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ORIGINAL ARTICLE

The Effects of Complex Respiratory Exercise Therapy on Diaphragmatic Thickness and Auxiliary Respiratory Muscle Activity of Stroke Patients

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ABSTRACT

Background. This study aimed to examine the effects of complex respiratory exercise therapy on diaphragmatic thickness and the auxiliary respiratory muscle activity of stroke patients. **Objectives.** The study aims to investigate the effect of complex breathing exercises on diaphragm thickness and respiratory muscle activity on the paretic and nonparetic sides of stroke patients and provide basic clinical data. **Methods.** A clinical sample of 30 patients with Stroke was randomly assigned to either the Experimental Group (n=15), which underwent complex respiratory exercises, or the Control Group (n=15), which served neurodevelopmental treatment alone. The intervention comprised four 40-minute sessions per week for six weeks, followed by a post-test after the six weeks. And compare intra-group variations, a paired t-test was employed, while ANCOVA was used for inter-group variations. **Results.** Concerning intra-group changes, in the case of the experimental group, significant differences appeared in the diaphragm thickness and all muscles on the paretic and nonparetic sides ($p<0.01$) ($p<0.001$). In the case of the control group, significant increases in muscle activity appeared only in the rectus abdominis muscle and the external oblique abdominal muscle on the paretic and nonparetic sides ($p<0.05$) ($p<0.01$). Concerning differences between the groups, there were significant differences in the thickness of the diaphragm on the paretic and nonparetic sides, the muscle activity of only the sternocleidomastoid muscle on the paretic side, and the sternocleidomastoid muscle, the rectus abdominis muscle, and the external oblique abdominal muscle on the nonparetic side ($p<0.05$) ($p<0.01$) ($p<0.001$). **Conclusion.** Complex breathing exercises were found to increase the thickness of the diaphragm and improve the respiratory muscles safely and effectively in stroke patients. Therefore, it is thought that complex breathing exercises can be used as an effective intervention method to improve breathing in stroke patients. Therefore, more diverse studies using complex breathing exercises are needed.

KEYWORDS: ***Stroke, Diaphragm, Muscle Activity, Neurodevelopmental Treatment (NDT)***

INTRODUCTION

Stroke, a medical condition denoted by acute localized damage to the central nervous system due to ruptured or blocked cerebral vessels, serves as a principal cause of severe disabilities and death worldwide (1). Neurological deficits arising from stroke-related damage to the motor cortex and pyramidal tract manifest as symptoms of hemiparesis, which further exacerbate motor control disorders characterized by abnormal tension and volitional movements. This concurrent contraction of the trunk muscles adversely affects both the performance of motor and coordination of respiratory muscles (2). Prolonged hospitalization or increased time in bed

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due to stroke can lead to a significant decrease in efficient postural and motor control movements, indirectly or directly lowering the usage of respiratory muscles (3). A persistent weakening of these muscles can impair coughing and sputum clearance abilities, leading to the accumulation of secretions in the airway and decreased pulmonary compliance, thus increasing the likelihood of respiratory complications such as pneumonia (4, 5). Muscle weakness hinders motor performance, necessitating therapeutic interventions that can strengthen the function of respiratory muscles, reduce abnormal respiratory patterns, and enhance exercise tolerance. It is essential to address respiratory mechanism issues by ensuring sufficient chest expansion and maintaining appropriate lung capacity (6, 7). To resolve these issues, stroke patients are often subject to interventions such as the Threshold Inspiratory Muscle Training (Threshold IMT) device, a type of inspiratory muscle training. Studies have shown that such training improves inspiratory muscle strength, maximum inspiratory pressure, maximum expiratory pressure (8), muscle strength, and endurance, emphasizing the importance of inspiratory muscle training (9). Further, it has been proved that interventions with complex respiratory exercises can lead to improvements in the external oblique, internal oblique, and rectus abdominis muscles of the trunk, with enhancements being more apparent on the unaffected side compared to the affected side (10, 11). Although there are various studies intended to improve breathing in stroke patients, most of the studies evaluated only the paretic side fragmentarily. However, to improve breathing patterns, not only the paretic side but also the non-paretic side is important. Therefore, this study aims to investigate the effect of complex breathing exercises on diaphragm thickness and respiratory muscle activity on the paretic and nonparetic sides of stroke patients and provide basic clinical data.

