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Effect of Pulmonary Rehabilitation Therapy on Diaphragmatic Motion in Chronic Stroke Patients: A Randomized Controlled Study

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Abstract

Background: Respiratory muscle dysfunction, particularly of the diaphragm, is common after stroke and limits physical performance. Targeted diaphragmatic exercises may enhance respiratory efficiency and recovery. To evaluate the effect of diaphragmatic breathing exercises on diaphragmatic motion and functional performance in patients with chronic hemiplegia.

Methods: In this single-blind randomized controlled trial, 70 chronic hemiplegic patients were randomly assigned to two equal groups (n=35 each): a control group (traditional exercise) and an intervention group (traditional plus diaphragmatic breathing exercises). Over eight weeks, outcomes including diaphragmatic excursion (DE) (assessed via M-mode ultrasonography), six-minute walk distance (6MWD), modified Medical Research Council (mMRC) dyspnea scale, and Berg Balance Scale (BBS) were evaluated. Data were analyzed using SPSS version 25.0. Statistical methods included descriptive statistics, independent samples t-tests, paired samples t-tests, Chi-square tests, and analysis of covariance (ANCOVA) to compare post-intervention outcomes while adjusting for baseline values. A p-value < 0.05 was considered statistically significant.

Results: There were no statistically significant differences between the two groups in baseline characteristics (age, sex, BMI, smoking history) or in baseline assessments of 6MWD, BBS, or mMRC scores (P>0.05). After eight weeks, the intervention group showed significantly greater improvements in functional capacity, balance, dyspnea, and diaphragmatic function (6MWD, BBS, and mMRC scores) compared to the control group (P<0.05). DE improved significantly in the intervention group during tidal (P=0.005), deep (P=0.009), and sniff breathing (P<0.001), while the control group showed a significant change only in tidal excursion (P=0.027). ANCOVA confirmed these findings after baseline adjustment (P<0.05), with moderate to large effect sizes.

Conclusion: Diaphragmatic breathing exercises significantly enhance diaphragmatic movement, physical performance, and quality of life in chronic hemiplegic patients. These findings support incorporating targeted pulmonary rehabilitation in stroke management, with ultrasonography as a valuable non-invasive bedside monitoring tool.

Keywords: Stroke, Hemiplegia, Diaphragm, Ultrasonography, Pulmonary Rehabilitation

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Introduction

Stroke is a serious medical condition resulting from reduced blood flow to the brain, leading to neuronal cell death. The two main types are ischemic stroke, caused by impaired blood flow, and hemorrhagic stroke, caused by bleeding. Both types can significantly disrupt brain function (1).

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↑What is "already known" in this topic:
Pulmonary rehabilitation program has been used to improve respiratory muscle resistance during breathing, thereby improving respiratory functions. Pulmonary rehabilitation programs are capable of inducing positive effects on stroke patients' respiratory muscles.

→What this article adds:
Breathing exercise improves mMRC dyspnea score, diaphragmatic motion, and quality of life in hemiplegic patients. Diaphragmatic ultrasound is an effective bedside test in the follow-up of a pulmonary rehabilitation program.

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Stroke frequently impairs motor function due to muscle weakness, degraded motor control, and loss of coordinated movement. These effects lead to a marked reduction in physical activities, including walking ability (WA) and balance ability (BA), largely due to decreased efficiency of the trunk-stabilizing muscles (2). In hemiplegic patients, the coordination of respiratory muscle contractions is often compromised, negatively affecting exercise capacity (3).

As the diaphragm is the primary muscle responsible for respiration, understanding how stroke impacts its strength and function is essential for the rehabilitation of hemiplegic patients (4). The diaphragm is controlled by two major descending neural pathways: the corticospinal tract, originating in the cortex and responsible for voluntary breathing, and the bulbospinal tract, which arises in the medulla and controls automatic breathing. Additionally, there appears to be a cortical connection to the pontomedullary respiratory centers. Lesions above the brainstem, as seen in hemiplegia, can therefore impair diaphragmatic motion (5).

Fluoroscopy has traditionally been used to assess diaphragmatic movement but poses disadvantages such as radiation exposure and the need for patient transport. In contrast, ultrasonography offers a safe, radiation-free, and bedside-accessible alternative, making it an ideal tool for evaluating diaphragmatic motion in hemiplegic patients (6).

