J. Phys. Ther. Sci.
25: 1321–1324, 2013

An Ankle Proprioceptive Control Program Improves Balance, Gait Ability of Chronic Stroke Patients

Yu-Hyung Park, PT, MSc[1)], Yu-mi Kim, PT, DPT[1)], Byoung-Hee Lee, PT, PhD[2)*]

[1)] *Graduate School of Physical Therapy, Sahmyook University, Republic of Korea*
[2)] *Department of Physical Therapy, Sahmyook University: 815 Hwarang-ro, Nowon-gu, Seoul 139-742, Republic of Korea*

Abstract. [Purpose] Balance and gait ability determine to a large degree the level of independence of daily living which is an important goal of rehabilitation. This study was conducted in order to examine the effectiveness of an ankle proprioceptive control program on ankle muscle strength, balance, and gait of chronic stroke patients. [Methods] Thirteen chronic stroke patients more than six months post-stroke were recruited. All subjects received ankle proprioceptive control training for 30 minutes per session, two days per week, over a period of six weeks. Outcome measures were ankle strength (BTE-Primus), the Timed Up and Go test (TUG), and spatiotemporal parameters measured by a GAITRite instrument. [Results] Significant improvements in ankle dorsiflexor strength, TUG, gait speed and cadence, step length, and stride length were observed on the paretic side. [Conclusion] The results of this study provide evidence in support of incorporation of an ankle proprioceptive control program for effective improvement of both balance and gait ability of chronic stroke patients. The findings of this study suggest the feasibility and suitability of an ankle proprioceptive control program for chronic stroke patients.
Key words: Stroke, Proprioception, Ankle

(This article was submitted Apr. 10, 2013, and was accepted May 29, 2013)

INTRODUCTION

Functional weakness of the lower extremity due to stroke is caused not only by muscular weakness, but also by decreases in muscular endurance, and stability of the joint, and loss of proprioceptive sense. Clinically, proprioceptive sense is an important factor in the evaluation and treatment of patients with neurologic problems; and its weakness leads to declines in postural control, protective reflex, joint movement, balance ability, and gait[1)].

Due to weakness of dorsiflexors, mass flexor pattern, or mass extensor pattern, instead of reciprocal innervations, stiffness of the ankle joint, and loss of proprioceptive sense, permanent disabilities, such as foot drop, are common in stroke patients[2)]. The hip and ankle joints play important roles in the control of balance. Primary functions of the ankle joint are the provision of balance control against postural disturbance, absorption of shock during gait, and movement of the lower extremity. To provide these, it is necessary to maintain a sufficient range of motion of the ankle joint, muscular strength, and proprioceptive sense[3)]. Limitation of ankle dorsiflexion is a common gait problem of hemiparetic stroke patients. Due to abnormal increase of muscle tension in the triceps surae, stroke patients cannot actively control dorsiflexion, and the foot drop tends to occur[4)].

A normal range of motion of the ankle joint in the standing position is essential for normal gait[5)]. Muscle cooperation in the ankle joint strategy puts the center of gravity on the ankle joint in the standing position. The ankle joint strategy used on solid ground maintains balance. It requires a normal range of motion of the ankle joint and muscular strength. If the range of motion of the ankle joint is limited, postural control provided by the ankle joint is also limited[6)].

Compared with subjects without proprioceptive sense, subjects with proprioceptive sense appear to show a greater increase of postural sway, and lowering of balance measure scores[7)], all of which have important roles in gait pattern. Re-education of the ankle joint movement for control of balance is an important factor in remedying gait or balance problems caused by abnormal muscular contraction or proprioception deficit[8)]. Therefore, this study investigated the effect of a proprioceptive exercise training program for improvement on the muscular strength of the ankle joint, static balance, dynamic balance, and gait of stroke patients.

