Original Article

JER

https://doi.org/10.12965/jer.2550256.128

Journal of Exercise Rehabilitation 2025;21(3):131-139

Effects of inspiratory muscle training on pulmonary function, trunk stability, and balance in stroke patients: a stratified randomized controlled trial

Dae-Hee Lee, Hye-Joo Jeon*

Department of Physical Therapy, U1 University, Yeongdong, Korea

This study examined the impact of inspiratory muscle training (IMT) on respiratory function, trunk control, and balance in individual's post-stroke. Thirty stroke patients were randomly divided into an IMT group (n=15) and a conventional neurodevelopmental treatment (CNT) group (n=15). Both groups underwent 30-min sessions, 5 times per week, over 6 weeks. Respiratory function was measured using the POWERbreathe K5 and a spirometer. Balance was evaluated using the trunk impairment scale (TIS), Berg Balance Scale (BBS), and the Timed Up and Go (TUG) test. The IMT group showed significant improvements in maximal inspiratory pressure, maximal inspiratory flow rate, maximal inspiratory capacity, peak expiratory flow, and forced expiratory volume in 1 sec ($P<0.05$). The CNT group showed no significant changes in respiratory outcomes. Both groups improved in TIS, BBS, and TUG scores, with no significant differences between them. IMT led to notable gains in respiratory function and showed positive trends in trunk control and balance. These results indicate that IMT may be a beneficial addition to stroke rehabilitation focused on respiratory and postural improvement.

Keywords: Inspiratory muscle training, Respiratory function, Trunk control, Balance, Stroke

INTRODUCTION

Stroke is one of the primary causes of illness and long-term disability globally (Markus, 2023). Stroke is one of the leading causes of death and disability worldwide, with approximately 12 million new cases each year and over 100 million stroke survivors globally (Johnson et al., 2019). It affects not only sensory, motor, cognitive, and language functions but also significantly impairs respiratory function (Ghoreyshi et al., 2022). Respiratory dysfunction in stroke patients can result in reduced oxygen supply, weakened cough, difficulty clearing airway secretions, and decreased cardiopulmonary endurance, all of which can adversely affect physical health and quality of life (de Almeida et al., 2011).

Individuals who are bedridden or rely on a wheelchair often experience trunk muscle weakness and imbalance (Verheyden et al., 2014). Hemiplegia commonly leads to asymmetrical posture and increased trunk flexion, both of which can limit inspiratory capacity (Lima et al., 2014). Impaired trunk extension and postural asymmetry reduce the efficiency of the respiratory muscles and restrict chest wall movement, leading to diminished inspiratory and expiratory function (Britto et al., 2011). Studies have shown that stroke patients have significantly lower maximal inspiratory pressure (MIP, 17–57 cmH_2O) and maximal expiratory pressure (MEP, 25–68 cmH_2O) compared to healthy individuals (Menezes et al., 2016).

Respiratory muscle training is a structured approach designed to strengthen the inspiratory or expiratory muscles by increasing MIP and MEP (Illi et al., 2012). Among these methods, inspiratory muscle training (IMT) has been shown to improve respiratory function, reduce dyspnea, enhance postural stability and balance, and increase quality of life in individuals with stroke (Xiao et al., 2012). IMT is grounded in key principles of skeletal muscle conditioning—overload, specificity, and reversibility—and promotes increased diaphragmatic strength and thickness through progres-

*Corresponding author: Hye-Joo Jeon https://orcid.org/0000-0001-8491-3074
Department of Physical Therapy, U1 University, 310 Daehak-ro, Yeongdong-eup, Yeongdong 29131, Korea
Email: bluestar@u1.ac.kr
Received: May 5, 2025 / Revised: May 17, 2025 / Accepted: May 26, 2025

pISSN 2288-176X
eISSN 2288-1778

sive resistance (Souza et al., 2014; Zhang et al., 2020). The diaphragm plays a dual role in respiration and trunk stability through its co-activation with abdominal and spinal muscles, particularly during postural adjustments (Develi et al., 2021; Nason et al., 2012). This functional linkage supports the use of IMT to influence trunk control and balance in individuals recovering from stroke.

Stroke often results in respiratory dysfunction due to weakened inspiratory muscles, reduced lung volumes, and impaired neuromuscular control, increasing the risk of complications such as pneumonia (Sutbeyaz et al., 2010). IMT plays a vital role in rehabilitation by strengthening respiratory muscles, thereby improving pulmonary function, enhancing cough efficiency, and promoting oxygenation (Britto et al., 2011). IMT also improves exercise tolerance and functional recovery, making it a key component of poststroke rehabilitation.