Pulmonary rehabilitation programs, including diaphragmatic and pursed-lip breathing exercises, have been shown to improve respiratory muscle endurance and function. As such, pulmonary physiotherapy (PPT) holds promise in enhancing respiratory capacity and overall quality of life in stroke survivors (7). The aim of the current study was to evaluate the effect of diaphragmatic breathing exercises on diaphragmatic motion and functional performance in patients with chronic hemiplegia.

Methods

Study Design and Setting

This prospective randomized controlled trial was conducted at the Departments of Chest Diseases, Neurology, and Physical Medicine and Rehabilitation at Al-Azhar University Hospitals, Cairo, Egypt. The study period extended from October 6, 2021, to October 6, 2022. This trial was not registered in a clinical trials registry.

Study Participants

All hemiplegic patients attending the neurology clinic during the study period were assessed for eligibility. Among them, 100 patients with chronic hemiplegia met the inclusion criteria. Of these, 80 consented to participate, and 70 completed the full eight-week exercise program. These 70 patients were enrolled and randomly assigned to two equal groups:

- *Group 1 (Control group):* 35 hemiplegic patients received traditional exercises only.
- *Group 2 (Intervention group):* 35 hemiplegic patients received both traditional exercises and diaphragmatic breathing exercises.

Inclusion criteria included: a first mono-hemispheric stroke above the brainstem confirmed by computed tomography (CT) or magnetic resonance imaging (MRI), chronic hemiplegia, age ≥18 years, ability to provide informed consent, and completion of all study requirements. Exclusion criteria included: significant cardiopulmonary or neuromuscular disease, presence of a tracheostomy or chest wall deformity, obesity (body mass index; BMI ≥ 30 kg/m²), cognitive impairment (Mini-Mental State Examination; MMSE) score ≤ 20, or severe aphasia preventing cooperation.

Randomization and Blinding

Participants were randomly allocated using a computerized random sequence generator. Allocation concealment was ensured through the use of sequentially numbered, opaque, sealed envelopes prepared by an independent staff member not involved in participant recruitment or assessment.

Due to the nature of the intervention, participants were informed of their assigned exercise program, making blinding of participants infeasible. Therefore, the study is classified as single-blind, where only the outcome assessors were blinded to group allocation to reduce assessment bias. The potential influence of non-blinded participants on self-reported outcomes is acknowledged as a study limitation.

Clinical and Demographic Evaluation

All participants underwent a full clinical examination and detailed medical history. Special focus was placed on age, sex, stroke duration, and smoking history. Non-smokers were defined as individuals who had never regularly smoked one or more cigarettes a day or who had smoked one or more cigarettes a day for less than one year (8).

Body mass index (BMI) was calculated according to the following equation: [weight (kg)/height (m)^2].

Outcome Measures

Dyspnea Assessment

The modified Medical Research Council (mMRC) dyspnea scale was used to assess dyspnea severity on a 5-point scale:

- Grade 0: Dyspnea with strenuous exercise.
- Grade 1: Dyspnea when hurrying or walking up a slight hill.
- Grade 2: Walks slower than peers or stops for breath when walking at own pace.
- Grade 3: Stops for breath after about 100 yards or a few minutes of walking.
- Grade 4: Too breathless to leave the house or with dressing/undressing.

Six-Minute Walk Test (6MWT)

Exercise capacity was evaluated using the 6MWT, according to the American Thoracic Society (ATS) Guideline (2002) as follows:

The patient was instructed to walk at his own pace along a 27-meter straight corridor with a flat, firm ground and

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with two cones placed at each end of the course for six minutes. Heart rate and oxygen saturation (SaO_2) were measured at the start (0 min) and at the end (6 min) of the walk test. Patients were asked to cover as much ground as possible in six minutes. The distance in meters was recorded at the end of the six minutes. Subjects could stop and rest during the test if they had experienced dizziness, leg cramps, chest pain, or dyspnea and were instructed to resume walking as soon as they felt able to do (9).

Balance Assessment

The Berg Balance Scale (BBS) was used to assess static and dynamic balance. It includes 14 tasks applied to the three ambits of sitting, standing, and posture change, scored on a 0–4 scale, with a maximum total score of 56.

Diaphragmatic ultrasonography

Diaphragmatic ultrasonography was performed using a curvilinear (convex) 3–5 MHz probe (Soundscape A Medical Systems, Shenzhen, China). Brightness-mode (B-mode) was used to identify the diaphragm and to assess position, and Motion mode (M-mode) assessed diaphragmatic excursion (DE) during quiet (tidal) breathing (DTE), deep breathing (DDE), and sniffing maneuver (DSE).

