Walking Training with a Weight Support Feedback Cane Improves Lower Limb Muscle Activity and Gait Ability in Patients with Chronic Stroke: A Randomized Controlled Trial

Authors' Contribution:
Study Design A
Data Collection B
Statistical Analysis C
Data Interpretation D
Manuscript Preparation E
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Background: Induction of proper weight transfer to the affected lower limb should be considered the most essential factor for successful stroke cane gait training. This study aimed to investigate the effect of walking training with a weight support feedback cane on lower limb muscle activity and gait ability of chronic stroke patients.

Material/Methods: Thirty stroke patients were randomized into 2 groups: a weight support feedback cane gait training group (WSFC group, n=15) and a conventional cane gait training group (CC group, n=15). All subjects were enrolled in standard rehabilitation programs for 4 weeks. Additionally, the WSFC group participated in WSFC gait training and the CC group participated in conventional cane gait training for 4 weeks. During WSFC gait training, the weight support rate loaded on the cane was reduced by 10% every week from 60% to 30% based on the measured initial cane dependence, while the CC group participated in conventional cane gait training with verbal instruction to reduce cane dependence. Lower limb muscle activity and gait ability were measured using wireless surface electromyography and a 3-axis accelerometer during walking.

Results: The WSFC group showed significantly greater improvement than the CC group in lower limb muscle activity and gait ability ($P<0.05$).

Conclusions: Cane gait training significantly improved lower limb muscle activity and gait ability in stroke regardless of the training method; however, the addition of real-time weight support feedback to cane gait training appears to provide further benefit compared with conventional cane gait training in chronic stroke patients.

Keywords: Body-Weight Trajectory • Gait • Stroke

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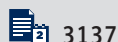
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Background

Stroke is classified as ischemic, caused by blockage of blood vessels supplying blood to the brain, and hemorrhagic, caused by rupture of blood vessels in the brain [1]. Stroke is a leading cause of death and dysfunction worldwide [2] and in general, it is associated with muscle weakness, decreased sensation, decreased cognitive function, depression, and decreased quality of life [3-5]. In particular, muscle weakness in the affected side causes overuse and asymmetrical weight shift to the non-affected lower limb [6], leading to an increased risk of falls, decreased independence in daily life, decreased postural control, and asymmetrical walking pattern [7,8]. Therefore, rehabilitation for symmetrical weight transfer and gait enhancement is fundamental to improve the independence and quality of life of patients with stroke [9,10].

In clinical practice, various assistive devices, such as parallel bars, walker, and cane, are used for balance and gait training of stroke patients. Among them, a cane can help to increase the base of support for stroke patients to provide postural stability and improves weight transfer ability in the standing position and walking [11-13]. Using a cane during the single-limb stance phase helps to retrain weight transfer to the affected lower limb and provides tactile information about the ground [14,15]. In addition, using a cane can contribute to stable postural control by controlling the rapid movement of the center of gravity during the stance phase [16]. Park reported that the use of a cane is effective in improving the weight support rate of the affected lower limb in patients with stroke [17]. Moreover, Boonsinsukh et al reported that cane training with auditory feedback according to the weight support rate of the affected lower limb leads to improvement of muscle activity in the affected tensor fasciae latae and vastus medialis [18]. In contrast, several studies have shown that the use of a cane in the early rehabilitation period caused a decrease in muscle activity of the affected lower limb [12,19] and it interferes with symmetrical weight distribution, which ultimately interferes with acquisition of independent gait ability [20,21]. Although the main purpose of using a cane is to help weight distribution to the affected lower limb, improper use of a cane can contribute to an asymmetrical gait pattern by inducing excessive weight support to the non-affected lower limb [16].

Therefore, for successful cane gait training, induction of proper weight transfer to the affected lower limb should be considered the most essential factor [6,22]. However, in clinical practice, it is difficult to quantitatively monitor the weight carried on the cane during cane gait training due to technical problems. Additionally, it is difficult for patients to receive accurate feedback on weight support on the paretic lower limb during cane gait training [23]. Moreover, there is insufficient information on the effects of progressive weight support induction on the affected lower limb during cane gait training on muscle activity and gait in patients with stroke.

