Effect on Spasticity After Performance of Dynamic-repeated-passive Ankle Joint Motion Exercise in Chronic Stroke Patients

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Spasticity associated with abnormal muscle tone is a common motor disorder following stroke, and the spastic ankle may affect ambulatory function. The purpose of this study was to investigate the short-term effect of dynamic-repeated-passive ankle movements with weight loading on ambulatory function and spastic hypertonia of chronic stroke patients. In this study, 12 chronic stroke patients with ankle spasticity and inefficient ambulatory ability were enrolled. Stretching of the plantar-flexors of the ankle in the standing position for 15 minutes was performed passively by a constant-speed and electrically powered device. The following evaluations were done before and immediately after the dynamic-repeated-passive ankle movements. Spastic hypertonia was assessed by the Modified Ashworth Scale (MAS; range, 0–4), Achilles tendon reflexes test (DTR; range, 0–4), and ankle clonus (range, 0–5). Improvement in ambulatory ability was determined by the timed up-and-go test (TUG), the 10-minute walking test, and cadence (steps/minute). In addition, subjective experience of the influence of ankle spasticity on ambulation was scored by visual analog scale (VAS). Subjective satisfaction with the therapeutic effect of spasticity reduction was evaluated by a five-point questionnaire (1 = very poor, 2 = poor, 3 = acceptable, 4 = good, 5 = very good). By comparison of the results before and after intervention, these 12 chronic stroke patients presented significant reduction in MAS and VAS for ankle spasticity, the time for TUG and 10-minute walking speed ($p < 0.01$). The cadence also increased significantly ($p < 0.05$). In addition, subjective satisfaction with the short-term therapeutic effect was mainly good (ranging from acceptable to very good). In conclusion, 15 minutes of dynamic-repeated-passive ankle joint motion exercise with weight loading in the standing position by this simple constant-speed machine is effective in reducing ankle spasticity and improving ambulatory ability.

Key Words: ankle spasticity, chronic stroke, continuous passive motion, dynamic stretch
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Spasticity associated with abnormal muscle tone is a common motor disorder following stroke and can be severely disabling. It is defined as a velocity-dependent increase in the tonic stretch reflex with exaggerated tendon reflex, resulting from hyperexcitability of the stretch reflex [1]. Excessive and uncontrolled spasticity limits functional recovery, causes pain, and is associated with contracture [2]. The hemiplegic spastic ankle influences ambulatory quality and decreases activities of daily life. Therefore, many therapeutic paradigms in neurologic rehabilitation are applied to

reduce spasticity to diminish disability and improve function, ranging from the use of modalities such as biofeedback to complex neurosurgical procedures such as dorsal rhizotomies [3]. One treatment option is passive movement or stretching of the joint.

Passive stretching is one common intervention used for spastic joints to maintain or increase its range of motion (ROM). In physical therapy, passive stretching can be applied by manually moving the joint through its ROM to reduce spasticity and to restore movement and function. However, manual stretching is laborious and the outcome may depend on the ability of the therapist to gauge the limits of the ROM or "end feel" [4]. Thus, many devices have been used for static or dynamic stretching, including tilt table [5], cast [6,7], computer-controlled isokinetic dynamometers [3,8,9], and a feedback-controlled and programmed stretching device [4].

Cyclic motion has been reported to be more effective than static holds at decreasing stiffness of the ankle joint [10,11]. However, only a few studies have focused on repeated stretching of spastic joints in stroke patients [3,4,8,9]. Moreover, most of these devices for repeated passive movement of spastic lower limbs were performed with patients in the sitting or supine position, which would eliminate the contribution of weight loading. To our knowledge, there are no studies of dynamic passive stretch programs in the standing position for ankle spasticity. We hypothesized that the therapeutic effect may be greatly improved if repeated passive motion was performed combined with the effect of weight loading for the spastic ankle. Thus, in this study, a simple constant-speed device for dynamic-repeated-passive ankle joint motion exercise in the standing position was used to treat the spastic ankle of patients with chronic stroke. The purpose of this study was to assess the short-term effect of dynamic-repeated-passive ankle joint motion combined with weight loading on spastic hypertonia and the ambulatory function of chronic stroke patients.

MATERIALS AND METHODS

Patient selection

Subjects with stable chronic stroke who met the inclusion criteria were enrolled from the rehabilitation clinic of a university medical center in southern Taiwan. The inclusion criteria consisted of: (1) an interval of longer than 6 months since the onset of unilateral stroke (infarct or hemorrhage, diagnosed by clinical presentation and brain computed tomography/magnetic resonance image); (2) no further progression or recovery of neurologic deficits for at least 3 months before enrollment; (3) spasticity of the ankle (Modified Ashworth Scale [MAS] ≥1); (4) ability to ambulate with or without assistive devices; (5) preserved cognitive and communicative ability; (6) stable general health status; (7) no preexisting functional limitations of the affected lower extremity; and (8) no contracture of the ankle joint. The following details were recorded for each case: gender, age, time from stroke onset, stroke type and locus in brain, hemiplegic side, and use of antispastic medications.

