



Original Article

## The effect of newly designed multi joint ankle foot orthosis on the gait and dynamic balance of stroke patients with foot drop

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**Abstract.** [Purpose] The purpose of this study is to investigate the effect of the newly designed multi joint ankle-foot orthosis on the gait and dynamic balance of stroke patients having foot drop. [Subjects and Methods] This study was conducted with 15 subjects who were diagnosed with stroke. 10-meter walk test, functional reaching test and timed up and go test were measured after each subjects wore a plastic ankle-foot orthosis and a multi joint ankle-foot orthosis that consists of orthosis joints (having free joint, anterior-stop joint, poster-stop joint, and Klenzak joint functions). In the case of the newly developed multi joint ankle-foot orthosis, the experiments were performed using posterior-stop joint and Klenzak joint. [Results] 10-meter walk test, functional reaching test and timed up and go test showed significant differences in the orthosis using posterior joint-stop function and Klenzak joint function. [Conclusion] The appropriate use of the four functions of the newly designed multi joint ankle-foot orthosis is expected to have a positive effect on improving the gait and balancing ability of stroke patients having foot drop.

**Key words:** Multi joint ankle foot orthosis, Stroke, Gait

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### INTRODUCTION

Many stroke patients have abnormal gait due to paralysis, limb muscle weakness, spasticity, and sensorimotor control<sup>1)</sup>. Equino-varus foot is the most common cause of stroke patients' abnormal gait. Equino-varus foot which is commonly seen in these patients, shift the weight support of the heel to the lateral-plantar surface of the paralyzed foot and causes incomplete weight support<sup>2)</sup>. This gait disturbance causes compensatory motion patterns, slows gait speed, and limits functional movements. In severe cases, the risk of falling increases<sup>3-5)</sup>. Therefore, many stroke patients wear an ankle foot orthosis (AFO), which facilitates better walking, to correct Equino-varus foot deformity<sup>6)</sup>. An AFO is also used to improve standing position and control motions<sup>7)</sup>. In many cases, it is used to improve gait by correcting the deformed foot and ankle alignment<sup>7)</sup>. In particular, it supports the dorsiflexion of the ankle during the swing phase of the paralyzed lower limb of stroke patients. It is also known to increase the stability of the knee during the early stance phase involving foot drop<sup>8)</sup>.

In addition, use of an AFO reduces energy consumption while walking<sup>9)</sup>. Many previous studies have been published on these effects of AFO. However, the effect of this intervention is still unclear. Simons et al.<sup>10)</sup> demonstrated that there were significant differences in the 10-meter walk test and the majority of functional tests (Berg balance test, timed up and go test) between the stroke patient group wearing AFO on their paralyzed feet and the non-AFO wearing group. On the other hand, Lewallen et al.<sup>11)</sup> reported that there were no significant differences in the spatiotemporal gait analysis between the two groups.

However, the existing AFO has some disadvantages. It sometimes limits the movement of the ankle completely, causes contractures, goes against aesthetic sensibilities, and is very inconvenient to wear by oneself<sup>8, 12)</sup>.

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Therefore, the purpose of this study is to investigate the effect of the newly designed multi joint AFO (MJ AFO) on the gait and dynamic balance of stroke patients having foot drop.

## SUBJECTS AND METHODS

Fifteen subjects were recruited and all subject met the inclusion criteria for study procedure. Subjects were recruited from D rehabilitation center, after providing informed, written consent. Written informed consent according to the ethical standards of the Declaration of Helsinki was provided by all subjects prior to participation, and all agree to participate in this study. Subjects include 9 males and 6 females; stroke types included 5 hemorrhagic and 10 infarction. The mean age of the subjects was  $58.53 \pm 5.70$  years, height was  $167.66 \pm 8.39$  cm, weight was  $64.80 \pm 10.75$  kg, MMSE-K score was  $26.66 \pm 0.81$  score and months since onset  $10.53 \pm 2.72$  months. The enrollment criteria applied were as follows: (1) Index stroke >6 months prior in women or men with foot drop (equino-varus deformity), (2) Brunnstrom's stage of motor recovery for the affected lower limb range of 3–5, (3) residual hemiparetic gait deficits, operationally defined as reduced stance phase in the paretic leg and ambulatory with or without any assistive device<sup>13</sup>, (4) ability to understand and follow simple verbal instructions, (5) independent gait ability to walk at least 15 m without assistance, (6) no disability in visual, auditory, and vestibular organs, (7) no history of orthopedic diseases, such as contracture, fracture, or arthritis in lower limbs, and (8) a Mini-Mental State Examination score greater than 24/30<sup>14</sup>.

Exclusion criteria were as follows: (1) neurological problems other than stroke that would interfere with gait and balance control, (2) pain, limited motion, or weakness in the non-paretic lower extremity that affected performance of daily activities (by self-report).

The newly designed multi joint AFO consists of orthosis joints (having free joint, anterior-stop joint, poster-stop joint, and Klenzak joint functions) and a rehabilitation assistant device including a sensing system for gait training (Fig. 1).

10-meter walk test (10 MWT), functional reaching test (FRT) and timed up and go test (TUG) were measured after each subjects wore a plastic AFO and a multi joint AFO. In the case of the newly developed multi joint AFO, the experiments were performed using posterior-stop joint and Klenzak joint. All measurements were taken three times by two physical therapists, and their mean values were used. All measurements were expressed as mean  $\pm$  SD.