SUBJECTS AND METHODS

Thirteen outpatients with stroke voluntarily participated in this study. To be included, patients met the following criteria: stroke onset of more than six months previously, in order to minimize the effects of natural recovery; ability to walk without use of a walking aid for a minimum of 15 m; a Mini-Mental State Examination score greater than 24/30; and ability to comprehend and follow simple instructions.

*To whom correspondence should be addressed.
E-mail: 3679@syu.ac.kr

Subjects participated in a general physical therapy program lasting 30 minutes per session, two sessions per week, for a period of six weeks. In addition, all subjects practiced additional ankle proprioceptive control training, consisting of 30 minutes per session, two sessions per week, for a period of six weeks. Subjects' general characteristics were: male 10, female 3; mean ± SD age 58.46 years ± 8.53; height 161.09 cm ± 7.28; weight 61.83 kg ± 10.15; stroke onset 53.15 months ± 7.28, and Modified Ashworth Scale (MAS) scores of 0–1 (n=10), 1+ (n=3).

Subjects performed not only a general physical therapy program but also the ankle proprioceptive control training program. The ankle proprioceptive control training program consisted of a program for improvement of balance ability and gait by reinforcement of ankle proprioceptive control. The program consisted of three stages: mobility of the ankle joint and muscular strength (stage 1); weight bearing in a static standing position (stage 2); and a weight bearing and assignment training program (stage 3)[9] (Table 1). The general physical therapy program included neuro-developmental treatment (NDT). Each program was provided 2 times per week for 30 min each session for six weeks.

The muscular strength of the ankle joint was measured using a BTE-Primus (BTE technology, USA, 2006). This equipment evaluates patient's range of motion, muscular strength, endurance, activities of daily living, and task performance. We measured the patients' ankle dorsiflexion and plantar flexion in the sitting position with placement of the foot on a foothold.

Subjects performed the Timed Up and Go test (TUG) before and after six weeks of physical therapy. TUG has shown high intra-rater (ICC=0.99) and inter-rater (ICC=0.99) reliabilities and is an evaluation of dynamic balance ability[10]. The test was performed three times and the mean was used in the analysis of this study.

Gait function was measured using GAITRite (GAITRite, CIR system Inc., Havertown, PA, USA). The standard GAITRite walkway has six sensor pads encapsulated in a rolled-up carpet with an active area of 3.66 m length and 0.61 m width. As a subject walks along the walkway, the sensors capture each footfall as a function of time and transfer the gathered information to a personal computer for processing into footfall patterns. GAITRite was used for the measurement of spatiotemporal parameters, including gait velocity, cadence, step length, and stride length[11].

The SPSS 17.0 program (SPSS Inc., Chicago, IL, USA) was used for statistical analysis. The Shapiro-Wilk test was used to test the distribution of the general characteristics and outcome measures of the subjects. Repeated measures ANOVA was used to compare pretest, posttest, and retest results within groups. Values of $p<0.05$ were considered significant.

RESULTS

At the end of the proprioceptive control training program, muscular strength of the ankle dorsiflexor showed a statistically significant increases ($p<0.001$) from 29.54 N before training to 33.43 N at week 4, and 36.84 N at week 6.

TUG, a functional balance ability test, showed significant improvements from 20.47 s before training to, 17.94 s (4 wks), and 15.27 s (6 wks) ($p<0.001$).

In temporal gait ability, gait velocity showed significant increases from 50.35 cm/s before training to, 60.45 cm/s (4 wks), and 67.55 cm/s (6 wks). Cadence showed significant improvements from 76.78 steps/min before training to 81.42 steps/min (4 wks) and 88.81 steps/min (6 wks). In spatial gait ability, step length on the paretic side significantly increased from 38.88 cm before training to 44.12 cm (4 wks), and 45.16 cm (6 wks) ($p<0.001$), and significantly increased from 36.34 cm before training to 42.30 cm (4 wks), and 43.79 cm (6 wks) on the non-paretic side ($p<0.001$). Significant increases in stride length from 72.84 cm before training to 86.63 cm (4 wks), and 88.92 cm (6 wks), were observed on the paretic side ($p<0.001$), and from 75.85 cm before training to 86.70 cm (4 wks), and 88.90 cm (6 wks) on the non-paretic side ($p<0.001$).

