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Efficacy of lateral stair walking training in patients with chronic stroke: A pilot randomized controlled study☆

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ABSTRACT

Background: Patients with chronic stroke have reduced capacity for performing activities of daily living (ADLs) and are at increased risk for falls during walking due to long-term changes to muscle tone and force, as well as movement control.
Research question: To investigate the efficacy of lateral stair walking training on muscle strength of affected lower extremities, balance, ADLs, and gait ability in patients with chronic stroke.
Methods: The experimental group received 15 min of lateral stair walking exercise along with 15 min of traditional physiotherapy, whereas the control group received only traditional physiotherapy for 30 min. Both groups received the intervention once a week for 12 weeks. Outcome measurements included muscle strength, postural assessment scale for stroke patients (PASS), Fugal–Meyer assessment for lower extremity (FMA-LE), Barthel index (BI), timed up and go test (TUG), and the gait parameters which were determined by the Reha-Watch system.
Results: A total of 24 participants completed the study. The experimental group showed significant improvements in hip extensor, flexor, and abductor strength of the affected limb, FMA-LE, BI, TUG, and gait parameters of stride length, velocity, and cadence. Significant differences in affected limb ankle plantar strength ($p = 0.024$), PASS ($p = 0.017$), BI ($p = 0.039$), TUG ($p = 0.049$), and gait velocity ($p < 0.001$) were observed between the 2 groups.
Significance: Lateral stair walking training alongside physical therapy resulted in significant improvements in hip muscle strength and gait parameters in patients with chronic stroke. Our results support the incorporation of lateral stair walking training into clinical rehabilitation programs. Lateral stair walking training in patients with chronic stroke can be used as an effective treatment to improve gait, balance performance, and ADLs.

1. Introduction

More than half of patients with stroke suffer from moderate disabilities [1]. Hemiparesis, the most common symptom, causes difficulty in sitting, standing, balancing, or walking [2,3]. Thus, patients with stroke are at high risk for forward, backward, or even lateral falls owing to their poor balance [4]. Moreover, patients with stroke exhibit ipsilateral hip flexor, gluteus maximus, hip abductor, and knee extensor weakness [5,6] or changes in muscle tone [7] that may cause abnormal gait [8,9] and consequently increase the risk for falls during walking [10].

Patients suffering from hemiplegia following a stroke have limited muscle function due to muscle weakness and antagonist muscle hyperactivation, which decreases muscle strength [11]. As such, hip flexor, extensor, abductor, adductor, and knee extensor muscle strength must be trained after a stroke [12].

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Patients with hemiplegia after a stroke are more likely to bear their weight on the contralateral lower extremity, which can result in poor postural control and increased risk for falls [13]. Stair walking often forms part of individuals' daily routine. During clinical rehabilitation, gait training on flat ground is generally followed by stair walking training [14]. A previous report showed that stair walking training can improve the static standing balance of patients with stroke [15]. Although several current studies have focused on frontal stair walking training [15,16], no study to date has focused on lateral stair walking training, which greatly involves hip abduction and adduction. While lateral stair walking training can theoretically reduce lateral falls and improve balance, limited research evidence has been available in support thereof.

The current study, therefore, aimed to investigate the efficacy of lateral stair walking training on affected lower extremity muscle strength, balance, activities of daily living (ADLs), and walking performance throughout the gait cycle in patients with chronic stroke.

2. Methods

2.1. Participants

This study was an assessor-blinded experimental design. This pilot randomized controlled trial was performed in one university-affiliated medical center from January 2016 to December 2017. Subjects were randomized into two groups using computer-generated random numbers held in sealed envelopes by an individual not involved with the study. This study is registered with Clinicaltrials.gov (NCT03702517) and had been approved by the Institutional Review Board of Kaohsiung Veterans General Hospital, Taiwan (IRB No.: VGHKS15-CT8-23).

Thirty patients with chronic stroke visiting the outpatient rehabilitation department of a tertiary care medical center were invited to participate in this study. After the initial screening evaluation, eligible patients were then enrolled in the study. The inclusion criteria were as follows: diagnosis of one stroke within 6 months to 6 years by a neurologist or physiatrists, computed tomography or magnetic resonance imaging showing unilateral cerebral hemorrhage or infarction, a score of 24 or higher on the Mini Mental State Examination (MMSE), absence of serious bone and joint problems, ability to follow instructions and experimental procedures, and ability to walk 15 m independently. The exclusion criteria were as follows: cognitive or visual impairment and inability to receive training due to other diseases (lung, heart, gastrointestinal tract, bone, muscle, nervous system, etc.). Patients agreed not to receive other physical therapies during the study period.

