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ORIGINAL RESEARCH

Strength Training of the Nonhemiplegic Side Promotes Motor Function Recovery in Patients With Stroke: A Randomized Controlled Trial

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Abstract

Objective: To observe the effect of strength training of the nonhemiplegic side (NHS) on balance function, mobility, and muscle strength of patients with stroke.

Design: A single-blinded (evaluator) randomized controlled trial.

Setting: A tertiary hospital rehabilitation center.

Participants: 139 patients with first stroke (N=139) were recruited and randomly separated into a trial (n=69) or control group (n=70).

Interventions: The control group underwent usual rehabilitation training, including step training and trunk control training in standing position. The trial group underwent strength training of NHS on the basis of usual rehabilitation training. The strength training of NHS included lower limb stepping training with resisting elastic belt and upper limb pulling elastic belt training in standing position. The training for both groups was 45 min, once a day, 5 days a week for 6 weeks.

Main Outcome Measures: Balance evaluation was done with the Berg Balance Scale (BBS); mobility assessment with the 6-minute walk test (6-MWT); activities of daily life was examined via the modified Barthel Index (MBI); muscle strengths of the biceps brachii, iliopsoas, and quadriceps were measured via the isokinetic muscle strength testing system. All assessments were performed at baseline ($T0$) and after intervention ($T1$).

Results: The trial group performed better than control group in BBS scores (adjusted mean difference: 6.83; 95% confidence interval [CI]: 4.71-8.94) and 6-MWT (adjusted mean difference: 50.32; 95% CI: 40.58-60.05) after intervention. In terms of muscle strength of the hemiplegic side, the trial group displayed greater gains in biceps brachii, iliopsoas, and quadriceps than control group after intervention.

Conclusion: Strength training of the NHS can promote recovery of balance, mobility, and muscle strength of the paretic side of patients with stroke.
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Stroke is a common cause of disability, which induces a marked decline in activities of daily life (ADL) and social participation. Motor function recovery is a major rehabilitation target for patients with stroke. Stroke not only paralyzes the affected side but also reduces muscle strength of the contralateral side.[1-3] Harris et al[4] demonstrated that leg weakness develops on the nonhemiplegic side (NHS) in the first week after acute stroke. This decline in NHS muscle strength must not be ignored in patients with stroke, because it is highly associated with functional performance,[5] and it can be used as an independent predictor of short-term functional gain and outcomes after stroke.[6,7] From this point of view, enhancing NHS muscle strength may be beneficial for motor functional recovery in patients with stroke. Previous studies revealed that NHS strength training improves muscle strength of the hemiplegic side (HS) in patients with stroke.[8-11] This procedure of strength transfer, also called cross training, is generally attributed to neural adaptations.[12] However, the aforementioned investigations primarily focused on the alteration of muscle strength. Whether this strength enhancement can translate into functional task improvement or promote motor recovery in patients with stroke is still unclear. So far, studies on the effect of NHS muscle strength training on motor function in patients with stroke is lacking. Therefore, we conducted a randomized controlled trial to observe the effect of

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Fig 1 Muscle strength training of nonhemiplegic limbs.

NHS strength training on balance function, mobility, and muscle strength of patients with stroke. Our findings may be helpful in reducing stroke-related disability.

Methods

Participants

Patients with first-ever stroke were recruited from the Rehabilitation Medicine Center between July and December in 2021. The inclusion criteria were as follows: (1) non-functional ambulators (Hoffer's classification: Ⅱ)[13]; (2) 45-75 years of age; (3) within 6 weeks after onset; (4) has sufficient cognitive and language abilities to complete rehabilitation treatment and assessment. The exclusion criteria were as follows: (1) has severe cardiopulmonary diseases or liver or kidney dysfunction; (2) has severe bone or joint diseases (3) co-morbid other neurologic disorders; (4) refusal to participate. This study received ethical approval from the hospital (No: 202104044K01). Signed informed consent was obtained from all participants.

Design

This was a single-blinded (the evaluators) randomized controlled trial. The participants were randomly separated into a trial or control group. The sample size was determined using the Berg Balance Scale (BBS), with a suggested minimal detectable change of 4.66.[14] Assuming that the standard deviation value was 9, then 116 patients were required at a 5% significance level (2-tailed) and 80% power to detect a difference of 4.66 between 2 groups. Considering a possible dropout rate of 20%, a total of 139 participants were included for analysis.

