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The effectiveness of core stabilization exercise using ultrasound biofeedback on motor function, balance control, gait speed and activities of daily living in stroke patients

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Abstract.
BACKGROUND: Patients with hemiparetic stroke experience diminished motor function, dynamic balance, and gait speed, which influence their activities of daily living (ADL).
OBJECTIVE: This study aimed to determine the therapeutic effects of ultrasound biofeedback core exercise (UBCE) on Fugl-Meyer assessment (FMA), Time up and go (TUG), 10-meter walking test (10MWT) and functional independent measure (FIM) in participants with stroke.
METHODS: Twenty-four stroke survivors consistently underwent UBCE or abdominal draw-in maneuver (ADIM) for 30 min/session, 3 days a week for 4 weeks. Clinical outcome measurements – the FMA, TUG, 10MWT, and FIM – were observed pre-and post-intervention.
RESULTS: We detected significant changes in the FMA-lower extremities, TUG, 10MWT, and FIM scores between the UBCE and ADIM groups. UBCE and ADIM showed significant improvements in FMA-lower extremities, TUG, 10MWT, and FIM scores. However, UBCE showed more favorable results than ADIM in patients with stroke.
CONCLUSIONS: Our research provides novel therapeutic suggestion of neurorehabilitation in stroke patients.

Keywords: Stroke, somatosensory-evoked potential, balance, gait

1. Introduction

Stroke is a major global health issue that causes a high death and morbidity rate [1]. Weakness, spasticity, and loss of balance on the hemiparetic side, which impacts activities of daily living (ADL) and the inability to maintain postural alignment, are common challenges associated with stroke [2]. Core instability is a common neuromusculoskeletal system impairment in stroke. During static and dynamic postural changes, the core stability is the primary critical location that enables the body to stay firm and modifies weight shifting [3]. Previous research has reported a decrease in motor function, asymmetry of the trunk during hemiplegic gait, significant weakening, and delayed activation of the gait muscles during

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gait [4]. Such irregular diaphragm functions may amend the instruction of intra-abdominal pressure (IAP) [5,6]. This might lead to inadequate postural control and core stabilization during dynamic gait and motor function [6]. Movements such as running, jumping, and lifting impose a huge stress on the spine and cause an increase in intra-abdominal pressure (IAP). It is still unclear what this pressure increase's purpose is. According to early theories, the pressure inside the belly cavity could help the lumbar spine bear some of its weight. These theories were developed on the theory that pressure created in the abdominal cavity applied a hydrostatic force on the diaphragm and the pelvic floor. It was believed that this force would lessen the spine's compression force since it increased the spine's tension and created a trunk extension moment [7]. Maintaining and moving in the standing position, stabilizing the body for everyday tasks, and regaining balance and stability are all possible due to trunk control function [8]. Furthermore, an increase in physical function levels and living quality standards is essential. It reduces their ability to maintain cooperative action, impairs their rib cage movement, and affects their trunk and respiratory muscles' ability to maintain normal posture [9]. Breathing becomes less effective as a result of the dysfunctional trunk postures caused by the injured trunk muscles [10]. Generally speaking, the deep multifidus and deep abdominal muscles work together to stabilize the trunk [11]. Reduced trunk postural stability impedes stroke patients' ability to regain their full mobility. Among patients with stroke, one of the best indicators of their functional prognosis is their capacity for unassisted sitting [12]. Frequently employed in a clinical context, the abdominal drawer-in maneuver (ADIM) selectively contracts the rectus abdominis (RA), transverse abdominis (TrA) muscle as well as internal oblique (IO), and external obliques (EO) more quickly than other superficial muscles to support the trunk [13,14]. To do this, the transversus abdominis must be particularly engaged before the other abdominal muscles are activated. This method is crucial for maintaining the stability of spinal segments. Rather than using diaphragm movement, it is frequently utilized to increase the stability of the lumbar spine and pelvis by rebuilding the TrA and IO muscles [15]. Nevertheless, several laboratory studies have indicated that ADIM may have both positive and negative effects on the spine, potentially influencing the incidence of stroke, according to the existing systematic data [14].