DISCUSSION

Weakened muscle strength in post-stroke patients is one of the factors limiting functional recovery. As a psychological factor, in particular, patient's self-confidence can lead to a fall, due to self-limitation of activities Weakened muscle strength. It is attributable to loss of balance, and decline of functional independence[12]. Balance maintenance of anteroposterior postural sway is dependent on co-operative activities between the anterior tibial muscle and internal abdominal muscle. In other words, the activity of the internal abdominal muscle begins before the body falls over a vertical line and the anterior tibial muscle activates before the body becomes posturally erect[13].

Andrews and Bohannon[2] studied the recovery of stroke patients' lower extremity muscle strengths over a short period of time. They reported a statistically significant improvement in ankle dorsiflexion on the paretic side, from 75.6 *N* during hospitalization to 102.4 *N* after intervention. In a study of lower extremity muscle torque in the movement of stroke patients, Kim and Eng[14] reported that ankle dorsiflexion was weaker than ankle plantarflexion. Docherty et al.[15] demonstrated there was a statistically significant increase in dorsiflexor and eversion strength after an ankle joint movement program lasting six weeks. In this study, ankle dorsiflexors showed statistically significant increases on the paretic side from 29.54 *N* before training to, 33.43 *N* at week 4, and 36.83 *N* at week 6. However, despite the increase in ankle dorsiflexor strengths: 44.50 *N* (0 wk), 47.13 *N* (4 wks), and 49.39 *N* (6 wks), plantarflexors showed no significant difference. These results suggest that impairment of proprioceptive sense leads to difficulty in maintaining balance and postural control due to loss of cognitive ability of postural position in the environment[16, 17]; however, proprioceptive sense was improved by participation in the proprioceptive ankle movement program.

The increased static postural perturbation of stroke patients may be a result of balance loss due to malfunction of proprioceptive sense or proper weight bearing. The Timed Up and Go (TUG) test, Berg Balance Scale (BBS), and

Table 1. Ankle proprioceptive control program

proprioceptive control program	section/minute
Stage 1: Ankle range of motion or muscular strength exercises	20/10
Facilitate range of motion of the ankle joint in a sitting position	5/ 3
Repetitive ankle flexion and extension	5/ 2
Repetitive ankle dorsiflexion and plantar flexion	10/ 5
Stage 2: Weight bearing in a static standing position	20/10
Weight bearing on paralyzed side with changing body position from sitting to standing	10/ 5
Weight bearing in various directions in a standing position	10/ 5
Stage 3: Weight bearing or training task on a single leg stance	20/10
Lift non-paretic side leg in a stand position	5/ 2
Various weight bearing on paretic side in a single leg stance	10/ 5
Training task for upper extremity in a single leg stance	5/ 3

Table 2. Comparison of balance and gait abilities (N=13)

		0 wk	4 wks	6 wks
Ankle dorsiflexion (N)		29.5 (23.8)[a]	33.4 (22.1)	36.8 (22.6) ***
Ankle plantarflexion (N)		44.5 (38.3)	47.1 (30.0)	49.4 (25.3)
TUG (sec)		20.5 (10.4)	17.9 (9.3)	15.3 (7.5) ***
Velocity (cm/s)		50.4 (22.8)	60.5 (22.4)	67.6 (24.1) ***
Cadence (steps/min)		76.8 (24.3)	81.4 (18.6)	88.8 (18.6) ***
Step length (cm)	P	38.9 (8.2)[b]	44.1 (8.9)	45.2 (8.0) ***
	NP	36.3 (9.5)	42.3 (9.8)	43.8 (9.3) ***
Stride length (cm)	P	72.8 (16.4)	86.6 (17.8)	88.9 (16.8) ***
	NP	75.8 (16.6)	86.7 (17.6)	88.9 (16.3) ***

Values are [a] mean (SD). TUG: Timed up and go test, P: paretic side, NP: non-paretic side, *$p<0.05$, **$p<0.01$, ***$p<0.001$

Functional Reach Test (FRT) are standard assessments of stroke patients' dynamic balance ability. Among them, the reliability and the validity of TUG has been proven for the measurement of clinical changes in dynamic balance ability and functional movement with time[18]. Walker et al.[19] reported that TUG was 50.9 sec in the first stage of stroke and 24.9 sec after three months.

