

Article

Effects of Inspiratory Muscles Training Plus Rib Cage Mobilization on Chest Expansion, Inspiratory Accessory Muscles Activity and Pulmonary Function in Stroke Patients

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Abstract: After stroke, limited ribcage movement may lead to impaired respiratory function. Combining threshold inspiratory muscle training with rib cage joint mobilization has been shown to enhance the recovery of respiratory function in patients with stroke. The present study investigated whether the combination of rib cage joint mobilization and inspiratory muscle training would improve chest expansion, inspiratory muscle activity, and pulmonary function after stroke. Thirty stroke patients were recruited and randomly assigned to one of the two groups, namely 6-week rib cage joint mobilization with inspiratory muscle training (experimental group) or inspiratory muscle training alone (control group). Outcome measures included upper and lower chest expansion, activity of accessory inspiratory muscles (latissimus dorsi (LD) and upper trapezius (UT)), and pulmonary function (forced vital capacity (FVC), forced expiratory volume in 1 s (FEV1), and peak expiratory flow (PEF)). All evaluations were conducted at baseline and after 6 weeks of inspiratory muscle training. Significant increases were observed in upper and lower chest expansion, LD and UT muscle activity, FVC, FEV1, and PEF in both the groups. Upper and lower chest expansion and muscle activity of UT and LD were significantly higher in the experimental group than in the control group. No significant differences were observed in FVC, FEV1, and PEF between the groups. Inspiratory muscle training is effective in improving chest expansion, inspiratory muscle activity, and pulmonary function after stroke. The addition of rib cage joint mobilization further increases chest expansion and inspiratory muscle activity.

Keywords: joint mobilization; inspiratory muscle training; chest expansion; pulmonary function; muscle activity

1. Introduction

The respiratory system in stroke patients is affected due to neurological impairment [1,2]. Decreased respiratory function in stroke patients may lead to an increased incidence of respiratory complications [3]. Therefore, stroke patients need respiratory physiotherapy to prevent and minimize the complications of respiratory failure [4].

Stroke patients usually exhibit a decrease in the chest wall movements on the paretic side [5], reduced respiratory muscle activity [6], and decreased pulmonary function [7]. Particularly, lower functional levels in stroke patients lead to inspiratory muscle weakness more frequently than expiratory muscle weakness [8]. Since the decrease in the inspiratory capacity in the chronic stage occurs due to rib cage contracture [9], intervention methods to address restrictive respiratory dysfunction in stroke

patients should be designed to increase the total volume of the ribcage [10] and to strengthen the inspiratory muscles [11].

In patients with chronic stroke, anteroposterior excursion of the affected hemithorax is decreased in deep breathing when compared with that of the nonaffected hemithorax [12]. Stroke patients showed a significant decrease in chest excursions compared to healthy subjects [13]. Total lung capacity is decreased when rib cage expansion is restricted. However, lung function returns to normal when the restriction is removed [14].

Joint mobilization is a manual therapy that applies passive movements to the joint capsules and the soft tissue to restore the arthrokinematics rather than the osteokinematics of the joint [15]. The sustained stretch mobilization performed in the present study is used to increase the range of motion by changing the viscoelastic structures [15]. Joint mobilization and inspiratory muscle training are used clinically to increase the inspiratory capacity in order to restore the chest wall movements. Thoracic spine joint mobilization can improve chest expansion [16], inspiratory muscle strength [17], pulmonary function [18], inspiratory function, and dynamic balance [19].

Although these interventions are commonly used in the clinical setting, evidence regarding the effectiveness of rib cage joint mobilization and inspiratory muscle training for chest expansion, inspiratory muscle activity, and pulmonary function in stroke patients is still lacking. In addition, not only the spine movements, but also the movements of the ribs are required for better expansion of the chest wall for respiration [20].

Therefore, the specific aim of the present study was to investigate the effect of the combination of ribcage joint mobilization and inspiratory muscle training on chest expansion, inspiratory muscle activity, and pulmonary function in stroke patients and to compare this effect with that of intervention with inspiratory muscle training alone.