To mitigate the ultrasound biofeedback core exercise (UBCE) in stroke, To transfer energy and produce coordinated force, proximal segment (core) stability must be achieved and connected to the fractured neighboring segment [5]. It has been determined that a noninvasive way to record the morphological characteristics and contraction thickness of muscles is real-time ultrasound biofeedback. It has been widely employed in research as well as therapeutic settings [16]. It has previously been shown that ultrasonic detection techniques are reliable for measuring muscle thickness and contraction [16]. The idea for normalizing the UBCE exercise originated in the field of developmental kinesiology [6]. The synchronized coactivation of the system's deep and superficial muscles is a key component of the UBCE normalization procedure [9]. During deep inhalation, the deep muscular facilitation specifically involves the co-activation of the diaphragm, TrA-multifidus-pelvic floor as well as IO, and EO muscle, resulting in internal stability by using ultrasound biofeedback [9]. The superficial muscles are facilitated by the external core stabilization force, which is connected to the hip extensor muscles. To be more precise, the theory states that during the inspiration phase, After IAP is naturally generated by the deep core stability muscles (diaphragm-TrA/IO-multifidus-pelvic floor), it is further stabilized by reflexively coactivating the exterior core stabilizers (EO, rectus abdominis; RA, erector spinae; ES) [9]. Furthermore, in response to external perturbations and dynamic motions of the distal extremities section, the integrative internal and external core stabilization forces provide sufficient stability or moving forces in the proximal core segment [11]. However, Despite the important roles and large clinical benefits of the recommended core stabilization strategies, the therapeutic effectiveness and underlying motor control patterns and processes

Table 1
Demographic features of the sub-acute stroke participants ($n = 24$)

		UBCE ($n = 13$)	ADIM ($n = 11$)	p
Sex	Male	7	6	
	Female	6	5	0.97
Paretic side	Right	8	7	
	Left	5	4	0.92
Onset time (weeks)		7.23 ± 2.16	7.09 ± 2.25	0.87
Age (year)		61.46 ± 12.88	62.63 ± 12.53	0.82
Height (cm)		162.92 ± 8.41	164.63 ± 11.57	0.67
Weight (kg)		64.85 ± 13.49	64.28 ± 10.92	0.91
MMSE (score)		26.30 ± 1.65	26.18 ± 1.66	0.85

UBCE: Ultrasound biofeedback core-exercise; ADIM: Abdominal breathing in maneuver; MMSE: Mini-mental state examination; Mean ± Standard deviation.

underpinning the UBCE and ADIM in stroke patients remain unknown. Therefore, this study aims to determine the therapeutic effectiveness of UBCE on motor function (Fugl-Meyer assessment; FMA), balance control (Time up and go; TUG), gait speed (10-meter walking test; 10MWT) and ADL (functional independent measure; FIM) in participants with stroke. We hypothesized that UBCE would demonstrate better motor function, balance control, gait speed, and ADL than ADIM.

2. Method

2.1. Animal experiments to measure ABR

2.1.1. Participants

Twenty-four adults with hemiparetic stroke (males 13, females 11; age 62 ± 12.45 years;) were recruited from a neurorehabilitation center. For four weeks, the participants underwent UBCE ($n = 13$) and ADIM ($n = 11$) for thirty minutes a day, three days a week. Every subject gave their informed permission and underwent ADIM core stabilization as well as UBCE. The participants who could follow instructions (Mini-Mental State Examination [MMSE] mean score of 26.25 ± 1.62) and experienced a subacute (3–6 month) hemiplegic stroke (post-stroke duration $<$ 12 weeks; mean weeks 7.16 ± 2.16) were included [17]. But stroke victims who experience severe visual hemianopia, history of cerebellar/brainstem stroke, cardiopulmonary impairments preventing ambulation tests, uncontrolled hypertension (stage 2) with blood pressure $>$ 160/100 mmHg, and a history of prior surgery were eliminated. The subjects' clinical and demographic details are shown in Table 1. The group homogeneity was supported by Levene's test, which showed no discernible variation in the individuals' baseline characteristics. Standard deviation and averages were incorporated in descriptive statistical data analysis. The independent t-test was employed to compare the baseline demographic features of the groups for continuous variables.