Thus, this study aimed to investigate the effect of weight support feedback cane gait training that provided real-time feedback of the user's weight support loaded on a cane on the lower limb muscle activity and gait ability of patients with chronic stroke. We hypothesized that 4 weeks of weight support feedback cane gait training would show improvements in lower limb muscle activity and gait ability in chronic stroke patients.

Material and Methods

Study design

This randomized controlled trial was conducted at a rehabilitation hospital (experimental period: June 2019 to December 2019). All subjects were randomized into 2 groups: a weight support feedback cane gait training group (WSFC group) and a conventional cane gait training group (CC group). Sealed envelopes were used to conduct randomization. The inside of each sealed envelope was marked with an O or X. Subjects who selected envelopes marked with O were assigned to the WSFC group, and those who selected envelopes marked with X were assigned to the CC group. Randomization was conducted before the pre-test by a physical therapist who did not participate in this study. In addition, until the post-test was performed, the randomization was concealed. The study was approved by the local ethics committee (KNUT IRB -2019-15) and conducted in accordance with the approved guidelines. Written informed consent was obtained from all subjects before inclusion.

Subjects

A minimum sample size of 15 participants per group was calculated using a power calculation tool (G*Power 3.1.9.3 software; Heinrich Heine University, Düsseldorf, Germany) with a power and alpha set at 0.80 and 0.05, respectively, and an effect size set at 0.87. Thirty-three stroke patients were recruited to perform this study. We included subjects with (1) residual hemiparesis at least 6 months after the onset of stroke, (2) those with adequate cognitive levels to perform this study (the score of the Korean version of the Mini-Mental State examination ≥24), (3) those who walked using a cane (functional ambulation category 2-3 levels), and (4) those who supported 7% or more of their body weight on a cane [24]. We excluded subjects with (1) a potential musculoskeletal condition that could interfere with safe walking, (2) hemispatial neglect, and (3) severe heart disease or uncontrolled hypertension. Three subjects were excluded because they did not meet the selection criteria (uncontrolled hypertension and MMSE 20 points).
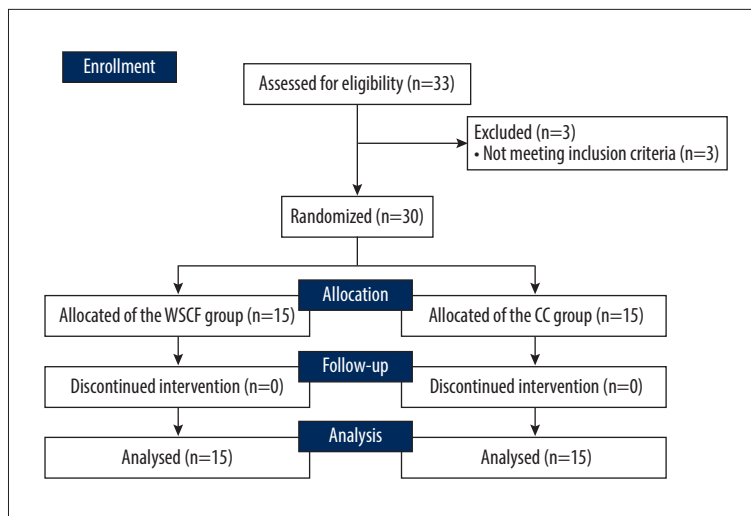
Figure 1. Study flowchart.

Finally, 30 subjects were included and randomly divided into 2 equal groups (**Figure 1**). The general characteristics of enrolled subjects are described in **Table 1**.

