



Original Article

Relative activity of respiratory muscles during prescribed inspiratory muscle training in healthy people

JU-HYEON JUNG, MS, PT¹⁾, NAN-SOO KIM, PhD, PT^{2)*}

¹⁾ Department of Physical Therapy, Gimhae College, Republic of Korea

²⁾ Department of Physical Therapy, College of Health Sciences, Catholic University of Pusa: 9 Bugok 3-dong, Geumjung-gu, Busan 609-757, Republic of Korea

Abstract. [Purpose] This study aimed to determine the effects of different intensities of inspiratory muscle training on the relative respiratory muscle activity in healthy adults. [Subjects and Methods] Thirteen healthy male volunteers were instructed to perform inspiratory muscle training (0%, 40%, 60%, and 80% maximal inspiratory pressure) on the basis of their individual intensities. The inspiratory muscle training was performed in random order of intensities. Surface electromyography data were collected from the right-side diaphragm, external intercostal, and sternocleidomastoid, and pulmonary functions (forced expiratory volume in 1 s, forced vital capacity, and their ratio; peak expiratory flow; and maximal inspiratory pressure) were measured. [Results] Comparison of the relative activity of the diaphragm showed significant differences between the 60% and 80% maximal inspiratory pressure intensities and baseline during inspiratory muscle training. Furthermore, significant differences were found in sternocleidomastoid relative activity between the 60% and 80% maximal inspiratory pressure intensities and baseline during inspiratory muscle training. [Conclusion] During inspiratory muscle training in the clinic, the patients were assisted (verbally or through feedback) by therapists to avoid overactivation of their accessory muscles (sternocleidomastoid). This study recommends that inspiratory muscle training be performed at an accurate and appropriate intensity through the practice of proper deep breathing.

Key words: Respiratory muscle, Inspiratory muscle training intensity, Surface electromyography

(This article was submitted Nov. 24, 2015, and was accepted Dec. 15, 2015)

INTRODUCTION

Patients with respiratory diseases, including chronic obstructive pulmonary disease (COPD), experience respiratory muscle function disorder in which the muscular capacity decreases to compensate for the increased rate of breathing and the increased muscular ventilation load¹⁻³⁾. To address these problems, respiratory muscle training (RMT) is being practiced in clinics⁴⁻⁶⁾ and, among the different kinds of RMTs, inspiratory muscle training (IMT) has been reported to be effective in improving pulmonary function, inspiratory muscle strength and endurance, exercise capacity, and dyspnea^{4, 6)}. Furthermore, when IMT training is used in clinics, the loading pressure can be adjusted on the basis of the individual characteristics of the participants⁴⁾. However, several studies^{7, 8)} showed that many factors (load level and modulation, muscle shortening speed, and respiratory pattern) must be considered when creating the best IMT protocol, and that the training protocol varies according to different researchers.

A previous study showed that a strong relation exists between the maximal inspiratory pressure (MIP) increase and the activation of the sternocleidomastoid (SCM) and scalene muscles⁹⁾. Moreover, activation of the diaphragm (DI) and intercostal (IC) muscles was shown to increase during inspiratory muscle loading by using a threshold inspiratory loading

*Corresponding author. Nan-soo Kim (E-mail: hnskim@cup.ac.kr)

©2016 The Society of Physical Therapy Science. Published by IPEC Inc.

This is an open-access article distributed under the terms of the Creative Commons Attribution Non-Commercial No Derivatives (by-nc-nd) License <<http://creativecommons.org/licenses/by-nc-nd/4.0/>>.

device¹⁰). On the basis of these results, if the load on the inspiratory muscle is enhanced by increasing the training intensity during IMT training, activation of the neck muscles, including the SCM and scalene muscles, will also be increased. As a result, rib-cage movement will increase and the sternum will become elevated in a costal respiratory pattern¹¹. Furthermore, abdominal movement will be decreased during inspiratory movement, thereby resulting in decreased activation of the DI¹¹. Therefore, these data indicate that problems with functional reversal of the primary muscles and accessory muscles can arise during IMT training.