Recent evidence from systematic reviews and meta-analyses has further substantiated the role of IMT in stroke rehabilitation. Zhang et al. (2024) conducted a meta-analysis demonstrating that respiratory muscle training significantly enhances MIP, MEP, forced vital capacity (FVC), and overall functional capacity in patients with early-stage stroke. In addition, Fabero-Garrido et al. (2022) reported that IMT contributes to measurable improvements in diaphragmatic thickness, inspiratory muscle strength, and exercise tolerance, highlighting its efficacy in promoting structural and functional recovery of the respiratory system in stroke survivors. Likewise, Li et al. (2024) found that threshold respiratory muscle training led to significant gains in both inspiratory and expiratory muscle strength, as well as improvements in pulmonary function parameters (e.g., FVC etc.) and exercise endurance, further supporting its integration into poststroke rehabilitation protocols.

Although a number of studies have investigated the effects of IMT on respiratory muscle strength and exercise capacity in individuals with stroke (Tovar-Alcaraz et al., 2021; Vaz et al., 2021), relatively few have explored its impact on trunk control and balance—both of which are critical for functional independence and fall prevention. Moreover, many existing studies are limited by small sample sizes or lack of methodological rigor. For instance, Aydoğan Arslan et al. (2022) reported notable improvements in respiratory function, trunk control, and balance following IMT; however, comprehensive, well-designed trials remain scarce.

This study aims to address these gaps by investigating the effects of IMT on respiratory function, trunk control, and balance in patients with subacute stroke using a stratified randomized controlled design. In particular, the study focuses on how targeted respiratory intervention may influence neuromuscular coordination essential for postural control. We hypothesized that a structured IMT protocol would elicit significant enhancements in respiratory performance, trunk stability, and balance, thereby contributing to a more comprehensive functional recovery in individual's poststroke.

METERIALS AND METHODS

Study design

This prospective, single-blind, stratified randomized controlled trial was conducted at Suwon Centum Hospital in South Korea between December 2024 and March 2025, with the study design illustrated in Fig. 1. The study protocol was approved by the Institutional Review Board of U1 University (IRB No. U1IRB2024-12).

Participants

Thirty stroke patients who were hospitalized during the study period and voluntarily provided informed consent after receiving a full explanation of the study objectives were enrolled. The required sample size was determined using the G*Power software (ver. 3.1, Franz Faul, University of Kiel), based on the effect sizes reported in prior research (Faul et al., 2007). A paired sample *t*-test was used, with an alpha level of 0.05, a power of 0.95, and an effect size of 1.61, indicating a minimum of 10 participants per group (20 in total). To accommodate possible dropouts, 30 participants were recruited. The inclusion criteria were (a) a clinical diagnosis of stroke, (b) age between 30 and 70 years with either patient or legal guardian consent, (c) the ability to walk independently for at least 10 m (use of assistive devices allowed), (d) no history of cardiovascular or respiratory disease, and (e) a score of 24 or higher on the Korean version of the Mini-Mental State Examination. Exclusion criteria were (a) not meeting the inclusion criteria and (b) voluntary withdrawal from the study for personal reasons. Participant characteristics are shown in Table 1.

Interventional methods

Thirty stroke patients were assigned to either the study group (n = 15) or the control group (n = 15) using a stratified randomization method. The study group received IMT, whereas the control group underwent conventional neurodevelopmental treatment. The intervention lasted for 6 weeks, with sessions conducted 5 times per week, each lasting 30 min.

Study group

IMT was carried out using the POWERbreathe K5 (POWERbreathe K5, International Ltd.). Each session lasted 30 min and

