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Research Article

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Effects of an Elastic AFO on the Walking Patterns of Foot-drop Patients with Stroke

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| Abstract |

PURPOSE: Many patients with stroke have difficulties in walking with foot-drop. Various types of ankle-foot orthoses (AFOs) have been developed, but their weight needs to be reduced with the assistance of the ankle dorsiflexor. Therefore, an elastic AFO (E-AFO) was devised that not only improves the stability and flexibility of the ankle but also assists with ankle dorsiflexion while walking. This study examined the effects of an E-AFO, on the walking patterns of foot-drop patients with stroke.

METHODS: Fourteen patients walked with and without an E-AFO, and the gait parameters were assessed using the GAITRite system. The spatiotemporal data on the gait patterns of stroke patients with foot-drop were compared using paired t-tests; the level of statistical significance was set to $\alpha < .05$.

RESULTS: No significant differences were observed in the velocity ($p = .066$) and affecte+d step length ($p = .980$), but the affected and less-affected stance ($p = .022$, $p = .002$) and swing time ($p = .012$, $p = .005$) were significantly different. The E-AFO produced a significant difference in the less-affected step length ($p = .032$).

CONCLUSION: The E-AFO has a significant effect on the walking patterns of individuals with foot-drop and stroke. The E-AFO could be a useful assistive device for gait training in stroke patients.

Key Words: Ankle foot orthosis, Drop-foot, Gait, Hemiplegia, Stroke

Ⅰ. Introduction

The incidence of stroke among the general population is relatively high, and the performance of the activities of daily living is limited in stroke patients because of the sensory, motor, and cognitive deficits [1]. One of the most common sensorimotor problems is impaired gait, and many patients in the early stages of stroke cannot walk [2]. Individuals with stroke experience difficulty in walking because of the insufficient muscular strength, and spasticity that affects joint motion [3-7]. Stroke patients with sensory deficits show impaired proprioception; as the foot contacts the floor, the hip, knee, ankle, and foot position are not recognized in the normal way [8].

Foot-drop usually occurs because the muscles that lift the foot are weakened by the neural system impairment

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[9]. Once patients realize that they cannot move their bodies safely, they may attempt to compensate for the loss of motor control by hyperextending the knee or striking the ground with force [10]. Gait compensatory modification occurs instantaneously when sensory deficits and muscle weakness coincide. To correct this, the visual system must be recruited to identify the site of paralysis in the affected limb [8,10].

An ankle-foot orthosis (AFO) is a device used to improve gait in stroke patients. The AFO improves the motion of the subtalar joint, while also providing anterior–posterior and medial–lateral stability [11]. Currently, several types of AFOs made from various materials are available. Despite this, AFOs cause discomfort and fatigue in the lower extremities owing to abnormal muscle activity [12,13]. Moreover, they limit ankle joint movement, which further hinders muscle activity [14,15]. Some clinicians also suspect that AFOs do not help patients relearning how to walk because of the altered kinematics and clonus that occur with AFO use [16].

In this study, an AFO was devised using an elastic loop (elastic AFO; E-AFO) that not only improves the stability and flexibility of the ankle but also assists with ankle dorsiflexion while walking. This study investigated the effects of the E-AFO on the walking patterns of foot-drop patients with stroke, as well as its usefulness as a gait-training tool in clinical settings.

Ⅱ. Methods

1. Participants

Fourteen stroke patients with foot-drop from I and J Hospital in Busan, South Korea volunteered to participate in this study. Among the 14 participants (10 males and four females), six had right hemiplegia, and eight had left hemiplegia. The sample size was similar to that reported in previous studies [17,18]. The inclusion criteria were as follows: (a) diagnosis of hemiplegia due to hemorrhagic or ischemic stroke; (b) more than six months elapsed since the stroke; (c) ability to follow simple instructions; and (d) ability to walk independently or using assistive devices [19]. The exclusion criteria were (a) medical problems other than a neurological lesion that affected the gait patterns, (b) bilateral limb involvement [19], (c) score > 2 on the modified Ashworth scale, and (d) premorbid or current orthopedic problems related to the feet [19]. All participants provided informed consent prior to the study, which is in keeping with the requirements of the Human Ethics Committee of Hoseo University Faculty (1041231-170810-HR-060-02). Table 1 lists the general characteristics of the subjects. Fig. 1 presents a flowchart of the study.