On the other hand, research is recently being carried out on the appropriate load level during IMT training¹²), and various IMT methods are being verified^{4, 13}). However, until now, the relation between the main inspiratory muscles, including the DI and external IC muscles, and the accessory muscles according to the load level of IMT has not been identified; thus, studies investigating the proper training methods when applying IMT are needed^{4, 8}).

Therefore, the present study aimed to identify the relative activity of the main inspiratory muscles and accessory muscles of respiration, depending on the load level during IMT, and to provide a basis for better establishing the proper methods for IMT by discerning any approaches that require caution during clinical IMT sessions.

SUBJECTS AND METHODS

The subjects of this study were 13 healthy adult men who received an explanation of the purpose of the study and provided written consent to participate. The exclusion criteria were as follows: subjects with neurological findings and who had undergone operations, those receiving surgical treatment, or those taking pain medications on a regular basis. The study was approved by the ethics committee of the Catholic University of Pusan. The subjects' average age, height, and weight were 24.92 ± 2.81 years, 172.76 ± 8.57 cm, and 72.00 ± 14.87 kg, respectively.

Before the experiment, pulmonary function (forced vital capacity [FVC], forced expiratory volume in 1 s [FEV₁], the FEV₁/FVC ratio, peak expiratory flow [PEF], and MIP) were measured by using a spirometer (CHESTGRAPH HI 101; Chest M.I. Inc., Tokyo, Japan) and MIP (Powerbreathe K5; POWERbreathe International Ltd., Warwickshire, UK) according to previously proposed methods^{13, 18}). The average pulmonary function measurements were as follows: FVC 83.92 ± 9.63 , FEV₁ 94.46 ± 10.04 , FEV₁/FVC 103.15 ± 8.34 , PEF 86.46 ± 15.61 , and MIP 91.27 ± 24.46 . No signs of obstructive diseases or restrictive diseases were observed.

Surface electromyography (sEMG) was used to measure respiratory muscle function during IMT. The electrodes for sEMG were attached to the DI, external IC, and SCM; the locations of the electrodes were consistent with those of previous studies^{2, 10, 14, 15}). The EMG responses were amplified (gain $\times 1,000$) (MP36; BIOPAC System Inc., Santa Barbara, CA, USA); the band-pass was filtered between 5 and 500 Hz, and was digitized at a sampling rate of 1 kHz by using an analogue-to-digital converter. The acquired data were later analyzed by using commercially available software (AcqKnowledge 3.8.1; BIOPAC System Inc.).

A pressure threshold inspiratory loading device (POWERbreathe Medic, POWERbreathe International Ltd.) was used to provide the acute bout of inspiratory muscle loading (40%, 60%, and 80% MIP)^{10, 12, 19}). The intensity and duration of IMT were based on prior research protocols¹²). Each subject performed the training at the specified training intensities in random order; the EMG responses were measured during the performance of one to two sets of IMT. The participants were given a 10–15-min rest period between each test condition.

The EMG signal was obtained in the same manner as described previously^{2, 10}). The root mean square sEMG values were analyzed by using one-way repeated-measures analysis of variance and the Bonferroni post hoc test to assess the difference between the baseline and low, middle, and high intensities. P-values < 0.05 were considered statistically significant. Statistical analyses were performed by using SPSS v18.0 for Windows (SPSS Inc., Chicago, IL, USA)¹⁰).

RESULTS

The measurement results for the inspiratory muscle (DI, external IC, and SCM) EMG responses are summarized in Table 1.

DISCUSSION

IMT, which is a training method in which sustained training intensity can be applied on the basis of the overload principle, can have a positive effect on pulmonary function, work capacity, power output, exercise performance, and recovery times^{5, 12}). On the other hand, the increase in the strength of the respiratory muscles through IMT can be explained by a mechanism involving an improved neuromuscular recruitment pattern^{4, 5, 12}). A recent study reported that a group of subjects who trained at 80% intensity of MIP experienced increased vital capacity and total lung capacity, which indicates that the inspiratory muscles had an increased ability to expand the thorax¹²). However, the problem with these findings is that a greater contribution is needed from the upper thorax and neck muscles when the lung volume increases, and neck muscle activity will increase as the training intensity of IMT increases^{2, 12}).