2. Subject and Methods

2.1. Participants

The present study included 30 stroke patients admitted to the medical care hospital. Initially, 50 patients were recruited for the study. Among them, 30 patients met the include criteria. The inclusion criteria were (1) single stroke diagnosis and disease duration ≥ 6 months and < 24 months, (2) no restricted movement of the orbicularis oris muscle, (3) presence of abnormal findings on palpation during lateral flexion of the trunk [21], (4) no orthopedic surgery of the spine and no neurological disease except stroke, (5) Korean Mini-Mental State Examination score ≥ 24 , and (6) voluntary participation. The exclusion criteria were (1) no pulmonary function test; (2) skin allergic reaction after application of electrodes; (3) cardiopulmonary disease; (4) clinical symptoms of cardiopulmonary disease; (5) pain in the rib cage while breathing; (6) aphasia, apraxia, and hemineglect; and (7) severe dizziness or coughing during the tests.

2.2. Sample Size

To determine the sample size, software G*Power 3.19 (Heinrich Heine University, Dusseldorf, Germany) was used. Based on a pilot study of 6 subjects, the effect size was set at 1.46 (upper chest expansion) and 1.28 (lower chest expansion). The total required sample size (α error probability: 0.05, power: 0.80) was 18 and 20, respectively. In the present study, 30 subjects were included considering the dropouts.

2.3. Randomization

The present study was a single-blind randomized controlled clinical trial. The evaluation procedure (baseline) was performed after obtaining a signed informed consent from all subjects. Randomization was performed after the initial evaluation. Thirty subjects were randomly assigned to the experimental group (joint mobilization and inspiratory muscle straining, $n = 15$) or to the control

group (inspiratory muscle training alone, $n = 15$) using the “randomization.com” website. To minimize bias, randomization was performed ensuring homogeneity of baselines characteristics between the groups (Figure 1). The subjects were not informed about the alternative hypothesis and they were instructed not to discuss the information related to the intervention methods. The experimental and the control groups completed the 6-week intervention program followed by post hoc evaluation. The evaluator was blinded to the assignment of the subjects to the experimental group or the control group. All subjects gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of Yong-in University (2-1040966-AB-N-01-201506-HSR-033-1).

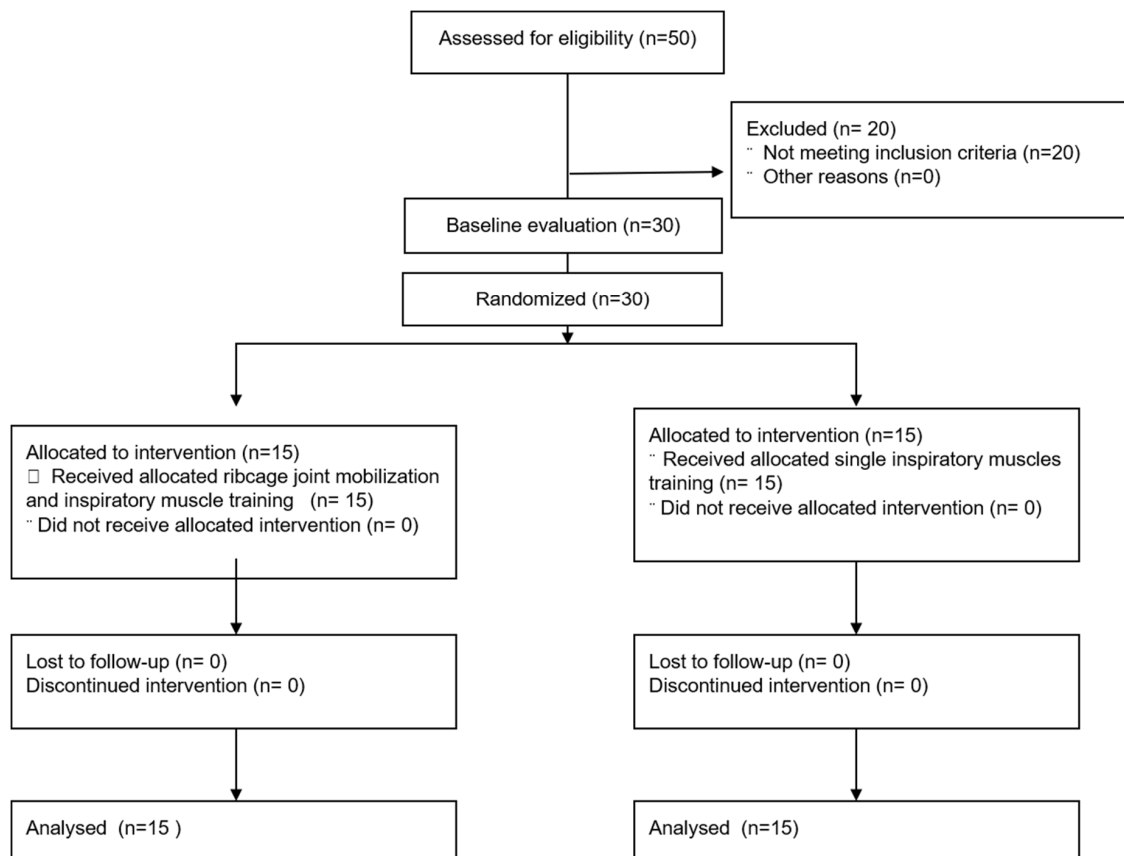


Figure 1. Flowchart of randomization.