Table 1. Subjects' Characteristics

Variables	Mean (SD)	N
Age (years)	63.50 (10.11)	
Weight (kg)	64.01 (9.49)	
Height (cm)	162.02 (6.74)	
Onset (months)	36.28 (28.68)	
Gender (male/female)		10/4
Stage of recovery (chronic)		14
Etiology of stroke (ischemic/hemorrhagic)		11/3
Side of hemiparesis (left/right)		8/6
None/Monocane/Short brace		11/2/1

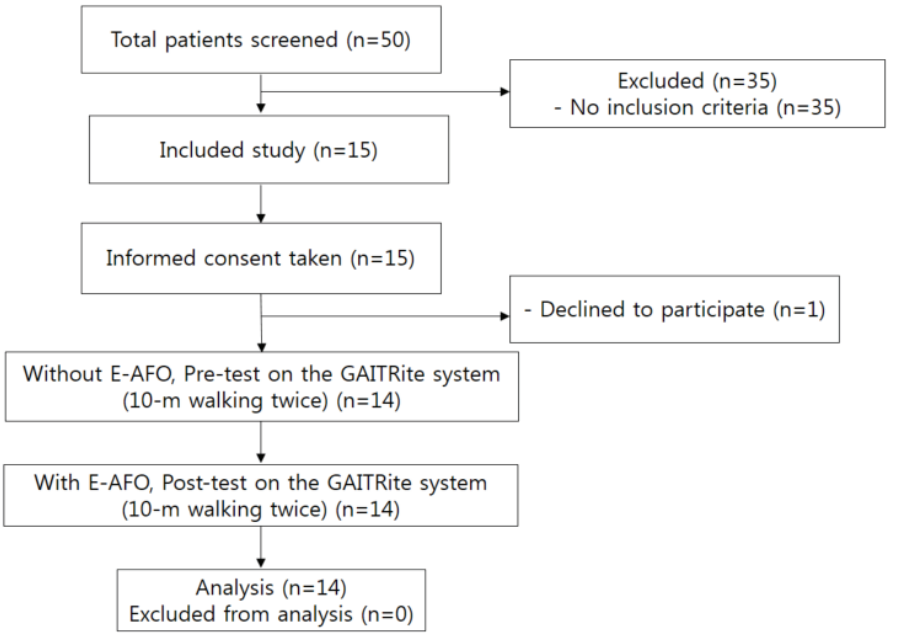

Fig. 1. Study flowchart.

2. Measurement

1) GAITRite System

The GAITRite System (CIR Systems, Easton, PA, USA) was used to analyze the spatiotemporal gait parameters, such as the gait velocity, cadence, stance time, swing time, stride length, and step length. This system collects information on the spatiotemporal variables using an 8.3 × 0.89-m electronic gait mat, in which 13,824 1-cm-diameter sensors are arranged vertically at 1.27cm intervals. A 3.66 × 0.61-m area in the center of the gait mat is the designated "active area," in which the sensors measure the pressure. As the participant walks on the gait mat, the machine measures the loads imposed by the feet at a sampling rate of 80Hz and sends the information to the computer through a serial interface cable. The validity of the device showed an excellent level of agreement with intraclass correlation coefficients (ICCs) between .92 and .99 [20]. In addition, the inter-rater reliability was also excellent for the step length, step, and stance time (ICC ≥ .94; lower limit confidence intervals (95% Cis) ≥ .86) [21].

2) Elastic Ankle-Foot-Orthosis

The Elastic Ankle-Foot-Orthosis (E-AFO) was composed of a fabric belt, two Velcro straps, two hooks, and an elastic loop. The outer elements of the E-AFO included an elastic loop (Fig. 2a), two hooks (Fig. 2b-1, 2), a Velcro strap (strap 1; Fig. 2c), and an elastic support (Fig. 2d) attached to the back of a fabric belt (Fig. 2e). The fabric belt is a belt made of woven paper, which is 40 ~ 60cm long and 10 ~ 20cm wide. The length and tension of the elastic loop (approximately 5 ~ 10cm in width) are controlled using the two hooks. The elastic loop uses the silver level of the elastic band (amplitude of elastic bands: black > silver > blue > green > red > yellow). The elastic loop tension was applied, and the ROM of ankle dorsiflexion appeared to be at least 0° when the patient lifted their leg while wearing it.