In this study, after participation in an ankle proprioceptive control training program, TUG scores showed a significant improvements from 20.47 sec (0 wk), to 17.9 sec (4 wk), and 15.27 sec (6 wk). These results can be interpreted as suggesting that dynamic balance ability was improved by increase of ankle sense of position through proprioceptive control, and they are in agreement with the results of previous studies.

Improvement of gait ability during a stroke patient's functional recovery process is the main goal of both the patient and the therapist, because it is an important factor for the accomplishment of functional independence[20]. In a study of stroke patients' walking patterns, Edwards[1] reported that cadence was 89–131 steps/min and stride length was 1.08–1.63 m. In a walking step analysis using GAITRite of 62 healthy subjects, step lengths were 74.3 cm on the right side and 73.9 cm on the left side. Stride lengths were 148.6 cm on the right side and 149.1 cm on the left side. Walking velocity was 149.5 cm/s[21].

In this study, during participation in an ankle proprioceptive control program, subjects gait velocities increased from, 50.35 cm/s (0 wk), to 60.45 cm/s (4 wk), and 67.55 cm/s (6 wk), and cadence improved from 76.78 steps/min (0 wk), to 81.42 steps/min (4 wk), and 88.81 steps/min (6 wk). Step length increased from 38.88 cm (0 wk), to 44.12 cm (4 wk), and 45.16 cm (6 wk) on the paretic side, and statistically significant increases from 36.34 cm (0 wk), to 42.30 cm (4 wk), and 43.79 cm (6 wk) were also observed on the non-paretic side. Stride length increased from 72.84 cm (0 wk), to 86.63 cm (4 wk), and 88.92 cm (6 wk) on the paretic side, and statistically significant increases from 75.85 cm (0 wk), to 86.70 cm (4 wk), and 88.90 cm (6 wk) were also observed on the non-paretic side. In this study, after participation in an ankle proprioceptive control program, subjects' gait velocities increased. Cadence and step length increased on the paretic side, and statistically significant increases were observed on the non-paretic side as well. Stride length were increased on the paretic side, and statistically significant increases were also observed on the non-paretic side (Table 2).

In this study, the ankle proprioceptive control program improved the spatial-temporal walking pattern of patients with stroke and the results agree with those of previous studies. We consider the ankle proprioceptive control program strengthened the ankle dorsiflexors, which led to improvement in gait ability, due to prevention of foot drop in the swing phase and the provision of lower extremity stability at initial contact. In addition, a more stable walking pattern might have been achieved through improvement of static-dynamic balance ability leading to decreased postural perturbation. This study investigated the effect of an ankle proprioceptive control program on the recovery of balance and gait abilities of hemiparetic patients stroke. The ankle proprioceptive control program focusing on somatosensory sense for the recovery of stroke patients' balance and walking abilities proved effective. This study used an ankle proprioceptive control program that consisted of three stages: mobility of the ankle joint and muscular strength (stage 1); weight bearing in a static standing position (stage 2); weight bearing and assignment training program (stage 3). However, we did not compare the three stages to determine which is the most effective for balance, gait ability, or muscle strength. A follow-up study should compare them, to determine which stages are most effective at improving patients' balance, gait ability and muscle strength.