Technique

Patients were examined in the semi-recumbent position. For the right diaphragm in the anterior subcostal view, the probe was placed between the mid-clavicular and anterior axillary lines using the liver as an acoustic window. For the left side, the probe was placed in the subcostal area and more laterally between the anterior and mid-axillary lines. The diaphragm appears as an echogenic 1-2 mm thick line that contract with inspiration.

Diaphragm Excursion (DE)

The convex probe is placed subcostally parallel to the intercostal space to measure the range of diaphragmatic movement using M-mode with the cursor crossing the diaphragm and assess the high and low peak points as indicators for the diaphragmatic mobility range. Patients are evaluated during quiet, deep breathing and during a sniffing maneuver to cover the different physiological changes in lung volumes in relation to diaphragmatic activity. These measures are taken before and after the diaphragmatic breathing exercise program (3).

Traditional and diaphragmatic breathing exercises:

Chronic hemiplegic patients were asked to perform traditional exercise only for group 1 (G1=35) while group 2 (G2= 35) was asked to perform traditional and diaphragmatic breathing exercises for 8 weeks.

Traditional exercise

Traditional exercise was used for 8 weeks, 5 sessions/week, 40 minutes/session. Intervention was performed, controlling intensities for warm-up, cool-down, mat activity, neurodevelopmental treatment (NDT), and gait training at the patient level.

● *Strengthening exercise: (10,11)*

1-Knee Extensions: For this leg exercise, start in a seated position while maintaining good postural alignment. Then, extend the patient's leg to straighten the knee while asking the patient to contract his thigh (quadriceps) muscles. Hold for 3 seconds, then slowly bring the foot back down to the floor. Repeat with the right leg, alternating back and forth between legs for a total of 20 repetitions (10 on each leg).

2-Seated Marching: This stroke recovery exercise is good for increasing hip flexor strength, which is important for picking up our feet when walking and for stairs. Stay in a seated position and then lift the patient knee up towards the chest. Then place the foot back down onto the floor. Repeat on the other leg, alternating back and forth for a total of 20 repetitions.

3-Ankle Dorsiflexion Exercise: Stroke patients who have ankle stiffness or struggle with foot drop will greatly benefit from this particular stroke exercise. Start with the affected leg crossed over other leg. Then, flex the foot back towards the shin ,Slowly pump the ankles up and down for a total of 15 to 20 repetitions, then switch sides.

● *Shoulder Exercise*

Gentle stretching and mobilization to increase external rotation and abduction of the humerus. Active range of motion should be increased gradually in conjunction with strengthening weak muscles in the shoulder girdle.

● *Stroke Exercises for Wrists, Hands, and Fingers* All tests are repeated 10 times slowly.

1) Hand Surface Stretch.
2) Wrist Flexion and Extension.
3) Wrist Windshield Wipers.
4) Hand Rolling Movement.

● *Balance exercises*

1) Seated balance training
2) Weight transfer in sitting from hip to hip
3) Pelvic movements forward and backwards
4) Swizz ball training

Breathing exercises

The patients were trained to perform the exercises daily at home for the first week 5 times\day for 5-10 minutes, then to increase time to be at least one hour a day, and were asked to perform 3 sessions per week of observed exercise at our hospital.

Deep breathing exercise (Pursed lips breathing technique):

Patient takes a deep breath from the nose slowly to fill his chest, then exhales it slowly through pursed lips to empty his chest. During expiration he presses on his epigastric area to help during expiration.

Diaphragmatic exercises

The patient is instructed to lie on his back on the flat surface or in bed, with knee bent and head supported. The patient can use a pillow under his knee to support his leg, place one hand on upper chest and the other just below the rib cage; breathe in slowly through the nose so that the stomach moves out against his hand. The hand on the chest should remain as still as possible.

Patient is instructed to tighten their stomach muscles, letting them fall inward as they exhale through pursed lips, the hand on the chest should remain as still as possible.

Follow-Up

All parameters, including DE, mMRC score, 6MWT distance, and BBS, were assessed at baseline and after the 8-week intervention.

Sample size and Sampling technique

Sample size calculation was performed using the following formula:

Sample size (N) = $(Z\alpha/2+1-\beta)^2 * 2 * SD^2 / \Delta^2$. (12).

