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Original Article

Early effects of a knee-ankle-foot orthosis on static standing balance in people with subacute stroke

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Abstract. [Purpose] The purpose of this study was to evaluate the early effects of a knee-ankle-foot orthosis on static standing balance in people with subacute stroke. [Participants and Methods] Timed static standing balance in four standing conditions (feet apart with eyes open, feet apart with eyes closed, feet together with eyes open, and tandem stance with eyes open) was assessed in 29 inpatients (mean age: 67.3 ± 13.3 years) with subacute stroke with and without a knee-ankle-foot orthosis on the paretic lower limb. [Results] In the group of participants who were unable to stand without a knee-ankle-foot orthosis, the proportion of participants who were able to stand with a knee-ankle-foot orthosis was significantly increased in the following conditions: feet apart with eyes open and feet apart with eyes closed. In the group of participants who were able to stand without a knee-ankle-foot orthosis, the mean duration of time for which the participants with a knee-ankle-foot orthosis were able to stand was significantly longer than that for those without a knee-ankle-foot orthosis for all standing conditions. [Conclusion] A knee-ankle-foot orthosis may be a useful assistive device to support static standing balance for people with subacute stroke.
Key words: Stroke, Knee-ankle-foot orthosis, Static standing balance

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INTRODUCTION

The most common and widely recognized impairment caused by stroke is motor impairment[1]. Motor impairments after stroke, as represented by muscle weakness or spasticity, can cause abnormal gait patterns that are characterized by drop foot, knee collapse, or genu recurvatum during stance. To treat abnormal gait patterns or stance, lower-limb orthoses are provided shortly after stroke onset, and rehabilitation using lower-limb orthoses for standing and walking is performed[2]. To ensure that evidence-based clinical decisions are made, it is important to investigate the best type of lower-limb orthoses, optimal time to prescribe orthoses, duration of use, adverse effects, and factors that can influence the acceptability and adherence to their short- and long-term use[3].

Using an ankle-foot orthosis (AFO) on people with stroke who have drop foot or equinovarus foot during walking is recommended in several stroke guidelines[4–6]. To stabilize the foot and ankle while weight-bearing and lifting the toes while stepping, an AFO is used[3]. The use of an AFO immediately improves walking abilities, such as walking independence[7], walking speed[8], endurance[9], step length[10], and standing balance[11]. Furthermore, long-term use of an AFO improves walking speed[12].

Conversely, a knee-ankle-foot orthosis (KAFO) is usually provided only to people with severe motor impairment[2, 13]

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when bracing with an AFO is insufficient to adequately control knee instability[14, 15]. A KAFO controls knee instability while weight bearing and is used to enable people with severe stroke to stand and walk early after stroke onset. However, to our knowledge, there are no reports on the effectiveness of a KAFO for standing balance in people with stroke. One of the purposes for using a KAFO is to immediately improve standing balance. Standing movements are frequently required in activities of daily living (ADL), such as transferring, walking, and toilet use and therefore improving standing balance is important. As a result, it is important to confirm whether using a KAFO improves standing balance. Lower limb orthoses are used to compensate for stability in paretic lower limb in clinical settings[2], and an AFO immediately improved standing balance of people with stroke who had mild disabilities[16–18]. Similar to the influence AFO has on standing balance[16–18], we hypothesized that the use of a KAFO improves static standing balance of people with stroke who have severe disabilities by compensating for the lack of stability in a paretic lower limb. The purpose of this study was to evaluate the early effects of a KAFO on static standing balance in people with subacute stroke.

PARTICIPANTS AND METHODS

A within-participants repeated measures experimental design was adopted. This study was approved by the Ethics Committee of Kyorin University (28–4) and Hatsudai Rehabilitation Hospital (H27-85).

The study participants were 29 inpatients with subacute stroke (mean age 66.3 ± 13.9 years, mean post-stroke interval at admission 26.8 ± 10.5 days) and at a rehabilitation hospital (Table 1). The inclusion criteria were (1) first-ever stroke, (2) post-stroke interval at admission within 60 days, (3) out of lower limb orthoses, a KAFO was provided for the first time after stroke onset to evaluate early effects of a KAFO, and (4) the ability to follow simple verbal commands or instructions. This study excluded people with a stroke due to other intracranial diseases, such as subarachnoid hemorrhage and traumatic brain injury. All of the participants provided written informed consent.