https://doi.org/10.12965/jer.2550256.128

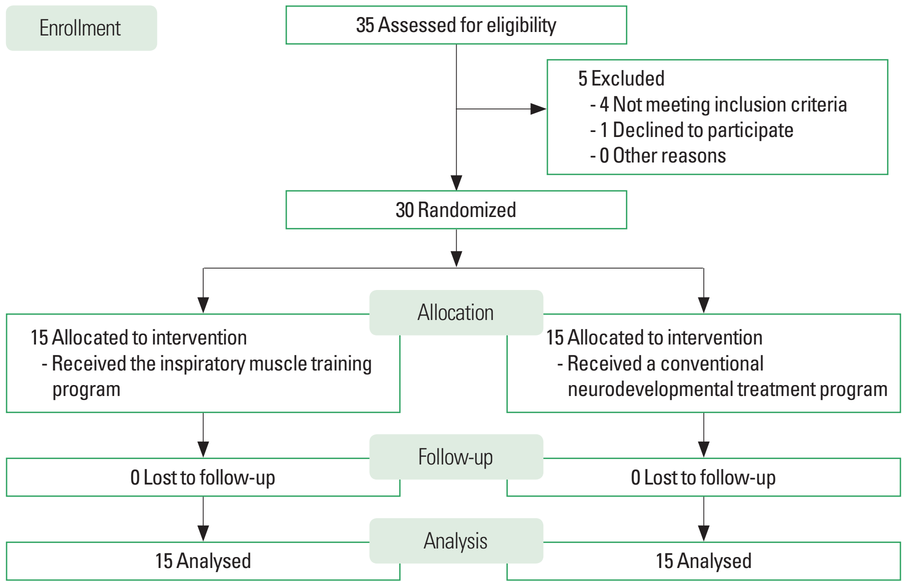

Fig. 1. Flow chart of study participants.

Table 1. General characteristics of both groups

Variable	Study group	Control group
Age (yr)	53.60±9.11	54.67±8.90
Weight (kg)	66.63±11.47	69.03±12.72
Height (cm)	166.48±8.49	169.13±9.71
Onset (mo)	11.40±2.09	11.93±2.57
Gender, male:female	7 (46.7):8 (53.3)	7 (46.7):8 (53.3)
Paretic side, left:right	9 (60.0):6 (40.0)	9 (60.0):6 (40.0)
Diagnosis, infarction:hemorrhage	7 (46.7):8 (53.3)	8 (53.3):7 (46.7)

Quantitative data (age, weight, height, and onset) are presented as mean±standard deviation and were analyzed using independent *t*-tests. Categorical data (gender, paretic side, and diagnosis) are presented as frequencies and percentages and were analyzed using the chi-square test.

included 15 min of diaphragmatic breathing, followed by two 5-min training sets, with a 5-min rest between sets. Participants used a nasal clip and sealed their lips tightly around the mouthpiece, fully exhaling their residual lung volume before performing a rapid and forceful inhalation. Training began at 40% of MIP resistance (auto mode–very light) and gradually increased to 60% (auto mode–moderate). IMT was supervised by a licensed physical therapist with more than 3 years of clinical experience in neurological rehabilitation and specialized training in respiratory therapy. To ensure consistency and reliability, all assessments were conducted by the same evaluator throughout the study period.

Control group

Neurodevelopmental treatment, a problem-solving approach, was customized according to each participant's functional status, specific needs, and preferences. The treatment included bridge exercises, stretching and elongation exercises, functional strengthening of trunk muscles, and balance and gait training. All sessions were conducted by a licensed physical therapist with over 3 years of clinical experience.

Assessment tools

Inspiratory function test

The inspiratory function was assessed using the POWERbreathe K5 device to measure MIP, maximal inspiratory flow, and maximal inspiratory volume. Assessments were performed with participants seated comfortably, using a mouthpiece. The device has high reliability, with intrarater reliability ranging from intraclass correlation coefficient (ICC)=0.959 to 0.986 and interrater reliability from ICC=0.933 to 0.985 (Lee et al., 2016).

Expiratory function test

Expiratory function was measured using a spirometer (PF-200, Microlife AG) to assess peak expiratory flow (PEF) and forced expiratory volume in 1 sec (FEV_1). Participants were seated comfortably, held the spirometer mouthpiece, performed a full inhalation, and then exhaled forcefully.

Trunk impairment scale

The trunk impairment scale (TIS) evaluates trunk control, static and dynamic balance, and coordination in individuals with neurological impairments. It consists of three subcomponents, with a total score ranging from 0 to 23: 6 points for static balance (maintaining an upright seated posture with feet on the ground and crossing the unaffected leg over the affected leg), 7 points for dynamic balance (assessing trunk control in the frontal plane), and 10 points for coordination (evaluating coordination between the head and upper and lower trunk). Higher scores indicate better trunk control. During the evaluation, the therapist may explain or demonstrate the movements. Each item was performed three times, and the highest score was recorded. The test-retest reliability ranges from 0.85 to 0.96, and the interrater reliability ranges from 0.85 to 0.99 (Fukata et al., 2021).

Timed Up and Go test

The Timed Up and Go (TUG) test measures the time it takes for a participant to stand from a seated position in a chair with armrests, walk 3 m forward, turn at a designated point, return to the chair, and sit back down. It is a reliable measure of balance, gait speed, and functional mobility. The intrarater and interrater reliability for the test is high, at $r=0.99$ and $r=0.98$, respectively. For this study, the test was performed 3 times, and the average time was used for analysis (Shumway-Cook et al., 2000).

Berg Balance Scale

The Berg Balance Scale (BBS) is used to objectively evaluate both static and dynamic balance in stroke patients. It includes 14 tasks, each rated from 0 to 4, with a maximum possible score of 56. Reported interrater and intrarater reliability for stroke populations are $r=0.98$ and $r=0.97$, respectively (Blum and Komer-Bitensky, 2008).