N= $(1.96+0.84)^2 * 2 * (1.5)^2 / (1)^2 = 35$

Where SD= Standard deviation of diaphragmatic mobility in deep breath from the previous study, and Δ^2 = effect size estimated between the groups α = Level of significance, and 1−β = Power of the study.

Accordingly, we will work with at least 35 patients in each group, with a total sample 70 were needed to provide the study with a sufficient statistical power of 0.8 and an alpha of 0.05.

Statistics analysis

Data were collected, coded, and analyzed using the Statistical Package for Social Sciences (SPSS) version 25.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were performed using means and standard deviations (SD) for continuous variables and frequencies with percentages for categorical variables. For inferential statistics, the independent samples t-test was used to compare continuous variables between the two groups, the paired samples t-test to compare pre- and post-intervention outcomes within each group, and the Chi-square test and Fisher's exact test for comparison of categorical variables. To account for baseline differences and improve estimate precision, analysis of covariance (ANCOVA) was conducted to compare post-intervention outcomes between groups using baseline scores as covariates. A two-tailed p-value < 0.05 was considered statistically significant. Results were presented in tables and figures for clarity and ease of interpretation.

Results

There were no statistically significant differences between the two groups regarding demographic characteristics, including age, sex, BMI, or smoking history (*P*>0.05) (Table 1).

Baseline functional assessments showed no significant differences between both groups with regard to the 6MWD, BBS score, or mMRC dyspnea scale (*P*>0.05). However, after eight weeks of intervention, group 2 (which received both traditional and diaphragmatic breathing exercises) demonstrated statistically significant improvements in 6MWD, BBS score, and mMRC score compared to group 1 (which received traditional exercise only) (*P*<0.001) (Table 2).

Regarding DE, Group 2 exhibited significant post-

Table 1. Characteristics of the Studied Groups.

Variable		Group 1 n= 35 (%)	Group 2 n= 35 (%)	*P*-value
Age (years)	Mean ± SD	59.19±7.72	57.27±7.81	0.342
Sex	Male	30 (85.7)	35 (100)	0.492
	Female	5 (14.3)	0 (0)	
BMI	Mean ± SD	27.93±3.57	28.12±5.77	0.878
Smoking history	Current	27 (77.1)	25 (71.4)	0.643
	Non-smoker	3 (8.6)	2 (5.7)	
	Ex-smoker	5 (14.3)	8 (22.8)	
Pack /year	Mean ± SD	76.12±71.06	75.47±15.52	0.961
Stroke duration (months)	Mean ± SD	17.20±4.37	17.90±3.51	0.496

Values present as mean ± SD were analyzed by an Independent Samples t-test.
Values present as numbers and percentages were analyzed by Chi-square or Fisher's exact tests.

Table 2. Comparison of variables in the studied groups before and after 8 weeks of exercise.

Variable		Group 1 n= (35)	Group 2 n= (35)	*P*-value
Physical activity				
6MWD (m)	pre	248.86±11.66	245.30 ±88.02	0.826
	post	259.11±50.31	285.0±44.62	0.039*
BBS (score)	pre	42.60 ±16.12	45.62±17.07	0.483
	post	46.21±18.61	56.34±17.00	0.031*
mMRC (score)	pre	2.34±0.73	2.08 ±0.65	0.150
	post	2.00±0.94	1.52±0.46	<0.001*
Diaphragmatic excursion by ultrasound				
DTE (cm)	pre	2.77±0.91	2.69±0.73	0.708
	post	3.25±0.72	3.65±0.21	0.005*
DDE (cm)	pre	4.01±0.46	4.38±0.96	0.061
	post	4.27±1.49	5.36 ±1.67	0.009*
DSE (cm)	pre	2.08±0.65	2.34±0.73	0.150
	post	2.40±1.04	3.52±1.26	<0.001*

Values present as mean ± SD were analyzed by Paired samples t-test.
* significance difference (*P*<0.05).

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Table 3. Effectiveness of traditional exercise on physical activity, quality of life, and ultrasonography diaphragmatic motion in hemiplegic patients

Variable	Group 1 n=35			
	Pre	After 8 weeks	% change	*P*-value
Physical activity				
6MWT (m)	248.86±11.66	259.11±50.31	4%	0.281
BBS (score)	42.60 ±16.12	46.21±18.61	8.5%	0.425
mMRC (score)	2.34±0.73	2.00±0.94	14.5%	0.123
Diaphragmatic excursion by ultrasound				
DTE (cm)	2.77±0.91	3.25±0.72	17.3%	0.027*
DDE (cm)	4.01±0.46	4.27±1.49	6.5%	0.364
DSE (cm)	2.08± 0.65	2.40±1.04	15.4%	0.158

Values present as mean ± SD were analyzed by a Paired samples t-test.
* significance difference ($P<0.05$).

