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Original Article

Cross training effects of non-paralytic dorsiflexion muscle strengthening exercise on paralytic dorsiflexor muscle activity, gait ability, and balancing ability in patients with chronic stroke: A randomized, controlled, pilot trial

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Abstract

Objective: To investigate the effects of non-paralytic dorsiflexion muscle strengthening exercise on functional abilities in chronic hemiplegic patients after stroke. **Methods**: A total of 21 patients with chronic stroke underwent dorsiflexion muscle strengthening exercise (MST) 5 times a week for 6 weeks (the experimental group, MST to non-paralytic dorsiflexion muscles, n=11; the control group, MST to paralytic dorsiflexion muscles; n=10). Paralytic dorsiflexor muscle activities (DFA) and 10 m walking tests (10MWT) and timed up and go tests (TUG) were measured before and after intervention. **Results**: A significant increase in DFA was observed after intervention in the experimental and control groups ($p<0.05$) (experimental 886.6% for reference voluntary contraction (RVC), control 931.6% for RVC). TUG and 10MWT results showed significant reductions post-intervention in the experimental and control groups (experimental group -5.6 sec, control -4.8 sec; experimental group -3.1 sec, control, -3.9 sec; respectively). No significant intergroup difference was observed between changes in DFA or between changes in TUG and 10MWT results after intervention ($p>.05$). **Conclusion**: Strengthening exercise performed on non-paralytic dorsiflexion muscles had positive cross-training effects on paralytic dorsiflexor muscle activities, balance abilities, and walking abilities in patients with chronic stroke.

Keywords: Balance, Cross-Training, Muscle Activity, Stroke, Walking

Introduction

Poor balance and walking abilities are typical disabilities after stroke[1]. Reduced balance ability and gait functions cause difficulties in daily life, and are major factors of poor quality of life among patients with stroke, and also have substantial socioeconomic impacts[2,3]. The main reason for balance and gait limitations in stroke patients is loss of voluntary control due to weakness or paralysis in lower limbs[4]. Furthermore, patients with chronic stroke have been reported to exhibit muscle weakness in non-paralytic as well as in paralytic lower limbs[5]. In particular, weakness of dorsiflexion muscles in paralytic lower limbs causes an inefficient swing phase of paralytic lower limbs during gait in patients with stroke and decisively reduces walking speeds[6,7].

Strengthening exercises on paralytic lower extremities have been demonstrated to have positive effects on the walking speeds of patients with stroke and to resolve weight support imbalance between paralytic and non-paralytic sides[8]. However, in some patients with stroke, serious loss of strength in paralytic lower limbs makes it difficult to apply direct strength-enhancing exercises to paralytic lower limbs and tends to increase psychological stress when a patient fails to perform the required exercise[6,9].

Cross-training is an intervention method based on the theory that exercise of muscles in one limb induces

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contralateral muscular contractions in the opposite limb[10]. This effect is explained by lack of peripheral adaptation of skeletal muscle in untrained limbs[11] and activations of neural circuits that chronically modify the efficacy of motor pathways that project to the opposite untrained limb[12]. In addition, the cross-training effect is explained by functional magnetic resonance imaging, which reveals bilateral activation of the corticospinal tract during unilateral contractions[13].

Sun et al. demonstrated the effectiveness of cross-training by applying high-strength isometric resistance exercise to non-paralytic wrist extension muscles in patients with chronic stroke[14], and Dragert et al. demonstrated the effect of cross-training on non-paralytic sides of lower extremities by conducting high-strength isometric resistance training on paralytic dorsiflexion muscles in patients with chronic stroke[6]. However, previous studies on the effects of cross-training in patients with stroke focused on the effects of isometric resistance exercise on non-paralytic upper and lower extremities. Furthermore, few studies have been conducted on the effects of muscle-strengthening exercise applied to non-paralytic or paralytic sides. Therefore, the purpose of this study was to investigate the cross-training effect of high-intensity strengthening exercise on paralytic dorsiflexor muscle activity and gait and balancing abilities in patients with chronic stroke, and to compare the intervention effects of muscle-strengthening exercises performed on non-paralytic or paralytic lower limbs in patients with chronic stroke. The hypotheses of this study were as follows. First, non-paralytic dorsiflexion muscle-strengthening exercise would effectively improve paralytic dorsiflexor muscle activity and gait and balancing abilities in patients with chronic stroke. Second, paralytic dorsiflexion muscle strengthening exercise would be more effective at improving intervention effects in patients with chronic stroke than non-paralytic dorsiflexion muscle strengthening exercise.