REFERENCES

1) Edwards S: Neurological Physiotherapy: A Problem-Solving Approach. Edingburgh: Churchill Livingstone, 2001, pp 26–37.
2) Andrews AW, Bohannon RW: Short-term recovery of limb strength after acute stroke. Arch Phys Med Rehabil, 2003, 84: 125–130. [CrossRef] [Medline]
3) Donald AN: Kinesiology of the Musculoskeletal System: Foundations for Physical Rehabilitation. Mosby Publication, 2002, pp 528–529.
4) Burridge JH, Taylar PN, Hagan SA: The effects of common peroneal stimulation on the effort and speed of walking: a randomized. Clin Rehabil, 1997, 11: 201–210. [CrossRef] [Medline]
5) McCollum G, Shupert CL, Nashner LM: Organizing sensory information for postural control in altered sensory environments. J Theor Biol, 1996, 180: 257–270. [CrossRef] [Medline]
6) Shumway-Cook A, Wollacott M: Attentional demands and postural control: the effect of sensory context. J Gerontol A Biol Sci Med Sci, 2000, 55: 10–16. [CrossRef] [Medline]
7) Niam S, Wayne C, Patricia E, et al.: Balance and physical impairments after stroke. Arch Phys Med Rehabil, 1999, 80: 1227–1233. [CrossRef] [Medline]
8) Lin PY, Yang YR, Cheng SJ, et al.: The relation between ankle impairments and gait velocity and symmetry in people with stroke. Arch Phys Med Rehabil, 2006, 87: 562–568. [Medline]
9) Lynch M, Grisogono V: Stroke and head injuries. London: John Murray, 1991, pp 113–136.
10) Podsiadlo D, Richardson S: The timed "Up and Go": a test of basic functional mobility for frail elderly person. J Am Geriatr Soc, 1991, 39: 142–148. [Medline]
11) McDonough AL, Batavia M, Chen FC, et al.: The validity and reliability of the GAITRite system's measurements: a preliminary evaluation. Arch Phys Med Rehabil, 2001, 82: 419–425. [CrossRef] [Medline]
12) Whitney SL, Poole JL, Cass SP: A review of balance instruments for older adults. Am J Occup Ther, 1998, 52: 666–671. [CrossRef] [Medline]
13) Almeida GL, Carvalho RL, Talis VL: Postural strategy to keep balance on the seesaw. Gait Posture, 2006, 23: 17–21. [CrossRef] [Medline]
14) Kim CM, Eng JJ: The relationship of lower-extremity muscle torque to locomotor performance in people with stroke. Phys Ther, 2003, 83: 49–57. [Medline]
15) Docherty CL, Arnold BL, Zinder SM, et al.: Relationship between two proprioceptive measure and stiffness at the ankle. J Electromyogr Kinesiol, 2004, 14: 317–324. [CrossRef] [Medline]
16) Horak FB, Nashner L, Diener H: Postural strategies associated with somatosensory and vestibular loss. Exp Brain Res, 1990, 82: 167–177. [CrossRef] [Medline]
17) Horak FB, Henry SH, Shumway-Cook A: Postural pertubations: new insight for treatment of balance disorders. Phys Ther, 1997, 77: 517–533. [Medline]
18) Ng SS, Hui-Chan CW: The timed Up & Go test: its reliability and association with lower-limb impairment and locomotor capacities in people with chronic stroke. Arch Phys Med Rehabil, 2005, 86: 1641–1647. [CrossRef] [Medline]
19) Walker C, Brouwer BJ, Culham EG: Use of visual feedback in retraining balance following acute stroke. Phys Ther, 2000, 80: 886–895. [Medline]
20) Turnbull GI, Charteris J, Wall JC: A comparison of the range of walking speeds between normal and hemiplegia subjects. Scand J Rehabil Med, 1995, 27: 175–182. [Medline]
21) Titianova EB, Pitkanen K, Paakkonen A, et al.: Gait characteristics and functional ambulation profile in patients with chronic unilateral stroke. Am J Phys Med Rehabil, 2003, 82: 778–786. [CrossRef] [Medline]