2.2. Procedures

All patients provided informed consent prior to study participation. Test procedure are summarized in Fig. 1. The experimental group received 15 min of lateral stair walking exercise and 15 min of traditional physiotherapy (strengthening exercise, balance training, and gait training) once a week for 12 weeks. For lateral stair walking training, the dynamic stair trainer (DPE Medical Ltd) featured four steps. The step height can be adjusted from 0 to 16.5 cm, while the stair was 74 cm in width, with each step being 16 cm deep. The experimental group performed lateral stair walking training using different stair heights according to the patients' ability. The patients ascended the stairs using the affected leg first and descended with the unaffected leg first. For safety purposes, subjects held a handrail during the lateral stair walking exercise. The control group received traditional physiotherapy (strengthening exercise of the affected side, balance training, and gait training) for 30 min once a week for 12 weeks. All interventions were conducted by the same physical therapist.

2.3. Outcome measures

Measurements were performed by one experienced physical therapist (not involved in the intervention) before receiving the intervention and at week 0 (pre) and week13 (post). Each subject required 45 min to complete all measures during each session. The outcome measures were as follows:

(1) MicroFET2 hand-held dynamometer (Hoggan Scientific LLC). This hand-held dynamometer, which can measure muscle strength in Newtons, has been found to have good reliability and had been used to assess subjects' muscle strength [17]. Three measurements were taken, the interval between contractions was 30 s, the highest performance was considered for analysis. Each

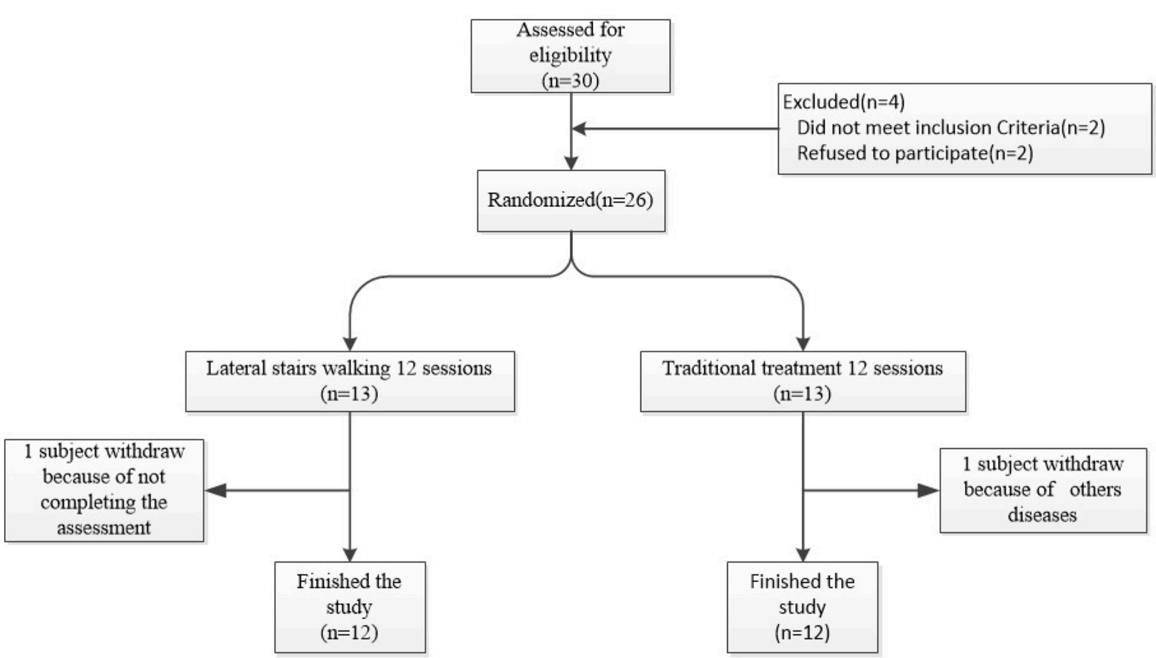

Fig. 1. Flow chart for the study.

participant performed maximum isometric contraction for 5 s for hip flexors, hip extensors, abductors, knee flexors, knee extensors, ankle dorsiflexors and plantar flexors. The testing position was lying in the bed for hip flexors. The testing position was prone position in the bed for hip extensors. The testing position for the other muscles was sitting position.