Statistical analysis

All statistical analyses were conducted using IBM SPSS ver. 18.0 (IBM Co.). The general characteristics of the participants were analyzed using descriptive statistics, with results presented as means and standard deviations. Group differences were evaluated using the chi-square test and independent t-test to ensure group homogeneity. Within-group pre- and postintervention comparisons were made using paired t-tests, and between-group differences in dependent variables were assessed using independent t-tests. Changes from pre- to postintervention between the study and control groups were also compared using independent t-tests. In addition, a two-way repeated measures analysis of variance was performed to examine the interaction effects between time (pre- and postintervention) and group (study and control). The significance level (α) for all analyses was set at 0.05. All assessments were performed 3 times, and the average value was used.

RESULTS

Inspiratory function

In the study group, MIP significantly increased from 36.10 ± 4.29 cmH_2O at baseline to 50.77 ± 4.81 cmH_2O after the intervention ($P<0.001$). In contrast, the control group showed no significant change, with MIP increasing slightly from 36.22 ± 3.16 cmH_2O to 36.60 ± 2.98 cmH_2O ($P>0.05$). The maximal inspiratory flow rate (MIFR) in the study group also increased significantly, from 1.54 ± 0.50 L/sec to 3.22 ± 0.65 L/sec ($P<0.001$). The control group showed no significant change, with MIFR increasing slightly from 1.69 ± 0.47 L/sec to 1.72 ± 0.49 L/sec ($P>0.05$). Maximal inspiratory capacity (MIC) in the study group significantly increased from 1.28 ± 0.39 L to 1.71 ± 0.33 L ($P<0.001$), whereas the control group showed no significant change, with MIC increasing slightly from 1.25 ± 0.35 L to 1.30 ± 0.35 L ($P>0.05$). Between-group comparisons revealed significant differences in MIP ($P<0.001$) and MIFR ($P<0.05$), while the difference in MIC was not statistically significant ($P>0.05$), as shown in Table 2.

Expiratory function

In the study group, PEF significantly increased from 277.40 ± 51.75 L/min to 383.30 ± 59.94 L/min ($P<0.001$). The control group showed no significant change, with PEF rising from 266.80 ± 43.69 L/min to 289.40 ± 58.90 L/min ($P>0.05$). FEV_1 in the

Table 2. Comparison of inspiratory function within and between groups

Variable	Study group	Control group	*P*-value
MIP (cmH_2O)			
Pretreatment	36.10 ± 4.29	36.22 ± 3.16	0.934
Posttreatment	50.77 ± 4.81	36.60 ± 2.98	< 0.001
P-value	< 0.001	0.090	
MIFR (L/sec)			
Pretreatment	1.54 ± 0.50	1.69 ± 0.47	0.416
Posttreatment	3.22 ± 0.65	1.72 ± 0.49	< 0.001
P-value	< 0.001	0.096	
MIC (L)			
Pretreatment	1.28 ± 0.39	1.25 ± 0.35	0.819
Posttreatment	1.71 ± 0.33	1.30 ± 0.35	0.003
P-value	< 0.001	0.353	

Values are presented as mean ± standard deviation.
MIP, maximal inspiratory pressure; MIFR, maximal inspiratory flow rate; MIC, maximal inspiratory capacity.

 https://doi.org/10.12965/jer.2550256.128

Table 3. Comparison of expiratory function within and between groups

Variable	Study group	Control group	*P*-value
PEF (L/min)			
Pretreatment	277.40±51.75	266.80±43.69	0.563
Posttreatment	383.30±59.93	289.40±58.90	<0.001
P-value	<0.001	0.124	
FEV_1 (L)			
Pretreatment	1.60±0.35	1.67±0.31	0.605
Posttreatment	2.27±0.48	1.68±0.32	0.001
P-value	<0.001	0.077	

Values are presented as mean±standard deviation.
PEF, peak expiratory flow; FEV_1, forced expiratory volume in 1 sec.

study group significantly increased from 1.60±0.35 L to 2.27±0.48 L ($P<0.001$). In contrast, the control group showed no significant change, with FEV_1 changing slightly from 1.67±0.31 L to 1.68±0.32 L ($P>0.05$). Between-group comparisons showed significant differences in PEF ($P<0.001$) and FEV_1 ($P<0.05$), as presented in Table 3.

Trunk impairment scale

TIS scores significantly improved in both groups. In the study group, scores increased from 11.40±3.59 to 14.73±2.98 ($P<0.001$), and in the control group, from 11.53±2.45 to 12.80±2.23 ($P<0.001$). However, the between-group difference was not statistically significant ($P>0.05$), as shown in Table 4.