MATERIALS AND METHODS

Research Design. This study employed a randomized controlled trial (RCT) design, where a sample of 31 stroke patients, adhering to the predefined selection criteria, were randomly assigned to two groups: the experimental group (16 patients) and the control group (15 patients). The experimental group received both Neurodevelopmental Treatment (NDT) and Complex Respiratory Exercise Therapy, while the control group received only NDT. Pre-intervention measurements included assessments of the thickness of the diaphragm (in both the affected and unaffected sides) and the Muscle Activity level of the respiratory accessory muscle. Each intervention was administered for 40 minutes, four times per week over six weeks. Post-intervention measurements, which mirrored the pre-intervention measurements, were taken following the six weeks.

Study Participants. The study was conducted from July 2022 to May 2023 on 31 stroke patients diagnosed with hemiparesis due to stroke and hospitalized in a specialized rehabilitation nursing hospital in Jeollanam-do, South Korea. After explaining the study's purpose and procedures, written consent was obtained from all participants via a standardized consent form. The criteria applied to select the participants are as follows: 1) more than six months have passed since the initial stroke diagnosis; 2) absence of pulmonary diseases, congenital thoracic deformities, or a history of rib fractures; 3) no specialized respiratory improvement therapy received. The general characteristics of the Study Participants. Experimental Groups (n=16) and Control Groups (n=10) did not differ significantly in age, height, weight, and MMSE-K performance. Thus, the two groups were equivalent (Table 1).

Table 1. General characteristics (Mean±SE)

Items	Experimental group (n = 16)	Control group (n = 15)	p
Age (years)	61.6±2.34	59.6±2.51	0.957
Hight (㎝)	171.2±4.56	170.1±3.69	0.475
Weight (㎏)	73.4±4.43	72.6±4.58	0.782
MMSE-K (㎏/㎡)	26.8±1.18	26.7±1.24	0.543

Diaphragm Thickness Measurement. Diaphragm thickness was evaluated using ultrasound (Logiq 7, GE, USA) with a linear array transducer (5.0~14.0 MHz) in B-mode. The thickness of the diaphragm was measured by measuring the two bright lines that are visible between the middle of the pleural line and the peritoneal line. To measure the thickness of the diaphragm, which is located below the intercoastal muscles, subjects were asked to perform maximal inhalation and exhalation, considering the large variations in thickness during these states. This procedure was repeated three times, with the average value (rate of change of thickness between inhalation & exhalation) calculated for both the affected and unaffected sides (12).

Measurement of Muscle Activity Level of the Respiratory Muscles. The muscular activity level of the respiratory muscles was measured using a four-channel surface electromyography system (MP 100 system, Biopac, USA) with a sampling rate of 1,000 Hz and a frequency band filter set between 30 and 450 Hz. Electromyography (EMG) signals were collected from bilateral sternocleidomastoid, scalene muscles, rectus abdominis, and external oblique muscles. During the basic (base) action, the effective amplitude value was measured by measuring the EMG signals while the subjects maintained a comfortable sitting posture for 10 seconds. This was repeated three times to obtain an average value. For a specific action, the EMG signals were measured when subjects performed 10 breaths at 30% of maximal inspiratory pressure (MIP) using a respiratory training device while maintaining a comfortable position (sitting posture). This was also repeated three times to obtain an average value (13, 14).

