ± 9.2	83.8 ± 12.8	81.3 ± 16.3	83.0 ± 16.8	77.1 ± 20.5	75.6 ± 18.5	91.0 ± 20.1	93.4 ± 20.5	69.8 ± 12.2	66.8 ± 9.8	99.6 ± 41.9	93.8 ± 28.4
2 min	58.0 ± 14.4	62.5 ± 24.9	74.7 ± 13.6	79.9 ± 16.0	82.4 ± 20.8	79.8 ± 19.2	73.5 ± 23.1	69.0 ± 11.4	78.3 ± 20.9*	78.7 ± 17.6**	65.5 ± 14.6	61.0 ± 11.0	91.1 ± 42.4	86.8 ± 27.6
4 min	61.4 ± 14.6	58.7 ± 17.4	73.8 ± 8.0	77.3 ± 13.4	84.4 ± 19.6	85.4 ± 19.1	75.8 ± 20.8	68.4 ± 17.7	84.6 ± 14.8	78.9 ± 17.2**	62.4 ± 11.5	60.6 ± 10.9	91.6 ± 45.7	87.0 ± 28.5
6 min	62.2 ± 14.3	60.8 ± 18.9	75.5 ± 7.6	76.4 ± 17.0	86.9 ± 21.4	82.4 ± 17.5	70.2 ± 20.3	69.3 ± 12.2	79.9 ± 20.7	85.2 ± 21.1	61.9 ± 12.9	61.1 ± 12.0	93.4 ± 45.2	85.0 ± 28.8
8 min	58.7 ± 10.7	62.6 ± 25.2	73.4 ± 11.4	75.3 ± 14.1	78.7 ± 24.3	79.8 ± 15.6	73.4 ± 22.7	70.4 ± 12.4	83.8 ± 19.8	76.9 ± 19.8**	68.7 ± 16.4	62.0 ± 8.5	94.2 ± 45.2	86.9 ± 24.2
10 min	60.0 ± 17.0	68.2 ± 27.2	75.3 ± 8.6	76.0 ± 20.0	84.2 ± 21.1	82.4 ± 15.5	70.2 ± 20.1	71.4 ± 14.2	82.1 ± 15.5	77.4 ± 20.1**	66.1 ± 14.2	60.9 ± 11.2	95.1 ± 44.0	84.0 ± 23.6
12 min	57.7 ± 11.9	61.9 ± 24.8	73.4 ± 9.4	76.0 ± 13.1	85.4 ± 16.8	78.0 ± 16.3	72.3 ± 24.4	73.5 ± 19.7	83.7 ± 19.3	81.5 ± 18.4*	64.5 ± 13.2	63.4 ± 9.5	92.4 ± 43.5	87.3 ± 26.2
14 min	60.2 ± 11.3	63.6 ± 24.8	72.4 ± 9.2	80.0 ± 15.2	80.9 ± 19.7	81.8 ± 19.2	71.0 ± 15.3	70.3 ± 19.6	81.9 ± 22.6	85.6 ± 20.2	66.2 ± 16.1	62.2 ± 11.4	91.9 ± 41.2	84.1 ± 30.5
16 min	62.6 ± 15.3	65.0 ± 18.5	70.5 ± 8.6**	73.5 ± 18.8**	80.5 ± 15.7	82.5 ± 20.9	70.6 ± 19.7	73.5 ± 25.1	82.2 ± 18.9	79.6 ± 21.0**	66.4 ± 20.9	62.7 ± 10.2	88.1 ± 41.0	81.8 ± 32.3
