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Original Article

The correlation between diaphragm thickness, diaphragmatic excursion, and pulmonary function in patients with chronic stroke

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Abstract. [Purpose] This study aimed to investigate the correlation between the diaphragm thickness and diaphragm excursion, and pulmonary function in individuals with stroke. [Subjects and Methods] One hundred fourteen patients who were clinically diagnosed with ischemic or hemorrhagic stroke were included. The diaphragm thickness and excursion were assessed using ultrasonography, and the diaphragm thickening ratio was standardized using a formula. To analyze pulmonary function, we measured the forced vital capacity, forced expiratory volume in one second, and peak expiratory flow. [Results] A statistically significant correlation was found between the diaphragm thickness, thickness ratio, and diaphragm excursion; and the forced vital capacity, forced expiratory volume in one second, and peak expiratory flow. [Conclusion] This study demonstrated that there is a relationship between respiratory function and diaphragm thickness and diaphragm excursion, especially in the paretic side of the diaphragm. Therefore, the role of the respiratory muscles of the paretic side is important in rehabilitation programs to improve the respiratory function of stroke patients.
Key words: Diaphragm thickness, Respiratory function, Stroke

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INTRODUCTION

Stroke not only causes weakness in the muscles of the upper and lower limbs, but it can also affect the respiratory system[1)]. Patients with stroke experience decreases in the maximal voluntary strength and inspiratory and expiratory muscle endurance[1–4)]. It is caused by impaired central drive to the muscles, rather than reduced intrinsic muscle strength[2)]. Furthermore, previous studies reported that stroke-induced hemiplegia caused damage to voluntary motor function and coordination of the trunk muscles due to abnormalities in posture and muscle tone[4, 5)], as well as impaired motor control, which are necessary for the coordination of the respiratory muscles[5)].

On the other hand, impaired hemispheric lesions that are caused by a stroke are followed by a phenomenon in which decreased chest wall movement on the paretic side and decreased contraction of the respiratory muscles[6, 7)] as well as relatively increased diaphragm movement on the non-paretic side, are combined[8)]. This mechanism leads to increased asymmetry in the respiratory muscles in patients with stroke[9)], causing the diaphragm, one of the major respiratory muscles, to dysfunction, which in turn triggers a decrease in the lung volume[10)].

Previous studies used the lung volume, maximal inspiratory pressure (MIP), and maximal expiratory pressure (MEP) as common measures to assess the respiratory function in stroke patients and the effectiveness of treatment interventions[2–4)]. However, these tests are based on the theory that measured airflow and pressure reflect the function of the respiratory muscles[11)]. Similar to stroke patients, those with impaired respiratory function due to problems with motor control require

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tests that can directly measure the function of the respiratory muscles on the paretic side[8].

For that purpose, the diaphragm thickness and excursion have been measured with ultrasound in a previous study[11]. The diaphragm thickness and thickening ratio are measured using the muscular cross-sectional area of the diaphragm to evaluate the diaphragm strength[12, 13], and the posterior dome of the diaphragm excursion is assessed using the diaphragmatic excursion technique[8, 11]. These tests facilitate the evaluation of the respiratory muscle function on the paretic and non-paretic sides of stroke patients and their respiratory muscle control.

Therefore, this study aimed to identify the impact of paretic-side diaphragm function on the pulmonary function of patients with stroke by assessing the correlation between diaphragmatic thickness and diaphragm excursion on the paretic side and pulmonary function in patients with stroke.

SUBJECTS AND METHODS

We included 114 patients who were diagnosed with stroke using computed tomography. The criteria for selecting subjects for this study followed the standard set by previous research[14, 15]. The participants had a full understanding of, and voluntarily consented to participate in, this study. In all patients, the onset of stroke occurred at least 6 months prior to the study. There were 59 men and 55 women, and the average age, height, weight, and body mass index were 57.29 ± 7.06 years, 159.30 ± 7.93 cm, 61.70 ± 10.62 kg, and 24.22 ± 3.29 kg/m^2, respectively. 64 patients had right-sided paresis and 48 patients had left-sided paresis, and 61 patients were infarction type and 53 patients were hemorrhage type. This study was approved by the institutional review board of the Catholic University of Pusan (Approval number: CUPIRB-2013–021).

A spirometer (CHESTGRAPH HI 101, Chest M.I. Inc., Tokyo, Japan) was used to measure the pulmonary function (the forced vital capacity [FVC], forced expiratory volume in 1 second [FEV1], FEV1/FVC ratio, and peak expiratory flow [PEF])[14, 16]. Changes in the diaphragm thickness and excursion were measured using ultrasonography (Logiq 7, GE Healthcare, Phoenix, AZ, USA), based on a previously proposed method[16–18].

The diaphragm thickness ratio (TR) was standardized using the following formula: TR=(diaphragm thickness during the MIP maneuver at the functional residual capacity [FRC] / the mean thickness while relaxing at FRC)[12].

To statistically analyze the data, we used Pearson's correlation test for parametric variables, and the results are expressed as the mean and standard deviation. The statistical significance was set at a p-value of <0.05. The collected data were analyzed using PASW Statistics for Windows version 18.0.