The demographic and clinical characteristics of the participants were recorded within 1 week before receiving a KAFO (Table 1). Demographic characteristics such as age, gender, stroke type, lesion side, and period of time from stroke onset to admission or KAFO provision were investigated. As clinical characteristics, the severity of motor paralysis of a paretic lower limb and the knee extension strength of a non-paretic lower limb were assessed by physical therapists. The severity of motor paralysis of a paretic lower limb was evaluated using the Brunnstrom recovery stage (BRS)[19, 20]. The BRS was scored on a 6-level Likert-type scale (stage I to VI) where a higher stage represented better motor function. The knee extension strength of a non-paretic lower limb was evaluated using quadriceps MMT item of the Stroke Impairment Assessment Set (SIAS)[21], which uses a rating from 0 (severely impaired) to 3 (normal).

All participants were provided with a KAFO after admission for the first time. A doctor, physical therapist, and prosthetist evaluated whether to provide an inpatient with a KAFO early after admission. A KAFO was provided on the basis of the results of an evaluation of standing and walking performance with or without the use of lower-limb orthoses. A KAFO was provided when (1) the patient was able to undergo standing or walking training but the knee and ankle joints were unstable due to severe motor impairments; (2) the patient exhibited spasticity patterns predominantly in the flexor muscles and could not keep a knee extension position while standing or walking; and (3) the patient displayed insufficient knee control or knee instability and an AFO was insufficient to adequately control knee instability[22]. All participants were given a traditional KAFO equipped with bilateral metal struts that could be used as an AFO by removing the portions for the knee joint and thigh. The suppliers of the traditional KAFO were Kawamura Gishi Co., Ltd., Osaka, Japan, or MEDX. Co., Ltd., Tokyo, Japan.

For static standing balance, 4 standing conditions were measured, with and without a KAFO, on paretic lower limbs. The standing conditions were (a) feet shoulder-width apart with eyes open, (b) feet shoulder-width apart with eyes closed, (c) feet together with eyes open, and (d) a tandem stance in which participants stood with paretic foot directly in front of non-paretic

Table 1. Participants characteristics

Age, yrs	66.3 ± 13.9
Gender, male/female, n	15/14
Stroke type, hemorrhage/infarction, n	12/17
Affected side, R/L, n	14/15
Periods from stroke onset to admission, d	26.8 ± 10.5
Periods from stroke onset to KAFO prescription, d	35.5 ± 14.3
Brunnstrom recovery stage of paretic lower limb, II/III/IV, n	16/10/3
Quadriceps MMT item of SIAS, 2/3, n	10/19
Type of KAFO, 1/2, n	27/2

KAFO: knee-ankle-foot orthosis; SIAS: Stroke Impairment Assessment Set. Type of KAFO; 1: KAFO with SPEX knee joint and Klenzak ankle joint, 2: KAFO with ring lock knee joint and Klenzak ankle joint.

foot, with the toes of the rear foot contacting the heel of the front foot, with eyes open. The participant's performance in these standing positions was quantified (refer to the protocol described in the previous study[23)]). The participants were instructed to stand as long as possible during each condition and a stopwatch was used to measure the standing time in each condition. The time ended when the participant needed physical assistance for postural support, moved a foot to maintain balance, opened their eyes on an eyes closed condition, or a maximum of 60 s in the condition had elapsed. The first test was measured without a KAFO and the second test was measured with a KAFO. These tests were performed on the same day within one week after providing a KAFO. All participants wore shoes on non-paretic lower limbs in tests with a KAFO, and they performed barefoot in tests without a KAFO. The KAFOs used in this study were those provided to the participants after admission.