2.4. Intervention Methods

Both groups underwent inspiratory muscle training. The experimental group was additionally subjected to rib cage joint mobilization. Patients in the control group were instructed to maintain the resting conditions for a period (10 min rest) similar to that of rib cage joint mobilization. Respiratory muscle training was performed under the guidance of four physical therapists including the researcher. All physical therapists had clinical experience of 5 to 10 years in stroke rehabilitation. Rib cage joint mobilization was performed under the guidance of a physical therapist who had more than 160 h of joint mobilization education. The experimental groups were applied with IMT (20 min) + mobilization (10 min). The control group was applied with IMT (20 min) + resting conditions (10 min rest). The intervention period was conducted for 30 min, three times per week for six weeks. During the IMT, all subjects received supervision from a physical therapist. The control group was supervised by the research assistants for a 10 min rest.

2.5. Rib Cage Joint Mobilization

To improve chest expansion (costovertebral region between the T5 and T10 vertebrae, third intercostal space) [22], rib cage joint mobilization was performed using the following three methods [15]. (1) Intercostal transverse frictional massage was applied to the third and the fourth intercostal space (intercostal muscles) with the patients lying on their sides. (2) For specific upper rib mobilization, transverse processes of the T5 vertebra were fixed and grade III sustained stretch technique (ventral-lateral-caudal direction) was applied to the rib at the costovertebral region of the T5 vertebra. (3) For specific lower rib mobilization, grade III sustained stretch technique was applied in the ventral-lateral-cranial direction to the rib at the costovertebral region of the T10 vertebra in the same way as described in the second method. Rib cage joint mobilization was applied to each segment thrice for 1 min (30 s mobilization, 30 s rest). The duration of intervention was approximately 10 min.

2.6. Inspiratory Muscle Training

A threshold inspiratory muscle training device (Philips Respironics, Murrysville, PA, USA) was used for inspiratory muscle training in order to improve the inspiratory muscle strength. First, assessment of maximal inspiratory pressures (MIP) was performed using Micro-RPM (Care Fusion, UK). The MIP was collected by performing a strong inspiration for 1 s in an occluded mouthpiece. The initial threshold was set to 30% of the MIP and the pressure was gradually increased using the Borg rating of perceived exertion (RPE) scale. For the exertion level of RPE 13, pressure was increased by 2 cm H₂O. For the exertion levels of RPE 13–15, pressure was increased by 1 cm H₂O. If the exertion level reached RPE 17, the pressure was lowered by 2 cm H₂O and the intervention was carried out not exceeding the exertion level of RPE 15. If discomfort was noticed during the intervention, pressure was reduced by 2 cm H₂O or rest was provided [23]. Inspiratory muscle training was applied in 3 sets of 30 breaths with 60-second rest between the sets [24].

2.7. Assessment Methods

The primary outcome variables were upper and lower chest expansion. The secondary outcome variables were inspiratory muscle activity (latissimus dorsi [LD] and upper trapezius [UT]) and pulmonary function. All outcome measures were evaluated by a physiotherapist not directly involved in this study. The outcome measures were evaluated at baseline and after 6 weeks of intervention.

2.7.1. Primary Outcome

The primary outcome measures used in the present study were upper and lower chest expansion. Chest expansion was measured using a measurement tape (Baseline 12–1201 with Gulick attachment, Fabrication Enterprises Inc., New York, NY, USA) to determine the difference between rib cage circumference at the end of forced expiration and rib cage circumference at the end of forced inspiration. Chest expansion measurement is highly reliable with an interexaminer intraclass correlation coefficient of 0.99 [22]. Before measuring the upper chest circumference, anatomical landmarks including the third intercostal space and the spinous process of the T5 vertebra were marked along the midclavicular line using markers harmless to the human body. Before measuring the lower chest circumference, anatomical landmarks including the tip of the xiphoid process and the spinous process of the T10 vertebra were marked. Chest circumference was measured horizontally using the measurement tape with the help of the marked reference points for tape placement.