List of abbreviations:

6-MWT	**6-minute walk test**
ADL	**activities of daily living**
BBS	**Berg Balance Scale**
CI	**confidence interval**
HS	**hemiplegic side**
MBI	**modified Barthel Index**
NHS	**nonhemiplegic side**

Intervention

The control group underwent usual rehabilitation training, including step training and trunk control training in standing position. Methods: (1) Non-hemiplegic lower limb stepping forward training repeatedly, 10-15 times as a group, 3 groups. (2) Hemiplegic lower limb stepped over an obstacle or climbed a platform repeatedly, 10-15 times as a group, 3 groups. (3) The patients stretched arms to touch distant objects repeatedly in standing position. The training time was 45 min, once a day, 5 days a week for 6 weeks. The participants were allowed to rest for 3-5 min during each training.

In the trial group, the participants underwent strength training of NHS (fig 1) on the basis of usual rehabilitation training. Methods: (1) Non-hemiplegic lower limb stepping forward training repeatedly with resisting elastic belt (Thera-Band), 10-15 times as a group, 3 groups. (2) Non-hemiplegic upper limb pulling elastic belt repeatedly in standing position, 10-15 times as a group, 3 groups. The elastic belt (red, green, or blue) was selected according to the patient's own state, and the elastic belt should be stretched double during the training. (3) Hemiplegic lower limb stepped over an obstacle or climbed a platform repeatedly, 10-15 times as a group, 3 groups. (4) The patients stretched arms to touch distant objects repeatedly in standing position. The training time was also 45 min, once a day, 5 days a week for 6 weeks. The participants were allowed to rest for 3-5 min during each training.

In addition, both groups also received ADL training for 30 min (dressing, transfers), bicycle dynamometer training for 15 min, hand function training for 30 min, and electrotherapy for 30 min.

The treatments were performed daily over 5 days a week for a total of 6 weeks.

Outcome measures

Primary outcome

The balance function was assessed using a 14-item BBS. Each item is a 5-point ordinal scale ranging from 0 to 4, with 0 representing complete inability to finish a task, and 4 representing the ability to finish a task. The total score can be between 0 and 56. An elevated score denotes enhanced postural control. The BBS has excellent internal consistency (Cronbach's alpha=0.92) and test-retest reliability for patients with stroke (ICC=0.98).[15]

Secondary outcomes

Mobility was evaluated via the 6-minute walk test (6-MWT). Method: The participants was instructed to walk as far as possible for 6 minutes at their own speed, along a length of 30-m walking track marked by a cone at each end, which instructed to the participants to walk back.

ADL was evaluated via the modified Barthel Index (MBI). The MBI score includes feeding, grooming, dressing, bathing, toileting, bladder and bowel continence, transfers, ambulation, and stair climbing. A total score of 0-20 points suggests total dependence in ADL; 21-60 points suggests severe dependence; 61-90 points suggests moderate dependence; 91-99 points suggests slight dependence. 100 points suggests complete independence.[16]

The maximum muscle strength (peak torque) of the iliopsoas, quadriceps, and biceps brachii were assessed via the isokinetic muscle test (IsoMed2000, German). The isokinetic dynamometry has good reliability for maximal strength test in patients with stroke (ICC from 0.85 to 0.97 for knee and ankle).[17] The entire procedure of isokinetic testing was explained to participants to achieve maximum orientation. Each action was carried out with 5 maximal contractions at 60°/s angular velocity. The test protocol was as follows: (1) Iliopsoas evaluation: The participants were in supine position. Transverse line passing through greater trochanter of femur was accepted as the motion axis for hip joint. Dynamometer effort arm was parallel to the femur, and resistance action point was fixed at the distal femur. Shoulder supports and thigh restraint adapter were employed to fix the trunk and contralateral lower limb. (2) Quadriceps evaluation: The participants remained seated, with the seat back adjusted to 70 degrees from the horizontal plane. Transverse line through the femoral condyles was regarded as the motion axis of the knee joint. Dynamometer effort arm was determined according to the crus length. Waist belt and shoulder supports were employed to provide trunk stabilization. (3) Biceps brachii evaluation: The participants remained seated, with the seat back tilted to 70 degrees from the horizontal plane. A transverse line passing through the ulnar olecranon was regarded as the motion axis for the elbow joint. Resistance action point was fixed at the distal forearm femur or palm, and a shoulder support was used to fix the contralateral shoulder joint.