Methods

Design overview

This study utilized a 2 arm, assessor-blinded, experimental design with random assignment to control and experimental arms. Two trained research assistants, unaware of treatment allocations, measured all outcomes at baseline and after 6 weeks in face-to-face meetings at our rehabilitation center. Each patient was assessed by the same assessor on each occasion.

Participants

The subjects of this study were 21 patients with a diagnosis of hemiplegic stroke hospitalized at Daejeon rehabilitation hospital. The criteria used for subject selection were a diagnosis of stroke made >6 months previously, the ability to walk ≥10 m independently without using any walking device, a muscle tone of paralytic dorsiflexor according to the modified Ashworth scale of ≤1+ degrees[15], a muscle power of paralytic dorsiflexor according to the manual muscle testing scale of P+ or F grade[16], a passive dorsiflexion movement range of ≥5 degrees with the knee joint in extension, and a Korean Mini-Mental Status Examination (MMSE-K) score of ≥24. The exclusion criteria were a history of orthopedic injury that might affect walking, a dorsiflexion muscle result of below trace grade as determined by the manual muscle test, compromised visual or auditory perception, or a serious cardiovascular problem. The treating physical therapist identified participants satisfying these criteria. These participants were given standard oral and written explanations of the study, the objective of the training method, and general associated risks and then completed an institutional review board-approved informed consent form. These participants were then consecutively invited by a researcher to participate in the study. The ethics committee of the University of Daejeon approved the study protocol (IRB: 1040647-201506-HR-011-03). The study was performed in accordance with the Helsinki Declaration (1975) regarding the treatment of human participants in research. This study conforms to all CONSORT guidelines and reports the required information accordingly (see Supplementary Checklist, http://www.consort-statement.org).

Randomization

This study was conducted using a pretest-posttest, two-group design. Pre-intervention, general patient characteristics, paralytic dorsiflexor muscle activity, balance ability, and walking ability were evaluated. After pre-intervention testing, the 21 participants were randomly and assigned to two groups, that is, to an experimental group, participants of which underwent strengthening exercise on the nonparalytic dorsiflexion muscle, to a control group, participants of which underwent strengthening exercise on paralytic dorsiflexion muscles. Participants were allocated to these groups by drawing lots, and the randomization process was supervised by a blinded clinical physiotherapist with 7 years of experience.

Procedure

Participants in the experimental group and the control group underwent neurodevelopmental therapy, which consisted of stretching, range of motion exercise, strengthening exercise, balance and gait training, and functional electrical stimulation treatment (NOVASTIM CU-FS1, CU Medical Systems, Inc., Wonju City, Korea) 60 minutes a day, 5 days a week for six weeks. In addition, participants of the experimental group performed muscle-strengthening exercise of nonparalytic dorsiflexion muscles for 30 minutes, 3 times a week for six weeks. Participants of the control group performed muscle-strengthening exercise of paralytic dorsiflexion muscles for the same time and duration. To determine the effect of strengthening exercise on non-paralytic dorsiflexion muscles, paralytic dorsiflexor muscle activity, and balance and gait abilities were evaluated by two clinical six-year physiotherapists who did not participate in the study randomization process before intervention.

Table 1. Strengthening exercise program.

		Experimental group (n=11)	Control group (n=10)
CRT		Neurodevelopmental treatment, functional electrical stimulation	Neurodevelopmental treatment, functional electrical stimulation
SRT	Warm-up	Range of motion exercise on both ankle joints	Range of motion exercise on both ankle joints
	Main	Strength strengthening exercise on NP dorsiflexion muscles	Strength strengthening exercise on P dorsiflexion muscles
	Cool down	Light walking training	Light walking training

CRT, comprehensive rehabilitation therapy, 60 minutes a day, 5 days a week for six weeks; SRT, strengthening training, 30 minutes a day, 3 times a week for six weeks; NP, non-paralytic; P, paralytic.