Instruments and procedure

All enrolled subjects received dynamic-repeated-passive ankle joint motion exercise in the standing position for 15 minutes. The duration of stretching was selected based on the findings of our preliminary study in which training duration of 15 minutes had resulted in optimal spasticity reduction with fewest number of side effects (soreness or weakness over calf muscles). An automatic constant-speed machine (Yu Kuang Machinery Factory, Taiwan) was used, which consisted of an electrically powered footplate, handrails, a timer, and a back support belt (Figure 1). The ROM of the automatic footplate was from 5° to 20° dorsiflexion. The speed of the motion was 9 seconds/cycle with 1-second holding in both extreme positions before turning back to the opposite direction. During the passive dynamic stretching exercise, participants were asked to stand on the footplate of the machine with their hemiplegic knees strapped by a gaiter and hands tied to the rail by an elastic bandage. A belt was buckled between the handrails behind the back of the patient's waist for safety.

Outcome evaluation

The following evaluations were done immediately before and after the intervention by the same physician. The patient was positioned in a chair with knees and hips at approximately 90° flexion and their feet hanging down. Muscle tone in ankle plantar-flexors was assessed clinically according to the MAS (range, 0–4) [12]. Achilles tendon reflexes were tested on the affected side and scored on a five-point scale (DTR; range, 0–4), and ankle clonus was rated on a six-point
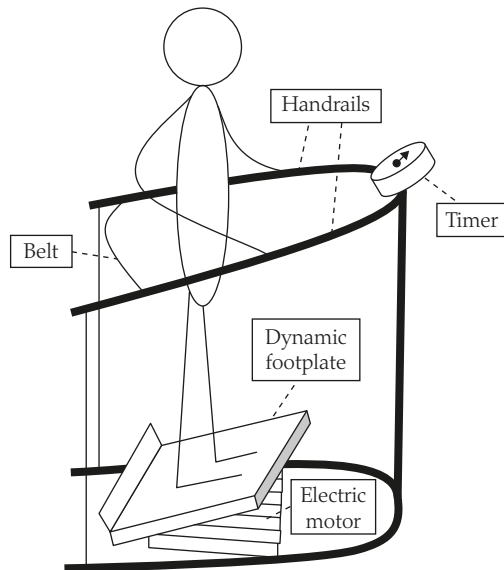
Figure 1. *Illustration of the simple constant-speed device (Yu Kuang Machinery Factory, Taiwan) for dynamic-repeated-passive ankle joint motion exercise in the standing position.*

scale [13]. Then, the timed up-and-go test (TUG) [14] and the 10-minute walking test [15] were performed by having the subjects walk at their preferred speed with or without assistive devices. We measured the performance time in seconds and adopted the fastest of three trials. The TUG consisted of standing up from a chair (seat height, 45 cm), walking straight for 3 m, turning, returning to the chair, and sitting down. The 10-minute walking test was done on a level floor during which the cadence (steps/minute) was also obtained by dividing the number of steps by the time spent. In addition, subjective experience of the influence of ankle spasticity on ambulation was scored by the visual analog scale (VAS). The VAS ranged from 0 to 10, with 0 representing spasticity-free status and 10 representing maximally intractable spastic intensity that prevented ambulation. At the end of this investigation, all the subjects were asked to answer a five-point satisfaction questionnaire, ranging from very poor, poor, acceptable, good and very good, for subjective experience of the extent of spasticity reduction after intervention.

Statistical analysis

For all outcome variables, we calculated the group mean and standard deviation at baseline and follow-up. All statistical analyses were carried out with SPSS version 10 (SPSS Inc., Chicago, IL, USA). Wilcoxon

tests were employed and used to test whether or not the change between before and after treatment was statistically significant, with a significance level of $p < 0.05$.

RESULTS

There were 12 patients, nine males and three females, enrolled in this study, with a mean age of 53.7 years (range, 39–80 years); the mean time from stroke onset was 36.04 months (range, 7–105 months). Demographic data are shown in the Table. Nine participants had left-sided hemiplegia and three had right-sided hemiplegia. The type of stroke was ischemic in seven patients and hemorrhagic in five. Six of the 12 patients had received antispastic medications.