Procedure

All subjects participated in standard rehabilitation programs composed of physical and occupational therapy conducted for 4 weeks (5 times per week). Neurodevelopmental treatment was provided in physical therapy, and upper limb functional training for improving daily living performance was performed in occupational therapy. In addition, the subjects from the WSFC group participated in weight support feedback cane gait training conducted for 30 min per day, 3 times per week, for 4 weeks, while the subjects from the CC group participated in conventional cane gait training conducted for 30 min per day, 3 times per week, for 4 weeks. Pre- and post-tests for lower limb muscle activity and gait ability were conducted 1 week before the intervention period and 1 day after the intervention period. Pre- and post-tests were conducted by 3 physical therapists blinded to treatment allocations. In addition, before starting the intervention, cane dependence (average weight support loaded on a cane while walking) was assessed in all subjects during a 20-m walk through a smartphone application connected to the weight support feedback cane via Bluetooth. Average weight support was calculated by dividing the sum of the degree of weight support at each step by the number of steps.

Intervention

Weight Support Feedback Cane (WSFC) Gait Training

WSFC gait training was performed with a WSFC and a smartphone application capable of quantitative measurement of cane dependence during walking (**Figure 2**). WSFC measured

the cane dependence by a load cell located at the bottom of the WSFC handle, and the measured cane dependence was displayed on the WSFC handle and the smartphone application in real time. Based on cane dependence, the subject set a different weight support rate (60% to 30% of cane dependence) for each week. Setting the weight support rate was performed using the smartphone application. If a weight above the preset weight support rate was loaded on the WSFC during gait training, a beeping sound was generated until the weight support loaded on the WSFC was below the preset weight support rate. According to the pilot study on 3 stroke patients and recommendations from clinical experts, the weight support rate loaded on the WSFC was reduced by 10% every week, from 60% (weight support rate in the first week of training) to 30% (weight support rate in the fourth week of training), based on the initial measured cane dependence. During every training session, the gait success rate (the proportion of the number of steps that showed cane dependence below the preset weight bearing rate of the total number of steps in WSFC gait training) was recorded by the smart phone application. When the gait success rate for a week was more than 80%, the weight support rate of the next step (from 60% to 30%) was applied. WSFC gait training was performed at a comfortable speed and the subjects were asked to walk without generating an auditory feedback (beeping sound) as much as possible during WSFC gait training.

Conventional Cane (CC) Gait Training

The subjects in the CC gait training group participated in gait training using a conventional standard mono cane without auditory feedback (beeping sound) for the same amount of time as those in the WSFC group. The subjects were verbally asked to reduce the weight support loaded on the cane during CC gait training for each week instead of providing auditory feedback according to the set weight support rate. In the

Table 1. Homogeneity test for general characteristics and dependent variables of the subjects (N=30).

	WSFC group (n=15)	CC group (n=15)	p-values
General characteristics			
Gender (Male/Female)	10/5	11/4	
Paretic side (right/left)	10/5	11/4	
Brunstrom stage (1/2/3/4)	0/9/4/2	1/9/3/2	
FAC (2/3)	8/7	12/3	.123
Age, *years*	58.2±13.8	60.1±13.1	.826
Height, *cm*	166.1±8.4	165.9±9.9	.802
Weight, *kg*	65.9±9.9	65.6±10.2	.500
Post-stroke duration, *month*	12.8±8.3	14.7±6.6	.487
MMSE-K, *points*	28.2±2.4	28.2±2.4	.551
Percentage of BW for AWS, *%BW*	17.4±5.2	19.4±4.4	.278
AWS, *kg*	11.7±3.7	12.8±3.9	.371
Dependent variables			
Muscle activation			
Rectus femoris, %RVC	274.1±123.0	247.6±120.8	.557
Biceps femoris, %RVC	201.3±90.9	222.0±113.2	.586
Medial gastrocnemius, %RVC	224.9±90.6	181.4±63.0	.287
Gluteus medius, %RVC	204.7±78.9	195.5±136.2	.823
Gait ability			
Velocity, m/sec	6.0±2.5	6.7±3.0	.512
Cadence, steps/min	65.8±22.5	69.2±22.2	.823
P-Single-limb support phase, %	29.0±6.6	28.9±5.2	.964
Symmetry Index	75.0±17.5	77.3±13.2	.686