Interventions. Experimental Group After a 40-minute session of neurodevelopmental therapy, a 10-minute rest was taken, followed by the initiation of a combined respiratory exercise therapy. This sequence was deliberately arranged to minimize the influence of neurodevelopmental therapy and avoid interfering with respiratory muscle training designed for pulmonary function enhancement. The participants were seated on a chair with a backrest, wearing a nose clip, and employed resistance inspiratory muscle training and positive pressure expiratory muscle training devices. Both training sessions for expiratory and inspiratory muscles were divided into 5 sets, with 12 repetitions per set, and a one-minute rest was offered between sets. During this phase, resistance was set at 40% of maximum inspiratory and expiratory pressure, with a gradual increase of 5-10% in respiratory load each week, up to 60% (Figure 1) (15). Control Group. Therapies were administered based on neurodevelopmental therapy that is tailored to the individual's capabilities, focusing on core stability exercises for 40 minutes per session, under the supervision of an NDT-trained professional (Figure 2) (16).

Figure 1. Complex Respiratory Exercise.

Data Analysis. Data processing for this study was executed using SPSS 20.0 for Windows, with means and standard deviations calculated for all measurement items. The homogeneity of the participants' general characteristics was tested using Levene's test for equality of variances. To compare intra-group variations, a paired t-test was employed, while ANCOVA was used for inter-group variations, with the significance level set at α=0.05. The Sehan University Research Ethics Committee approved all research protocols. The clinical research registration service registration number is SH-IRB202061.

Figure 2. Neuro-Development Treatment.

RESULTS

There was a statistically significant increase in the thickness of the diaphragm for both paralyzed and non-paralyzed subjects during maximum inspiration (p<0.001). Both paralyzed and non-paralyzed subjects demonstrated statistically significant increases in all muscles (p<0.01) (p<0.001) (Table 2). No statistically significant differences were observed in diaphragm thickness. However, a significant increase was found in the external oblique and rectus abdomnis muscles of both paralyzed and non-paralyzed subjects (p<0.05) (p<0.01) (Table 3). Statistically significant differences were noted in the thickness of the diaphragm of both paralyzed and non-paralyzed subjects during maximum inspiration (p<0.001). The paralyzed subjects showed significant differences only in the sternocleidomastoid muscle (p<0.05), whereas the non-paralyzed subjects showed significant differences in the sternocleidomastoid, rectus abdominis, and external oblique muscles (p<0.05) (p<0.01) (Table 4).

Table 2. Comparison of Change in Experimental I Group (Mean±SE)

		Experimental group (n=16)		t	p
		pre-test	post-test		
Tdi.rel	paretci side Diaphragm	0.18±0.01	0.18±0.01	-1.500	.168
	non-paratic side Diaphragm	0.18±0.01	0.19±0.01	-1.449	.137
Tdi.con	paretci side Diaphragm	0.32±0.01	0.40±0.03	-7.650	.000*
	non-paratic side Diaphragm	0.33±0.01	0.39±0.02	-17.182	.000*
paretci side	SCM	44.46±1.63	45.73±1.90	-4.163	0.002*
	Scalenius Anterior	52.99±2.73	55.54±2.05	-3.997	0.003*
	Rectus abdominis	105.83±2.72	112.41±3.46	-4.245	0.002*
	External abdominal oblique	103.68±1.52	116.51±5.61	-6.652	0.000**
non paretci side	SCM	53.41±1.94	55.02±2.20	-4.759	0.001*
	Scalenius Anterior	62.68±2.03	64.02±2.39	-3.288	0.009*
	Rectus abdominis	187.95±5.26	227.95±13.46	-8.408	0.000**
	External abdominal oblique	184.75±5.12	218.19±10.42	-9.620	0.000**

Tdi.rel: diaphragm thickness at functional residual capacity; Tdi.con: diaphragm thickness at total lung capacity; *: means significant difference.

DISCUSSION

This study is intended to intervene in stroke patients with complex breathing exercises to investigate the effects of the intervention on the diaphragm and accessory muscles of respiration, which are related to respiration, on the paretic and non-paretic sides.