2.7.2. Secondary Outcome

Secondary outcome measures included inspiratory muscle activity and pulmonary function. Wireless surface electromyography (Wave-Wireless EMG, Cometa, Italy) was used for the evaluation of inspiratory muscle activity. UT and LD muscles on the paretic side were selected for the measurement based on previous studies [25]. EMG measurements were performed in a sitting position. To measure

the activity of UT, the electrode was attached to the center of the line joining the acromion of the scapula and the C7 vertebra. To measure the activity of LD, an electrode was attached to the inferior angle of the scapula corresponding to the position of the T10 vertebra. Since it is difficult to calculate accurate maximal voluntary contraction values in stroke patients, normalization was performed using percentage reference voluntary contraction (RVCs) [26,27]. All subjects underwent a voluntary inspiratory contraction in a sitting position. Subjects maintained a voluntary inspiratory contraction for 5 s at the end of forced inspiration. For data analysis, assessor collected 3 s in the middle of 5 s contractions (excluding the initial 1 s and the final 1 s). Between trials, all subjects were given a 1 min break. The average of three trials for each muscle activity was taken as RVC. The EMG signals collected during involuntary breathing (automatic, unconscious process) were expressed as a percentage of the calculated RMS of RVCs (%RVC). To remove noise, band pass filtering was performed at 10–200 Hz of raw data and rectification was performed to root mean square 20 ms. For the removal of ECG artifacts, the evaluator manually selects EMG signal parts in between QRS complexes. The EMG sampling rate used in the present study was 2000 Hz. After removing foreign substances from the skin surface before EMG measurement, the electrode was wiped with medical alcohol and attached to the muscle belly.

Pulmonary function measures included FVC, FEV1, and PEF measured by a spirometer (MicroLab ML3500 MK6, CareFusion, Chatham, UK). In the preparatory phase of the measurement, the subjects were asked to wear a nose clip and a disposable mouthpiece. After breathing at rest for three times, maximum possible inspiration was performed followed by a strong exhalation for 6 s.

3. Statistical Analysis

The independent t-test, chi-squared test, and Kolmogorov–Smirnov test were used to confirm the homogeneity and normal distribution of the general characteristics at baseline (Table 1). The effects of treatment on chest expansion, inspiratory muscle activity, and pulmonary function were examined using two-way repeated measures analysis of variance. The baseline and the post-test (time) were the within-subjects factors. The experimental group and the control group were the between-subjects factors. When a significant difference was observed, t-test was used for the comparison of within-subjects factors (baseline and post-test; time) and the between-subjects factors (experimental and control group; interaction). Statistical significance was set at $\alpha = 0.05$. Statistical analysis was performed using IBM SPSS Statistics version 20.0 (IBM Corp., Armonk, NY, USA).

Table 1. Subject characteristics.

Classification	Experimental Group (n = 15)	Control Group (n = 15)	p-Value ^c	p-Value ^d
Gender (male/female)	10/5	10/5	0.100	
Paretic side (left/right)	7/8	7/8	0.100	
Pathogenesis (hemorrhages/infarction)	2/13	4/11	0.651	
Disease duration (months) ^a	15 ± 4	15 ± 5		0.723
Age (years) ^a	63 ± 7	64 ± 9		0.911
Weight (kg) ^a	65 ± 8	63 ± 8		0.639
Height (cm) ^a	168 ± 6	165 ± 6		0.351
K-MMSE ^e (point) ^a	26 ± 2	26 ± 1		0.241
K-NIHSS ^f (point) ^a	10 ± 2	11 ± 2		0.932
Baseline maximal inspiratory pressure				
Maximal inspiratory pressure (MIP, mmHg) ^b	47.00 ± 10.83	45.73 ± 10.53		0.748
MIP predicted normal absolute values ^b	78.47 ± 17.97	78.27 ± 18.53		0.976
% of MIP predicted normal values ^b	62.07 ± 16.82	62.00 ± 20.32		0.992
Baseline pulmonary function				
Forced vital capacity (FVC, ℓ) ^b	2.89 ± 0.81	2.65 ± 0.80		0.418
FVC predicted normal values ^b	3.08 ± 0.45	2.96 ± 0.45		0.472
% of FVC predicted normal values ^b	92.47 ± 18.65	90.40 ± 28.14		0.936
Forced expiratory volume in 1 s (FEV1, ℓ) ^b	2.32 ± 0.65	2.19 ± 0.68		0.596
FEV1 predicted normal absolute values ^b	2.83 ± 0.55	2.69 ± 0.53		0.512
% of FEV1 predicted normal values ^b	82.07 ± 18.53	82.73 ± 26.14		0.936
Peak expiratory flow (PEF, ℓ/min) ^b	276.67 ± 72.54	255.33 ± 75.52		0.437
PEF predicted normal absolute values ^b	432.40 ± 81.85	420.80 ± 85.54		0.707
% of PEF predicted normal values ^b	64.67 ± 15.90	64.53 ± 29.24		0.988