Table 4. Effectiveness of traditional and diaphragm breathing exercises on physical activity, quality of life, and ultrasonography diaphragmatic motion in hemiplegic patients

Variable	Group 2 n=35			
	Pre	After 8 weeks	% change	*P*-value
Physical activity				
6MWT (m)	245.30± 88.02	285.0±44.62	16%	0.031*
BBS (score)	45.62±17.07	56.34±17.00	24%	0.017*
mMRC (score)	2.08± 0.65	1.52±0.46	27%	<0.001*
Diaphragmatic excursion by ultrasound				
DTE (cm)	2.69±0.73	3.65±0.21	35.7%	0.029*
DDE (cm)	4.38±0.96	5.36 ±1.67	22.4%	0.007*
DSE (cm)	2.34±0.73	3.52±1.26	50%	<0.001*

Values present as mean ± SD were analyzed by Paired samples t-test.
* significance difference ($P<0.05$).

intervention improvements during deep breathing (DDE) ($p = 0.009$), sniffing (DSE) ($P<0.001$), and quiet (tidal) breathing (DTE) ($P=0.005$) relative to group 1 (Table 2). In contrast, group 1 showed a significant increase only in tidal breathing (DTE) after eight weeks of traditional exercise ($P=0.027$) (Table 3).

Within-group comparisons confirmed that participants in Group 2 experienced significant improvements across all measured outcomes, including 6MWD, BBS score, mMRC score, and DE at all breathing volumes ($P<0.05$). (Table 4 and Figure 1).

A multi-panel line graph for pre- and post-intervention trends for the primary outcomes (6MWD, BBS score, mMRC score, DDE, DSE, and DTE) in both groups is illustrated in Figure 2.

To further account for any baseline variability, ANCOVA was conducted with post-intervention scores as dependent variables and baseline values as covariates. The

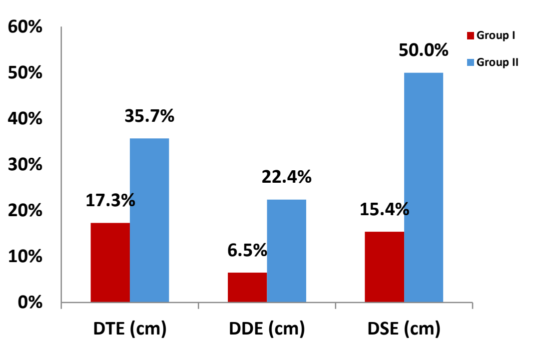

Figure 1. Percent change in findings of diaphragmatic excursion by ultrasound among the studied groups

ANCOVA results confirmed significantly greater improvements in Group 2 compared to Group 1 across all primary outcomes. The 6MWD increased significantly more in Group 2 ($P=0.005$, $\eta^2_p=0.11$). Similarly, significant differences were observed in BBS ($P=0.002$, $\eta^2_p=0.13$), mMRC scores ($P=0.001$, $\eta^2_p=0.15$), and all measures of diaphragmatic excursion; DTE ($P=0.012$, $\eta^2_p=0.09$), DDE ($p=0.008$, $\eta^2_p=0.10$), and DSE ($P<0.001$, $\eta^2_p=0.17$). These findings indicate moderate to large effect sizes and support the enhanced effectiveness of combined traditional and diaphragmatic breathing exercises for chronic hemiplegic patients (Table 5).

Discussion

A variety of functional disorders can be precipitated by stroke, among which impairment of respiratory function is a frequent and serious complication in stroke patients (13).

The diaphragm is the major respiratory muscle, contributing up to 70% to resting lung ventilation. Since the diaphragm has a major role in respiration, knowledge of the effects of stroke on diaphragmatic function is important for the rehabilitation of hemiplegic patients. Usually, the unilateral involvement of the diaphragm is paucisymptomatic in hemiplegic patients. Therefore, diaphragm paralysis is underdiagnosed because of its varied and often nonspecific presentation. Early detection of diaphragm dysfunction is important for protecting patients from comorbid pulmonary problems (14).