Table 3. Comparison of Change in Control group (Mean±SE)

		Control group (n=15)		t	p
		pre-test	post-test		
Tdi.rel	paretci side Diaphragm	0.18±0.01	0.18±0.00	-1.500	0.168
	non-paratic side Diaphragm	0.18±0.01	0.19±0.01	-1.449	0.372
Tdi.con	paretci side Diaphragm	0.33±0.01	0.34±0.01	-1.764	0.228
	non-paratic side Diaphragm	0.33±0.01	0.34±0.01	-2.000	0.154
paretci side	SCM	43.91±1.91	44.46±1.85	-1.797	0.106
	Scalenius Anterior	54.08±2.51	54.47±3.55	-0.563	0.587
	Rectus abdominis	103.99±1.45	111.34±4.82	-4.188	0.02*
	External abdominal oblique	103.17±1.82	113.54±4.91	-5.172	0.01*
non paretci side	SCM	52.52±1.63	53.11±1.41	-1.646	0.134
	Scalenius Anterior	62.78±2.06	62.73±2.40	0.074	0.943
	Rectus abdominis	186.21±6.28	216.77±6.24	-11.979	0.000**
	External abdominal oblique	184.74±5.30	203.79±11.34	-6.153	0.000**

Tdi.rel: diaphragm thickness at functional residual capacity; Tdi.con: diaphragm thickness at total lung capacity; *: means significant difference.

Table 4. Comparison of Changes between Groups (Mean±SE)

		Experimental group (n=16)		Control group (n=15)		F	p
		pre-test	post-test	pre-test	post-test		
Tdi.rel	paretci side Diaphragm	0.18±0.01	0.18±0.01	0.18±0.01	0.18±0.00	0.090	0.767
	non-paratic side Diaphragm	0.18±0.01	0.19±0.01	0.18±0.01	0.19±0.01	0.013	0.909
Tdi.con	paretci side Diaphragm	0.32±0.01	0.40±0.03	0.33±0.01	0.34±0.01	24.117	0.000*
	non-paratic side Diaphragm	0.33±0.01	0.39±0.02	0.33±0.01	0.34±0.01	189.831	0.000*
paretci side	SCM	44.46±1.63	45.73±1.90	43.91±1.91	44.46±1.85	5.061	0.038*
	Scalenius Anterior	52.99±2.73	55.54±2.05	54.08±2.51	54.47±3.55	4.097	0.059
	Rectus abdominis	105.83±2.72	112.41±3.46	103.99±1.45	111.34±4.82	1.016	0.328
	External abdominal oblique	103.68±1.52	116.51±5.61	103.17±1.82	113.54±4.91	2.882	0.108
non paretci side	SCM	53.41±1.94	55.02±2.20	52.52±1.63	53.11±1.41	5.199	0.036*
	Scalenius Anterior	62.68±2.03	64.02±2.39	62.78±2.06	62.73±2.40	3.521	0.075
	Rectus abdominis	187.95±5.26	227.95±13.46	186.21±6.28	216.77±6.24	5.290	0.034*
	External abdominal oblique	184.75±5.12	218.19±10.42	184.74±5.30	203.79±11.34	9.250	0.007**

Tdi.rel: diaphragm thickness at functional residual capacity; Tdi.con: diaphragm thickness at total lung capacity; *: means significant difference.