Values are expressed as Mean±SD. WSFC – Weight Support Feedback Cane Training; CC – Conventional Cane Training; MMSE-K – Mini-Mental Status Examination-Korean version; FAC – functional ambulation category; BW – body weight; AWS – average weight support loaded on the cane during walking at initial measurement; RVC – reference voluntary contraction; P – paretic side. Symmetry Index=(Paretic side stance phase (% of gait cycle))/(Non-paretic side stance phase (% of gait cycle))×100.

first week of CC gait training, subjects were asked to walk at a comfortable speed and 60% of their usual cane dependence; in the following weeks of training, they were asked to walk at their comfortable speed with a reduction in cane dependence to 10% in the last week.

Measurement

The affected lower limb muscle activity during the stance phase of the gait cycle was measured using wireless surface electromyography (sEMG). Wireless sEMG electrode attachment was conducted at the 4 major muscles of the affected lower limb (rectus femoris, biceps femoris, medial gastrocnemius, and gluteus medius). Before the start of measurement, the skin hair at the attachment site was removed to avoid skin resistance,

and the attachment site was cleaned using an alcohol. Finally, the wireless sEMG electrode was attached in accordance with the direction of muscle fibers. The EMG Analyzer v. 2.9.37.0 (BTS Bioengineering, Milano, Italy) was used to obtain lower limb muscle activity during the stance phase of the gait cycle. To eliminate high-frequency noise, sEMG raw data were filtered at 20-500 Hz. The root mean square values were calculated over a time constant of 50 ms and all values were expressed as% reference voluntary contraction to normalize the sEMG signal. The affected lower limb muscle activity during the stance phase of the gait cycle was measured 3 times, and the average value was used.

To measure gait ability, a 3-axis accelerometer (G-Walk, BTS Bioengineering, Milano, Italy) was used. The 3-axis accelerometer

Figure 2. A weight support feedback cane (WSFC). The WSFC measures the cane dependence by a load cell located at the bottom of the WSFC handle, and the measured cane dependence is displayed on the WSFC handle (**A**) and smartphone application in real time (**B**).

is a portable and wireless system with wearable sensors. The wearable sensor was attached at the first sacrum level of the subjects using a semi-elastic belt. All acceleration data (velocity, cadence, single-limb support phase of the affected side, and symmetry index) were transmitted via Bluetooth to the special software program G-Studio (BTS Bioengineering, Milano, Italy).

Statistical Analysis

SPSS (version 21.0; IBM Corp., Armonk, NY) was used to conduct statistical analyses. To confirm the normal distribution of all variables, the Shapiro-Wilk test was used. The independent t test and chi-square test were used to test homogeneity in general characteristics and dependent variables. In addition, the paired t test and independent t test were used to confirm the changes of dependent variables within and between groups after interventions. The significance level was set at 0.05.

Results

The general characteristics and baseline clinical assessment of the subjects are summarized in **Table 1**. No significant differences were observed between the WSFC and CC groups.

Changes in lower limb muscle activity and gait ability after intervention are shown in **Table 2**. In lower limb muscle activity, both groups showed significant improvements in the rectus femoris (WSFC group: 274.1 to 311.0%RVC, CC group: 247.6 to 273.8%RVC), biceps femoris (WSFC group: 201.3 to 237.8%RVC, CC group: 222.0 to 235.2%RVC), medial gastrocnemius (WSFC group: 224.9 to 279.4%RVC, CC group: 181.4 to 204.8%RVC), and gluteus medius (WSFC group: 204.7 to 261. 7%RVC, CC group: 195.5 to 206.7%RVC, the CC group showed no statistical significance) (P<0.05). However, the WSFC group showed significantly greater improvement than the CC group in the rectus femoris (36.9 vs 26.2%RVC), medial gastrocnemius (55.1 vs 23.4%RVC), and gluteus medius (57.0 vs 11.2%RVC) (P<0.05).