The elasticity could be adjusted for each patient to

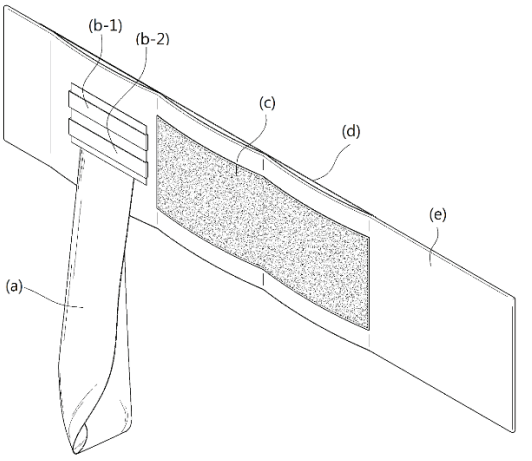

Fig. 2. Outer elements of the elastic ankle-foot orthosis (E-AFO) device.
(a) Elastic loop; (b-1, 2) Hooks 1 and 2; (c) Velcro strap 1; and (d) Elastic support attached to the back of (e) The fabric belt.

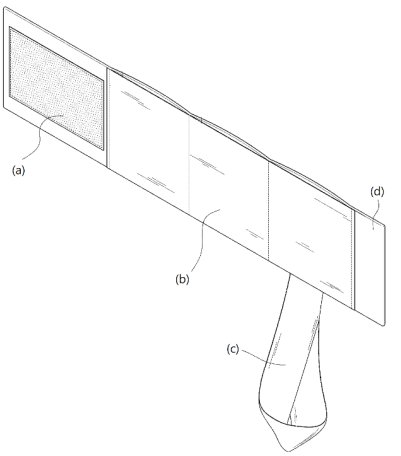

Fig. 3. Reverse side of the E-AFO device.
(a) Velcro strap 2, (b) Elastic support, (c) Elastic loop, (d) Fabric belt.

provide the appropriate assistance for ankle dorsiflexion (Fig. 3). The E-AFO was worn with the inner elastic band behind the calf and the loop in the front (Fig. 3). The E-AFO enabled flexible movement of the ankle while preventing foot-drop by assisting with ankle dorsiflexion, but it still allowed for normal contact of the heel with the ground while walking.

The inner part of the E-AFO was comprised of a Velcro strap (strap 2; Fig. 2a) and elastic support (Fig. 2b) attached to the fabric belt (Fig. 2d). The elastic support can be approximately two-thirds the length of the fabric belt. The belt was wrapped around the calf bearing the weight of the paralyzed foot. The elastic support (Fig. 2b), which was attached to the inner side of the fabric belt, was divided

Table 2. Gait Parameters with and Without the E-AFO

	Without E-AFO	With E-AFO	t	p
Velocity (cm/s)	32.60 ± 15.50	36.94 ± 21.56	-2.006	.066
Affected limb Stance Time (s)	1.37 ± .79	1.24 ± .67	2.607	.022*
Less-affected Limb Stance Time (s)	1.59 ± .90	1.43 ± .77	3.748	.002*
Affected Limb Swing Time (s)	1.92 ± .87	1.77 ± .77	2.923	.012*
Less-affected Limb Swing Time (s)	1.93 ± .88	1.78 ± .76	3.375	.005*
Affected Limb Step Length (cm)	29.09 ± 9.15	29.05 ± 11.92	.025	.980
Less-affected Limb Step Length (cm)	24.95 ± 8.31	27.27 ± 10.24	-2.402	.032*

into three parts, and their total length was slightly less than that of the fabric belt. When a patient wore the E-AFO, the elastic support (Fig. 2b) surrounding the calf stretched, increasing the elasticity of the part that was in contact with the skin. At the same time, the attachment to strap 2 (Fig. 2a) ensured that the elastic loop (Fig. 2c) maintained the force for lifting the paralyzed foot (Fig. 3).

3) Procedure

The participants were asked to walk on the gait mat twice during each test, the first twice while wearing the E-AFO on the affected limb and the last twice without it. A 5-min rest was allowed after walking under each condition. The patient was seated in a chair near the GAITRite System, and the walking mat was adjusted to a distance of 1 m from the patient. The participants were allowed to walk approximately 1~2 m to gain control of their movements and adjust to the E-AFO; the short distance walked minimized the learning effects. The investigator demonstrated the process of walking on the mat before each participant was allowed to walk on the mat. The averages of the parameters on each test were assessed. The reason for the repeated measurements with and without E-AFO was to investigate the immediate effects of wearing the E-AFO on the walking pattern of the foot-drop patients while minimizing any learning effects.

4) Data Analysis

A Shapiro-Wilk test was used for the normality test, and the normality of data was satisfied ($\alpha > .05$). Therefore, spatiotemporal data on the gait patterns of stroke patients with and without the E-AFO were compared using paired t-tests, and analyzed using SPSS for Windows software (ver. 20.0; SPSS Inc., Chicago, IL, USA). The level of statistical significance was set to $\alpha < .05$.