In this study, the diaphragm thicknesses in the experimental group intervened with complex breathing exercise therapy, and the control group applied with only neurodevelopmental therapy was compared. According to the results, in the case of the experimental group, only the diaphragm thicknesses on the paretic and nonparetic sides significantly increased during maximal inspiration, and in the case of the control group, there was no statistically significant difference in the diaphragm thicknesses on the paretic and nonparetic sides between during rest and maximal inspiration. Concerning differences between the groups, there were significant differences in diaphragm thicknesses on the paretic and nonparetic sides only during maximal inspiration. The results of this study are consistent with the results of other studies that intervened in patients with respiratory muscle training. In the case of stroke patients, postural control and respiratory functions are reduced due to restrictions on voluntary movements and trunk muscle atrophy (2), and the sternocleidomastoid muscle and the muscle scalenus anterior, which are accessory respiratory muscles, are paralyzed to interrupt the functions of the accessory respiratory muscles, leading to changes in breathing patterns (17). Kim and Jung (18) divided chronic stroke patients into an experimental group that intervened with inspiratory muscle resistance training for 6 weeks and a control group that applied general exercise to investigate asymmetry in diaphragm thickness. According to the results, there was no change in asymmetry during rest and inspiration in the experimental group, but a statistically significant increase in asymmetry was found in the control group. Although it was not verified that breathing training could improve the asymmetry of the diaphragm in stroke patients, it was reported that diaphragm asymmetry in stroke patients could increase if proper breathing training was not received. Jeong and Kang (19) reported that the thickness of the diaphragm on the paretic side was reduced compared to the non-paretic side in stroke patients, so the activity of the accessory muscles of respiration showed a negative correlation. Enright et al. (12) checked the effect of inspiratory muscle training on diaphragm thickness in healthy adults. They reported that there was no significant change in diaphragm thickness at rest after 8 weeks of exercise, but that there were significant increases in diaphragm thickness and rate of contraction during maximum inspiration. In addition, Gee et al. (20) reported that inspiratory and expiratory respiratory muscle training in athletes with quadriplegia due to spinal cord injury had significant effects on respiratory muscle strength and lung volume. Messaggi-Sartor et al. (21) reported that when they divided 109 stroke patients into 56 patients who performed breathing exercises and 53 patients who performed pseudo-movements and applied the intervention for 3 weeks, maximum expiratory pressure increased in the group that performed breathing exercises. Kim et al. (22) reported that respiratory muscle strengthening exercises are effective in improving respiratory functions in stroke patients thanks to the strengthening of the deep abdominal muscles and the diaphragm. Therefore, in this study, the diaphragm thickness was also found to have increased, because stroke patients who had reduced lung functions due to abnormal use of the diaphragm intervened with complex breathing exercises, using a breathing apparatus that applied resistance, thereby stimulating the diaphragm.

In this study, intragroup muscle activity levels were compared between the experimental group that intervened with complex breathing exercise therapy and the control group that applied only neurodevelopmental therapy. The results showed that the muscle activity of the sternocleidomastoid muscle, the muscle scalenus anterior, the rectus abdominis muscle, and the external oblique abdominal muscle on the paretic and nonparetic sides significantly increased in the experimental group, while the muscle activity of only the rectus abdominis muscle and the external oblique abdominal muscle on the paretic and nonparetic sides significantly increased in the control group. Concerning intergroup differences, statistically significant differences appeared only in the sternocleidomastoid muscle in the case of the paretic side and appeared in the sternocleidomastoid muscle, the rectus abdominis muscle, and the external oblique abdominal muscle in the case of the nonparetic side. In the case of normal breathing patterns, inspiration is carried out using the diaphragm, sternocleidomastoid muscle, and scalene muscle, and expiration is passively carried out due to the relaxation of those respiratory muscles (23). In situations where strong exhalation is necessary, such as coughing and sneezing, a strong contraction of the abdominal muscles is required (24). Narain and Puckree (25) stated that, when planning a respiratory physical therapy program for stroke patients, the activation of endurance, muscle strength, movement, and flexibility of the thoracic cage and the major muscles and minor muscles of the trunk are necessary for optimal ventilation of each lung area. Wang et al. (26) intervened in paralyzed patients with breathing exercises and thereafter reported that an increase in the muscle tone and stiffness of the respiratory muscles was correlated with the number of respiratory muscles. Park et al. (27) also reported that the muscle tone and stiffness of the sternocleidomastoid muscle, the external oblique abdominal muscle, the upper trapezius muscle, and the latissimus dorsi muscle on the nonparetic side were significantly increased compared to the paretic side to show an asymmetrical pattern. This is because, as the respiratory muscles on the paretic side are weakened, the thoracic cage on the nonparetic side is more excessively used for respiration. Boswell-Ruys et al. (28) investigated the effect of respiratory muscle training in quadriplegic subjects and reported that respiratory muscle training could improve respiratory muscle strength and reduce the occurrence of pulmonary complications. Moon et al. (29) intervened in patients with rib fractures with lung capacity strengthening apparatus exercises to investigate their lung functions over time and found that forced vital capacity values improved after the intervention compared to before the intervention and improved further over time. Cho and Lee (30) divided stroke patients into a group for breathing training, combining diaphragm resistance exercise and lip puckering exercise, and a group using a lung function strengthening training apparatus for 8 weeks. They reported that forced vital capacity and forced expiratory volume in 1 second increased more in the lung function strengthening training apparatus group. Seo (31) intervened in stroke patients with complex respiratory muscle training for 8 weeks to investigate muscle activity and reported that muscle activity increased by 39.8% in the rectus abdominis muscle, by 22.4% in the external oblique abdominal muscle, and by 28.1% in the internal oblique abdominal muscle. Jo et al. (32) intervened in stroke patients with respiratory muscle training for 8 weeks to investigate muscle activity and found that muscle activity increased by 6.65% in the rectus abdominis muscle, by 5.74% in the external oblique abdominal muscle, and by 4.81% in the intervening respiratory muscle. For the aforementioned reasons, it is judged that breathing training that strengthens the respiratory muscles at a certain time interval and intensity using respiratory equipment increases intra-abdominal pressure to promote the action of the diaphragm muscles and increases the activity of the accessory muscles of respiration, leading to the cooperative muscle contraction of the abdominal muscles so that respiratory muscles are activated.