In each standing condition, the participants were divided into two groups, on the basis of the results of testing without a KAFO, that is, participants who were unable to stand without a KAFO and participants who were able to stand without a KAFO. In the group of participants who were unable to stand without a KAFO, a χ^2 test was conducted to compare the proportion of participants who were able to stand between with and without a KAFO in each standing condition. In the group of participants who were able to stand without a KAFO, a Shapiro-Wilk test was conducted to assess the normality of the time distribution observed in those with and without a KAFO, in each standing condition. Then, comparable analysis to examine the differences of amounts of time participants could stand between with and without a KAFO in each condition was conducted. The statistical significance level was set at 0.05, and all analyses were conducted using IBM SPSS version 23.0 (IBM Corp., Chicago, IL, USA).

RESULTS

According to the results of testing without a KAFO, the number of participants who were unable to stand and the number of participants who were able to stand were 15 and 14 in standing conditions (a) feet apart with eyes open and (b) feet apart with eyes closed, 17 and 12 in standing condition (c) feet together with eyes open, and 20 and 9 in standing condition (d) tandem stance with eyes open, respectively.

In the group of participants who were unable to stand without a KAFO, the χ^2 test showed that the proportion of participants who were able to stand with a KAFO was significantly increased in standing conditions (a) feet apart with eyes open and (b) feet apart with eyes closed (Table 2). In the participants who were able to stand with a KAFO in each standing condition, the mean amount of time for standing condition (a) feet apart with eyes open with a KAFO was 43.3 ± 23.9 s, standing condition (b) feet apart with eyes closed with a KAFO was 22.9 ± 25.4 s, standing condition (c) feet together with eyes open with a KAFO was 32.1 ± 25.7 s, and standing condition (d) tandem stance with eyes open with a KAFO was 0.7 ± 0.4 s.

In the group of participants who were able to stand without a KAFO, the Shapiro-Wilk test showed that all data did not significantly follow a normal distribution. The Wilcoxon rank-sum test showed that the mean amount of time participants could stand with a KAFO was significantly longer than without a KAFO in standing conditions (a) feet apart with eyes open (57.4 ± 9.6 s vs. 42.0 ± 24.1 s, p=0.046, amount of change 15.4 ± 26.3 s), (b) feet apart with eyes closed (53.0 ± 18.0 s vs. 30.1 ± 27.1 s, p=0.017, amount of change 22.9 ± 27.0 s), (c) feet together with eyes open (55.6 ± 15.2 s vs. 31.6 ± 27.5 s, p=0.018, amount of change 24.1 ± 27.1 s), and (d) tandem stance with eyes open (18.3 ± 17.4 s vs. 6.8 ± 6.2 s, p=0.028, amount of change 11.4 ± 14.1 s) (Fig. 1).

DISCUSSION

To evaluate the early effect of a KAFO on static standing balance in people with subacute stroke, the amount of time the study participant could stand with and without a KAFO, in several standing conditions, was measured along with standing performance. This study revealed two important findings that are a KAFO increased standing ability in each standing condi-

Table 2. Comparisons of the proportion of participants who were able to stand between with and without a KAFO in 4 standing conditions in the group of participants who were unable to stand without a KAFO

		Condition (a) feet apart with eyes open		Condition (b) feet apart with eyes closed		Condition (c) feet together with eyes open		Condition (d) tandem stance with eyes open	
		Unable to stand	Able to stand	Unable to stand	Able to stand	Unable to stand	Able to stand	Unable to stand	Able to stand
Without a KAFO	n (%)	15 (100.0)	0 (0.0)	15 (100.0)	0 (0.0)	17 (100.0)	0 (0.0)	20 (100.0)	0 (0.0)
	Ajusted residual	3.586	−3.586	3.022	−3.022	1.814	−1.814	1.451	−1.451
With a KAFO	n (%)	6 (40.0)	9 (60.0)	8 (53.3)	7 (46.7)	14 (82.4)	3 (17.6)	18 (90.0)	2 (10.0)
	Ajusted residual	−3.586	3.586	−3.022	3.022	−1.814	1.814	−1.451	1.451
		$p<0.001$, $X^2 = 12.857$		$p=0.003$, $X^2 = 9.130$		$p=0.070$, $X^2 = 3.290$		$p=0.147$, $X^2=2.105$	

KAFO: knee-ankle-foot orthosis.