^a Values are denoted as mean (whole number) ± SD; ^b values are denoted as mean (include decimal place) ± SD;

^c Chi-square test among two intervention groups; ^d independent t test among two intervention groups; ^e K-MMSE: Korean-mini mental state examination; ^f K-NIHSS: Korean-national institute of health stroke scale.

4. Results

No significant differences were observed in the general characteristics at baseline between the experimental group and the control group (Table 1). Both the groups showed a significant increase in the upper and the lower chest expansion, muscle activity of UT and LD, FVC, FEV1, and PEF after the intervention when compared with the baseline values (Table 2). In addition, the experimental group displayed a significant increase in the upper and the lower chest expansion and in muscle activity of UT and LD when compared with the control group (Table 2).

Table 2. Changes of in primary outcome and secondary outcome on two intervention groups.

Measure/Group	Baseline Test ^a	Post-Test ^a	Within-Subjects Change ^b	Between Group Change ^b
Primary outcome				
Upper chest (cm)				
Experimental group	1.10 ± 0.65	2.52 ± 0.73	1.43 (1.09, 1.76) *	0.79 (0.37, 1.21) **
Control group	1.05 ± 0.42	1.69 ± 0.73	0.64 (0.35, 0.93) *	
Lower chest (cm)				
Experimental group	1.74 ± 0.95	3.32 ± 0.44	1.58 (1.18, 1.98) *	0.84 (0.40, 1.29) **
Control group	1.70 ± 0.61	2.43 ± 0.55	0.73 (0.50, 0.97) *	
Secondary outcome				
UT (%RVC)				
Experimental group	102.98 ± 2.29	139.91 ± 16.78	36.93 (27.68, 46.17) *	22.14 (11.35, 32.93) **
Control group	102.66 ± 2.65	117.44 ± 11.98	14.79 (8.29, 21.28) *	
LD (%RVC)				
Experimental group	103.99 ± 2.91	143.20 ± 17.86	39.21 (28.71, 49.71) *	24.15 (11.93, 36.36) **
Control group	103.55 ± 2.75	118.61 ± 13.79	15.06 (7.90, 22.22) *	
FEV1 (ℓ)				
Experimental group	2.32 ± 0.65	2.65 ± 0.61	0.33 (0.21, 0.45) *	0.12 (−0.06, 0.29)
Control group	2.19 ± 0.68	2.40 ± 0.77	0.22 (0.08, 0.35) *	
FVC (ℓ)				
Experimental group	2.89 ± 0.81	3.34 ± 0.71	0.45 (0.29, 0.60) *	0.18 (−0.33, 0.39)
Control group	2.65 ± 0.80	2.92 ± 0.90	0.27 (0.10, 0.43) *	
PEF (ℓ/min)				
Experimental group	276.67 ± 72.54	359.73 ± 79.83	83.07 (37.56, 128.57) *	10.87 (−50.93, 72.67)
Control group	255.33 ± 75.52	327.53 ± 93.51	72.20(26.20, 118.20) *	

^a Values are means (include decimal place) ± SD; ^b values are 95% confidence interval; * within subjects factors: significant increase than the baseline test; ** between-subjects factors (interaction): significant increase than the control group; experimental group: rib cage joint mobilization and inspiratory muscle exercise; control group: inspiratory muscle exercise; FEV1: forced expiratory volume in 1 s; FVC: forced vital capacity; PEF: peak expiratory flow; UT: upper trapezius muscle activity of paretic side; LD: latissimus dorsi muscle activity of paretic side.

5. Discussion

The results of the present study suggested that rib cage joint mobilization and inspiratory muscle training aimed at improving chest wall movements resulted in increased pulmonary function, increased chest expansion, and improved inspiratory muscle activity. Furthermore, it was observed that additional joint mobilization augments respiratory function when compared with inspiratory muscle training alone. These results indicate the importance of rib cage joint mobilization in pulmonary rehabilitation of stroke patients. These results are consistent with the results of other studies, which showed that addition of joint mobilization to conventional rehabilitation induces treatment effects on pulmonary function at which the respiratory intervention is specifically aimed [16–18,28].