18 min	61.1 ± 18.5	62.1 ± 19.9	73.9 ± 10.4	74.2 ± 15.3*	85.6 ± 24.0	76.0 ± 18.4	71.0 ± 24.3	71.3 ± 15.2	79.5 ± 18.4	80.5 ± 19.8**	60.5 ± 13.8	59.8 ± 11.2	87.8 ± 39.3	80.6 ± 27.5
20 min	57.9 ± 10.2	62.6 ± 23.7	71.9 ± 8.8*	74.0 ± 15.3*	86.2 ± 19.6	78.6 ± 17.1	71.8 ± 26.9	75.3 ± 24.7	77.7 ± 12.2*	76.6 ± 20.5**	61.5 ± 9.9	61.1 ± 10.1	90.4 ± 40.7	82.8 ± 29.6
5 min rest	56.8 ± 16.1	63.4 ± 25.7	72.8 ± 9.2	79.6 ± 12.9	83.7 ± 20.6	76.6 ± 14.4	71.1 ± 18.8	70.5 ± 16.1	82.4 ± 13.9	78.7 ± 21.2**	63.7 ± 13.4	60.5 ± 11.6	93.4 ± 45.1	83.0 ± 30.4
10 min rest	61.0 ± 16.4	62.2 ± 21.5	73.3 ± 10.9	76.8 ± 16.7	75.7 ± 17.3	75.2 ± 19.4	75.6 ± 21.1	68.5 ± 18.3	82.0 ± 17.4	76.4 ± 17.3**	64.0 ± 11.9	65.8 ± 12.9	89.7 ± 44.1	90.9 ± 31.1
15 min rest	59.1 ± 14.9	64.8 ± 23.1	71.5 ± 7.2*	81.2 ± 15.3	79.6 ± 17.4	76.2 ± 16.4	73.3 ± 19.8	71.4 ± 16.1	78.5 ± 17.6*	76.5 ± 18.4**	64.8 ± 15.4	66.4 ± 13.9	85.1 ± 23.6	88.7 ± 32.7
20 min rest	52.5 ± 10.8	64.5 ± 19.5	74.2 ± 10.5	76.1 ± 13.3	79.0 ± 21.1	77.4 ± 12.7	72.8 ± 22.2	72.1 ± 17.9	80.7 ± 20.0	79.1 ± 15.5**	62.9 ± 14.0	62.4 ± 9.8	84.6 ± 29.3	89.6 ± 27.7
25 min rest	57.6 ± 17.6	63.7 ± 27.7	72.7 ± 7.9	76.1 ± 15.4	78.3 ± 17.3	80.1 ± 15.3	74.5 ± 26.8	67.8 ± 14.0	77.2 ± 17.8**	79.2 ± 19.4**	63.4 ± 10.4	61.0 ± 10.4	84.4 ± 22.8	85.7 ± 26.2
30 min rest	63.9 ± 15.8	65.9 ± 20.9	67.5 ± 8.3**	76.0 ± 15.6	73.1 ± 16.1	77.2 ± 16.4	73.1 ± 25.8	69.5 ± 16.5	82.7 ± 18.4	79.4 ± 21.8**	62.6 ± 13.9	66.5 ± 12.7	85.0 ± 23.8	84.6 ± 28.1