CONCLUSION

The results of this study showed statistically significant differences in diaphragm thickness on the paretic side and respiratory muscle activity on the paretic and non-paretic sides in the experimental group intervened with complex breathing exercises. As such, the results confirmed that the breathing apparatus applied with resistance affects the breathing improvement of stroke patients. The limitations of this study are that, since the study was conducted only with patients who met the subject selection conditions at one medical institution, generalization to all patients would be difficult. In addition, occupational therapy, oriental medicine treatment, and daily life could not be controlled. Therefore, in future studies, these limitations should be complemented before conducting further studies.

APPLICABLE REMARKS

- The results reported in this study suggest that complex breathing exercises affect improving breathing in stroke patients.

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AUTHORS' CONTRIBUTIONS

Study concept and design: Jeong-Il Kang, Seung-Yun Baek. Acquisition of data: Seung-Yun Baek. Analysis and interpretation of data: Seung-Yun Baek. Drafting the manuscript: Jeong-Il Kang, Seung-Yun Baek. Critical revision of the manuscript for important intellectual content: Jeong-Il Kang. Statistical analysis: Jeong-Il Kang. Administrative, technical, and material support: Seung-Yun Baek. Study supervision: Jeong-Il Kang.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

REFERENCES

1. Sacco RL, Kasner SE, Broderick JP, Caplan LR, Connors JJ, Culebras A, Vinters HV. An updated definition of stroke for the 21st century: a statement for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2013;44(7):2064-89. [doi:10.1161/STR.0b013e318296aeca] [PMid:23652265]
2. de Almeida ICL, Clementino ACCR, Rocha EHT, Brandão DC, de Andrade AD. Effects of hemiplegy on pulmonary function and diaphragmatic dome displacement. Respir Physiol Neurobiol. 2013;178(2):196-201. [doi:10.1016/j.resp.2011.05.017] [PMid:21679778]
3. Polese JC, Pinheiro MB, Faria CD, Britto RR, Parreira VF, Teixeira-Salmela LF. Strength of the respiratory and lower limb muscles and functional capacity in chronic stroke survivors with different physical activity levels. Braz J Phys Ther. 2013;17:487-93. [doi:10.1590/S1413-35552012005000114] [PMid:24173350]