The spasticity of the ankle (mean MAS) was 1.75 ± 0.62 at baseline and decreased significantly after therapy to 1.08 ± 0.51 ($p < 0.01$) (Figure 2). Ankle DTR and clonus also decreased, but did not reach significance ($p = 0.083$ and 0.081, respectively). As for ambulatory tests, both TUG and 10-minute walking test times showed statistically significant improvement ($p < 0.01$), from 33.7 ± 15.2 to 29.1 ± 14.64 seconds (Figure 3) and from 29.83 ± 15.19 to 27 ± 14.25 seconds (Figure 4), respectively. Cadence also increased significantly ($p < 0.05$) (Figure 5). Change in VAS scores was highly significant from 5.92 ± 1.56 to 4.42 ± 1.56 ($p < 0.01$) (Figure 6). Subjective experiences of the therapeutic effect of spasticity reduction were acceptable in four, good in seven, and very good in one patient.

DISCUSSION

Fifteen minutes of dynamic-repeated-passive ankle joint motion exercise in the standing position by this simple machine resulted in significant reduction in MAS of ankle joints, VAS for spasticity reduction, time for TUG and 10-minute walking ($p < 0.01$), and increase in cadence ($p < 0.05$) in patients with stable chronic stroke. It indicated that dynamic passive stretching combined with weight loading was effective in reducing ankle spasticity and improving ambulatory ability in chronic stroke patients.

Passive stretching, both static and dynamic, plays an important role in the management of spasticity. Previous studies [5–7,16] have shown that stretching

Table. Patient characteristics

Subject	Age (yr)	Sex	Time post-onset (mo)	Side affected	Lesion type	Lesion site	Ankle MAS	Antispastic medication
1	67	F	25	L	I	Corona radiata	1	Yes
2	39	M	30	R	H	Caudate nucleus	1	No
3	54	M	7	L	H	Putamen	2	Yes
4	50	M	34	L	I	Caudate nucleus	2	No
5	53	M	60	L	I	Caudate nucleus	2	Yes
6	52	M	46	L	H	Putamen	3	Yes
7	50	M	32	L	I	Caudate nucleus and pons	1	No
8	53	M	16	L	H	Putamen	2	No
9	55	M	15	R	I	Basal ganglion	1	No
10	80	F	48	R	I	Corona radiata and external capsule	2	No
11	51	M	8.5	L	I	Internal capsule	2	Yes
12	39	F	105	L	H	Parieto-temporal lobe	2	Yes
Mean/ ratio	53.7 ± 11.04	M:F 9:3	36.04 ± 27.24	L:R 9:3	H:I 5:7		1.75 ± 0.62	Yes:No 6:6

MAS = Modified Ashworth Scale; F = female; M = male; L = left; R = right; H = hemorrhage; I = infarction.
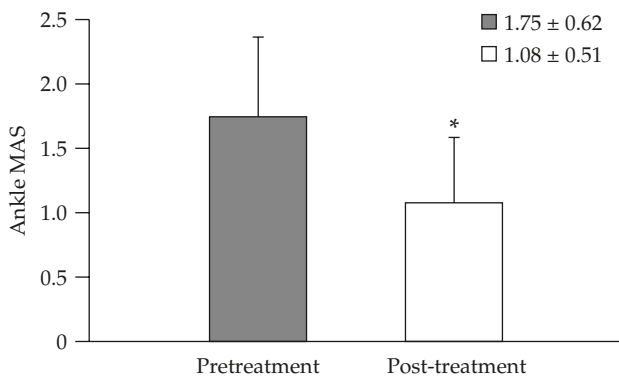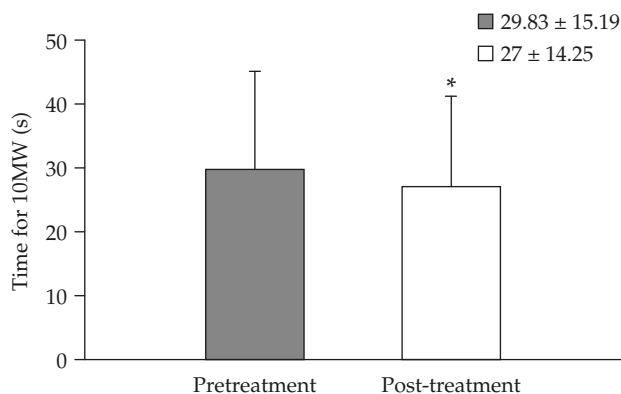