Figure 1. Stages of muscle-strengthening exercise for non-paralytic dorsiflexion muscles. A, 1–2 weeks, in a supine position; B, 3–4 weeks, in a sitting position; and C, 5-6 weeks, in a standing position.

Intervention

Strengthening exercise in the experimental group consisted of warm-up, the main exercise, and cool-down exercise (Table 1). The warm-up exercise was performed in the supine position and involved movements of both ankle joints for 5 minutes to secure mobility of ankle joints and surrounded connective tissue[17]. The main exercise was based on resistance exercise. The strength strengthening exercise was performed on non-paralytic dorsiflexion muscles and consisted of 2 seconds of concentric-contraction resistance exercise, 2 seconds of isometric-contraction resistance exercise, and 2 seconds of eccentric-contraction resistance exercise. Ten repetitions constituted an exercise set and 5 sets were performed during the 20-minute exercise time with a 3-5-minute rest between sets. To prevent muscle fatigue, follow on sets were initiated after checking subject readiness. Exercise force resistance for the exercise according to the three types of muscle contraction (concentric-contraction, isometric-contraction, and eccentric-contraction) of non-paralytic dorsiflexion muscles was applied by a blinded physical therapist with five years of clinical experience. Force resistance was applied at an intensity of 5-6 (according to the Borg rating of the perceived exertion scale) such that each subject could repeat 10 centric-contraction, isometric-contraction, and eccentric-contraction movements with sub-maximum force[3]. Manual resistance was applied by force from the end of the non-paralytic great toe to the medial 1/3 of the foot or to the center of the metatarsal head. In order to control exercise

Table 2. Demographic characteristics of the participants at baseline.

Demographic features	Experimental group (n=11)	Control group (n=10)	*p*
Sex (male/female)	8/3	4/6	.198
Age (years)	59.1 (11.2)	65.6 (6.7)	.128
Height (cm)	165.6 (10.0)	160.3 (8.4)	.212
Weight (kg)	70.8 (13.2)	56.9 (10.5)	.476
Paralytic side (right/left)	6/5	5/5	1.000
Onset duration (months)	25.7 (21.5)	24.1 (17.6)	.853
Stroke type (infarction/hemorrhage)	7/4	7/3	1.000
MBI	50.0 (12.1)	44.6 (11.3)	.305
MMSE	25.7 (3.8)	24.3 (5.0)	.468

Results are expressed as frequencies or as means (SD). MBI, modified Barthel index; MMSE, mini mental state examination.

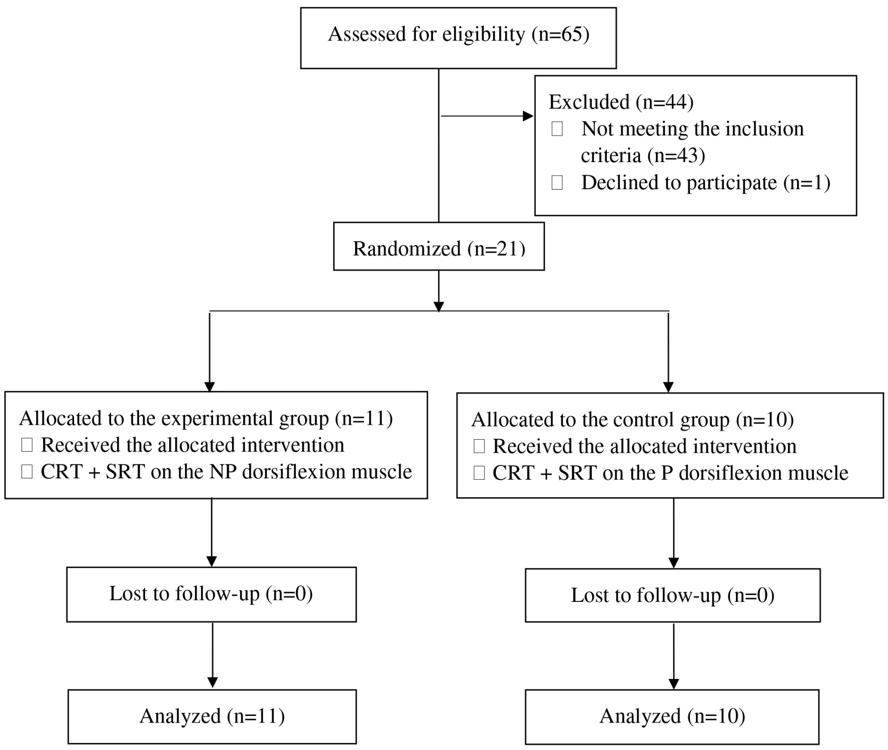

Figure 2. CONSORT diagram showing the study flow. CRT, comprehensive rehabilitation therapy; SRT, strengthening training; NP, non-paralytic; P, paralytic.