2.1.2. Materials and procedure

All the participants underwent consistent standardized clinical testing- pre and post-test in a safe environment. The clinical test included the motor function (FMA), balance control (TUG), gait speed (10MWT), and ADL (FIM) evaluation were conducted, to determine each stroke patient's functional ability before versus after the intervention. The FMA is a performance-based impairment measure related to stroke. It is intended to evaluate pain, sensation, motor function, range of motion, balance, and post-stroke hemiplegia in patients. The scoring is based on observation of stroke patient's performance. The scale items use a 3-point scale, with 0 = incapable to perform; 1 = partly performed; 2 = completely performed. The entire score was 226 points [18]. This test has shown good validity [19]. The TUG test is a simple and useful test of balance and mobility that consists of upright from a chair, mobile 3 meters straight, and turning at a turning point. It is widely used mainly for patients with stroke, mobility impairment, and Parkinson's disease. This test has shown excellent validity and reliability and is also used to assess fall risk or measure intervention outcomes [20]. 10MWT is an evaluation tool that evaluates walking speed among the walking abilities of stroke patients [21]. Walking speed was determined by monitoring the amount of time spent walking on the 10-meter track. In this study, an acceleration distance of three meters and a deceleration distance of three meters were placed at the front and rear of the track, respectively. Participants used walking aids when necessary. FIM is a commonly utilized instrument for assessing daily living activities. It offers a way to measure how well stroke victims are recovering neurologically and functionally. It has demonstrated outstanding dependability and has been applied to test the effects of interventions or evaluate ADL. The degree of impairment and care load are assessed using the 18 items on the FIM. Impairment in motor functions is defined by 13 items, whereas impairment in cognitive functions is defined by 5 things. Every item is graded on a seven-point rating system, where 1 represents total assistance and 7 represents entire independence [22]. FIM is a validity and reliability instrument of examining the stroke patient's functional mobility [23].

2.1.3. Intervention

UBCE and ADIM, two distinct core stabilization exercises, were employed. These were the main methods of stabilization. The diaphragm descends synkinesis during inspiration in the UBCE, which co-activates the abdominal and pelvic floor muscles and modifies IAP to give core stability. The standardized UBCE steps are as follows: (1) In order to enable normalized or natural diaphragmatic breathing, participants' sternum, ribcage, and thoracolumbar spine alignment were centralized or normalized while they were supine; (2) Then, to activate the TrA/IO, the subject had to keep their chest and spine in alignment while performing an instinctive or subconscious descending diaphragmatic movement during a regular inhale. The lower portion of the sternum and the ten to twelve ribs were enlarged anterolaterally from the midclavicular line and posteriorly along the angulus costae, as demonstrated by an appropriate UBCE movement. Consequently, deep core muscles and IAP control are activated by the diaphragm's descending motions and the intercostal space's expansion. The patient utilized ultrasonography to give feedback on the exact diaphragm descent during UBCE [24]. In the inspiration phase, the diaphragm contracts and approaches the transducer and appears as an upward inflection on the ultrasound image. In the expiration phase, the diaphragm moved away from the ultrasonic transducer and appears as a downward inflection. The patient was instructed to use visual feedback during inspiration to ensure that the diaphragm approached the ultrasound probe [24]. After mastering the basic UBCE skills in the supine position, participants can practice unilateral or bilateral shoulder and hip flexion-extension motions at a more demanding level (supine, prone, quadruped, sitting, and standing postures). Participants in the ADIM group engaged in the pelvic tilting exercise. The following were the specific guidelines for the ADIM technique. (1) Contraction of the deep abdominal muscles without hyperactivation of the superficial muscles should be done while breathing softly and drawing the belly button up and in toward the spine with a pelvic posterior tilting movement (sternocleidomastoid, upper trapezius, rectus abdominis). Each participant's motions were examined by the therapist, who made any required adjustments. More difficult exercises for core stability were conducted after the individual successfully completed the selective pelvic tilting exercise. These activities included: (3) unilateral or bilateral shoulder movements and (4) hip flexion-extension motions in both sitting and standing postures [15]. Five postures were used for

Table 2
Data on motor, balance and gait performance comparing UBCE and ADIM

Clinical test		UBCE	ADIM	p
FMA-upper	Pre-test	32.15 ± 23.43	31.45 ± 24.18	
	Post-test	40.92 ± 22.14	37.18 ± 22.86	0.68
	t	−2.90*	−4.12*	
FMA-lsower	Pre-test	19.15 ± 5.82	22.54 ± 5.24	
	Post-test	29.23 ± 2.58	25.81 ± 4.30	0.02*
	t	−8.70*	−5.28*	
TUG	Pre-test	60.38 ± 14.32	60.45 ± 23.36	
	Post-test	26.26 ± 11.70	42.90 ± 21.59	0.02*
	t	7.97*	4.89*	
10MWT	Pre-test	57.30 ± 16.09	58.09 ± 24.46	
	Post-test	24.76 ± 11.20	37.00 ± 19.73	0.07
	t	7.54*	4.96*	
FIM	Pre-test	56.38 ± 10.78	62.72 ± 15.39	
	Post-test	83.92 ± 13.93	70.09 ± 17.10	0.04*
	t	−9.96*	−4.35*	