Unit: Hz (Mean ± standard deviation); n=16.
Comparison with pre-load, *p<0.05, **p<0.01; Comparison with +20 min load and rest, †p<0.05, ††p<0.01.
MDF: median power frequency; NC: normal control group; PImax: maximum inspiratory mouth pressure; PEmax: maximum expiratory mouth pressure.

respiratory muscle improved fatigue tolerance of the rectus abdominis, external oblique, and internal oblique, which are the expiratory muscles, and that of the sternocleidomastoid, which is the inspiratory accessory muscle.

In the NC group, there were no significant changes in PImax, PEmax, or muscle fatigue of each respiratory muscle after 4 weeks compared to before the study. This suggests that the effect of EMT was observed in healthy patients.

In terms of respiratory muscle strength, PEmax in the EMT group was significantly increased by 22.1 cmH_2O (approximately 20%) after the study compared with before the study. Although this study was conducted in healthy adult males, the results were consistent with previous studies on COPD by Mota et al[13)].

In terms of respiratory function, the PEF in the EMT group significantly increased after the study compared to before the study. EMT-mediated expiratory muscle enhancement has been reported to be effective in improving Peak Cough Flow, an indicator of coughing ability[22)]. Increased PEF is thought to be related to increased expiratory muscle strength due to EMT.

Muscle fatigue of each respiratory muscle was evaluated using MDF with sEMG. MDF in an EMG frequency analysis is used as an indicator to evaluate muscle fatigue by sEMG[6, 8)]. The EMG waveform contains various frequencies. The distribution of frequency components is called the EMG power spectrum. The square of the amplitude of each frequency component was used as the power of the signal[23)]. MDF is a representative value of the frequency that divides the area of the EMG power spectrum in the extracted muscle radioform into two equal areas[24)], and it is an index of the overall muscle fatigue of the EMG spectrum waveform. In addition, MDF transitions to the lower frequency band over time when muscle fatigue appears, both during maximal and submaximal exertion of muscle strength[23, 24)]. Regarding muscle fatigue by electromyogram frequency analysis, since "movement of the EMG power spectrum to a lower frequency (wave slowing)" is defined as muscle fatigue[24)], decrease in MDF was defined as muscle fatigue.

The effects of EMT on each respiratory muscle will be discussed based on a comparison of changes before to after the study period in the MDF. Furthermore, the effect of EMT on the muscle fatigue of each respiratory muscle was improved fatigue tolerance of the rectus abdominis, external oblique, and internal oblique, which are the expiratory muscles, and that of the sternocleidomastoid, which is the inspiratory accessory muscle. MDF of EMT before study, showed muscle fatigue after 10 and 18 min during the inspiratory muscle loading for the rectus abdominis; after 2 and 4 min during the loading for the external oblique; after 5, 20, and 30 min of resting following interruption of the loading for the internal oblique; and after 2 min and from after 10 min to 14 min, from after 18 min to 20 min during the loading, and from after 5 min to 25 min of resting for the sternocleidomastoid. This showed that the timing of onset of muscle fatigue was not consistent. This suggests that inspiratory muscles may be coordinated and made active by mobilizing muscle fiber types in an orderly manner to create an optimal exercise pattern in order to make respiratory muscles less likely to fatigue[25)], and compensates so that the inspiratory and expiratory muscles do not become fatigue at the same time[26)]. The muscle fatigue of these respiratory muscles did not show any significant decrease in MDF during the inspiratory muscle loading or after resting. Neves et al.[27)] reported that EMT is an effective method for improving the strength of inspiratory and expiratory muscles. This suggests that EMT improved fatigue tolerance of not only the rectus abdominis, external oblique, internal oblique, which are the expiratory muscles but also that of the sternocleidomastoid, which is the inspiratory accessory muscle. For other findings of the trapezius, pectoralis major, and diaphragm, no signs of fatigue could be detected from the MDF by electromyogram frequency analysis in both groups. The results of this study were similar to those of the previous study by Tsukamoto et al[10)]. It was assumed that the inspiratory muscle loading used in this study did not cause signs of fatigue in trapezius, pectoralis major, and diaphragm.

In the EMT group, before the study, muscle fatigue of sternocleidomastoid, rectus abdominis, external oblique, and internal oblique was observed. However, the 4-week EMT showed no muscle fatigue in all sternocleidomastoid, rectus abdominis, external oblique, and internal oblique muscles, suggesting improved muscle fatigue tolerance. We will discuss the effect of 4-weeks of EMT suppressing muscle fatigue in respiratory muscles from the three following perspectives.

First, the fatigue tolerance of the sternocleidomastoid was improved. The signs of muscle fatigue (MDF decreased from 93.0 to 74.8 Hz, which is a decrease of approximately 20%) seen before the study in the sternocleidomastoid were absent after the study (decrease from 84.9 to 81.7 Hz, which is a decrease of approximately 4%), showing improved muscle fatigue tolerance. Since sternocleidomastoid has been reported to exhibit activity under strong expiratory muscle loading[28)], setting the load setting of EMT to 50% induced activity. In addition to the expiratory muscle enhancement by EMT, it was thought to be a factor that improves fatigue tolerance of sternocleidomastoid.

