

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

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Abstract. [Purpose] This study investigated the effects of progressive load and fixed load high-intensity inspiratory muscle training on the asymmetry of diaphragm thickness in stroke patients. [Subjects] Twenty-one stroke patients were assigned to one of three groups: progressive load high-intensity inspiratory muscle training (n = 8), fixed load high-intensity inspiratory muscle training (n = 6), and controls (n = 7). [Methods] The progressive load and fixed load high-intensity inspiratory muscle training participants undertook an exercise program for 20 minutes, three times weekly, for 6 weeks. After each session, diaphragm thickness was measured using ultrasonography. The diaphragm asymmetry ratio and diaphragm thickening ratio were standardized using a formula. [Results] After intervention, the diaphragm asymmetry ratio significantly differed among the three groups, and the diaphragm asymmetry ratio significantly increased in the control group. A significant increase was identified in the diaphragm thickening ratio within the progressive load and fixed load high-intensity inspiratory muscle training groups. [Conclusion] Progressive load and fixed load high-intensity inspiratory muscle training decreased the asymmetry of diaphragm thickness in stroke patients; this effect, in turn, increased the diaphragm thickening ratio in stroke patients. The two interventions examined here should be selectively applied to individuals in the clinical field.

Key words: Diaphragm thickness asymmetry, High-intensity inspiratory muscle training, Stroke

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INTRODUCTION

Stroke patients show impaired coughing ability owing to respiratory muscle weakness and changed chest wall kinematics. Respiratory muscle weakness appears in the acute stages of stroke^{1, 2)}. It is caused by impaired central drive to the muscles rather than reduction in intrinsic muscle strength¹⁾. Irrespective of the mechanism, a means of improving respiratory muscle strength and central drive to the muscle may be beneficial for stroke patients^{1, 3, 4)}. Furthermore, it has been reported that hemiplegia resulting from stroke damages the voluntary motor functions and coordination of the trunk muscle, causing abnormalities in posture and muscle tone^{4, 5)}, damage to motor control function necessary for coordination of the respiratory muscles³⁾, and increased asymmetry of the paretic and nonparetic sides of the diaphragm⁵⁾.

In patients with such neurological problems, respiratory muscle training may have a beneficial effect on respiratory muscle function. In particular, inspiratory muscle training (IMT) has been widely applied to patients suffering from different diseases to improve inspiratory muscle strength and endurance, exercise capacity, and dyspnea^{2, 6-9)}. A potential treatment aimed at enhancing muscle function and cough ability and decreasing chest infections could benefit stroke patients¹⁰⁾. Such a treatment could improve stroke patients' activities of daily living, quality of life, walking ability, and cardiorespiratory fitness¹⁻⁴⁾. However, interest in effective rehabilitation strategies aimed at improving stroke patients' respiratory muscle function is relatively low¹⁾.

IMT intensity and methods have been controversial in the past. In recent research, IMT training intensity has been studied for multiple diseases, and high-intensity IMT was presented as the most appropriate training method for increasing maximum inspiratory pressure (MIP), sustained MIP, lung volume, and work capacity^{7, 11, 12)}. However, another study suggested that there was no difference between high- and low-intensity IMT, making the effectiveness of IMT controversial¹³⁾. Some preliminary clinical studies of stroke patients conducted IMT with gradual pressure load in exercise intensity according to an individual's MIP^{3, 4)}. However, studies have not yet examined the effect of high-

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Table 1. Within-group and between-group comparisons of outcome measures