UBCE: Ultrasound biofeedback core-exercise; ADIM: Abdominal breathing in maneuver; FMA: Fugl-meyer assessment; TUG: Timed up-and-go test; 10MWT: 10-meter walking test; FIM: Functional independence measure; *$p < 0.05$, derived from the main and interaction effects.

each session: quadruped, sitting, prone, supine, and standing. Ten seconds were allocated to maintaining shoulder flexion-extension and hip flexion-extension during each session, with ten repetitions of the implementation. There was a two-minute break between each session. For a total of four weeks, the complete group received treatment interventions for thirty minutes each session, three times a week. The experiment was conducted by five physiotherapists with at least three years of clinical experience who were NDT certified.

2.1.4. Statistical analysis

Standard deviations and means were incorporated in descriptive statistical data analysis. The independent t-test was employed to compare the baseline demographic features of the groups for continuous variables. To look at the variations between the pre- and post-tests in each group, paired t-tests were used. To confirm the post-intervention differences between the groups, independent t-tests were used. A 0.05 threshold for statistical significance (α) was established. Statistical analyses were performed using the Statistical Package for the Social Sciences (SPSS) for Windows version 25.0 (SPSS, Chicago, IL, USA).

3. Results

3.1. FMA (motor function data)

Table 2 showed a comparison of motor functions between UBCE and ADIM. The pre-test and post-test FMA evaluations in the UBCE and ADIM groups were compared using paired t-tests. Each group's motor function (FMA upper extremity/lower extremity) test resulted in a substantial increase ($p < 0.05$). The post-test differences for the UBCE and ADIM groups were assessed using independent t-tests. After 4 weeks of intervention, the FMA-lower extremity test was significantly increased in UBCE than in ADIM ($p < 0.05$) (Table 2).

3.2. TUG (balance control data)

The pre-test and post-test TUG evaluations in the UBCE and ADIM groups were compared using paired t-tests. Within each group, there was a substantial rise in the balancing control (TUG) test ($p < 0.01$). The differences between the post-test for the UBCE and ADIM groups were assessed using independent t-tests. After 4 weeks of intervention, the TUG test significantly decreased in UBCE than ADIM ($p < 0.05$) (Table 2).

3.3. 10MWT (gait speed data)

The pre-test and post-test 10MWT evaluations in the UBCE and ADIM groups were compared using paired t-tests. Within each group, there was a substantial increase in the gait speed (10MWT) test ($p < 0.01$). The post-test differences for the UBCE and ADIM groups were assessed using independent t-tests. There was no statistically significant difference in 10MWT from UBCE and ADIM after 4 weeks of intervention ($p > 0.05$) (Table 2).

3.4. FIM (activities of daily living data)

The pre-test and post-test FIM evaluations in the UBCE and ADIM groups were compared using paired t-tests. Each group's activities of daily life (FIM) test considerably increased ($p < 0.01$). The post-test differences for the UBCE and ADIM groups were assessed using independent t-tests. After 4 weeks of intervention, the FIM test significantly increased in UBCE than in ADIM ($p < 0.05$) (Table 2).

4. Discussion

In this study, stroke patients' motor function, balance control, gait speed, and ADL were examined in relation to the therapeutic benefits of the UBCE. The UBCE group considerably outperformed the ADIM group in terms of motor function, balance control, gait speed, and ADLs, supporting our hypothesis. Significantly, compared to the ADIM group, the UBCE group showed clinically more significant improvements in motor function, balance control, gait speed, and ADL in stroke survivors.