Diaphragmatic breathing shows a significant increase in flexibility of the respiratory muscle and thoracic cavity, in addition to an improvement in the length-tension relationship, leading to improved performance of respiratory mechanics. The diaphragm and abdominal muscles control

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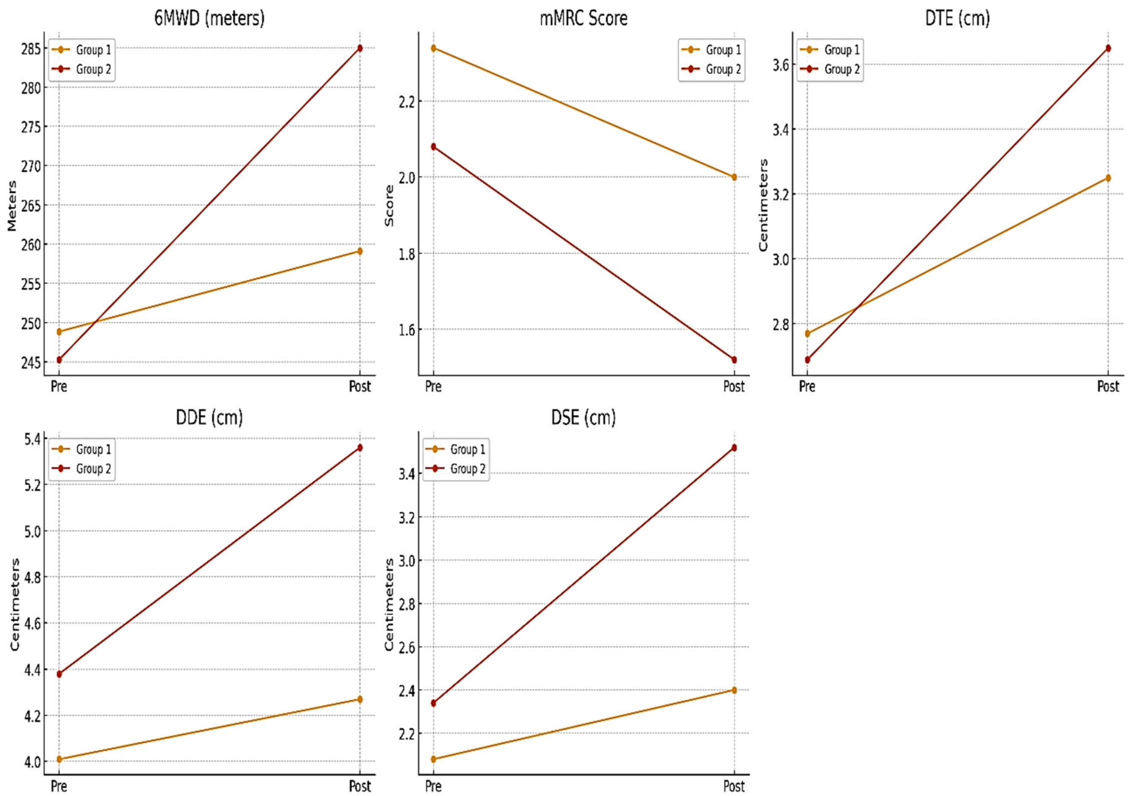

Figure 2. A multi-panel line graph of pre- and post-intervention trends for the primary outcomes in both groups

Table 5. ANCOVA results comparing adjusted post-intervention outcomes between both groups (controlling for baseline)

Outcome variable	Adjusted mean (G1) ± SD	Adjusted mean (G2) ± SD	F-value	p-value (adjusted)	η^2_p
Physical activity					
6MWD (m)	261.71 ± 40.35	282.4 ± 39.86	8.23	0.005 *	0.11
BBS (score)	47.32 ± 13.26	55.28 ± 12.38	10.12	0.002 *	0.13
mMRC (score)	1.97 ± 0.61	1.55 ± 0.49	12.35	<0.001 *	0.15
Diaphragmatic excursion by ultrasound					
DTE (cm)	2.91 ± 0.76	3.61 ± 0.18	6.74	0.012 *	0.09
DDE (cm)	4.18 ± 0.91	5.27 ± 0.79	7.45	0.008 *	0.10
DSE (cm)	2.25 ± 0.82	3.44 ± 0.95	13.89	<0.001 *	0.17

η^2_p : Partial Eta squared.
* significance difference (P<0.05).

breathing by controlling intra-abdominal pressure. Previous research related to the diaphragm showed an improvement in pulmonary function in stroke patients as a result of performing diaphragm exercises for 6 weeks (15, 16).