Timed Up and Go

TUG scores significantly improved in both groups. The study group showed a decrease from 36.29±7.12 sec to 28.54±5.26 sec ($P<0.001$), and the control group from 34.24±6.90 sec to 31.89±5.83 sec ($P<0.001$). Despite improvements within each group, the between-group difference was not statistically significant ($P>0.05$), as shown in Table 4.

Berg Balance Scale

BBS scores also significantly improved in both groups. In the study group, scores increased from 34.87±3.54 to 38.47±2.70 ($P<0.001$), and in the control group, from 35.40±3.32 to 36.40±3.07 ($P<0.001$). However, the difference between groups was not statistically significant ($P>0.05$), as shown in Table 4.

Group, time, and interaction effects on functional outcomes following IMT

A mixed-design analysis of variance revealed statistically significant main effects of time for all outcome variables, indicating

Table 4. Comparison of balance ability within and between groups

Variable	Study group	Control group	*P*-value
TIS (score)			
Pretreatment	11.40±3.59	11.53±2.45	0.909
Posttreatment	14.73±2.98	12.80±2.23	0.062
P-value	<0.001	<0.001	
TUG (sec)			
Pretreatment	36.29±7.12	34.24±6.90	0.445
Posttreatment	28.54±5.26	31.89±5.83	0.121
P-value	<0.001	<0.001	
BBS (score)			
Pretreatment	34.87±3.54	35.40±3.32	0.684
Posttreatment	38.47±2.70	36.40±3.07	0.069
P-value	<0.001	<0.001	

Values are presented as mean±standard deviation.
TIS, Trunk impairment scale; TUG, timed up and go; BBS, Berg Balance Scale.

that both groups experienced overall improvements following the intervention. Specifically, significant time effects were observed for MIP, MIFR, MIC, PEF, FEV_1, TIS, TUG, and BBS, with all *P*-values less than 0.001 and large effect sizes (partial η^2 ranging from 0.469 to 0.822).

Significant main effects of group were also found for MIP ($P<0.001$, $\eta^2=0.575$), MIFR ($P<0.001$, $\eta^2=0.384$), and PEF ($P=0.006$, $\eta^2=0.238$), indicating that the experimental group performed better than the control group regardless of time. The group effect for FEV_1 approached significance ($P=0.057$), while no significant group effects were found for MIC, TIS, TUG, or BBS.

Importantly, significant interaction effects between group and time were observed for all variables. This indicates that the magnitude of improvement over time differed significantly between the experimental and control groups. Notably, the experimental group demonstrated greater gains in respiratory function (MIP, MIFR, MIC, PEF, FEV_1), trunk control (TIS), mobility (TUG), and balance (BBS) compared to the control group, with all interaction effects reaching statistical significance ($P<0.001$) and effect sizes ranging from moderate to large (partial $\eta^2=0.359$ to 0.680), as shown in Table 5.

DISCUSSION

The aim of this study was to examine the effects of IMT on respiratory function, trunk control, and balance in stroke patients. IMT plays a vital role in stroke rehabilitation, focusing primarily on maintaining and restoring pulmonary function (Chen et al., 2016). In this study, the study group showed significant improve-

Table 5. Results of mixed-design analysis of variance for within- and between-group effects

Variable	Main effect						Interaction effect		
	Time			Group			Group×Time		
	F	*P*-value	η^2	*F*	*P*-value	η^2	*F*	*P*-value	η^2
MIP (cmH_2O)	66.19	<0.001	0.703	37.59	<0.001	0.575	59.62	<0.001	0.680
MFIR (L/sec)	51.91	<0.001	0.650	17.48	<0.001	0.384	47.74	<0.001	0.630
MIC (L)	24.71	<0.001	0.469	3.11	0.089	0.100	15.67	<0.001	0.359
PEF (L/min)	39.90	<0.001	0.588	8.73	0.006	0.238	16.77	<0.001	0.375
FEV_1 (L)	47.74	<0.001	0.630	3.94	0.057	0.123	43.73	<0.001	0.610
TIS (score)	129.68	<0.001	0.822	0.72	0.404	0.025	26.18	<0.001	0.483
TUG (sec)	101.09	<0.001	0.783	0.08	0.783	0.003	28.95	<0.001	0.508
BBS (score)	97.45	<0.001	0.777	0.42	0.520	0.015	31.13	<0.001	0.526

MIP, maximal inspiratory pressure; MIFR, maximal inspiratory flow rate; MIC, maximal inspiratory capacity; PEF, peak expiratory flow; FEV_1, forced expiratory volume in 1 sec; TIS, trunk impairment scale; TUG, Timed Up and Go; BBS, Berg Balance Scale.

ments in MIP, MIFR, MIC, PEF, and FEV_1 after the intervention ($P<0.001$). In contrast, the control group did not demonstrate statistically significant changes ($P>0.05$). Between-group comparisons also revealed significant differences in MIP, MIFR, MIC, PEF, and FEV_1 ($P<0.05$), indicating that the intervention was effective in enhancing respiratory function.