According to FMA analysis, UBCE had a higher impact than ADIM (38.12%), which is consistent with other studies that looked at how UBCE affected stroke patients' motor abilities. Chen et al. (2020) informed an improved FMA score following 48 sessions of core muscle stability training (23.58%) when compared to the control group in 180 stroke patients with hemiplegia [25]. Park et al (2022) stated an improvement in FMA score in 38 patients with ischemic and hemorrhagic stroke after 48 sessions of core muscle stability exercise with music-combined rehabilitation training (29.81%) compared to conventional rehabilitation exercise combined with trunk muscle control [26]. These results were consistent with previous studies that shown increased co-activation (1.2:1) of the muscle around the trunk during lifting activities in those without symptoms, which is associated with IO-multifidus muscle chain stability [27]. This discovery seems to reprogram UBCE breathing rhythm. Furthermore, it is known that an increase in IAP produces "relative stiffness," or the control of the spine that is necessary for functional activities. It has been demonstrated that isolated diaphragm contraction, even in the absence of back and abdominal muscle activity, increases IAP and aids in spinal control [27]. During dynamic hip movement, such as in the UBCE, these anterior muscular oblique chains may be counterbalanced by the posterior chain muscles to make the complete spinal segment upright and stabilize the movement of externally (negative) stabilizing forces [27]. The distal section moves on an anatomical foundation from the core. To keep the spine stable, core stability requires the capacity to control trunk motion over the pelvis and legs. It was anticipated that adding core stability would increase stability and enable better force production and control over lower leg movement [28]. However, the patient's abnormal flexion synergy may be connected to the significant decline in upper extremity function. One of the main things influencing patients' neuroplasticity and motor rehabilitation is abnormal upper extremity flexion synergy. The daily motor repertoire may include maladaptive strategies as a result of abnormal upper extremity flexion synergy. When trying to improve movement, compensatory movement methods can be exceedingly frustrating for both the patient and the therapist to relearn [29].

Balance analysis demonstrated a superior effect of UBCE (27.48%) compared to ADIM. These results support previous research that examined the balanced clinical effects of UBCE in stroke. Chen et al. (2020) described an improved balance score following 48 sessions of core muscle stability training (32.50%) when compared to the control group of 180 stroke patients with hemiplegia [25]. The capacity to synchronize vestibular organs, muscles, tendons, joints, and visual impulses is known as balance ability. It is the fundamental idea that people should maintain their posture and execute technical moves correctly. After a stroke, aberrant muscle tone, strength, and motor control challenges are caused by disturbances in the motor or sensory pathways, which ultimately lead to balance problems [25]. The ability of people with hemiplegia from brain infarction to walk and perform their everyday activities is dependent on the balancing function. The ability to sustain the same muscle conditions in the trunk and pelvis during an exercise, offer a stable foundation for upper and lower limb movement, and synchronize the force of the two muscles to optimize power production, transfer, and control is known as core stabilization [5]. Core stability exercise may improve the body's ability to coordinate, communicate, balance, regulate, and integrate the power production of each muscle group [15]. Consequently, scientists have worked to create techniques that would improve core stability and strength. Core stability training has gained a lot of attention in the area of rehabilitative medicine [11]. Patients recovering from strokes may find that core stability training helps them walk and live more independently, which will facilitate their reintegration into society and family [11]. In order to attain an objective that necessitates an upright posture, balance is a complex process that involves the planning and execution of movement as well as the processing and integration of sensory information. Strokes can impact the different postural control systems or the interplay between these systems. The loss of balance following a stroke can be caused by a variety of circumstances, including weakness on one side of the body, loss of sensation in the affected side, especially the leg, brain injury, lack of attention, perceptual issues, vision problems, dizziness or vertigo, and pharmaceutical side effects [30].

Gait speed analysis demonstrated a superior effect of UBCE (20.48%) than ADIM. These results support previous research that inspected the gait speed effectiveness of UBCE in hemiplegic participants. Jung et al (2016) reported an improvement in gait speed after 20 sessions of core stability training (16.09%) compared to a control group in 24 hemiplegic stroke patients [31]. It implies that dynamic balance and gait speed may be enhanced by extra trunk exercises targeted at enhancing rotation of the upper and lower trunk as well as lateral flexion. It suggests that a deficit in any of the core stability exercises distorts the muscle's capacity to maintain balance and spinal stability, which harms community ambulation [32]. Additionally reinforced by this concept is the conception of the "core" as a box with the abdominals in the front, the diaphragm as the roof, the pelvic floor and hip girdle muscles as the bottom, and the paraspinal and gluteal muscles in the rear [32,33]. The upper and lower trunks move in unison and opposing directions along the vertical axis during a typical gait cycle. In healthy individuals, the maximum mobility in the frontal plane trunk function is reached at the toe of the sagittal plane trunk function, which peaks near each heel strike [34]. Trunk function is said to be crucial for hemiplegic gait. Muscle imbalance after a stroke significantly changes trunk motions. The trunk deficits are opposite to the extremities and bilateral [35]. During the swing phase, core strengthening enhanced center of gravity transfer and posterior pelvic tilt. It has been established that the transverse abdominis helps the body become ready for contralateral weight redistribution. Research indicates that muscles in the trunk, particularly the multifidus and TrA, contract before muscles in the upper and lower limbs. Additionally, it is thought that this feed-forward activation pattern of the core muscles contributes to more accurate limb control during locomotion and offers a more solid neuromuscular basis for muscular movement [6].