All outcome assessments were completed by a physician or physiotherapist at baseline ($T0$) and post-intervention ($T1$). The evaluators were blinded to the study aim and participants allocation.

Statistical analysis

SPSS 22.0 was employed for all data analyses. Descriptive statistics are presented as mean ± SD for continuous parameters and frequency for categorical parameters. Baseline inter-group differences were examined via *t* test for continuous data, and Chi-square tests for dichotomous variables. The Mann-Whitney test was used for inter-group comparison of non-normally distributed variables. The ANCOVA analyses were conducted to compare the primary and secondary outcomes after intervention, adjusting for baseline scores, and the magnitude of inter-group differences were calculated using η^2. We also calculated the muscle strength gains of hemiplegic limbs from baseline to post-intervention ($\triangle T1$-$T0$), the effect size were calculated via Cohen's *d* to assess the clinical importance of the measured changes. Significance levels were set at $P<.05$.

Results

Overall, 163 patients with stroke were screened for eligibility. Among them, 24 were excluded (18 patients with severe cardiopulmonary diseases and 6 declined participation). Ultimately, 139 patients were selected, and they were randomly separated into a trial (n=69) or control group (n=70). During the study period, 6 patients dropped out from the trial group and control group, respectively. Finally, 63 patients in trial group and 64 patients in control group were analyzed. Figure 2 shows a flow diagram of patient recruitment and retention. The baseline characteristics showed no significant differences between 2 groups (table 1). There were no associated undesirable effects either during or after treatment.

Comparison of the primary outcome measure

Both groups exhibited significant improvement in BBS scores after intervention, with adjusted baseline values, and there was a significant mean difference of 6.83 points between the 2 groups after intervention (95% confidence interval [CI]: 4.71-8.94, $P<0.001$) (table 2).

Comparison of secondary outcome measures

The trial group performed better than the control group in mobility (6-MWT) after intervention (adjusted mean difference: 50.32; 95% CI: 40.58-60.05, $P<0.001$). No significant difference was observed in ADL between the trial and control group after intervention (adjusted mean difference: 3.80; 95% CI: -0.85 to 8.64, $P=.108$) (table 2).

In terms of HS muscle strength, the trial group performed better than the control group after intervention (fig 3). The trial group displayed greater muscle strength gains in the biceps brachii (9.83±3.95 vs 6.58±4.11, $P<.001$), iliopsoas (19.11±9.04 vs 13.08±7.85, $P<.001$), and quadriceps (31.68±12.16 vs 22.80±11.57, $P<.001$) than control group after intervention (table 3, fig 4).

In terms of NHS muscle strength, both groups revealed significant enhancements in the biceps brachii, iliopsoas, and quadriceps after intervention. However, the trial group performed significantly better than the control group after intervention (table 4).

Discussion

Cross-education is a process whereby unilateral strength training is employed to enhance muscular strength of the contralateral