difficulty, resistance was applied in the supine position during the first stage (weeks 1-2), in the sitting position during the second stage (weeks 3-4), and in the standing position during the third stage (weeks 5-6) (Figure 1). During each stage, if less than 4 of the 5 exercise sets were not completed, the next exercise stage was conducted at the same level of difficulty. The cool-down exercise involved walking a training path with a light gait for 5 minutes under the supervision of or with the assistance of the therapist to stabilize blood pressure and respiratory frequency and minimize muscle fatigue caused by strength training[17].

Paralytic dorsiflexion muscle-strengthening exercise was performed on participants of the control group. In this group, the warm-up and cool-down exercises were the same as those described for the experimental group. The main strengthening exercise used on paralytic dorsiflexion muscles, was based on active exercise. With the paralytic ankle joint in dorsiflexion, the patient performed concentric-contraction for 2 seconds, isometric-contraction for 2 seconds, and eccentric-contraction for 2 seconds, while watching and feeling muscle contractions. Ten repetitions constituted and exercise set, and a total of 5 sets were performed using the same exercise and rest times used for the experimental group. The strengthening exercise was supervised by a blinded physical therapist with 7 years of clinical experience.

Outcome measures

A total of three common clinical outcome measurement tests were administered to participants during the six-week program at a physical therapy lab in our rehabilitation center. These tests were performed just before the program started and sometime after the six-week program had been completed. To avoid fatiguing participants, all assessments were conducted on days when they did not attend treatment sessions.

Primary outcome measures

Surface EMG (electromyography) was performed using a QEMG-4 unit (Laxtha Inc., Daejeon, Korea) to evaluate muscle activities of paralytic dorsiflexion muscles. EMG signals of maximum voluntary isometric contraction (MVIC) and reference voluntary contraction (RVC) were collected by selecting the tibialis anterior muscle before and after intervention. In order to obtain activity signals of the tibialis anterior, the skin area along the tibialis anterior gangway was epilated and sterilized using an alcohol swab. A surface EMG pad equipped with a disposable bilateral electrode (Ag/AgCl) was then attached. The surface EMG pad was attached to a point 2/3 of the distance between the outside of the tibia and first cuneiform bone, and the reference electrode was attached to the front of the tibia[18]. The signal transmitted from the EMG pad was collected using TeleScan ver 3.28 software (Laxtha Inc., Daejeon, Korea). Signals were collected using a sampling rate of 1024 Hz, notch filtering to remove signal noise at 60 Hz, and band-pass filtering at 20-500 Hz.

In order to collect and analyze muscle activity signals of paralytic dorsiflexor, EMG signals were collected during MVIC and RVC[19]. For measuring of EMG signals of MVIC, each subject was allowed to contract paralytic dorsiflexion muscles with full force for 5 seconds. EMG signals were collected by root mean square processing EMG signals for 3 seconds, that is, the first and fifth seconds were excluded. MVIC was measured three times with a 30 second rest period between measurements to minimize the effects of muscle fatigue. For measuring of EMG signals of RVC, each subject was looking forward without an aid or clinician assistance with feet at shoulder width during static standing for 5 seconds. In the same way as MVIC values, mean RVC values were calculated by measuring EMG signals for 3 times for 5 seconds and excluding the first and fifth seconds as described above. A 30-second break was provided between RVC measurements to minimize muscle fatigue. To obtain the data necessary for signal analysis, the following formula was applied. The mean values of EMG signal values of three measurements (% of RVC) = EMG signals of MVIC/EMG signals of RVC[19]. Muscle activities of paralytic anterior tibias were measured by a blinded physiotherapist with six years of clinical experience.