Figure 2. *Ankle Modified Ashworth Scale (MAS) before (pre-treatment) and after (post-treatment) intervention. Values are presented as mean ± standard deviation. *p < 0.01.*
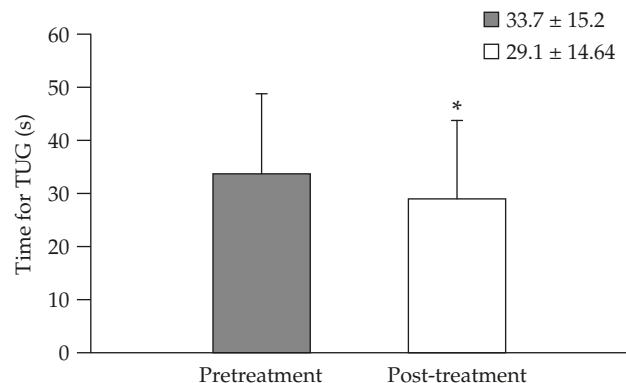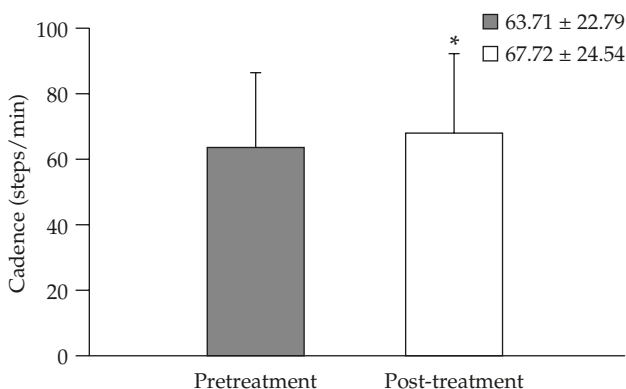

Figure 3. *Time for timed up-and-go test (TUG) before (pre-treatment) and after (post-treatment) intervention. Values are presented as mean ± standard deviation. *p < 0.01.*

of the plantar-flexor muscles by a tilt table or cast for a period ranging from 30 minutes to 6 weeks reduced passive ankle joint resistance, increased ankle joint ROM, and improved gait performance. The effects of a single session of prolonged muscle stretching on the spastic ankle of stroke patients by standing with the feet dorsiflexed on a tilt table for 30 minutes have also been reported [5]. The results showed that the passive ROM of ankle dorsiflexion was increased and motor neuron excitability of the triceps surae was reduced significantly. In addition to static stretch, continuous passive motion (CPM), which has been commonly used for rehabilitation of some orthopedic impairments, has been applied in the management

of neurologic disorders [3,11]. An *in vitro* model has suggested that cyclic stretching could lead to "increased flexibility and reduced tensile stress" so that joint ROM may increase [17]. In stroke patients, it was also demonstrated that repeated passive movement induced a decrease in spastic hypertonia through a combination of reflexive and mechanical factors [18]. Additionally, quantitative comparison of the effects on muscle tone by stretching and loading was made [7]. It showed that both stretching in the supine position and weight loading in the standing position with the feet in dorsiflexion or plantarflexion resulted in reduction of muscle tone, and the largest reduction was obtained by weight loading with stretch imposed
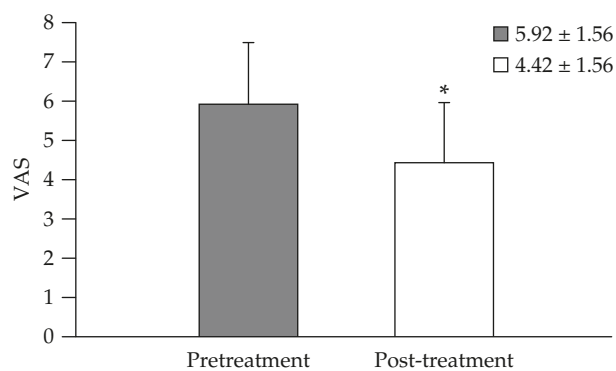
Figure 4. *Time for 10-minute walking test (10MW) before (pretreatment) and after (post-treatment) intervention. Values are presented as mean ± standard deviation. *p < 0.01.*

Figure 5. *Cadence before (pretreatment) and after (post-treatment) intervention. Values are presented as mean ± standard deviation. *p < 0.05.*

on the calf muscles. Moreover, research [10,11] has indicated that cyclic motion over the ankle joint may be more effective in reducing passive ankle stiffness than static calf stretching. In our study, the combination of dynamic passive stretching and weight loading was used, and the result in spasticity reduction was significant and supported the results of previous research studies.