ADL analysis demonstrated a superior effect of UBCE (37.15%) than the ADIM group. These results support a previous study that observed the gait speed effectiveness of UBCE in stroke participants. Haruyama et al. (2016) reported an improvement in ADL function in 32 participants with stroke after 16 sessions of a conventional therapy program with 400 min of core stabilization (25.40%) compared to the traditional physical therapy program alone [37]. In stroke hemiplegia, deep abdominal muscle activity is preserved. Hence, stroke victims can co-contract the trunk's global muscles while activating their core [37]. Regarding the intervention in this research, The program was created with the primary objective of improving core stability through the activation of the local core muscles [37]. As a result, we discovered that balance and mobility were enhanced by trunk stabilization due to core stability training [37]. This outcome was in parallel with the study by Cabanas-Valdés et al. (2017) on the intervention impact of improved core stability [38]. In contrast to our protocol, their core stability training included workouts of the local core muscles and consisted of bridge, reaching, and selected trunk or pelvic movement activities [39]. Although an intervention effect using core stability training as a supplemental training was requested, our protocol, which engages the local muscles of the core, revealed advantages without further training. Recent studies have shown that progressive programs have an effect and are useful in core stability exercises [34,35]. As a result, we created a unique progressive program for workouts including core stability. In terms of the protocol content, we sought to create a more targeted protocol than those found in earlier research by choosing a few specific training modalities. Most of the workouts were done while sitting upwards. It is safe and simple to use core stability training in a therapeutic context, and it proved beneficial when upright, and anti-gravity position compared to laying [40,41]. Several authors have shown that using ultrasound as a biofeedback technique can improve the deep core muscles' preferential activation in stroke patients. The ability of the lumbar multifidus muscle to contract preferentially was found to be substantially correlated with the muscle's capacity to recuperate, function, and maintain contraction during a restricted number of treatment sessions [16].

A limitation of this research was its small sample size for both groups due to the complications in employing patients at risk of falling. Consequently, even if the clinical outcome of the measurement data showed encouraging UBCE benefits, doctors should proceed with care when interpreting these results. Another limitation was that the anterior superficial and deep chain muscles and IAP were not measured. Therefore, more study is required to create an advanced sensor and motion magnetic resonance imaging (MRI) in order to accurately detect the motor control of the chain muscles that underlie dynamic hip or limb movement.

5. Conclusion

This study shows that stroke patients in UBCE had better treatment outcomes than those in ADIM. Our unique findings offer encouraging empirical proof that, when it comes to neuromuscular chain control, UBCE-based rehabilitation is more coordinated, balanced, well-moved, and fastened than ADIM. As such, it might be utilized as a substitute exercise for core stability. Important clinical insights on stroke rehabilitation are offered by this research.