(2) The postural assessment scale for stroke patients (PASS). The PASS assesses balance in lying, sitting, and standing positions. This scale has been designed for patients with stroke and is suitable for all individuals regardless of postural performance. Its advantage lies in the lack of ceiling and floor effects, as well as the ability to assess the static and dynamic balance of patients with stroke. The PASS is rated on a scale from 0 to 3 (total score of 36), with higher scores indicating better balance in patients with stroke [18].

(3) Fugl–Meyer assessment for lower extremity (FMA-L/E). This assessment scale had been developed based on Brunnstrom stage L/E and specifically caters to patients with stroke. The FMA-L/E, which is rated on a scale from 0 to 2, has been determined to have good reliability and validity [19].

(4) Barthel index for ADLs. This index is a reliable and valid basic scale for assessing functional independence, covering 10 items, such as feeding, bathing, grooming, dressing, bowel control, bladder control, toilet use, transfers (bed to chair and back), and mobility on level surfaces and stairs. The total score, which ranges from 0 to 100, is a progressive indication for ADLs [20].

(5) Timed up and go test (TUG). This test assesses the time it takes for a patient to rise from a chair, walk 3 m, turn, walk back, and sit down. The TUG has been found to have good sensitivity and specificity (87 % and 87 %, respectively) for predicting falls in patients with stroke [21,22].

(6) Reha-Watch system (Hasomed GmbH, Magdeburg, Germany). Wearing this highly reliable three-axis gyro sensor on the shoes allows for gait data collection and subsequent analysis using a microcomputer via Bluetooth. RehaGait comes with up to 7 Motion Sensors which can be fitted to bilateral measures of the feet, lower legs, thighs, and hip. The ideal walking distance is about 10 m. During walking, the foot movement is measured, especially the patterns of acceleration and angular velocity. Reha-Watch system records the bilateral stance and swing phase (%), single support time(%), double support time (%), stride length (m), velocity (m/sec) and cadence(steps/min) during the gait cycle [23].

2.4. Statistical analysis

The sample size was calculated by using the G-power software (Ver. 3.1). The sample size was estimated to be 12 participants per group (power, 0.8; alpha, 0.05; effect size, 0.8). Data were analyzed using SPSS version 22.0 (Chicago, Illinois). The values in each group were expressed as means and standard deviations. Descriptive statistics were used to analyze baseline data of the subjects. All category data are nominal scales, such as gender, affected side, type of stroke (hemorrhage & ischemia), and use of assistive devices (cane or quadricane). Nominal data were all analyzed by fisher's exact Test, which is suitable for the scale. The changes in outcome measures between pre- and post-intervention of the subjects were analyzed and compared between groups. Mann Whitney *U* test was used for analysis of between experimental and control groups. Wilcoxon signed-rank test was used for analysis of differences for between pre- and post-intervention within each group. A p-value of <0.05 was considered statistically significant.

3. Results

A total of 30 patients with chronic hemiparesis poststroke were recruited to participate in this study. Among the recruited patients, two did not meet the inclusion criteria and two refused to participate in the study. As such, 26 participants were randomly assigned to the experimental (n = 13) and control (n = 13) group. One subject in the experimental group did not complete the assessment and withdrew before the experiment ended, While the other subject in the control group withdrew due to other disease (Fig. 1). A total of 24 participants (12 in each group) ultimately completed the study. No significant differences in disease characteristics and baseline measurements were observed between the groups (Table 1). The actual p- value comparing age factor between the two groups was 0.052, and it was not statistically significant.