Secondary outcome measures

The 10MWT (the 10 m walking test) was performed to measure walking functions in the experimental and control groups before and after the 6-week intervention period. For the 10MWT, a 14 m walking path was used, which included 2 m for acceleration and 2 m for deceleration marked on the floor of a room. Measurements were made using a Sw002 Digital Multi-function Stopwatch (Qingdao Tlead International Co., Ltd., Qingdao, China), which started from the moment a foot passed the start point to the end point, while the subject walked at a comfortable speed. Before the test, subjects were asked to perform one trial for familiarization purposes. All measurements were made by clinicians who did not participate in the randomization process. Average values of 3 measurements were used for the data analysis. The 10MWT has a high test-retest and inter-test reliabilities of 0.95 and 0.90, respectively[20].

The timed up and go (TUG) test is used to assess the balance abilities of patients with stroke, and in the present study was used to evaluate balance abilities in the two groups before and after the 6-week intervention period. TUG test results were defined as times taken to stand from a sitting position on a chair (with armrests), walk 3 m, return to the chair, and sit down. Subjects were asked to perform the test as quickly as possible. The reliability of the TUG test has been reported to be 0.99[21]. The inspector that determined 10MWT times also performed the TUG test. The TUG test was repeated three times and mean values were used in the data analysis.

Data analysis

The Shapiro-Wilk test was used to test data normality, and descriptive statistics were used to analyze general subject characteristics. The independent t-test for continuous variables and Fisher's exact test for dichotomous variables were used to compare the general characteristics of the experimental and control groups at baseline, and Wilcoxon's signed-rank test was used to determine the significances of intervention associated changes in muscle activity and balance and gait abilities. The Mann-Whitney's U-test was performed to compare intervention-associated changes in the two groups. Statistical significance was accepted for p values <0.05.

Results

A schematic of participant recruitment is provided in Figure 2. The 65 patients with stroke initially considered represented 60% of all patients with stroke admitted (at

Table 3. Pre- to post-intervention changes in muscle activity, balance, and walking variables in the two study groups.

		Experimental group (n=11)	Control group (n=10)	Z
EMG	Pre-test	358.6 (179.5 to 803.3)	344.9 (159.5 to 2099.4)	-.141
	Post-test	1119.5 (172.5 to 2639.0)	1692.8 (557.7 to 2614.4)	-.211
	Z	-2.578[a]	-1.886[a]	
	Δ (post-pre)	886.6 (81.3 to 1535.0)	931.6 (77.1 to 1515.1)	-.070
TUG	Pre-test	29.0 (14.7 to 48.2)	23.6 (13.9 to 49.7)	-.070
	Post-test	26.1 (10.8 to 33.4)	19.1 (12.6 to 44.6)	-.211
	Z	-2.576[a]	-2.701[a]	
	Δ (post-pre)	-5.6 (-10.1 to -2.7)	-4.8 (-11.2 to -2.7)	-.211
10 MWT	Pre-test	23.6 (13.9 to 42.8)	20.5 (12.7 to 52.6)	.000
	Post-test	19.4 (9.3 to 33.8)	15.7 (12.2 to 46.6)	-.352
	Z	-2.312[a]	-2.497[a]	
	Δ (post-pre)	-3.1 (-4.6 to -1.1)	-3.9 (-10.0 to -.6)	-.352

Results are expressed as medians (25-75% percentile). EMG (% of reference voluntary contraction), electromyography signals of paralytic dorsiflexor muscle, EMG signals of maximum voluntary isometric contraction/EMG signals of reference voluntary contraction); TUG (sec), timed up and go; 10 MWT (sec), 10 m walking test. [a]Significantly different (p<0.05) from pre-intervention results.

an average of 25 months after stroke) to our inpatient rehabilitation center. Forty-three of these patients with stroke could not participate in the study because they did not fulfill the inclusion criteria or met exclusion criteria, and one patient with stroke declined to participate for private reasons. Baseline measurements were obtained from the 21 participating patients with stroke who all completed the 6-week training period. No adverse events were reported in any of the two study groups.

Table 2 summarizes the general characteristics of the subjects in the experimental (n=11) and control groups (n=10). No significant intergroup difference was observed (p>0.05).