| | PH-IMT group (n = 8) | | | FH-IMT group (n = 6) | | | Control group (n = 7) | | |
|-----------------------|----------------------------|-------------|----------------------|---------------------------|-------------|----------------------|---------------------------|-------------|---|
| | Pre | Post | p value ^a | Pre | Post | p value ^a | Pre | Post | p value ^a p value ^b |
| | Mean difference | | | Mean difference | | | Mean difference | | |
| Asym D _{rel} | 0.05 ± 0.05 | 0.09 ± 0.09 | | 0.10 ± 0.10 | 0.03 ± 0.04 | | 0.07 ± 0.05 | 0.18 ± 0.12 | * * |
| | 0.03 ± 0.08 ^{†‡} | | | -0.06 ± 0.12 [†] | | | 0.10 ± 0.09 [‡] | | |
| Asym D _{con} | 0.13 ± 0.14 | 0.10 ± 0.11 | | 0.16 ± 0.12 | 0.08 ± 0.09 | | 0.07 ± 0.05 | 0.23 ± 0.10 | * * |
| | -0.02 ± 0.18 ^{†‡} | | | -0.08 ± 0.17 [†] | | | 0.15 ± 0.14 [‡] | | |
| Asym TR | 0.12 ± 0.12 | 0.10 ± 0.05 | | 0.14 ± 0.10 | 0.11 ± 0.08 | | 0.09 ± 0.02 | 0.13 ± 0.09 | |
| | -0.01 ± 0.16 | | | -0.03 ± 0.16 | | | 0.03 ± 0.11 | | |
| TR-P | 1.65 ± 0.26 | 2.25 ± 0.48 | * | 1.96 ± 0.31 | 2.22 ± 0.33 | | 1.66 ± 0.19 | 1.60 ± 0.25 | * |
| | 0.59 ± 0.41 [†] | | | 0.25 ± 0.37 ^{†‡} | | | -0.06 ± 0.24 [‡] | | |
| TR-NP | 1.65 ± 0.32 | 2.12 ± 0.27 | * | 1.75 ± 0.12 | 2.11 ± 0.11 | * | 1.70 ± 0.26 | 1.68 ± 0.32 | * |
| | 0.46 ± 0.26 [†] | | | 0.35 ± 0.09 [†] | | | -0.01 ± 0.30 [‡] | | |

^aWithin-group comparisons. ^bBetween-group comparisons.

Asym D_{rel}: asymmetry of diaphragm thickness at functional residual capacity; Asym D_{con}: asymmetry of diaphragm thickness at total lung capacity; Asym TR: asymmetry of thickening ratio; TR-P: thickening ratio of the paretic side; TR-NP: thickening ratio of the nonparetic side

*p < 0.05. †, ‡Statistical significance (p < 0.05)

intensity IMT using the methods for applying pressure load to stroke patients. Therefore, this study aimed to verify the effects of progressive load high-intensity IMT (PH-IMT) and fixed load high-intensity IMT (FH-IMT) on stroke patients' diaphragm asymmetry and to identify an IMT method appropriate for stroke patients.

SUBJECTS AND METHODS

The participants were 21 stroke patients (PH-IMT group: n = 8, FH-IMT group: n = 6, control group: n = 7) who had a full understanding of, and voluntarily consented to participate in, this study. The stroke patients had the disease for at least 6 months. The PH-IMT group consisted of 4 males and 4 females whose average age, height, weight, and body mass index (BMI) were 56.25 ± 6.04 years, 157.40 ± 7.20 cm, 60.01 ± 9.72 kg, and 24.18 ± 3.31 kg/m², respectively. The FH-IMT group consisted of 3 males and 3 females whose average age, height, weight, and BMI were 59.83 ± 8.44 years, 157.83 ± 7.70 cm, 59.76 ± 10.70 kg, and 23.87 ± 3.01 kg/m², respectively. The control group consisted of 4 males and 3 females whose average age, height, weight, and BMI were 62.85 ± 12.82 years, 161.58 ± 11.95 cm, 58.24 ± 9.19 kg, and 22.21 ± 1.39 kg/m², respectively. This study was approved by the Catholic of Pusan university institutional review board (CUPIRB-2013-021). The subjects were all patients who had been diagnosed with stroke using computed tomography. The criteria for selecting subjects for this study followed the standard set by previous research⁴. Before applying an intervention to each group, A spirometer (CHESTGRAPH HI 101, Chest M.I. Inc., Tokyo, Japan) was used to measure pulmonary function (forced vital capacity [FVC], forced expiratory volume in 1 second [FEV₁], FEV₁/FVC ratio, and peak expiratory flow [PEF])^{4, 14}. Changes in diaphragm thickness were measured using ultrasonography (Logiq 7, GE Healthcare, Arizona, USA) based on a previously proposed method^{6, 14, 15}. The diaphragm thickness

ratio (TR) was standardized using the following formula: TR = (diaphragm thickness during MIP maneuver of functional residual capacity [FRC] / mean thickness while relaxing at FRC). The diaphragm asymmetry ratio was calculated as |1 - (paretic diaphragm thickness/nonparetic diaphragm thickness)|⁵.