Comparisons of outcomes at week 0 (pre) and week 13 (post) are presented in Tables 2–4. Accordingly, no statistically significant differences in baseline measurements were observed between both groups. The experimental group exhibited a significant improvement in hip extensor, flexor, and abductor strength on the affected side, while the control group exhibited significant reduction in ankle plantar flexor strength on the affected side (Table 2). A significant between-group difference in affected side ankle plantar flexor strength was observed (P = 0.024) (Table 2). Although no significant difference in PASS was observed within each group, a significant between-group difference was noted (P = 0.017) (Table 3). Both groups exhibited significant improvements in FMA-L/E. The Barthel index improved significantly in the experimental group (P = 0.004), with a significant between-group difference having been noted (P = 0.039) (Table 3). The experimental group exhibited a significant reduction in TUG from 27.9 (±15.3) s at baseline to 23.9 (±14.1) s at week 13 (P = 0.002), with a significant between-group difference in the TUG favoring the experiment group (P = 0.049) (Table 3).

The experimental group showed significant improvement in gait parameters of stride length, velocity, and cadence after intervention. A significant between-group difference in gait velocity favoring the experimental group was noted after the intervention (P < 0.001) (Table 4). No significant between-group differences were observed in all the other gait parameters (Table 4).

4. Discussion

This pilot study demonstrated that 12 sessions of lateral stair walking training improved muscle strength, balance, and gait performance of patients with stroke. Our data revealed experimental group exhibited significant improvements in affected limb hip extensor, flexor, abductor strength, BI, and TUG.

Patients with stroke should emphasize lower extremity muscle

Table 1
Baseline characteristics of the participants (n = 24).

Characteristics	Experimental group (n = 12)	Control group (n = 12)	P Value
Gender, n(male/female)	9/3	9/3	0.671
Age (year)	53.67 ± 9.16	63.33 ± 13.31	0.052
Height (cm)	167.00 ± 7.94	163.75 ± 10.19	0.392
Weight (kg)	67.17 ± 11.42	69.75 ± 18.67	0.694
Affected side, n (right/left)	7/5	9/3	0.671
Type of stroke (hemorrhage & ischemia), n	4/8	4/8	1.000
Post stroke duration (mon)	28.67 ± 21.75	33.75 ± 16.32	0.523
Use of assistive devices (Cane or Quadricane), n (no/yes)	8/4	6/6	0.682

Values are means ± SD, EG: experimental group, CG: control group.
Fisher Exact Test was used for gender, affected side, type of stroke (hemorrhage & infarct), use of assistive devices (Cane or Quadricane).

Table 2
The comparisons of muscle strength changes for affected lower extremity (n = 24).

Variable	Experimental group				Control group				Experimental VS control
	n = 12				n = 12				
	Pre- (Week0)	Post- (Week12)	Change of variables	p¹-value	Pre- (Week0)	Post- (Week12)	Change of variables	p²-value	p³-value
Hip extensors	17.3 ± 16.1	25.5 ± 17.3	8.2 ± 10.3	0.008*	21.3 ± 21.1	25.3 ± 17.1	4.0 ± 12.0	0.515	0.091
Hip flexors	38.0 ± 12.2	44.2 ± 12.1	6.2 ± 12.8	0.049*	33.2 ± 18.0	34.7 ± 17.5	1.5 ± 10.0	0.79	0.106
Hip Abductors	29.2 ± 15.2	41.9 ± 7.9	12.7 ± 19.3	0.010*	33.6 ± 22.5	40.2 ± 13.3	6.6 ± 14.8	0.224	0.47
Knee extensors	35.7 ± 10.4	34.9 ± 9.3	−0.8 ± 7.1	0.445	40.1 ± 13.1	35.4 ± 10.9	−4.6 ± 11.1	0.209	0.419
Knee flexors	21.6 ± 16.6	29.2 ± 17.9	7.6 ± 13.9	0.091	23.5 ± 23.2	22.9 ± 13.2	−0.6 ± 17.3	0.859	0.165
Ankle plantar flexors	14.1 ± 13.6	17.0 ± 15.4	2.9 ± 6.7	0.128	19.2 ± 17.4	9.5 ± 14.3	−9.7 ± 16.1	0.036*	0.024*
Ankle dorsiflexors	13.7 ± 12.2	11.5 ± 9.7	−2.2 ± 10.5	0.678	13.5 ± 11.7	10.5 ± 10.1	−3.0 ± 6.7	0.208	0.682

Values are presented as means ± SD *: $p < 0.05$.
P^1 and P^2: Wilcoxon signed-rank test was used for analysis of differences between pre- and post-intervention within each group.
P^3: Mann Whitney *U* test was used for analysis of differences between experimental and control groups.

Table 3
The comparisons of other outcome measure changes between groups (n = 24).