The aim of the current study was to evaluate the effect of diaphragmatic breathing exercises on diaphragmatic movement measured by M-mode ultrasonography in patients with chronic hemiplegia and the quality of life in such patients.

In this study, we evaluated cases of chronic hemiplegia attending the neurology diseases clinic during the study period. A total of 70 patients completed exercises in 8 weeks. They were randomized into a control group (G 1) (n=35) that performed traditional exercise and an experimental group (G 2) (n=35) that performed traditional exercise and diaphragmatic breathing exercises.

The demographic data shown in Table 1 shows no statistically significant difference between the control group and experimental group regarding age, sex, BMI, and smoking history.

At the end of 8 weeks, we evaluated physical activity, dyspnea scoring, and DE by ultrasound for all cases in Table 2. From this table, we found that those patients in group 2 had significant improvement in 6MWT distance (increases) and mMRC dyspnea scale score (decreased) (P=0.001) in group 2 when compared to group 1 (control group).

Many studies have reported significant improvement in pulmonary function tests, both in healthy persons and stroke patients, after breathing exercises and diaphragmatic training programs (17–19). Parreiras de Menezes et al. 2019, reported a significant improvement in maximal inspiratory pressure after a program of eight weeks of inspiratory muscle exercise in chronic stroke patients (20).

Sunghee et al. 2015 demonstrated that a 5-week program of game-based breathing exercises improves pulmonary function in stroke patients, with an increase in lung volume and respiratory muscle power (21). Many studies reported that respiratory muscle training programs had a significant positive effect on maximum voluntary ventilation (MVV) and inspiratory muscles functions in stroke patients (22, 23).

On the other hand, studies that were done by Yamagutri et al. 2012 and Koppers et al. 2006 reported no significant improvement in pulmonary function tests after inspiratory muscle endurance training (24, 25).

The improvement in diaphragmatic functions and breathing capacity may be explained by the fact that breathing exercise increases diaphragm muscle strength and endurance in addition to increased excursion of abdominal wall muscle and reduction in accessory muscle activity, leading to improvement in breathing pattern which improves respiratory function and arterial blood gases (26–28).

Concerning the quality of life (mMRC) and physical activity (6 MWD) results of this study, there was a significant improvement in quality of life (mMRC) and physical activity (6 MWD) in group 2 in comparison to group 1 after 8 weeks (Table 2). Similar results were reported by Hye et al. 2018 who found that a diaphragm and inspiratory muscle strengthening exercise was used to increase mobility, power, and endurance of trunk muscles weakened by hemiplegia (29).

Choi and Oh (2012) reported a significant improvement in the ten-meter walk test (10MWT) with intensive 2-week chest mobility exercise (30). Jung et al. (2017) demonstrated significant improvement in stroke-induced hemiplegia patients in a comparison of within-group and between-group 6MWT when the experimental group performed breathing exercises (31). Lee et al. 2018 reported significantly improved dyspnea score and 10MWT in a group of patients with stroke after four weeks of breathing exercise (17).

This explained as the physiological effect of diaphragmatic breathing exercise is that breathing through full vital capacity and holding for 3-5 seconds ensure full inflation of the lung thus opening alveoli which have low volume and stimulates the production of surfactant, also diaphragmatic breathing exercises will decrease the activity of accessory muscles and reduce work of breathing (32).

Stroke dysfunction significantly degrades motor function due to muscle weakness, reduced motor control ability, and loss of coordinated movement on the affected side, which leads to a decrease in physical activities, such as independent WA and BA. In our current study, we found a significant improvement in the BBS in hemiplegic patients group 2 in comparison to group 1 with % change (27%vs 8.5%) (Tables 3 & 4) and similar results were reported by Hye et al. 2018 they found that diaphragmatic and deep abdominal muscle exercise (DDAME) is a positive exercise method for strengthening the diaphragm, inspiratory muscles, abdominal deep muscles, and superficial muscles needed to improve BA (29). Consistent with our results, a previous study was done by Shin et al. (2009) and Shim et al. (2014). These results suggest that the breathing ability is improved by increasing the muscle power of the trunk directly by DDAME (33, 34).

The main finding of this study is that DE improved following breathing exercises for 8 weeks (Table 1 and Figure 1). The pre exercises DE showed non-significant statistical difference in both groups however, at 8 weeks DE was significantly higher in group 2 when compared to group 1 with % change in (DTE, DDE, DDE) (35.7%, 22.4%, 50% in group 2 vs 17.3%, 6.5%, 15.4% in group 1).