For IMT training, a Threshold[®] Inspiratory Muscle Trainer (Respironics, Cedar Grove, NJ, USA) was employed using a method modified from previous studies. The PH-IMT group started to receive training with MIP (PI_{max}) at 30%, and exercise intensity was gradually increased by 5–10% in each session; the exercise session was considered complete when the Borg scale rating for perceived exertion score (RPE) reached 16 for each individual^{3, 4, 6}. The FH-IMT group began to receive training with PI_{max} at 80% and maintained exercise intensity¹⁰. Each intervention was conducted for sessions that lasted 20 minutes, three times per week, for 6 weeks, and a total of six resting times (60 to 45, 30, 15, 10, and 5 seconds) were provided^{11, 14}. The collected data were analyzed using PASW Statistics for Windows version 18.0. A paired t-test was conducted to verify changes within each group, and one-way analysis of variance was used to examine differences among the three groups. Duncan's post hoc analysis was employed. Statistical significance was set at p < 0.05.

RESULTS

The effects of the interventions over time within each group, and the results of comparisons among the groups after a 6-week intervention period, are set forth in Table 1.

DISCUSSION

Respiratory muscles, including the diaphragm, are morphologically or functionally skeletal muscles. Therefore, their responses may differ according to the type and intensity of

training using the appropriate physiological load, as do other skeletal muscles; in addition, respiratory muscle training using an appropriate load can potentially increase diaphragm thickness^{5, 11}). Further, in hemiplegic patients, the paretic and nonparetic sides of the diaphragm become more asymmetrical in thickness, and changes in the contraction of the diaphragm also become asymmetric; because the diaphragm is a major inspiratory muscle, this asymmetry can result in functional abnormality of the respiratory muscles⁵). In addition, previous studies have reported that when appropriate respiratory muscle training was not given, stroke patients' diaphragm thickness asymmetry increased, worsening their pulmonary functional disability^{4, 5}). In the present study as well, the control group's asymmetry (Asym) of diaphragm thickness at functional residual capacity (D_{rel}), Asym of diaphragm thickness at total lung capacity (D_{con}), and Asym of TR increased by 142%, 214%, and 33%, respectively, during 6 weeks. In contrast, the Asym D_{con} of the PH-IMT group and the FH-IMT group decreased by 15% and 50%, respectively, and the Asym TR of the PH-IMT group and FH-IMT group decreased by 8% and 21%, respectively; these results were consistent with those of previous research in which the diaphragm asymmetry ratio decreased with appropriate respiratory muscle training⁵). These results verify the finding that PH-IMT and FH-IMT are effective interventions for improving stroke patients' diaphragm thickness asymmetry ratio and related mobility.

This study examined whether fixed load resistance should be given during high-intensity IMT in the clinic, or whether changes in intensity should be periodically made for each session. The study results showed that both intervention methods were able to improve diaphragm thickness asymmetry ratio and diaphragm contraction. Such results were obtained because the principle of "overload", meaning that maximal training load should be applied to stimulate optimal physiologic adaptation within the skeletal muscle, was well applied¹²). The diaphragm and intercostal muscles are represented by the bilateral motor cortical regions; in addition, the diaphragm is reached via the corticospinal tract and has the same structure and contraction mechanism as the muscles of the extremities^{4, 16}). In stroke patients, damage to these mechanisms increases the muscle tone of the paretic side of the diaphragm and decreases the efficiency of contraction; further, this damage degrades the stability and mobility of the trunk⁴). Therefore, current research recommends the PH-IMT method based on the patient's RPE score rather than the FH-IMT method, in which high intensity should be maintained for patients whose trunk muscle tone is increased or who are at risk for high blood pressure and dizziness⁴). FH-IMT is considered effective for training aimed at strengthening the diaphragm muscle by improv-

ing diaphragm contractility. When high-intensity IMT is applied, individuals' clinical characteristics, fatigue level, and exercise endurance should be properly considered¹²). Thus, if the two interventions examined in this study are selectively applied to individuals in the clinical field, they will be helpful for effectively improving the functioning of stroke patients.

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