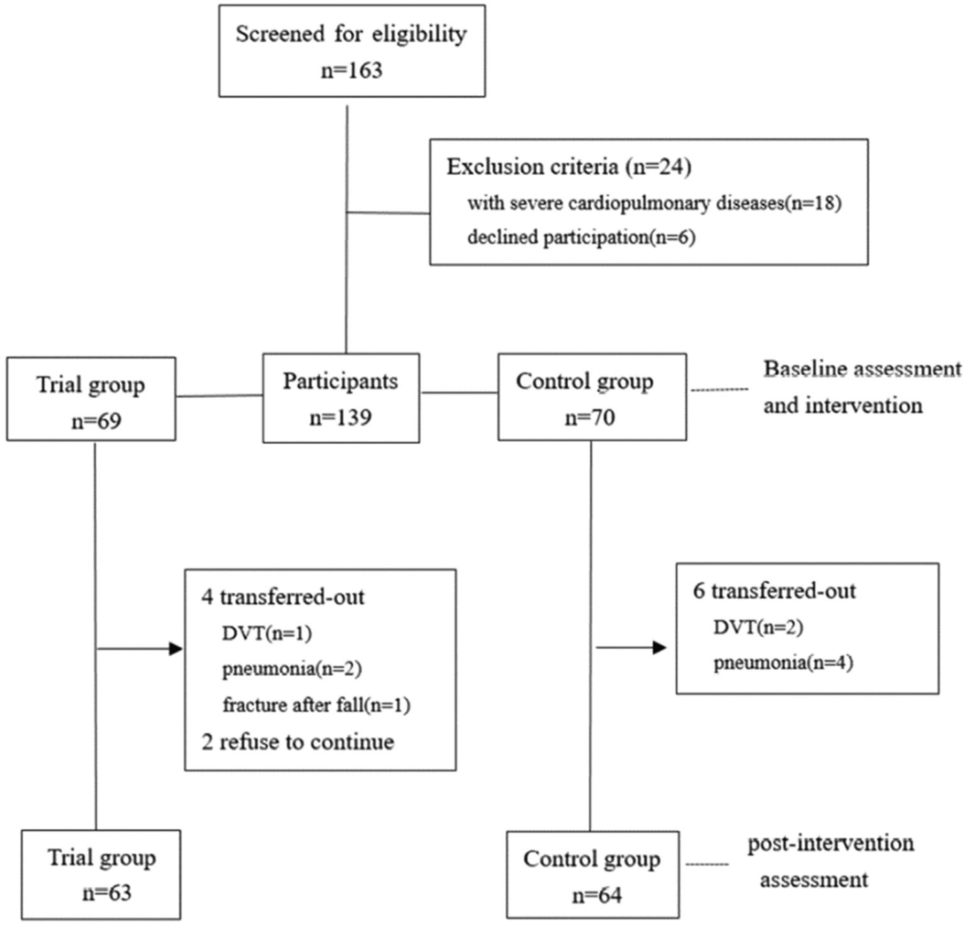

Fig 2 Flow diagram of the study protocol.

Table 1 Baseline demographics of both groups

Variables	Trial Group n= 63	Control Group n= 64	*P*
Age, y	(64.56±7.08)	(65.72±5.95)	0.318*
Sex, n (%)			0.802
Men	41 (65.1%)	43 (67.1%)	
Women	22 (34.9%)	21 (32.8%)	
BMI (kg/m^2)	19.14±4.16	18.42±4.07	0.326*
BMI<18.5, n (%)	21 (33.33%)	25 (39.06%)	0.502
NIHSS	16.25±3.69	15.97±3.30	0.647*
Course of disease (days)	21.78±4.07	21.50±3.60	0.685*
Etiology, n (%)			0.767
Ischemic	40 (63.5%)	39 (60.9%)	
Hemorrhage	23 (36.5%)	25 (39.1%)	
Paretic side, n (%)			0.783
Right	28 (44.5%)	30 (46.9%)	
Left	35 (55.5%)	34 (53.1%)	
With hypertension, n (%)	43 (68.2%)	47 (73.4%)	0.520
With diabetes, n (%)	35 (55.5%)	31 (48.4%)	0.422
With hyperlipidemia, n (%)	19 (30.1%)	17 (26.5%)	0.653
ADL (MBI)	35.30±5.58	35.84±5.93	0.597*
Balance function (BBS)	23.37±4.95	24.98±5.67	0.089*
6-MWT	56.31±25.67	60.51±21.99	0.354*
Muscle strength of paretic limb			
Biceps brachii	5.90±4.29	6.36±4.06	0.541†
Iliopsoas	14.56±7.86	15.03±8.08	0.737*
Quadriceps	18.08±7.68	19.13±11.45	0.923†
Muscle strength of non-paretic limb			
Biceps brachii	38.46±9.27	37.13±11.12	0.464*
Iliopsoas	65.70±14.68	64.72±16.42	0.724*
Quadriceps	96.16±28.11	93.48±26.01	0.579*

Abbreviations: BMI, body mass index; NIHSS, National Institute of Health Stroke Scale.
* By Student *t* test.
† By Mann-Whitney *U* test; otherwise by Chi-square test.

Table 2 Comparison of the primary and secondary outcomes between 2 groups

Measures	Time	Trial Group M (SD)	Control Group M (SD)	Adjusted Mean Difference (95% CI)	Effect Size η^2	*P* Value*
Primary outcome						
BBS	*T*0	23.37±4.95	24.98±5.67			
	*T*1	39.33±8.56	34.44±8.82			
	*T*1 (adjusted) †	40.30±0.75	33.47±0.74	6.83 (4.71 8.94)	0.24	<0.001
Secondary outcomes						
6-MWT	*T*0	56.31±25.67	60.51±21.99			
	*T*1	194.13±43.05	149.16±41.91			
	*T*1 (adjusted) †	196.82±3.48	146.45±3.45	50.32 (40.58 60.05)	0.45	<0.001
MBI	*T*0	35.30±5.58	35.84±5.93			
	*T*1	74.84±13.81	71.56±14.80			
	*T*1 (adjusted) †	75.10±1.66	71.30±1.65	3.80 (-0.85 8.46)	0.021	0.108

Abbreviations: *T*0, at baseline; *T*1, at post-intervention.
* Test for heterogeneity between 2 groups using F-criteria.
† Adjusted for baseline values (mean ± SE).