The improvement in respiratory function was linked to increased respiratory muscle strength, especially in the study group, where MIP, MIC, and MIFR showed significant increases ($P<0.001$). This suggests that the intervention effectively strengthened the inspiratory muscles. Similar results have been observed in previous studies (Sutbeyaz et al., 2010), reinforcing the notion that IMT positively affects lung capacity and respiratory muscle strength. Additionally, the significant rise in MIFR indicates improved airway resistance and airflow dynamics, suggesting that the intervention may have enhanced respiratory efficiency. In a 9-week study on stroke patients, Britto et al. (2011) found that participants who underwent IMT showed significant improvements in MIP and endurance (Kim et al., 2014). Likewise, Chen et al. (2016) conducted a study on 21 stroke patients and reported a substantial increase in MIP in the group that received IMT compared to the control group.

The significant improvements in PEF and FEV_1 in the study group ($P<0.001$, $P<0.05$) indicate enhanced expiratory effort and lung function. These results suggest that IMT effectively boosts lung capacity and airflow velocity. The increase in FEV_1 also points to improved lung elasticity and airway patency. Since the control group did not show similar changes, it is likely that the intervention directly contributed to the improvement in pulmonary function. A study by Sutbeyaz et al. (2010) found that an IMT program led to improvements in both FEV_1 and PEF. Previous research has shown that IMT enhances FEV_1, suggesting that IMT may reduce the risk of stroke recurrence (Hodges and Gandevia, 2000). An increase in PEF reflects stronger respiratory muscles, a lower risk of respiratory infections, and improved expiratory function (Myint et al., 2005). In stroke patients, PEF is approximately one-third lower than in healthy elderly individuals (Hodges et al., 2001a), and a reduced FEV_1 has been linked to a higher risk of stroke and its recurrence (Hodges et al., 2001b). Both groups demonstrated significant improvements in TIS, TUG, and BBS, reflecting gains in balance and functional mobility. However, no significant differences were found between the groups ($P>0.05$). This suggests that both groups likely participated in a comparable level of physical activity or that the balance and mobility assessment tools used in this study might not have been sensitive enough to detect subtle effects of the intervention. Nevertheless, the study group showed a stronger trend of improvement, indicating that a longer intervention period might produce more noticeable differences between the groups.

IMT may also aid in trunk control and balance by strengthening the diaphragm, which is essential for core stability. The diaphragm's contraction increases intra-abdominal pressure, working in conjunction with the pelvic floor and abdominal muscles to improve postural control (Ferraro et al., 2019). These findings are consistent with research by Aydoğan Arslan et al. (2022), which emphasized IMT's positive effects on breathing, trunk control, and balance in stroke patients. Moreover, growing scientific evidence supports the role of IMT in enhancing balance. IMT targets the diaphragm and related core muscles, which are crucial for maintaining postural stability. For instance, Ferraro et al. (2019) conducted a randomized, double-blind, placebo-controlled study showing that 8 weeks of unsupervised, home-based IMT significantly

https://doi.org/10.12965/jer.2550256.128

improved balance in healthy older adults, as assessed by the Mini-Balance Evaluation Systems Test (Xiao et al., 2012). These improvements were attributed to enhanced inspiratory muscle strength and function, which likely contributed to better postural control. More recent studies also affirm IMT's comprehensive benefits. For example, Lee and Kim (2018) reported that respiratory training significantly improved trunk control, pulmonary function, and trunk muscle activity in chronic stroke patients. Similarly, Jung and Bang (2017) demonstrated improvements in walking ability and inspiratory muscle strength following IMT in subacute stroke patients. Oh et al. (2016) found that IMT positively affected balance and abdominal muscle thickness. These studies support the growing consensus that IMT is not only beneficial for respiratory recovery but also for functional mobility and core stability. The findings of this study demonstrated that IMT produced significant improvements in respiratory function, trunk control, mobility, and balance in stroke patients. While both the experimental and control groups showed improvements over time, the magnitude of change was significantly greater in the experimental group across all measured outcomes. These results support the efficacy of IMT as an effective adjunct to conventional rehabilitation in enhancing functional recovery following stroke. The large effect sizes observed, particularly in inspiratory function and trunk stability, highlight the clinical relevance of incorporating IMT into stroke rehabilitation protocols.