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None to report.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] Katan M, Luft A, editors. Global burden of stroke. Seminars in neurology 2018; Thieme Medical Publishers.
[2] Langhorne P, Bernhardt J, Kwakkel G. Stroke rehabilitation. The Lancet. 2011; 377(9778): 1693-702.
[3] Gamble K, Chiu A, Peiris C. Core stability exercises in addition to usual care physiotherapy improve stability and balance after stroke: a systematic review and meta-analysis. Archives of Physical Medicine and Rehabilitation. 2021; 102(4): 762-75.
[4] Sun X, Gao Q, Dou H, Tang S. Which is better in the rehabilitation of stroke patients, core stability exercises or conventional exercises? Journal of Physical Therapy Science. 2016; 28(4): 1131-3.
[5] Yoon HS, Cha YJ, You JSH. Effects of dynamic core-postural chain stabilization on diaphragm movement, abdominal muscle thickness, and postural control in patients with subacute stroke: A randomized control trial. NeuroRehabilitation. 2020; 46(3): 381-9.
[6] Yoon HS, You JSH. Reflex-mediated dynamic neuromuscular stabilization in stroke patients: EMG processing and ultrasound imaging. Technology and Health Care. 2017; 25(S1): 99-106.
[7] Cholewicki J, Juluru K, McGill SM. Intra-abdominal pressure mechanism for stabilizing the lumbar spine. Journal of Biomechanics. 1999; 32(1): 13-7.
[8] Mahdieh L, Zolaktaf V, Karimi MT. Effects of dynamic neuromuscular stabilization (DNS) training on functional movements. Human Movement Science. 2020; 70: 102568.
[9] Frank C, Kobesova A, Kolar P. Dynamic neuromuscular stabilization & sports rehabilitation. International Journal of Sports Physical Therapy. 2013; 8(1): 62.
[10] Kobesova A, Davidek P, Morris CE, Andel R, Maxwell M, Oplatkova L, et al. Functional postural-stabilization tests according to Dynamic Neuromuscular Stabilization approach: Proposal of novel examination protocol. Journal of Bodywork and Movement Therapies. 2020; 24(3): 84-95.
[11] Sharma K, Yadav A. Dynamic neuromuscular stabilization-a narrative. International Journal of Health Sciences and Research. 2020; 10(9): 221-31.
[12] Son MS, Jung DH, You JSH, Yi CH, Jeon HS, Cha YJ. Effects of dynamic neuromuscular stabilization on diaphragm movement, postural control, balance and gait performance in cerebral palsy. NeuroRehabilitation. 2017; 41(4): 739-46.
[13] McGalliard MK, Dedrick GS, Brismée JM, Cook CE, Apte GG, Sizer PS. Jr., Changes in transversus abdominis thickness with use of the abdominal drawing-in maneuver during a functional task. PM&R. 2010; 2(3): 187-94.
[14] Moghadam N, Ghaffari MS, Noormohammadpour P, Rostami M, Zarei M, Moosavi M, Kordi R. Comparison of the recruitment of transverse abdominis through drawing-in and bracing in different core stability training positions. Journal of Exercise Rehabilitation. 2019; 15(6): 819.
[15] Su J, Ding Y, Cao Y, Zhang Z, Sun M, Zhang Y, et al. Diaphragmatic breathing combined with abdominal drawing-in maneuver for walking function in post-stroke patients: a randomized controlled study protocol. Trials. 2023; 24(1): 677.
[16] Sarafadeen R, Ganiyu SO, Ibrahim AA. Effects of spinal stabilization exercise with real-time ultrasound imaging biofeedback in individuals with chronic nonspecific low back pain: a pilot study. Journal of Exercise Rehabilitation. 2020; 16(3): 293.
[17] Bernhardt J, Hayward KS, Kwakkel G, Ward NS, Wolf SL, Borschmann K, et al. Agreed definitions and a shared vision for new standards in stroke recovery research: the stroke recovery and rehabilitation roundtable taskforce. International Journal of Stroke. 2017; 12(5): 444-50.