Variable	Experimental group				Control group				Experimental VS control
	(n = 12)				(n = 12)				
	Pre- (Week0)	Post- (Week12)	Change of variables	p¹-value	Pre- (Week0)	Post- (Week12)	Change of variables	p²-value	p³-value
PASS	32.4 ± 1.7	33.4 ± 1.6	1.0 ± 1.2	0.763	31.3 ± 1.9	32.3 ± 2.1	1.1 ± 1.1	0.110	0.017*
FMA-LE	19.4 ± 4.2	24.8 ± 3.5	5.3 ± 1.7	0.052	21.2 ± 5.4	23.3 ± 5.2	1.7 ± 2.1	0.082	0.772
BI	87.1 ± 6.6	95.0 ± 4.3	7.9 ± 6.2	0.004*	90.8 ± 11.6	92.5 ± 10.1	1.7 ± 8.9	0.495	0.039*
TUG (seconds)	27.9 ± 15.3	23.9 ± 14.1	−4.0 ± 2.7	0.002*	34.1 ± 20.1	32.0 ± 16.6	−2.2 ± 8.2	0.157	0.049*

Values are presented as mean ± SD *: $p < 0.05$ PASS: The postural assessment scale for patients with a stroke; FMA-LE: Fugl-Meyer assessment for Lower extremity. BI: Barthel Index; TUG: Timed Up and Go.
P^1 and P^2: Wilcoxon signed-rank test was used for analysis of differences between pre- and post-intervention within each group.
P^3: Mann Whitney *U* test was used for analysis of differences between experimental and control groups.

Table 4
The analysis of gait parameter changes after lateral stair walking training (n = 24).

Variable	Experimental group				Control group				Experimental VS control
	(n = 12)				(n = 12)				
	Pre- (Week0)	Post- (Week12)	Change of variables	p¹-value	Pre- (Week0)	Post- (Week12)	Change of variables	p²-value	p³-value
Stance phase (%)									
Non-affected side	71.4 ± 4.0	72.8 ± 5.5	1.4 ± 7.0	0.937	77.2 ± 9.7	77.5 ± 10.5	0.4 ± 6.6	0.875	1.000
affected side	63.4 ± 5.0	63.3 ± 5.5	−0.1 ± 5.6	0.754	71.7 ± 6.7	69.9 ± 8.8	−1.8 ± 8.4	0.408	0.273
Swing phase (%)									
Non-affected side	28.6 ± 4.0	27.2 ± 5.5	−1.4 ± 7.0	0.937	19.6 ± 11.2	22.5 ± 10.5	2.9 ± 6.0	0.084	0.133
affected side	36.7 ± 5.0	36.7 ± 5.5	0.1 ± 5.6	0.754	27.2 ± 6.9	30.1 ± 8.8	2.9 ± 9.5	0.308	0.204
Single support time, (%)									
Non-affected side	36.7 ± 5.0	37.0 ± 5.4	0.3 ± 5.8	0.530	28.4 ± 6.7	32.3 ± 10.7	4.0 ± 8.6	0.117	0.166
affected side	27.3 ± 4.5	27.4 ± 5.7	0.1 ± 8.2	0.388	22.9 ± 9.7	22.1 ± 10.1	−0.7 ± 6.7	0.754	0.564
Double support time, (%)									
Non-affected side	18.7 ± 5.2	20.1 ± 7.8	1.5 ± 7.9	0.937	23.1 ± 22.1	19.1 ± 12.6	−4.0 ± 20.2	0.433	0.356
affected side	15.0 ± 3.1	15.7 ± 4.3	0.7 ± 3.7	0.308	15.2 ± 9.6	13.4 ± 6.6	−1.8 ± 9.0	0.638	0.564
Stride length(m)	1.2 ± 0.5	1.0 ± 0.4	−0.2 ± 0.3	0.041*	1.5 ± 0.4	1.3 ± 0.4	−0.1 ± 0.7	0.480	1.000
Velocity(m/sec)	0.8 ± 0.3	1.0 ± 0.3	0.2 ± 0.1	0.002*	0.8 ± 0.2	0.7 ± 0.2	−0.04 ± 0.1	0.181	<0.001*
Cadence(steps/min)	72.5 ± 9.6	89.2 ± 13.5	16.7 ± 12.2	0.002*	70.3 ± 23.6	79.8 ± 24.2	9.5 ± 13.9	0.019*	0.083