This study has several limitations. First, the relatively small sample size may limit the statistical power and restrict the generalizability of the findings. Second, the absence of long-term follow-up hinders the ability to determine the sustained effects of the intervention over time. Third, participants in the control group may have engaged in unsupervised or incidental physical activity, potentially affecting the outcomes and contributing to the lack of statistically significant differences in certain measures such as balance and mobility. Fourth, all participants were recruited from a single institution, which may result in a relatively homogeneous sample and limit the external validity of the results. To address these limitations, future research should include a larger and more diverse sample population, employ multicenter trials to enhance generalizability, and incorporate long-term follow-up assessments to evaluate the persistence of treatment effects. Moreover, using objective and standardized tools to monitor physical activity and functional performance-especially in the control group-would help clarify the true effects of the intervention.

In conclusion, this intervention effectively improved trunk control, balance, and both inspiratory and expiratory functions. These findings suggest that the intervention is a valuable exercise rehabilitation approach for individuals with impaired respiratory function.

CONFLICT OF INTEREST

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

ACKNOWLEDGMENTS

The authors received no financial support for this article.

REFERENCES

Aydoğan Arslan S, Uğurlu K, Sakizli Erdal E, Keskin ED, Demirgüç A. Effects of inspiratory muscle training on respiratory muscle strength, trunk control, balance and functional capacity in stroke patients: a single-blinded randomized controlled study. Top Stroke Rehabil 2022; 29:40-48.

Blum L, Korner-Bitensky N. Usefulness of the Berg Balance Scale in stroke rehabilitation: a systematic review. Phys Ther 2008;88:559-566.

Britto RR, Rezende NR, Marinho KC, Torres, JL, Parreira VF, Teixeira-Salmela LF. Inspiratory muscular training in chronic stroke survivors: a randomized controlled trial. Arch Phys Med Rehabil 2011;92:184-190.

Chen PC, Liaw MY, Wang LY, Tsai YC, Hsin YJ, Chen YC, Chen SM, Lin MC. Inspiratory muscle training in stroke patients with congestive heart failure: a CONSORT-compliant prospective randomized single-blind controlled trial. Medicine (Baltimore) 2016;95:e4856.

de Almeida IC, Clementino AC, Rocha EH, Brandão DC, Dornelas de Andrade A. Effects of hemiplegy on pulmonary function and diaphragmatic dome displacement. Respir Physiol Neurobiol 2011;178:196-201.

Develi E, Subasi F, Aslan GK, Bingol Z. The effects of core stabilization training on dynamic balance and pulmonary parameters in patients with asthma. J Back Musculoskelet Rehabil 2021;34:639-648.

Fabero-Garrido R, Del Corral T, Angulo-Díaz-Parreño S, Plaza-Manzano G, Martín-Casas P, Cleland JA, López-de-Uralde-Villanueva I. Respiratory muscle training improves exercise tolerance and respiratory muscle function/structure post-stroke at short term: a systematic review and meta-analysis. Ann Phys Rehabil Med 2022;65:101596.

Faul F, Erdfelder E, Lang AG, Buchner A. G*Power 3: a flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behav Res Methods 2007;39:175-191.

Ferraro FV, Gavin JP, Wainwright T, McConnell A. The effects of 8 weeks of inspiratory muscle training on the balance of healthy older adults: a randomized, double-blind, placebo-controlled study. Physiol Rep 2019;7:e14076.

Fukata K, Amimoto K, Inoue M, Sekine D, Inoue M, Fujino Y, Makita S, Takahashi H. Effects of diagonally aligned sitting training with a tilted surface on sitting balance for low sitting performance in the early phase after stroke: a randomised controlled trial. Disabil Rehabil 2021;43: 1973-1981.

Ghoreyshi Z, Nilipour R, Bayat N, Nejad SS, Mehrpour M, Azimi T. The incidence of aphasia, cognitive deficits, apraxia, dysarthria, and dysphagia in acute post-stroke Persian-speaking adults. Indian J Otolaryngol Head Neck Surg 2022;74(Suppl 3):5685-5695.

Hodges PW, Cresswell AG, Daggfeldt K, Thorstensson A. In vivo measurement of the effect of intra-abdominal pressure on the human spine. J Biomech 2001a;34:347-353.

Hodges PW, Gandevia SC. Activation of the human diaphragm during a repetitive postural task. J Physiol 2000;522 Pt 1(Pt 1):165-175.