[18] Gladstone DJ, Danells CJ, Black SE. The Fugl-Meyer assessment of motor recovery after stroke: a critical review of its measurement properties. Neurorehabilitation and Neural Repair. 2002; 16(3): 232-40.
[19] Hsieh Y-W, Wu C-Y, Lin K-C, Chang Y-F, Chen C-L, Liu J-S. Responsiveness and validity of three outcome measures of motor function after stroke rehabilitation. Stroke. 2009; 40(4): 1386-91.
[20] Ng SS, Hui-Chan CW. The timed up & go test: its reliability and association with lower-limb impairments and locomotor capacities in people with chronic stroke. Archives of Physical Medicine and Rehabilitation. 2005; 86(8): 1641-7.
[21] Collen FM, Wade DT, Bradshaw CM. Mobility after stroke: reliability of measures of impairment and disability. International Disability Studies. 1990; 12(1): 6-9.
[22] Douglas Chumney D, Kristen Nollinger D, Kristina Shesko D, Karen Skop D, Madeleine Spencer D, Newton RA. Ability of Functional Independence Measure to accurately predict functional outcome of stroke-specific population: systematic review. Journal of Rehabilitation Research and Development. 2010; 47(1-5): 17-30.
[23] Gkouma A, Theotokatos G, Geladas N. Validity and Reliability Evidence of the Functional Independence Measurement (FIM) for individuals with Neurological Disorders in Greece. J Med-Clin Res & Rev. 2022; 6(5): 1-11.
[24] Mohammad Rahimi N, Mahdavinejad R, Attarzadeh Hosseini SR, Negahban H. Efficacy of dynamic neuromuscular stabilization breathing exercises on chest mobility, trunk muscles, and thoracic kyphosis: a randomized controlled 6-Week trial. Iranian Rehabilitation Journal. 2020; 18(3): 329-36.
[25] Chen X, Gan Z, Tian W, Lv Y. Effects of rehabilitation training of core muscle stability on stroke patients with hemiplegia. Pakistan Journal of Medical Sciences. 2020; 36(3): 461.
[26] Park JS, Yang KH, Lee DH. The Effects of Core Stability Exercise with Music on Balance and Functional Activity in Stroke. Journal of Korean Society for Neurotherapy. 2022; 26(1): 29-34.
[27] Choi H, Park C, Hwang J, You JSH. Neuromuscular Mechanisms and Effects of Core Stabilization on Trunk and Hip Muscle Activity during Lifting Movement. Journal of Mechanics in Medicine and Biology. 2021; 21(9): 2140042.
[28] Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. Sports Medicine. 2006; 36: 189-98.
[29] Kang DW, Roh JK, Lee YS, Song IC, Yoon BW, Chang KH. Neuronal metabolic changes in the cortical region after subcortical infarction: a proton MR spectroscopy study. Journal of Neurology, Neurosurgery & Psychiatry. 2000; 69(2): 222-7.
[30] Sharma V, Kaur J. Effect of core strengthening with pelvic proprioceptive neuromuscular facilitation on trunk, balance, gait, and function in chronic stroke. Journal of exercise rehabilitation. 2017; 13(2): 200.
[31] Jung KS, Cho HY, In TS. Trunk exercises performed on an unstable surface improve trunk muscle activation, postural control, and gait speed in patients with stroke. Journal of Physical Therapy Science. 2016; 28(3): 940-4.
[32] Billinger SA, Arena R, Bernhardt J, Eng JJ, Franklin BA, Johnson CM, et al. Physical activity and exercise recommendations for stroke survivors: a statement for healthcare professionals from the American Heart Association/American Stroke Association. Stroke. 2014; 45(8): 2532-53.
[33] Onwudiwe C, Ezema C, Nweke M, Anukam G, Okoy G. Effects of core strengthening exercises on dynamic balance and gait speed in stroke survivors. International Journal of Basic, Applied and Innovative Research. 2018; 7(2): 47-54.
[34] Van Criekinge T, Saeys W, Hallemans A, Velghe S, Viskens P-J, Vereeck L, et al. Trunk biomechanics during hemiplegic gait after stroke: a systematic review. Gait & Posture. 2017; 54: 133-43.
[35] Cabanas-Valdés R, Boix-Sala L, Grau-Pellicer M, Guzmán-Bernal JA, Caballero-Gómez FM, Urrútia G. The effectiveness of additional core stability exercises in improving dynamic sitting balance, gait and functional rehabilitation for subacute stroke patients (core-trial): Study protocol for a randomized controlled trial. International Journal of Environmental Research and Public Health. 2021; 18(12): 6615.
[36] Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Physical therapy. 1997; 77(2): 132-42.
[37] Haruyama K, Kawakami M, Otsuka T. Effect of core stability training on trunk function, standing balance, and mobility in stroke patients: a randomized controlled trial. Neurorehabilitation and neural repair. 2017; 31(3): 240-9.
[38] Cabanas-Valdés R, Bagur-Calafat C, Girabent-Farrés M, Caballero-Gómez FM, du Port de Pontcharra-Serra H, German-Romero A, Urrútia G. Long-term follow-up of a randomized controlled trial on additional core stability exercises training for improving dynamic sitting balance and trunk control in stroke patients. Clinical Rehabilitation. 2017; 31(11): 1492-9.
[39] Marsden J, Hough A, Shum G, Shaw S, Freeman J. Deep abdominal muscle activity following supratentorial stroke. Journal of Electromyography and Kinesiology. 2013; 23(4): 985-90.
[40] Rose D, Paris T, Crews E, Wu SS, Sun A, Behrman AL, Duncan P. Feasibility and effectiveness of circuit training in acute stroke rehabilitation. Neurorehabilitation and neural repair. 2011; 25(2): 140-8.
[41] Reeve A, Dilley A. Effects of posture on the thickness of transversus abdominis in pain-free subjects. Manual therapy. 2009; 14(6): 679-84.