Statistical analysis was performed using SPSS (SPSS Inc. Released 2009. PASW Statistics for Windows, Version 18.0. Chicago: SPSS Inc.). General characteristics were analyzed using descriptive statistics and results are reported as means and standard deviations. Comparisons of variables before and after the intervention were made using the paired t-test. The statistical significance level was set at  $\alpha=0.05$ .

## RESULTS

10 MWT, FRT, and TUG showed significant differences in the orthosis using posterior joint-stop function (Table 1). These tests also showed significant differences in the orthosis using Klenzak joint function (Table 2).

## DISCUSSION

This study was carried out to evaluate the effect of the newly designed multi joint AFO on the gait and dynamic balance of stroke patients with foot drop resulting from Equino-varus foot deformity. The multi joint AFO significantly improved the gait and balancing ability of stroke patients with foot drop, thereby supporting the hypothesis of this study that this orthosis would reduce foot drop in stroke patients and improve their gait.

When the posterior joint-stop function, among the four functions of the multi joint AFO was set up, their gait and balance were significantly improved in the 10 MWT, FTR, and TUG.

Chang et al.<sup>15</sup> reported that posterior joint-stop function of the AFO increased stroke patients' static balance, and Park et al.<sup>16</sup> demonstrated that it improved stroke patients' gait speed and stride length.

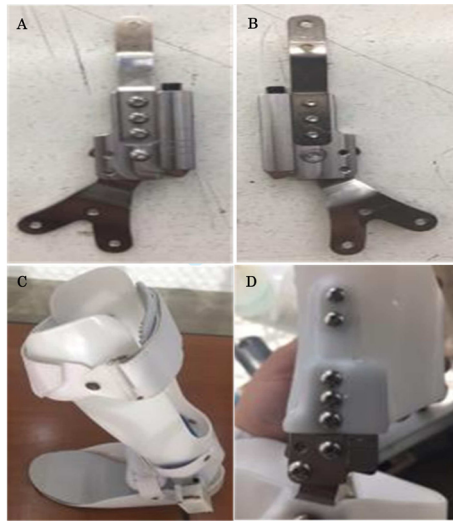
The posterior joint-stop prevents the excessive flexion of the knee during the early stance phase by preventing excessive limit in plantar flexion. In this study, the mechanical changes in the hip and knee joints, which resulted from preventing the excessive limit in plantar flexion, may have caused significant differences in the measured values.

When the Klenzak joint function among the four functions of the multi joint AFO was set up, the patients' gait and balance improved significantly in the 10 MWT, FRT, and TUG compared to those wearing the plastic AFO.

The Klenzak joint function helps dorsiflexion by spring action. In this study, significant differences in the measured values may have resulted from the decrease in the foot drop and heel-strike while walking by the spring-induced dorsiflexion of the ankle<sup>17</sup>.

Therefore, the appropriate use of the four functions of the newly designed multi joint AFO for circumventing the drawbacks of the traditional plastic AFO (which excessively limits the movement of the foot) is expected to have a positive effect on improving the gait and balancing ability of stroke patients having foot drop due to Equino-varus foot deformity.

The presents study has some limitation. First, the small sample size may have influenced certain variables and impacted on the results. Therefore, these results cannot be generalized to all stroke patients.



**Fig. 1.** Multi joint AFO  
 A: anterior view of multi joint, B: posterior view of multi joint, C: side view of multi joint AFO, D: joint part of multi joint AFO

**Table 1.** Comparison of the timed up and go test, 10-meter walk test and functional reaching test among the two condition (n=15)

	Mean $\pm$ SD		Change (95%CI)
	AFO	MJ-AFO (posterior joint stop)	
TUG (s)	35.15 $\pm$ 21.14	33.02 $\pm$ 21.11*	2.13 $\pm$ 1.23 (1.4558 to 2.8202)
10 MWT (s)	24.80 $\pm$ 13.82	20.92 $\pm$ 11.70*	3.87 $\pm$ 3.09 (2.1616 to 5.5930)
FRT (cm)	21.80 $\pm$ 3.72	24.60 $\pm$ 3.79*	-2.80 $\pm$ 1.32 (-3.5310 to -2.0689)

\*p<0.01 significance difference in compared to AFO

AFO: Ankle foot orthosis; MJ-AFO: Multi joint ankle foot orthosis; TUG: Timed up and go test; 10 MWT: 10-meter walk test; FRT: Functional reaching test

**Table 2.** Comparison of the timed up and go test, 10-meter walk test and functional reaching test among the two condition (n=15)

	Mean $\pm$ SD		Change (95%CI)
	AFO	MJ-AFO (Klenzak joint)	
TUG (s)	35.15 $\pm$ 21.14	30.86 $\pm$ 20.58*	4.29 $\pm$ 1.65 (3.3806 to 5.2153)
10 MWT (s)	24.80 $\pm$ 13.82	18.59 $\pm$ 9.93*	6.21 $\pm$ 5.05 (3.4107 to 9.0145)
FRT (cm)	21.80 $\pm$ 3.72	25.06 $\pm$ 3.91*	-3.26 $\pm$ 1.16 (-3.9106 to -2.6226)

\*p<0.01 significance difference in compared to AFO

AFO: Ankle foot orthosis; MJ-AFO: Multi joint ankle foot orthosis; TUG: Time up and go test; 10 MWT: 10-meter walk test; FRT: Functional reaching test

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