Values are presented as mean ± SD *: $p < 0.05$.
P^1 and P^2: Wilcoxon signed-rank test was used for differences between pre- and post-intervention within each group.
P^3: Mann Whitney *U* test was used for differences between experimental and control groups.

strength training and normalize the tone of lower extremity. The current study showed that 12 sessions of lateral stair walking training promoted increased hip flexor strength. According to the report by Seo et al., hospitalized patients with stroke were able to significantly improve rectus femoris strength after performing a step climbing exercise [16]. The findings were similar to our study. In our study, we demonstrated step climbing exercise can improve muscle strength of hip extensor, hip flexors and hip abductors in patients with stroke. However, the knee extensor strength did not show significant improvement. All participants in this study could walk overground. When the lateral stair walking training intensity of the knee extensor is not enough to reach muscle overload, the knee extensor can only maintain its muscle strength rather than increase muscle strength.

Lateral stair walking training can be considered a type of functional training. Accordingly, one study found that functional training was more important than muscle strength training using sandbags for the recovery of motion [24]. In clinical practice, patients with stroke generally receive weight training or traditional muscle strength training when the muscle strength of the lower limbs is insufficient. However, once the muscle strength is sufficient, patients should receive functional training, such as standing from a sitting position and stair walking. We suggest adding lateral stair walking training to increase lower extremity muscle strength in patients with chronic stroke and improve functional performance.

The high incidence of falls has remained one of the most significant concerns for patients with stroke. Accordingly, Persson et al. found that increase time measurements during the TUG, which is a clinical indicator of balance, agility, and mobility performance [25], was associated with an increased risk for falls after a recent stroke [26]. The present study found a significant decrease in TUG times within the experimental group, with a significant between-group difference also having been observed. After conducting a study on task-oriented circuit training in patients within a year after stroke, Salah et al. found that TUG improved from 24.4–23.2 s [27]. Another study reported that the minimum clinically important difference (MCID) in the TUG was 3.4 s [28]. The MCID of 3.4 s is sufficiently sensitive to reflect the real difference. In the current study, the experimental group exhibited a reduction in TUG time from 27.9–23.9 s after lateral stair walking training. The TUG is an objective clinical measure for assessing balance and functional mobility and thus the risk of falling [29]. Our study revealed that patients with chronic stroke who received lateral stair walking training may improve balance and reduced risk for falls compared to before training. A study by Seo et al. reported that stair gait training significantly improved the TUG results [16], a finding consistent with that presented herein.

The affected and non-affected sides of the bilateral stance and swing phase, the single support time, the double support time of the gait parameters did not change significantly after intervention. Our findings showed that lateral stair walking training improved the gait velocity of patients with a stroke. A study by Park et al. revealed that hospitalized patients with stroke who performed step climbing exercise and stair gait exercise for 15 min thrice a week for 8 weeks were able to increase step length [30]. Stair walking training involves moving one foot forward and shifting the center of gravity vertically, whereas lateral stair walking training involves bending one foot outward and moving either left or right, which requires more hip extensors, hip flexors, hip abductors muscle strength for movement control [31]. Nonetheless, stair walking gait training remains applicable in clinical functional activities and essential for patients with stroke considering the needs of those who live in an apartment or house with stairs.

4.1. Limitations

Several limitations of our study are worth noting. First, the number of participants included herein was relatively small. Given the few patients with chronic stroke recruited into our study, the results obtained herein may not be generalizable to all patients with a stroke. Second, our follow-up time was considerably short. As such, larger-scale studies with longer follow-up durations are needed to confirm the efficacy of lateral stair walking training in patients with stroke. Third, patients in both groups, as well as the physical therapist providing the intervention, had been not blinded. However, the evaluator had been blinded to the patient groupings.

5. Conclusion

Lateral stair walking training once a week for 12 sessions in patients with chronic stroke promoted improvements in muscle strength, motor recovery of lower extremities, and BI. Moreover, lateral stair walking training may reduce TUG times and walking performance throughout the gait cycle. We therefore recommend that patients with chronic stroke receive additional lateral stair walking training to help recover function in the affected lower limb.

Author statement

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Declaration of Competing Interest

No conflict of interest exits in the submission of this manuscript, and manuscript is approved by all authors for publication.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2021.04.026.