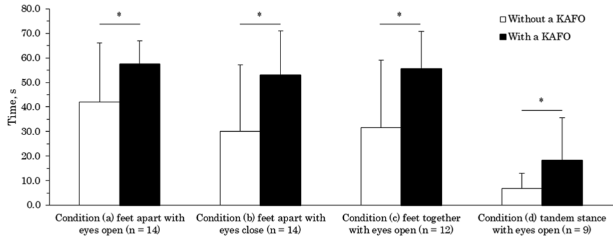

Fig. 1. Changes in the length of time to keep standing posture with or without a KAFO in 4 standing conditions in the group of participants who were able to stand without a KAFO.
*$p<0.05$, KAFO: knee-ankle-foot orthosis.

tion in participants who were unable to stand without a KAFO and a KAFO enabled longer standing time in participants who were able to stand without a KAFO. Our results support the hypothesis that a KAFO can improve static standing balance. To our knowledge, this is the first study that has demonstrated an early effect of a KAFO on static standing balance for people with subacute stroke.

Postural support requires the ability to load stance limbs without collapsing, and external supports are recommended to prevent knee collapse[24]. Previous systematic reviews reported that KAFOs are used when the mechanical control of a knee joint is required for weight-bearing[14, 25, 26]. AFOs are often used in a similar manner to KAFOs, and previous research on the effects of AFOs on standing balance have suggested that wearing AFOs to stabilize the ankle joint improved weight bearing on paretic lower limbs and decreased body sway in static standing[16–18]. Wearing AFOs also improved balance confidence[27] and evidence suggests enhanced peripheral somatosensory input, primarily from the feet[18, 28]. Therefore, we assumed that a KAFO might also improve not only the stability of paretic lower limbs but also the sensory feedback, balance confidence, and static standing balance in people with subacute stroke who had severe motor paralysis. Thus, a KAFO may contribute to the stability of paretic lower limbs and posture.

In the participants who were able to stand without a KAFO, a KAFO provided better stability in all standing conditions, whereas in participants who were unable to stand without a KAFO, the effect was not significant in either the feet together or tandem stance condition. Static standing in a narrow stance might be difficult for participants who were unable to stand without a KAFO. These results suggest that a KAFO might be effective in providing postural stability in easier standing conditions. It was implied that an early effect of a KAFO on static standing balance may be apparent, and people can handle the support of a KAFO more effectively for their stable balance in simpler and easier standing tasks.

Activity while standing is frequently required in ADL. Therefore, improving standing balance impaired by stroke is one of the main objectives of stroke rehabilitation[29]. In terms of motor learning, repetitive standing practice may be recommended to improve balance[30]. Increasing physical activity may also be an important factor to promote improvements in post-stroke disability. Furthermore, to perform standing exercises early after stroke onset, is important to prevent or minimize secondary changes of the musculoskeletal and cardiorespiratory systems by immobility[31]. However, many people with severe stroke require maximum physical assistance to perform standing and often have fewer opportunities to perform standing activities in daily living and rehabilitation. Furthermore, people with stroke develop an inactive lifestyle at several stages of post stroke[32, 33], and people with severe stroke typically spend much of their time in bed and are dependent on a wheelchair when out of bed. Intervening to increase physical activity while standing in people with severe stroke has not been fully examined. In this study, wearing a KAFO improved static standing balance and this result indicates that a KAFO can decrease the amount of physical assistance required to stand. A KAFO can be used in many places and by not only physical therapists but also other medical staff and caregivers. Thus, using a KAFO can create an opportunity to more frequently perform standing and other physical activities while standing for people with severe stroke. Further research is needed to investigate the use of a KAFO to increase physical activity while standing, improve static and dynamic standing balance, and walking. It is also essential to gain a better understanding of whether the effects of a KAFO on standing balance and walking translate into activity in hospital or home settings. The study population comprised a relatively small sample of people with subacute stroke, and our results cannot be generalized to post-stroke individuals or people using other types of KAFOs.

A KAFO improved static standing balance in people with subacute stroke. The early effects of a KAFO were apparent in relatively easy standing tasks in study participants who were unable to stand without a KAFO. In addition, a KAFO contributed to postural stability in 4 standing conditions in participants who were able to stand without a KAFO. These results suggest that a KAFO can be a useful assistive device to support static standing balance for people with subacute stroke.

Conflict of interest

None.

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