Table 3 shows muscle activities of the paralytic dorsiflexor and TUG and 10MWT results before and after intervention in the two study groups. Paralytic dorsiflexor muscle activities were significantly increased by intervention in both groups (p<0.05). The experimental group showed an RVC increase of 886.6% after intervention and the control group an increase of 931.6%. TUG test times were significantly lower after intervention in both groups (p<0.05), that is, by 5.6 seconds in the experimental group and by 4.8 seconds in the control group. 10MWT times were also significantly reduced by intervention in both study groups (p<0.05), by 3.1 seconds in the experimental group and by 3.9 seconds in the control group. However, there were no significant differences in paralytic dorsiflexor muscle activity changes, TUG test time changes, or 10MWT time changes after training between the two groups (p>0.05).

Discussion

The purpose of this study was to investigate the cross-training effects of non-paralytic dorsiflexion muscles strengthening exercise in patients with chronic stroke. We found muscle-strengthening exercise of non-paralytic dorsiflexion muscles significantly improved paralytic dorsiflexor muscle activity and balance and gait abilities. These results are in line with the hypothesis that the non-paralytic dorsiflexion muscles strengthening exercise have positive training effects. However, pre- to post-intervention changes were not significantly different between the non-paralytic dorsiflexion muscle strengthening exercise and the paralytic dorsiflexion muscle strengthening exercise. These results are not in-line with the hypothesis that paralytic dorsiflexion muscle-strengthening exercise is the more effective training regime, and suggest that the non-paralytic dorsiflexion muscle strengthening exercise and paralytic dorsiflexion muscle strengthening exercise have similar positive effects.

Dragert et al. conducted isometric resistance training on non-paralytic dorsiflexors for 6 weeks in patients with chronic stroke, and reported intervention improved the muscle activities of paralytic dorsiflexion muscles by 31%[6]. Manca et al. conducted 6 weeks of maximal intensity strengthening exercise of less affected dorsiflexors in patients with multiple sclerosis, and reported significant increases in peak moment at 10°/s ((20.7 (Nm) vs. 26.4 (Nm)) of most affected ankle dorsiflexion muscles after exercise[22]. These results support the observed increase in RVC achieved by non-paralytic dorsiflexion muscle-strengthening exercise from 886.6% observed in the present study. In addition, because the dorsiflexor muscle plays an important role during walking and in particular influences walking speed and walking endurance[7,23], it would appear increased muscle activity of the paralytic dorsiflexion muscle achieved by non-paralytic dorsiflexion muscle-strengthening exercise is clinically relevant.

In the present study, TUG times were significantly reduced by intervention by non-paralytic dorsiflexion muscles strengthening exercise. Ng and Hui-Chan (2005) considered TUG an important measure of balance ability in stroke patients[21]. Also, given that the minimum detectable TUG change is 3.5 seconds[24], our finding of a 5.6-second reduction TUG after non-paralytic dorsiflexion muscle-strengthening demonstrates the effectiveness of this exercise at improving balance ability in patients with stroke.

A significant difference in 10MWT times was observed after non-paralytic dorsiflexion muscle strengthening exercise. Cheng et al. reported a minimum detectable change for 10 MWT testing of 0.4 sec in stroke patients[25]. In our study, non-paralytic dorsiflexion muscle strengthening exercise reduced 10MWT times by 3.1 sec, and thus, our results show the effect of cross-training was clinically significant. Manca et al. reported significant reductions in 10MWT times after maximal intensity strengthening exercise of less affected dorsiflexors in patients with multiple sclerosis. Mean 10MWT time before the 6-week intervention was 9.3 sec, but after intervention, it decreased to 8.6 sec[22], which concurs with our results.

We found both non-paralytic and paralytic dorsiflexion muscles strengthening exercise were beneficial in patients with chronic stroke. However, the present study has a number of limitations that warrant consideration concerning the adoption of its results in clinical practice. In particular, the relatively short 6-week intervention period, the absence of retention tests to assess long-term intervention effects, and the pilot study design adopted limit the applications of our findings. Nevertheless, this study is clinically meaningful as it introduces an intervention method that improves the paralytic muscle activities, balance abilities, and walking abilities of patients with chronic stroke. If the cross-training benefits observed in the present study are confirmed by additional study, it is hoped the cross-training method described be subjected to clinical trial with a view toward improving the paralytic muscle activities, balance and walking abilities of patients with chronic stroke in which strength training cannot be performed on paralytic sides.

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