References

[1] H.S. Jørgensen, H. Nakayama, H.O. Raaschou, J. Vive-Larsen, M. Støier, T.S. Olsen, Outcome and time course of recovery in stroke. Part II: time course of recovery. The Copenhagen Stroke Study, Arch. Phys. Med. Rehabil. 76 (1995) 406–412, https://doi.org/10.1016/s0003-9993(95)80568-0.

[2] R. Schneider, J.C. Gautier, Leg weakness due to stroke site of lesions, weakness patterns and causes, Brain 117 (1994) 347–354, https://doi.org/10.1093/brain/117.2.347.

[3] H. Naritomi, H. Moriwaki, N. Metoki, H. Nishimura, Y. Higashi, Y. Yamamoto, et al., Effects of edaravone on muscle atrophy and locomotor function in patients with ischemic stroke: a randomized controlled pilot study, Drugs R D 10 (2010) 155–163, https://doi.org/10.2165/11586550-000000000-00000.

[4] F.A. Batchelor, S.B. Williams, T. Wijeratne, C.M. Said, S. Petty, Balance and gait impairment in transient ischemic attack and minor stroke, J. Stroke Cerebrovasc. Dis. 24 (2015) 2291–2297, https://doi.org/10.1016/j.jstrokecerebrovasdis.2015.06.014.

[5] C. Patten, J. Lexell, H.E. Brown, Weakness and strength training in persons with poststroke hemiplegia: rationale, method, and efficacy, J. Rehabil. Res. Dev. 41 (2004) 293–312, https://doi.org/10.1682/jrrd.2004.03.0293.

[6] S.S.M. Ng, R.B. Shepherd, Weakness in patients with stroke: implications for strength training in neurorehabilitation, Phys. Ther. Rev. 5 (2000) 227–238, https://doi.org/10.1179/108331900786166650.

[7] M.H. Rhee, L.J. Kim, Muscle tone changes in the lower limbs of stroke patients induced by trunk stabilization exercises, J. Phys. Ther. Sci. 27 (2015) 2663–2664, https://doi.org/10.1589/jpts.27.2663.

[8] U.B. Flansbjer, D. Downham, J. Lexell, Knee muscle strength, gait performance, and perceived participation after stroke, Arch. Phys. Med. Rehabil. 87 (2006) 974–980, https://doi.org/10.1016/j.apmr.2006.03.008.

[9] H.S. Jørgensen, H. Nakayama, H.O. Raaschou, T.S. Olsen, Recovery of walking function in stroke patients: the Copenhagen Stroke Study, Arch. Phys. Med. Rehabil. 76 (1995) 27–32, https://doi.org/10.1016/s0003-9993(95)80038-7.

[10] A. Tsur, Z. Segal, Falls in stroke patients: risk factors and risk management, Isr. Med. Assoc. J. 12 (2010) 216–219.

[11] M. Paci, Physiotherapy based on the Bobath concept for adults with post-stroke hemiplegia: a review of effectiveness studies, J. Rehabil. Med. 35 (2003) 2–7, https://doi.org/10.1080/16501970306106.

[12] J. Wang, C.P. Hurt, C.E. Capo-Lugo, D.A. Brown, Characteristics of horizontal force generation for individuals post-stroke walking against progressive resistive forces, Clin. Biomech. (Bristol, Avon) 30 (2015) 40–45, https://doi.org/10.1016/j.clinbiomech.2014.11.006.

[13] M. Kobayashi, K. Takahashi, M. Sato, S. Usuda, Association of performance of standing turns with physical impairments and walking ability in patients with hemiparetic stroke, J. Phys. Ther. Sci. 27 (2015) 75–78, https://doi.org/10.1589/jpts.27.75.

[14] D.A. Umphred, Umphred's Neurological Rehabilitation, sixth ed., Elsevier/Mosby, St. Louis, Mo, 2013.

[15] K. Seo, J. Kim, G. Wi, The effects of stair gait exercise on static balance ability of stroke patients, J. Phys. Ther. Sci. 26 (2014) 1835–1838, https://doi.org/10.1589/jpts.26.1835.

[16] K. Seo, S.H. Park, K. Park, The effects of stair gait training using proprioceptive neuromuscular facilitation on stroke patients' dynamic balance ability, J. Phys. Ther. Sci. 27 (2015) 1459–1462, https://doi.org/10.1589/jpts.27.1459.