Second, an increase in PEmax was associated with increased fatigue tolerance in the abdominal muscle group and an improvement in diaphragmatic contractile efficiency was associated with increased abdominal pressure[10)]. Before the study, there was a significant decrease in MDF due to muscle fatigue (rectus abdominis: a decrease of about 17% from 79.6 to 65.8 Hz; external oblique: a decrease of about 19% from 73.8 to 59.7 Hz; internal oblique: a decrease of about 17% from 108.9 to 90.3 Hz); after the study, there was no significant decrease (rectus abdominis: a decrease of about 9% from 79.4 to 72.1 Hz; external oblique: a decrease of about 6% from 67.5 to 63.6 Hz; and the internal oblique: a decrease of about 6% from 111.5 to 104.8 Hz). The abdominal muscle group, which consists of the expiratory muscles, is also said to have an effect on inhalation because the contraction of the abdominal muscle during exhalation pushes the diaphragm into the thoracic cavity and improves the efficiency of contraction of the diaphragm by bringing the diaphragm muscle fibers closer to the optimal length, and by affecting the shape and stability of the thorax[2, 29)]. Thus, it was thought that the improvement of fatigue tolerance in the abdominal muscle group directly improved fatigue tolerance in the expiratory muscles, and indirectly contributed to the improvement of fatigue tolerance in the inspiratory muscles. This was thought to be due to the fact that PImax and PEmax of the EMT group showed a decrease due to inspiratory muscle loading, whereas no decrease due to inspiratory muscle loading was observed after the study.

Third, fatigue tolerance improved due to structural changes in muscle. Ramirez-Sarmiento et al.[30] reported an approximately 38% increase in the proportion of type I fibers in the external intercostal muscles and an increase in durability during inspiratory muscle training (IMT) using a load of 50% PImax. Since the load used in this study and the duration of the study are similar, it is assumed that the proportion of type I fibers increased, leading to an improvement in fatigue tolerance.

In view of the abovementioned three points, it can be assumed that improved fatigue tolerance and muscle structure changes in the sternocleidomastoid and abdominal muscle groups suppressed respiratory muscle fatigue in both PImax and PEmax.

Therefore, the 4-week EMT significantly increased expiratory muscle strength (PEmax) and suppressed respiratory muscle fatigue during inspiratory muscle loading. Additionally, the state of muscle fatigue of the various expiratory muscles was evaluated from the electromyogram frequency analysis. It became evident that the fatigue tolerance of the rectus abdominis, external oblique, and internal oblique, which are the expiratory muscles, and the sternocleidomastoid, which is the inspiratory accessory muscle, was improved.

Limitations of this study include the fact that the measurement of respiratory muscle strength is performed at the maximum expiratory (residual air volume) and maximum inhaled (total pulmonary air volume) positions, that the values obtained include the elastic contractile force of the lung and thorax, and air leaks occur in the measurement circuit to prevent the use of glottal obstruction and cheek muscles when measuring respiratory muscle according to the standard method published in ATS/ERS[21]. Regarding the former, the study limitations and points worthy of consideration are that the effects of elastic contractile force of the lung and thorax in the measurement of respiratory muscle strength have not been investigated, and that the movement and flexibility of the thorax have not been investigated. Regarding the latter, the absolute value of the maximum oral pressure (PImax, PEmax) gradually decreases after recording the peak pressure. Therefore, a delay in the peak pressure does not reflect the lung volume pressure at the beginning of the measurement, and a limitation of the study is that it was not possible to determine lung volume due to the characteristics of the oral pressure measurement. Additionally, the study was conducted on healthy adult males, and so the effects of gender differences are unclear, the sample size is small, and respiratory muscle fatigue in COPD and chronic respiratory illness is not captured in the study and are therefore issues for future study.

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Conflict of interest

None.

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