The intention of including the TUG and 10-minute walking tests in our study was to test the immediate effect of stretching treatments on ambulatory function. Adequate ankle control during gait is important for a normal gait pattern [19]. Some gait studies [19,20] reported that stroke subjects walk at slower speeds compared with age-matched controls. Walking speed is one of the most widely accepted measures of lower-limb recovery [21]. Studies of test–retest reliability of the 10-minute walking test yielded intraclass correlation coefficients of 0.94 [15]. In addition, the TUG

Figure 6. *Visual analog scale (VAS) before (pretreatment) and after (post-treatment) intervention. Values are presented as mean ± standard deviation. *p < 0.01.*

reflects not only the subject's ambulatory ability but also the degree of activity in daily life [14]. After 15 minutes of dynamic stretching with weight loading in our study, the ambulatory function (TUG time, 10-minute walking speed, cadence) of the stroke patients showed significant improvement along with reduction of MAS of the spastic ankle. It may reflect the fact that ankle spasticity affects gait efficacy in chronic stroke patients.

The reflex properties of spastic ankles were quantified by DTR of Achilles' tendon and ankle clonus in our study. Despite the highly significant reduction in spasticity noted objectively (by MAS) and subjectively (by VAS), the decrease in both DTR and ankle clonus was not significant. These results are in accordance with those of numerous authors who proposed that nonreflex components (intrinsic muscular changes) are mainly responsible for spastic hypertonia in the lower limb [22–24].

In contrast to computer-controlled isokinetic dynamometers, the constant-speed CPM machine used in this study is not only convenient but also economical for chronic stroke patients. In previous research, CPM for spastic joints has required specialized equipment and training. The equipment that has been used included several kinds of isokinetic dynamometers [8,9] such as Cybex [23] and Kin-com dynamometer [3], and even a feedback-controlled and programmed stretching device [4]. However, all these delicate machines were expensive and usually needed an experienced technician to operate. However, the device we used in this study was simple, safe, and cheap, and was effective for spasticity reduction in stroke patients with variable severity of spasticity. Therefore, repeated

passive stretching with constant intensity and weight loading could be done effectively and safely.

Except for the positive results in spasticity reduction, two patients reported mild soreness over the calf muscles immediately after stretching, but the symptoms subsided a few minutes later. No other associated side effects were found in this study. However, therapeutic stretching involving mechanical load of extreme force should be performed cautiously to avoid muscle and tendon injury [25]. The synergistic effect of long-term cyclic stretch and inflammatory cytokines on tendons has also been observed *in vitro* [26]. To our knowledge, little is known about the side effects of dynamic stretching and weight loading. Thus, it needs to be further studied. This study only evaluated the immediate effects of 15-minute dynamic stretching with weight loading. The long-lasting effects were not measured. Further research should evaluate the long-term effects after a period of daily stretching programs and compare the effects between dynamic stretch with and without weight loading.

CONCLUSION

Our study supports the contention that cyclic stretching with weight loading is effective in reducing spasticity and improving gait performance. Furthermore, this simple machine is a safe, effective, and economical tool for treating ankle spasticity in chronic stroke patients. Further study needs to focus on the long-term effects of this therapy.

ACKNOWLEDGMENTS

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連續動態性被動式踝關節運動對
慢性中風病人痙攣之影響

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痙攣與異常的肌肉張力為中風後常見的運動障礙，且踝關節痙攣可能影響行走的功能。本研究的目的是為了檢視動態性被動踝關節運動，對於慢性中風患者下肢肌肉痙攣與行走功能的立即效應。共有十二位具有下肢痙攣及異常步態的慢性中風患者參與本研究，我們利用一台定速的直立式電動機器，讓中風病人於站立姿勢下作十五分鐘的踝關節動態性被動牽拉運動。評估的項目包括：踝關節的痙攣等級 (MAS；0－4級)、深腱反射 (DTR；0－4級)、肌陣攣程度 (0－5級) 等對肌張力的評估，以及計時性起立－行走時間測驗 (TUG)、十公尺行走時間測試和步頻等行走功能的測量。此外，病人對張力變化的主觀感受則用視覺類比量表 (visual analog scale，VAS) 和滿意度問卷來評估。比較治療前後的測試結果，我們發現病人於踝關節的痙攣等級、視覺類比量表值、計時性起立－行走時間測驗、十公尺行走時間測試等，均有非常顯著的進步 ($p < 0.01$)，同時步頻也有顯著的增加 ($p < 0.05$)，且多數病人對此治療的效果表示滿意。因此，我們的結論為：利用此直立式的等速機器，讓慢性中風的病人站立接受十五分鐘的動態性被動式踝關節運動，可以有效地降低其下肢的痙攣，並促進其行走的功能。

關鍵詞：踝關節痙攣，慢性中風，連續性被動關節運動，動態性牽拉
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