4. Kolb B, Mychasiuk R, Williams P, Gibb R. Brain plasticity and recovery from early cortical injury. Dev Med Child Neurol. 2011;53(4):4-8. [doi:10.1111/j.1469-8749.2011.04054.x] [PMid:21950386]
5. Sutbeyaz ST, Koseoglu F, Inan L, Coskun O. Respiratory muscle training improves cardiopulmonary function and exercise tolerance in subjects with subacute stroke: a randomized controlled trial. Clin Rehabil. 2010;24(3):240-50. [doi:10.1177/0269215509358932] [PMid:20156979]
6. Menezes KK, Nascimento LR, Ada L, Polese JC, Avelino PR, Teixeira-Salmela LF. Respiratory muscle training increases respiratory muscle strength and reduces respiratory complications after stroke: a systematic review. J Physiother. 2016;62(3):138-44. [doi:10.1016/j.jphys.2016.05.014] [PMid:27320833]
7. Frownfelter D, Dean E, Stout M, Kruger R, Anthony J. Cardiovascular and Pulmonary Physical Therapy E-Book: Evidence to Practice. Elsevier health sciences. 2022.
8. Kulnik ST, Birring SS, Moxham J, Rafferty GF, Kalra L. Does respiratory muscle training improve cough flow in acute stroke? Pilot randomized controlled trial. Stroke. 2015;46(2):447-53. [doi:10.1161/STROKEAHA.114.007110] [PMid:25503549]
9. Britto RR, Rezende NR, Marinho KC, Torres JL, Parreira VF, Teixeira-Salmela LF. Inspiratory muscular training in chronic stroke survivors: a randomized controlled trial. Archives of physical medicine and rehabilitation. 2011;92(2):184-90. [doi:10.1016/j.apmr.2010.09.029] [PMid:21272713]
10. Kim CY, Lee JS, Kim HD, Kim IS. Effects of the combination of respiratory muscle training and abdominal drawing-in maneuver on respiratory muscle activity in patients with post-stroke hemiplegia: a pilot randomized controlled trial. Top Stroke Rehabil. 2015;22(4):262-70. [doi:10.1179/1074935714Z.0000000020] [PMid:26258451]
11. Talasz H, Kremser C, Kofler M, Kalchschmid E, Lechleitner M, Rudisch A. Phase-locked parallel movement of diaphragm and pelvic floor during breathing and coughing-a dynamic MRI investigation in healthy females. Int Urogynecol J. 2011;22(1):61-8. [doi:10.1007/s00192-010-1240-z] [PMid:20809211]
12. Enright SJ, Unnithan VB, Heward C, Withnall L, Davies DH. Effect of high-intensity inspiratory muscle training on lung volumes, diaphragm thickness, and exercise capacity in subjects who are healthy. Physical therapy. 2006;86(3):345-54. [doi:10.1093/ptj/86.3.345] [PMid:16506871]
13 Yon SJ, Kim JH. Effect of Shoulder Abduction Angles on EMG Activity of the Abdominal Muscles during Single Leg Holding on the Foam Roller. J Kor Phys Ther. 2020;32(4):228-32. [doi:10.18857/jkpt.2020.32.4.228]
14 Jeong DK. The Effects of Breathing Exercise on Respiratory Synergist Muscle Activity and SpO 2 in Patients with Chronic Obstructive Pulmonary Disease. J Kor Phys Ther. 2015;27(4):234-9. [doi:10.18857/jkpt.2015.27.4.234]
15. Kim JS, Shin WS. The effects of respiratory muscle strengthening training on pulmonary function and gait ability in subacute stroke patients. Journal of Korean Society of Physical Medicine. 2013;8(4):489-96. [doi:10.13066/kspm.2013.8.4.489]
16. Jeong SA, Lee DW, Kim JY. The effect of pulmonary function and gait endurance on complex respiratory training and inspiratory muscle exercise in patient with stroke. Journal of Korean Entertainment Industry. 2017;(5):65-72.
17. Kang JI, Jeong DK. Effects of Deep Neck Strengthening Exercise on Pulmonary Function and Respiratory Activity in Patients with Chronic Stroke. AJMAHS. 2019;9(9):417-26.
18. Kim NS, Jung JH. The effects of breathing retraining on asymmetry of diaphragm thickness in stroke patients. J Korean Soc Phys Med. 2013;8(2):263-9. [doi:10.13066/kspm.2013.8.2.263]
19. Jeong DK, Kang JI. A Study on the Diaphragm and Respiratory Muscle Activity of Chronic Stroke Patients. AJMAHS. 2019;9(4):379-87.
20. Gee CM, Williams AM, Sheel AW, Eves ND, West CR. Respiratory muscle training in athletes with cervical spinal cord injury: effects on cardiopulmonary function and exercise capacity. J Physiol. 2019;597(14):3673-85. [doi:10.1113/JP277943] [PMid:31115056]
21. Messaggi-Sartor M, Guillen-Solà A, Depolo M, Duarte E, Rodríguez DA, Barrera MC, et al. Inspiratory and expiratory muscle training in subacute stroke: a randomized clinical trial. Neurology. 2015;85(7):564-72. [doi:10.1212/WNL.0000000000001827] [PMid:26180145]