[17] F. Buckinx, J.L. Croisier, J.Y. Reginster, N. Dardenne, C. Beaudart, J. Slomian, et al., Reliability of muscle strength measures obtained with a hand-held dynamometer in an elderly population, Clin. Physiol. Funct. Imaging 37 (3) (2017) 332–340, https://doi.org/10.1111/cpf.12300.

[18] W.H. Yu, K.L. Chen, Y.T. Chou, I.P. Hsueh, C.L. Hsieh, Responsiveness and predictive validity of the hierarchical balance short forms in people with stroke, Phys. Ther. 93 (2013) 798–808, https://doi.org/10.2522/ptj.20120259.

[19] A.R. Fugl-Meyer, L. Jääskö, I. Leyman, S. Olsson, S. Steglind, The post-stroke hemiplegic patient. 1. a method for evaluation of physical performance, Scand. J. Rehabil. Med. 7 (1975) 13–31.

[20] C. Collin, D.T. Wade, S. Davies, V. Horne, The Barthel ADL Index: a reliability study, Int. Disabil. Stud. 10 (1988) 61–63, https://doi.org/10.3109/09638288809164103.

[21] A. Shumway-Cook, S. Brauer, M. Woollacott, Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test, Phys. Ther. 80 (2000) 896–903, https://doi.org/10.1093/ptj/80.9.896.

[22] H. Manaf, M. Justine, M. Omar, Functional balance and motor impairment correlations with gait parameters during Timed Up and Go Test across three attentional loading conditions in stroke survivors, Stroke Res. Treat. 2014 (2014), 439304, https://doi.org/10.1155/2014/439304.

[23] R. Schwesig, S. Leuchte, D. Fischer, R. Ullmann, A. Kluttig, Inertial sensor based reference gait data for healthy subjects, Gait Posture 33 (2011) 673, https://doi.org/10.1016/j.gaitpost.2011.02.023, https://doi.org/10.1093/ptj/80.9.896678.

[24] M. Smith, Neurological rehabilitation: optimizing motor performance, Physiother. Can. 67 (2015) 215–216, https://doi.org/10.3138/ptc.67.2.rev2.

[25] O.A. Donoghue, N.F. Horgan, G.M. Savva, H. Cronin, C. O'Regan, R.A. Kenny, Association between timed up-and-go and memory, executive function, and processing speed, J. Am. Geriatr. Soc. 60 (2012) 1681–1686, https://doi.org/10.1111/j.1532-5415.2012.04120.x.

[26] C.U. Persson, P.O. Hansson, K.S. Sunnerhagen, Clinical tests performed in acute stroke identify the risk of falling during the first year: postural stroke study in Gothenburg (POSTGOT), J. Rehabil. Med. 43 (2011) 348–353, https://doi.org/10.2340/16501977-0677.

[27] N.M. Salbach, N.E. Mayo, S. Wood-Dauphinee, J.A. Hanley, C.L. Richards, R. Côté, A task-orientated intervention enhances walking distance and speed in the first year post stroke: a randomized controlled trial, Clin. Rehabil. 18 (2004) 509–519, https://doi.org/10.1191/0269215504cr763oa.

[28] O.P. Gautschi, M.N. Stienen, M.V. Corniola, H. Joswig, K. Schaller, G. Hildebrandt, et al., Assessment of the minimum clinically important difference in the timed up and go test after surgery for lumbar degenerative disc disease, Neurosurgery 80 (2017) 380–385, https://doi.org/10.1227/neu.0000000000001320.

[29] A. Shumway-Cook, S. Brauer, M. Woollacott, Predicting the probability for falls in community-dwelling older adults using the Timed Up & Go Test, Phys. Ther. 80 (2000) 896–903, https://doi.org/10.1093/ptj/77.8.812.

[30] K.H. Park, D.Y. Kim, T.H. Kim, The effect of step climbing exercise on balance and step length in chronic stroke patients, J. Phys. Ther. Sci. 27 (2015) 3515–3518, https://doi.org/10.1589/jpts.27.3515.

[31] R. Riener, M. Rabuffetti, C. Frigo, Stair ascent and descent at different inclinations, Gait Posture 15 (2002) 32–44, https://doi.org/10.1016/s0966-6362(01)00162-x.