In gait ability, both groups showed significant improvements in velocity (WSFC group: 6.0 to 6.7 m/sec, CC group: 6.7 to 7.1 m/sec), cadence (WSFC group: 65.8 to 71.2 steps/min, CC group: 69.2 to 74.1 steps/min), affected single-limb support phase (WSFC group: 29.0 to 35.4%, CC group: 28.9 to 30.5%) and symmetry index (WSFC group: 75.0 to 84.5, CC group: 77.3 to 82.3) (P<0.05). However, the WSFC group showed significantly greater improvement than the CC group in the affected single-limb support phase (6.4% vs 1.6%) and symmetry index (9.5 vs 5.0) (P<0.05).

Table 2. Changes of lower limb muscle activity and gait ability (N=30).

Parameters	WSFC group (n = 15)			CC group (n = 15)			t	p
	Pre-test	Post-test	Δ values	Pre-test	Post-test	Δ values		
Lower limb muscle activation (%RVC)								
Rectus femoris	274.1±123.0	311.0±97.3	36.9±36.9*	247.6±120.8	273.8±118.2	26.2±22.0*,**	0.957	.025
Biceps femoris	201.3±90.9	237.8±89.3	36.4±36.9*	222.0±113.2	235.2±104.1	13.2±19.8*	2.449	.130
Medial gastrocnemius	224.9±90.6	279.4±129.6	55.1±92.2*	181.4±63.0	204.8±61.3	23.4±27.1*,**	1.278	.016
Gluteus medius	204.7±78.9	261.7±97.2	57.0±47.9*	195.5±136.2	206.7±130.6	11.2±20.4**	3.402	.004
Gait ability								
Velocity (m/sec)	6.0±2.5	6.7±2.2	0.7±0.9*	6.7±3.0	7.1±3.0	0.4±0.5*	1.085	.083
Cadence (steps/min)	65.8±22.5	71.2±21.8	5.3±9.5*	69.2±22.2	74.1±21.4	4.8±6.1*	0.179	.187
P-Single-limb support phase (%)	29.0±6.6	35.4±4.6	6.4±4.0*	28.9±5.2	30.5±5.7	1.6±2.1*,**	4.074	.047
Symmetry Index	75.0±17.5	84.5±8.9	9.5±14*	77.3±13.2	82.3±11	5.0±4.4*,**	0.937	.008

Values are expressed as Mean±SD. WSFC – Weight Support Feedback Cane Training; CC – Conventional Cane Training; P – paretic side;
RVC – reference voluntary contraction.
Symmetry Index=(Paretic side stance phase (% of gait cycle))/(Non-paretic side stance phase (% of gait cycle))×100.
* Significant differences between pre and post-test, *P*<0.05; ** significant differences for change value between 2 groups, P<0.05.

Discussion

This study investigated the effect of WSFC gait training, which provides real-time feedback of the user's weight support loaded on a cane, on lower limb muscle activity and gait ability of stroke patients. As a result, lower limb muscle activity and gait ability were significantly improved in both the WSFC and CC groups who underwent 4 weeks of weight support feedback cane gait training and conventional cane gait training (*P*<0.05). However, the WSFC group showed greater improvement in lower limb muscle activity and gait ability compared to the CC group.

Improvement of gait function is an important measure of motor function recovery in stroke [25], and independent gait is an essential factor in increasing the quality of life [7]. Patients with stroke experience reduced muscle activity and gait function due to decreased weight support to the affected lower limb, and a cane is used to improve gait ability or to compensate for decreased gait function in patients with stroke [26]. Several previous studies have reported that proper use of a cane during gait training can induce an increase in weight support to the affected lower limb, thereby improving gait symmetry and stability [11,18,19]. Beauchamp et al reported that cane gait training was effective in improving gait symmetry, velocity, and distance in patients with stroke [27]. In addition, another study reported that the use of a cane was effective in improving the maximum walking distance in patients with

stroke [11]. The training protocols used on this study (both WSFC and CC groups) were designed to ensure a gradual decrease in the weight loaded on the cane as cane gait training progressed every week. Such training protocols might have induced functional improvement and weight support to the affected lower limb, as observed in previous studies.