DE showed improvement during deep breathing and during sniffing. These results support previous studies reporting that ultrasonography can be an effective tool in the assessment of the success of pulmonary rehabilitation programs as a low-cost, noninvasive technique. Crimi et al. 2018 reported that the improvement of the diaphragm is due to improved diaphragm muscle strength and endurance (35). Similar results were reported by Zupan et al. 1997 study showed that the activity of the abdominal muscles of quadriplegia patients was improved through respiratory muscle training (36). Respiratory rehabilitation exercise is considered to be capable of inducing positive effects on stroke patients' respiratory muscles through diaphragm breathing exercises and lip puckering breathing exercises (7).

Study Limitations

This study has several limitations that should be considered when interpreting the findings. First, this trial was not registered in a clinical trial registry, which may affect the transparency of the study. Although this was a non-pharmacological, academic study with minimal risk, future trials should be prospectively registered in accordance with international standards to enhance methodological rigor and public trust. Second, the relatively small sample size and short duration of follow-up may restrict the statistical power and limit the generalizability of the results. Additionally, the use of strict inclusion criteria may not fully represent the broader and more heterogeneous population of stroke patients, particularly those with varying degrees of impairment, comorbidities, or different stages of stroke recovery. Third, although randomization was employed, the absence of participant blinding and partial blinding of assessors may have introduced performance and assessment bias. Future studies should aim for double-blind designs, where feasible, to minimize the risk of subjective influence on outcome measures. Fourth, the reliance on patient effort-dependent outcomes such as the 6MWT and mMRC dyspnea scale may be influenced by motivational or psychological factors, which were not controlled for in this study. Fifth, while M-mode ultrasonography is a non-invasive and practical method for assessing diaphragmatic movement, it may be subject to operator dependency and inter-rater variability, which may affect measurement accuracy. Sixth, the use of multiple outcome measures increases the risk of type I error. While no correction (e.g., Bonferroni) was applied to preserve statistical power in this exploratory study, this may limit the interpretability of individual p-values. Future

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studies with larger samples should consider appropriate statistical adjustments. Finally, potential confounding variables such as medication use, nutritional status, and concurrent physical therapy interventions were not systematically controlled or documented, which could have affected the observed outcomes. Further longitudinal studies with larger, more diverse populations, standardized protocols, and rigorous blinding are warranted to confirm and extend the current findings.

Conclusion

Stroke survivors frequently experience reduced respiratory reserve and diaphragmatic weakness, which increases the risk of pulmonary complications and negatively impacts recovery. This study highlights the importance of incorporating early respiratory function assessment, particularly diaphragmatic evaluation, into post-stroke rehabilitation programs. This study demonstrates that pulmonary rehabilitation, particularly the inclusion of diaphragmatic breathing exercises, leads to meaningful improvements in DE, exercise capacity, dyspnea perception, walking endurance, and overall quality of life in patients with chronic hemiplegia. Notably, these breathing exercises are cost-effective, simple to perform, and do not require specialized equipment or continuous supervision, enhancing the feasibility of long-term adherence among stroke survivors. Moreover, diaphragmatic ultrasound was shown to be a practical, non-invasive, and effective bedside tool for monitoring the progression and effectiveness of pulmonary rehabilitation programs. These findings support the routine incorporation of diaphragmatic assessment and breathing exercises into comprehensive stroke rehabilitation protocols.

Authors' Contributions

All authors contributed to the conception and design of the work, reviewing the literature, data acquisition, analysis, manuscript writing, and revision. H.E and A.K wrote the first draft of the manuscript. E.M and M.H performed critical revision. All authors participated in the critical revision of the manuscript, approved the final manuscript as submitted, and agreed to be accountable for all aspects of the work.

Ethical Considerations

This study, with experimental protocols, was conducted after approval by the institutional review board (IRB# 1076, 3/11/2021), Faculty of Medicine for Girls Al-Azhar University, Cairo, Egypt. The study objectives and tools were explained to the participants. Participation was voluntary; informed consent was obtained from the study participants or their legal guardians before enrolment into the study. Each participant had the right to refuse participation or withdraw from the study at any time without giving any reasons and without affecting their rights to medical care. Also, data were anonymous and coded to ensure confidentiality of participants.

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Conflict of Interests

The authors declare that they have no competing interests.

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