When compared with studies regarding the effects of joint mobilization and manual therapy applied to the spine on respiratory function [18,19,28], the present study showed a wider range of therapeutic effects of rib cage joint mobilization such as improved chest expansion, inspiratory muscle activity, and pulmonary function.

A previous study evaluated respiratory function through the effect of only the pulmonary function after the application of cervical or thoracic mobilization. The wide range of therapeutic benefits observed in the present study may be explained by restricted chest wall movements and decreased pulmonary function in chronic stroke patients. Therefore, chest expansion and inspiratory muscle activity were additionally confirmed, and ribcage mobilization was applied. The variety of effects on inspiratory function may be explained by inspiratory muscle training and rib cage joint mobilization instead of spine mobilization [16] provided in the present study [24]. Thoracic kyphosis decreases respiratory function, while thoracic joint mobilization improves it with subsequent improvement in respiratory function. However, the movements required during inspiration are bucket handle movement and pump handle movement [20]. Rib cage joint mobilization was applied to increase the movement of the costovertebral joint and the costotransverse joint [15,16]. The movements of the ribs

from the thoracic spine can increase chest expansion by improving pump handle and bucket handle movements through rib cage joint mobilization [29,30].

Joint mobilization applied to T6 and T12 vertebrae was reported to increase the lower trapezius strength due to articular reflexogenic effects [31]. Joint mobilization increased maximal inspiratory pressure and maximal expiratory pressure in patients with chronic obstructive pulmonary disease [17]. Hence, the results of the present study may be attributed to increased rib cage flexibility and respiratory muscle length. Thus, inspiratory muscle activity may be improved through articular reflexogenic effects of rib cage joint mobilization, increased rib cage flexibility, and increased respiratory muscle length.

Stroke patients exhibit a significant decrease in pulmonary function and chest expansion when compared with healthy individuals [13]. Inspiratory muscle training has an indirect positive effect on FVC, FEV1, and PEF, which denote the expiratory pulmonary function [23]. In healthy people, FVC and FEV1 are positively correlated with upper and lower chest expansion [32]. However, stroke patients showed no significant correlation between pulmonary function and chest expansion [13]. Rib cage joint mobilization is designed to improve inspiration. The pulmonary function did not differ significantly between the experimental group and the control group. This finding may be attributed to the fact that FVC, FEV1, and PEF represent expiratory pulmonary function.

The strength of the present study is that it is the first study to confirm an improvement in chest expansion and inspiratory muscle activity after application of clinically performed rib cage joint mobilization. Joint mobilization is a field of orthopedic physical therapy related to musculoskeletal disorders. Recently, it has been applied to patients with neuromusculoskeletal disorders related to neurological and respiratory medical problems in addition to musculoskeletal disorders. Joint mobilization, which has been mainly applied for treatment or rehabilitation of injuries to the orthopedic system, needs to be applied to more diverse patients and conditions in the future.

The present study has several limitations. Rib cage joint mobilization requires skilled hand movements. In addition, care must be taken while performing joint mobilization, as the patient may complain of pain. The pulmonary function tests applied in the present study represent only the expiratory function. The residual volume or the maximal voluntary ventilation and inspiratory capacity were not analyzed in the present study. Since the patients included in this study suffered from mild to moderate stroke, the results cannot be generalized to all stroke patients. In order to further objectify the changes in this study, it is necessary to compare them with the no intervention group.

In order to support the hypothesis of this study, it is necessary to overcome these limitations and to conduct further studies. More studies are needed in the future to confirm the effectiveness of inspiratory muscle training with rib cage joint mobilization through various pulmonary function tests. In addition, a comparison with a third group with no intervention (a true control group) needs to be studied.

6. Conclusions

The present study showed that inspiratory muscle training improved inspiratory function in chronic stroke patients. In addition, it was confirmed that the addition of rib cage joint mobilization to inspiratory muscle training improved chest expansion and inspiratory muscle activity when compared with inspiratory muscle training alone. The present study provides new clinical evidence regarding the beneficial effect of rib cage joint mobilization for improving chest wall movements in chronic stroke patients. Future studies should investigate the effects of different intervention types with a variety of assessments to validate the results of this study.

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