Hodges PW, Heijnen I, Gandevia SC. Postural activity of the diaphragm is reduced in humans when respiratory demand increases. J Physiol 2001b;537(Pt 3):999-1008.

Illi SK, Held U, Frank I, Spengler CM. Effect of respiratory muscle training on exercise performance in healthy individuals: a systematic review and meta-analysis. Sports Med 2012;42:707-724.

Johnson CO, Nguyen M, Roth GA, Nichols E, Alam T, Abate D, et al. Global, regional, and national burden of stroke, 1990–2016: a systematic analysis for the Global Burden of Disease Study 2016. Lancet Neurol 2019;18:439-458.

Jung KM, Bang DH. Effect of inspiratory muscle training on respiratory capacity and walking ability with subacute stroke patients: a randomized controlled pilot trial. J Phys Ther Sci 2017;29:336-339.

Kim J, Park JH, Yim J. Effects of respiratory muscle and endurance training using an individualized training device on pulmonary function and exercise capacity in stroke patients. Med Sci Monit 2014;20:2543-2549.

Lee DK, Kim SH. The effect of respiratory exercise on trunk control, pulmonary function, and trunk muscle activity in chronic stroke patients. J Phys Ther Sci 2018;30:700-703.

Lee KB, Kim MK, Jeong JR, Lee WH. Reliability of an electronic inspiratory loading device for assessing pulmonary function in post-stroke patients. Med Sci Monit 2016;22:191-196.

Li L, Liu R, He J, Li J. Effects of threshold respiratory muscle training on respiratory muscle strength, pulmonary function and exercise endurance after stroke: a meta-analysis. J Stroke Cerebrovasc Dis 2024;33: 107837.

Lima IN, Fregonezi GA, Melo R, Cabral EE, Aliverti A, Campos TF, Ferreira GM. Acute effects of volume-oriented incentive spirometry on chest wall volumes in patients after a stroke. Respir Care 2014;59:1101-1107.

Markus HS. The global burden of stroke. Int J Stroke 2023;18:632-633.

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;62:138-144.

Myint PK, Luben RN, Surtees PG, Wainwright NW, Welch AA, Bingham SA, Wareham NJ, Day NE, Khaw KT. Respiratory function and self-reported functional health: EPIC-Norfolk population study. Eur Respir J 2005;26:494-502.

Nason LK, Walker CM, McNeeley MF, Burivong W, Fligner CL, Godwin JD. Imaging of the diaphragm: anatomy and function. Radiographics 2012;32:E51-E70.

Oh D, Kim G, Lee W, Shin MM. Effects of inspiratory muscle training on balance ability and abdominal muscle thickness in chronic stroke patients. J Phys Ther Sci 2016;28:107-111.

Shumway-Cook A, Brauer S, Woollacott M. Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test. Phys Ther 2000;80:896-903.

Souza H, Rocha T, Pessoa M, Rattes C, Brandão D, Fregonezi G, Campos S, Aliverti A, Dornelas A. Effects of inspiratory muscle training in elderly women on respiratory muscle strength, diaphragm thickness and mobility. J Gerontol A Biol Sci Med Sci 2014;69:1545-1553.

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; 24:240-250.

Tovar-Alcaraz A, de Oliveira-Sousa SL, Leon-Garzon MC, Gonzalez-Carrillo, MJ. Effects of inspiratory muscle training on respiratory function and balance in stroke survivors: a randomized controlled trial. Rev Neurol 2021;72:112-120.

Vaz LO, Almeida JC, Froes KSDSO, Dias C, Pinto EB, Oliveira-Filho J. Effects of inspiratory muscle training on walking capacity of individuals after stroke: a double-blind randomized trial. Clin Rehabil 2021;35: 1247-1256.

Verheyden G, Ruesen C, Gorissen M, Brumby V, Moran R, Burnett M, Ashburn A. Postural alignment is altered in people with chronic stroke and related to motor and functional performance. J Neurol Phys Ther 2014;38:239-245.

Xiao Y, Luo M, Wang J, Luo H. Inspiratory muscle training for the recovery of function after stroke. Cochrane Database Syst Rev 2012;2012: CD009360.

Zhang X, Zheng Y, Dang Y, Wang L, Cheng Y, Zhang X, Mao M, Lu X.

 https://doi.org/10.12965/jer.2550256.128

Can inspiratory muscle training benefit patients after stroke? A systematic review and meta-analysis of randomized controlled trials. Clin Rehabil 2020;34:866-876.

Zhang YS, Zhang K, Huang L, Wei JX, Bi ZT, Xiao JH, Zhang JM. The effects of respiratory muscle training on respiratory function and functional capacity in patients with early stroke: a meta-analysis. Eur Rev Aging Phys Act 2024;21:4.