In healthy persons, the DI is responsible for 60–70% of the tidal volume during rest, and DI activation occurs only during

Table 1. Relative activity (EMG) of the diaphragm and IC and SCM muscles during 40%, 60%, and 80% IMT intensities

Variable	Mean (SD)				
	0% Intensity	40% Intensity	60% Intensity	80% Intensity	
DI activity (%)	37.3 (15.5)	28.9 (16.9)	24.9 (17.3) ^a	21.0 (13.3) ^a	*
IC activity (%)	26.7 (8.4)	23.9 (13.7)	20.8 (10.9)	19.2 (11.4)	*
SCM activity (%)	35.8 (14.1)	47.1 (19.0)	54.2 (19.0) ^a	59.7 (18.3) ^{a, b}	*

EMG: electromyography; DI: diaphragm; IC: intercostal; SCM: sternocleidomastoid; MIP: maximal inspiratory pressure; IMT: inspiratory muscle training; 40% intensity IMT: participants who trained at 40% of sustained maximum inspiratory effort; 60% intensity IMT: participants who trained at 60% of sustained maximum inspiratory effort; 80% intensity IMT: participants who trained at 80% of sustained maximum inspiratory effort; * $p < 0.05$, ^a Significantly different from baseline, ^b significantly different from 40% intensity IMT

adverse conditions^{2, 16}). On the other hand, SCM muscle activation is only required during high ventilation levels in normal persons¹⁶). Meanwhile, previous studies reported that the SCM muscle and the DI improved simultaneously when a load response was generated by using a threshold IMT device^{13, 16}). Therefore, although IMT can improve the overall functionality of the inspiratory muscles, IMT may become problematic if it induces a change in the roles between primary muscles and accessory muscles in accordance with the training intensity. In this study, after measuring the relative muscle activity of the primary inspiratory muscles (DI and IC muscle) and the accessory muscle (SCM), we observed that the accessory inspiratory muscle activity increased more than the primary inspiratory muscle activity at training intensities of 60% and 80%. On the other hand, a previous study showed that a deficiency of respiratory mechanics will be established if SCM muscle activity continues to increase¹⁷), and other studies reported that abnormal overactivation of the accessory respiration muscles is an important indicator of respiratory system problems^{2, 14}). The results of this study verified that, when training is carried out by using the wrong methods during high-intensity IMT training, strength training occurs for the accessory muscle rather than for the primary muscle, thereby indicating that fluctuation in muscle recruitment is possible. In addition, by assigning inappropriate training intensity for a subject who has weak respiratory function, overactivation of the accessory muscles may occur owing to compensation from the inspiratory muscle. These situations may occur when the resistance to airflow generated by the threshold IMT device creates excessive resistance, resulting in the conversion to a costal respiratory type through the use of the neck muscles¹¹). Furthermore, the decline observed in the relative activation of the DI in accordance with increased training intensity would be due to the researchers' inability to actively prevent or consider compensation in the subjects.

Therefore, when training patients with IMT in a clinical setting, therapists should be actively engaged (verbally or through feedback) to emphasize the importance of practicing mixed predominance of thoracic expansion over abdominal expansion during inspiratory movements, or the costal respiratory pattern and abdominal respiratory pattern. Furthermore, IMT should be carried out with the application of deep breathing to prevent overactivation of the accessory inspiratory muscles. Finally, it is recommended that therapists minimize compensation by providing proper training at a suitable intensity through accurate identification of the patient's pulmonary functions.

ACKNOWLEDGEMENT

This study was supported by a 2015 research grant from the Catholic University of Pusan.

REFERENCES

- 1) Serres I, Hayot M, Préfaut C, et al.: Skeletal muscle abnormalities in patients with COPD: contribution to exercise intolerance. *Med Sci Sports Exerc*, 1998, 30: 1019–1027. [[Medline](#)] [[CrossRef](#)]
- 2) de Andrade AD, Silva TN, Vasconcelos H, et al.: Inspiratory muscular activation during threshold therapy in elderly healthy and patients with COPD. *J Electromyogr Kinesiol*, 2005, 15: 631–639. [[Medline](#)] [[CrossRef](#)]
- 3) Ito K, Nozoe T, Okuda M, et al.: Electrically stimulated ventilation feedback improves the ventilation pattern in patients with COPD. *J Phys Ther Sci*, 2015, 27: 325–330. [[Medline](#)] [[CrossRef](#)]
- 4) Xiao Y, Luo M, Wang J, et al.: Inspiratory muscle training for the recovery of function after stroke. *Cochrane Database Syst Rev*, 2012, 5: CD009360. [[Medline](#)]
- 5) Enright SJ, Unnithan VB, Heward C, et al.: 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. [[Medline](#)]
- 6) Hill K, Jenkins SC, Philippe DL, et al.: High-intensity inspiratory muscle training in COPD. *Eur Respir J*, 2006, 27:

- 1119–1128. [[Medline](#)] [[CrossRef](#)]
- 7) Lisboa C, Villafranca C, Leiva A, et al.: Inspiratory muscle training in chronic airflow limitation: effect on exercise performance. *Eur Respir J*, 1997, 10: 537–542. [[Medline](#)]
 - 8) Lötters F, van Tol B, Kwakkel G, et al.: Effects of controlled inspiratory muscle training in patients with COPD: a meta-analysis. *Eur Respir J*, 2002, 20: 570–576. [[Medline](#)] [[CrossRef](#)]
 - 9) Yokoba M, Abe T, Katagiri M, et al.: Respiratory muscle electromyogram and mouth pressure during isometric contraction. *Respir Physiol Neurobiol*, 2003, 137: 51–60. [[Medline](#)] [[CrossRef](#)]
 - 10) Hawkes EZ, Nowicky AV, McConnell AK: Diaphragm and intercostal surface EMG and muscle performance after acute inspiratory muscle loading. *Respir Physiol Neurobiol*, 2007, 155: 213–219. [[Medline](#)] [[CrossRef](#)]
 - 11) Nepomuceno V, Nepomuceno E, Regalo S, et al.: Electromyographic study on the sternocleidomastoid and pectoralis major muscles during respiratory activity in humans. *J Morphol*, 2014, 31: 98–102. [[CrossRef](#)]
 - 12) Enright SJ, Unnithan VB: Effect of inspiratory muscle training intensities on pulmonary function and work capacity in people who are healthy: a randomized controlled trial. *Phys Ther*, 2011, 91: 894–905. [[Medline](#)] [[CrossRef](#)]
 - 13) Jung JH, Shim JM, Kwon HY, et al.: Effects of abdominal stimulation during inspiratory muscle training on respiratory function of chronic stroke patients. *J Phys Ther Sci*, 2014, 26: 73–76. [[Medline](#)] [[CrossRef](#)]
 - 14) Tamplin J, Brazzale DJ, Pretto JJ, et al.: Assessment of breathing patterns and respiratory muscle recruitment during singing and speech in quadriplegia. *Arch Phys Med Rehabil*, 2011, 92: 250–256. [[Medline](#)] [[CrossRef](#)]
 - 15) da Silva ÁM, Cliquet A Jr, Boin IF: Profile of respiratory evaluation through surface electromyography, manovacuometry, and spirometry in candidates on the liver transplant waiting list. *Transplant Proc*, 2012, 44: 2403–2405. [[Medline](#)] [[CrossRef](#)]
 - 16) Mañanas MA, Jané R, Fiz JA, et al.: Study of myographic signals from sternomastoid muscle in patients with chronic obstructive pulmonary disease. *IEEE Trans Biomed Eng*, 2000, 47: 674–681. [[Medline](#)] [[CrossRef](#)]
 - 17) Costa D, Vitti M, de Oliveira Tosello D, et al.: Participation of the sternocleidomastoid muscle on deep inspiration in man. An electromyographic study. *Electromyogr Clin Neurophysiol*, 1994, 34: 315–320. [[Medline](#)]
 - 18) Kim K, Fell DW, Lee JH: Feedback respiratory training to enhance chest expansion and pulmonary function in chronic stroke: a double-blind, randomized controlled study. *J Phys Ther Sci*, 2011, 23: 75–79. [[CrossRef](#)]
 - 19) Jung JH, Kim NS: The effect of progressive high-intensity inspiratory muscle training and fixed high-intensity inspiratory muscle training on the asymmetry of diaphragm thickness in stroke patients. *J Phys Ther Sci*, 2015, 27: 3267–3269. [[Medline](#)] [[CrossRef](#)]