RESULTS

The measure of pulmonary function gave values of FVC, FEV_1, PEF, FEV_1/FVC of 1.92 ± 0.70 l, 1.74 ± 0.60 l, 3.32 ± 1.52 l/sec, 91.68 ± 7.65%, respectively. The diaphragm thickness and diaphragm excursion gave values of DE-P, DE-NP, D_{rel}-P, D_{rel}-NP, D_{con}-P, D_{con}-NP, TR-P, TR-NP of 4.64 ± 1.54 cm^2, 4.58 ± 1.46 cm^2, 0.19 ± 0.02 cm^2, 0.18 ± 0.02 cm^2, 0.36 ± 0.07 cm^2, 0.36 ± 0.06 cm^2, 1.91 ± 0.35, 1.91 ± 0.33, respectively.

The correlation between the diaphragm thickness and diaphragm excursion and spirometry variables is presented in Table 1.

DISCUSSION

Stroke patients have contralateral dysfunction of the ventilatory muscles due to impaired hemispheric lesions and reduced thoracic anteroposterior movement, as well as chest wall movement on the paretic side during voluntary deep breathing[6, 7]. These phenomena are attributed to the difference in ventilation response to CO_2 between the paretic and non-paretic sides[7] and tend to induce asymmetry in respiratory muscle activation and chest wall movement[9]. Previous studies have focused on discovering changes (usually decreases) in the diaphragm thickness and excursion on the paretic side after a stroke[8, 10].

Table 1. The correlation between diaphragm thickness and diaphragmatic excursion and spirometry variables

	DE-P	DE-NP	D_{rel}-P	D_{rel}-NP	D_{con}-P	D_{con}-NP	TR-P	TR-NP
FVC	0.558**	0.401**	−0.014	−0.164	0.430**	0.371**	0.414**	0.483**
FEV_1	0.544**	0.409**	−0.041	−0.197*	0.432**	0.367**	0.434**	0.504**
PEF	0.270**	0.251**	−0.046	−0.195*	0.264**	0.159	0.282**	0.299**
FEV_1/FVC	−0.159	−0.037	−0.136	−0.104	−0.048	−0.085	0.049	−0.008

FVC: forced vital capacity; FEV_1: forced expiratory volume in 1 second; PEF: peak expiratory flow; DE-P: diaphragmatic excursion of the paretic side; DE-NP: diaphragmatic excursion of the nonparetic side; D_{rel}-P: diaphragm thickness at the functional residual capacity of the paretic side; D_{rel}-NP: diaphragm thickness at the functional residual capacity of the nonparetic side; D_{con}-P: diaphragm thickness at the total lung capacity of the paretic side; D_{con}-NP: diaphragm thickness at the total lung capacity of the nonparetic side; TR-P: thickening ratio of the paretic side; TR-NP: thickening ratio of the nonparetic side.
**p<0.01, *p<0.05.

Therefore, this study aimed to identify the impact of the respiratory muscles on the paretic side on pulmonary function in stroke patients by assessing the correlation between the diaphragm and pulmonary functions.

Based on the results of this study, the diaphragm excursion on the paretic side and diaphragm thickness at the total lung capacity (TLC) were positively correlated, to a significant extent, with the FVC, which was one of the spirometry variables. These results are based on the underlying theory that an increase in the inspiratory volume in the range of 15–85% increases diaphragm excursion[19)] and that increased lung volume from the residual volume (RV) to TLC enables the diaphragm to both shorten by 25–35% and become thicker[12, 20)]. These results suggest that if stroke patients want to increase the FVC value, which is the maximal volume of air that is exhaled with the maximal force effort after maximal inspiration, their lung volume will vary based on the extent of paretic-side diaphragm participation[21)]. According to previous studies, to maintain the pre-existing inspiratory volume in stroke patients with decreased hemidiaphragm movement on the paretic side, respiratory compensation that increases hemidiaphragm movement on the non-paretic side occurs[10)]. In this study, the correlation between diaphragm function and FVC was greater on the paretic side than on the non-paretic side. That is, the respiratory activity of the diaphragm on the non-paretic side does not compensate for paresis in the diaphragm, thereby causing the overall lung capacity of stroke patients to decline[5, 7)]. Therefore, this result underlines the importance of paretic-side respiratory muscle function in changing the TLC of stroke patients.

The diaphragm excursion and thickness at the TLC on the paretic side were also significantly correlated with FEV1, which is measured using the first second of forced expiration from full inspiration[21)]. Forced expiration requires full inspiration, for which the diaphragm is actively involved. In particular, we confirmed that there was a positive correlation between the respiratory activity of the diaphragm on the paretic side and the first second of forced expiration. PEF also showed that there was a significant correlation between the diaphragm excursion and thickness ratio, but there was relatively low relevance. PEF indicates the maximum expiratory flow that is achieved during maximal forced expiration. To maintain adequate airflow, expiratory muscle activity is necessary because it can improve intrathoracic pressure[21)]. This is why PEF is not highly related to the activity of the diaphragm, one of the major inspiratory muscles[2, 21)].

In general, stroke patients exhibit restrictive patterns with reduced lung volume due to respiratory muscle weakness and altered chest wall kinematics[2, 4)]. The most essential treatment for these patients involves increasing respiratory muscle strength and the lung volume through improving the central drive to the muscle[2)]. This study confirms the importance of the contribution of the paretic-side respiratory muscles to boost the respiratory function in patients with stroke, and this result can be used for the training of the respiratory muscles in a clinical context.

This study has some limitations that should be acknowledged. Although the relationship between the thickness and excursion of the diaphragm, and pulmonary function was identified using ultrasonography, we did not evaluate other respiratory muscles in this study. Further studies are required to investigate the correlation between pulmonary function and other respiratory muscles such as the intercostal, parasternal, and abdominal muscles.

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