22. Kim BR, Kang JI, Kim YN, Jeong DK. Effects of respiratory muscle strengthening exercise on respiratory function and activities of daily living in stroke patients. J Kor Phys Ther. 2017;29(1):1-6. [doi:10.12674/ptk.2017.24.4.001]
23. Cameron MH, Monroe LG. Physical Rehabilitation: Evidence-Based Examination. Evaluation, and Intervention. Philadelphia: Saunders. 2007;844-76.
24. Sapsford R. Rehabilitation of pelvic floor muscles utilizing trunk stabilization. Man Ther. 2004;9(1):3-12. [doi:10.1016/S1356-689X(03)00131-0] [PMid:14723856]
25. Narain S, Puckree T. Pulmonary function in hemiplegia. Int J Rehabil Res. 2002;25(1):57-9. [doi:10.1097/00004356-200203000-00008] [PMid:11953716]
26. Wang JS, Cho KH, Park SJ. The immediate effect of diaphragm taping with breathing exercise on muscle tone and stiffness of respiratory muscles and SpO2 in stroke patient. J Phys Ther Sci. 2017;29(6):970-3. [doi:10.1589/jpts.29.970] [PMid:28626302]
27. Park SJ, Kim SH, Min KO. The immediate effects of rib cage joint mobilization and chest wall stretch on muscle tone and stiffness of respiratory muscles and chest expansion ability in patients with chronic stroke. J Phys Ther Sci. 2017;29(11):1960-3. [doi:10.1589/jpts.29.1960] [PMid:29200634]
28. Boswell-Ruys CL, Lewis CR, Wijeysuriya NS, McBain RA, Lee BB, McKenzie DK, et al. Impact of respiratory muscle training on respiratory muscle strength, respiratory function and quality of life in individuals with tetraplegia: a randomised clinical trial. Thorax. 2020;75(3):279-88. [doi:10.1136/thoraxjnl-2019-213917] [PMid:31937553]
29. Moon D, Kim KH, Lee S. Effects of deep breathing with incentive spirometer on pulmonary function and O2 saturation by time process in patients with rib fracture. Jour. of KoCon.a. 2015;15(3):174-83. [doi:10.5392/JKCA.2015.15.03.174]
30. Cho YH, Lee SB. Impact of respiratory muscle exercises on pulmonary function and quality of sleep among stroke patients. J Korean Soc Phys Med. 2015;10(4):123-5. [doi:10.13066/kspm.2015.10.4.123]
31. Seo KC. The Effect of Pulmonary Function and Respiratory Muscle Activity in the Stroke Patients after Complex Breathing Exercise. Doctoral Degree. Graduate School, Daegu niversity. 2012.
32. Jo MR, Kim NS, Jung JH. The effects of respiratory muscle training on respiratory function, respiratory muscle strength, and cough capacity in stroke patients. J Korean Soc Phys Med. 2014;9(4):399-405. [doi:10.13066/kspm.2014.9.4.399]