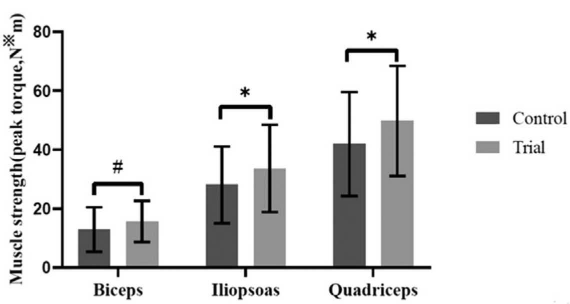

Fig 3 Comparison of muscle strength of hemiplegic limbs between two groups after intervention. **P*<0.05 vs control group, by Mann-Whitney *U* test. †*P*<0.05 vs control group, by Student *t* test.

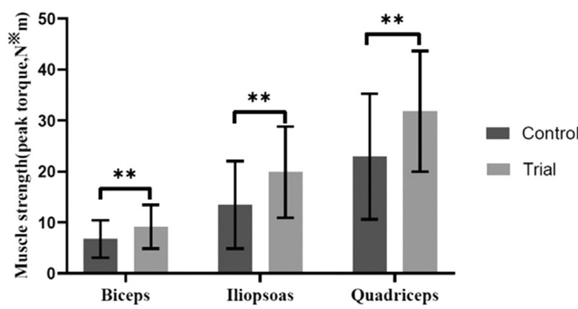

Fig 4 Comparison of muscle strength gains of hemiplegic limbs between two groups after intervention. **P*<0.01 vs control group, by Student *t* test.

side. More recently, emerging reports demonstrated larger contralateral gains. A recent meta-analysis estimated a 16.4% rise in contralateral lower limb strength after unilateral training.[9] This study explored the effect of strength training of NHS on motor function of patients with stroke and showed that it was effective in promoting the recovery of balance, mobility, and muscle strength of HS in patients with stroke. In terms of ADL (MBI scores), no significant difference was observed between the 2 groups after intervention.

In current rehabilitation practice for patients with stroke, balance and mobility remain essential goals. This is because poor balance and mobility exert adverse effect on social and mental activities.[18,19] Sun et al[20]assessed the extent of cross-education after arm strength training of NHS in 24 chronic patients with stroke, the results showed that the 4 participants had clinically meaningful increases in Fugl-Meyer scores, which indicated that the NHS strength training may exert a positive effect on the global motion recovery in patients with stroke. Recent studies revealed that NHS ankle dorsiflexion exercise significantly improves the ankle dorsiflexion muscle activity on the HS, along with balance and gait abilities in chronic patients with stroke.[21-23] However, the aforementioned studies were experiments involving a relatively small sample size.

In this study, the trial group exhibited better balance function (BBS scores) than control group after intervention. Given that the suggested minimal detectable change and estimated minimal clinically important difference of BBS scores were 4.66 and 5, respectively,[14,24] our finding of a significant mean difference of

Table 3 Comparison of muscle strength of hemiplegic limbs (mean ± SD)

Measures	Group	*T*0	*T*1	Δ*T*1 - *T*0	Between-Group Comparison Δ*T*1 - *T*0 *t* (*P*), ES
Biceps brachii	Trial	5.90±4.29	15.73±6.98*	9.83±3.95	4.53 (<0.001), 0.80
	Control	6.36±4.06	12.94±7.58	6.58±4.11	
Iliopsoas	Trial	14.56±7.86	33.67±14.80†	19.11±9.04	5.23 (<0.001), 0.71
	Control	15.03±8.08	28.11±12.96	13.08±7.85	
Quadriceps	Trial	18.08±7.68	49.76±18.64†	31.68±12.16	4.21 (<0.001), 0.74
	Control	19.13±11.45	41.92±17.59	22.80±11.57	

* *P*<0.05 vs control group, by Mann-Whitney *U* test.
† *P*<0.05 vs control group, by Student *t* test; ES: by Cohen's *d*.