An interesting finding of this study was that the WSFC group showed higher improvement in lower limb muscle activity (rectus femoris and medial gastrocnemius) and gait ability (affected single-limb support phase and symmetry index) compared to the CC group (all *P*<0.05). Improper use of a cane in patients with stroke favors cane dependence, thus reducing the muscle activity of the affected lower limb, which in turn may function as a factor causing asymmetrical walking [22,28]. Therefore, it is important to monitor cane dependence during gait training in patients with stroke. In clinical practice, verbal instructions, such as "please walk as you reduce the weight on the cane" are given by the therapists to reduce dependence on the cane during gait training in patients with stroke. However, such verbal instructions may not receive adequate feedback to reduce cane dependence. Thus, in this study, the average weight support loaded on the WSFC (cane dependence) was measured using a force sensor, and the threshold value was set based on the measured cane dependence. An auditory signal was generated when the weight support loaded on the cane exceeded the threshold value during WSFC gait training. The subject responded to the auditory signal by reducing the weight loaded

on the cane in order to prevent auditory signal generation. In other words, the auditory signal acted as a feedback signal to correct the subject's dependence on the cane. An appropriate physical response to the provided feedback improves the function of the somatosensory system of patients with stroke, which helps to control the center of mass and contributes to improvement of gait function [23]. Sungkarat et al reported that auditory feedback through a pressure sensor applied to the insole shoe wedge during gait training of patients with stroke was effective in improving the weight transfer ability and activating the muscles of the affected lower limb [29]. Another study reported that auditory feedback increased weight bearing to the paretic lower limb and induced an increase in single-limb support time in patients with stroke, which in turn led to improvements in gait velocity and symmetry [30]. Moreover, Jung et al reported that auditory feedback using a pressure sensor during cane gait training led to motor learning by inducing repetitive weight support to the affected lower limb and retraining of weight transfer ability [28]. In this study, the accurate auditory feedback based on quantitative measurements in the WSFC group might have triggered a rapid and accurate training response (immediate response that decreased weight support loaded on the cane). In addition, this immediate response might have induced weight transfer to the affected lower limb and contributed to improved muscle activity and gait ability of the lower limb muscle compared to the CC group.

Although this study was a randomized controlled trial sufficiently powered to determine the effect of WSFC gait training on lower limb muscle activity and gait in patients with chronic stroke, it has some limitations. First, the sample size was relatively small and the follow-up period was short; a large randomized controlled trial with a long follow-up period should be conducted for a more accurate analysis of the effects of weight support feedback cane gait training. Second, this study did not consider factors (eg, the extent of the lesion and dominant side) that may have affected functional recovery of stroke. Therefore, the possibility of these factors influencing the study cannot be excluded.

Third, the subjects in the WSFC gait training group participated in WSFC gait training with different weight support rate settings via the load cell located at the bottom of the WSFC handle. However, the CC group subjects were verbally asked to walk at 60%, 50%, 40%, and 30% of their usual cane dependence during CC gait training. The possibility that these differences in accuracy regarding cane dependence could have affected the study findings cannot be excluded. Finally, because the placebo effect was not considered in the CC group, it was difficult to clearly explain the effects of real-time weight support feedback. Thus, further studies considering the placebo effect should be conducted.

Conclusions

This study investigated the effect of weight support feedback cane gait training that provided real-time feedback of the user's weight support loaded on a cane on lower limb muscle activity and gait ability of patients with stroke. We found that cane gait training could significantly improve lower limb muscle activity and gait ability in patients with stroke by inducing weight support to the affected side regardless of the training method; however, the addition of real-time weight support feedback to cane gait training provided additional benefits compared to conventional cane gait training in stroke patients.

Conflict of Interest

None.

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