Table 4 Comparison of muscle strength of nonhemiplegic limbs (mean ± SD)

Measures	Group	*T*0	*T*1	Mean Difference (95% CI)	Intra-Group Comparison *t* (*P*)
Biceps brachii	Trial	38.46±9.27	46.67±11.15*	8.20 (5.51, 10.90)	6.08 (<0.001)
	Control	37.13±11.12	40.84±10.91	2.71 (0.51, 6.92)	2.31 (0.024)
Iliopsoas	Trial	65.70±14.68	82.84±13.39*	17.14 (13.33, 20.94)	9.04 (<0.001)
	Control	64.72±16.42	70.77±15.78	6.04 (1.83, 10.25)	2.87 (0.006)
Quadriceps	Trial	96.16±28.11	130.06±25.86*	33.90 (28.31, 39.49)	12.11 (<0.001)
	Control	93.48±26.01	106.20±24.38	12.71 (7.87, 17.56)	5.24 (<0.001)

* $P<0.01$ vs control group, by Student *t* test.

6.83 points between 2 groups after intervention further indicated the effectiveness of NHS strength training at promoting balance function recovery in patients with stroke. In terms of mobility (6-MWT), the trial group performed better than control group after intervention, with an adjusted mean difference of 50.32, which was higher than the minimum clinical difference of 44 meters of 6-MWT in a prior study.[25] This suggested that this training was also clinically significant at promoting mobility in patients with stroke.

Previous studies confirmed that strength of hip flexor and knee extensor on the HS are closely associated with balance function and walking endurance (6-MWT) in patients with stroke.[26-30] In this study, the trial group performed significantly better than control group in strength of hip flexor, knee extensor, and elbow flexor on the HS after intervention. This proved that the NHS strength training can effectively enhance HS muscle strength in patients with stroke. We speculated that this was 1 of the reasons for the enhanced recovery of balance function and mobility in trial group. Several studies proposed the mechanisms of power transfer, including that the non-lesioned hemisphere-originating ipsilateral corticospinal projections play an important role in inter-limb associations during chronic stroke,[31,32] unilateral strength training generally creates a "spillover" of neural drive to the untrained side, which, in turn, facilitates the adaptations of the contralateral limb.[33]

Similar studies[34,35] reported that the NHS dorsiflexor strength training and task-oriented training (such as kick ball) enhanced muscle strength of contralateral lower limb, and the results also revealed a translation of strength gains toward gait velocity enhancement and motor recovery. When we compared the strength gain of the trial group in our study with the above study,[34] the knee extensor strength gain was higher, whereas, the hip flexor strength gain was similar. This difference may be related to the heterogeneity among studies (baseline scores, measurement methods, intervention method, duration, and so on).

In addition, cardiopulmonary decline is a common complication in patients with stroke[36] and is intricately linked to walking endurance.[37] It is reported that resistance training has a positive effect on cardiopulmonary activity in patients with stroke.[38,39] In this study, the trial group underwent strength training of the NHS, which was beneficial to the cardiopulmonary fitness, and it may contribute to mobility recovery. With regard to ADL, no significant difference was observed between 2 groups after intervention in this study. One explanation may be that MBI has low sensitivity in assessing patients with stroke and relatively good ADL outcome. Moreover, this study targeted patients with stroke who have walking function at baseline. If targeting patients with stroke who were unable to walk, different findings may be obtained with respect to MBI.

Limitations

This study was associated with several limitations. Firstly, we did not assess the spasticity of hemiplegic limbs, although no record of drug usage or botulinum toxin administration was found to reduce spasticity in the trial group. However, spasticity still requires further evaluation. Secondly, we only observed differences between 2 groups after intervention. Hence, further studies are required to elucidate its long-term rehabilitation efficacy.

Conclusion

The present study demonstrated that NHS strength training can promote the recovery of balance, mobility, and HS muscle strength in patients with stroke. Therefore, we recommend NHS strength training as a potential rehabilitation treatment item for patients with stroke, even though it is opposite to the forced usage paradigm that is characteristic of most stroke rehabilitation procedures.

Keywords

Motor function; Nonhemiplegic side; Rehabilitation; Strength training; Stroke

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