Ⅲ. Results

When patients walked with the E-AFO, their walking velocity tended to increase as weak evidence compared to walking without the E-AFO ($p = .066$). On the other hand, the E-AFO improved the stance time of the affected and less-affected limbs significantly ($p = .022$ and $p = .002$, respectively), compared to that without the E-AFO (Table 2, Fig. 4). The affected and less-affected limb swing times were also reduced significantly compared to that without the E-AFO ($p = .012$, $p = .005$, respectively) (Table 2, Fig. 4). Although there were no significant differences in the affected limb step length ($p = .980$), the step length of the less-affected limb differed strongly between walking with and without the E-AFO ($p = .032$) (Table 2, Fig. 5).

Ⅳ. Discussion

The E-AFO was designed to address the disadvantages

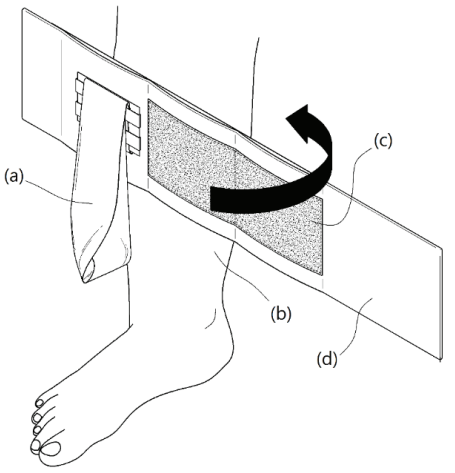

Fig. 4. Schematic diagram of the E-AFO device being worn.
(a) Elastic loop, (b) Lower leg, (c) Velcro strap 1, (d) Fabric belt.

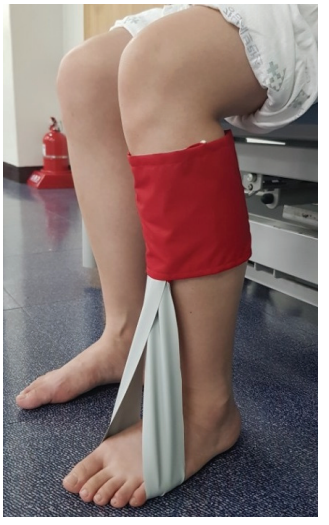

Fig. 5. Patient`s Application of the E-AFO.

of the conventional AFOs, which cause discomfort, limit ankle joint movement and active motion, and constitute a relatively heavy load for paralyzed limbs. The E-AFO, however, provides medial-lateral ankle stability via elastic tension, minimizing the limitation to ankle motion and reducing the weight added to the patient's lower limb. Furthermore, the device is designed to prevent foot-drop by simultaneously assisting with ankle dorsiflexion via the elastic band, while minimizing any interruption in sensory input arising from the foot. Therefore, the E-AFO, when used for gait training in stroke patients with foot-drop, provides medial-lateral stability in the swing phase, and tactile sensory input from the foot, to improve the patient's body scheme [22] and facilitate an effective gait pattern.

These results showed a trend toward increased walking velocity when wearing the E-AFO, even though the difference from the velocity without wearing the E-AFO was weak evidence. Some researchers reported no significant changes in the walking velocity using AFOs [5,23], but in other studies reported that the walking velocity increased when an AFO was worn [24-27]. One study used an AFO with an elastic band similar to that in the current study and reported a significant increase in velocity [23] [19]. Some authors suggested that increased speed using an AFO is caused by the preservation of the first rocker at the initial contact and enhanced weight acceptance [28]. On the other hand, Perry and Burnfield suggested that the gait speed decreased because of delayed weight transfer [10]. Therefore, owing to the difference in materials between the standard plastic AFO and the present E-AFO, the present device could provide sufficient tension to preserve the first rocker, confer medial-lateral stability, and enhance weight acceptance.

The use of the present E-AFO decreased sharply the stance and swing times of both limbs, which tended to increase the walking velocity, as well as the step length in the less-affected limb. Nolan and Yarossi also reported a significant decrease in both affected and less-affected limb swing times, as well as the stance time of the less-affected limb [28] when an AFO was worn. Another study showed that the step length when wearing a solid AFO, which mainly provides ankle stability, was significantly shorter in both lower limbs than that with an articulated AFO or a posterior-leaf spring AFO [29].

This suggests that the AFO, which mainly addresses stability, can decrease the step length. Tyson and Thornton reported significant differences in the stride length, in both the affected and less-affected limbs, using a hinged AFO, which also suggests a tendency for such devices to change the gait patterns [30].

On the other hand, Abe et al. reported that the plastic AFO increased the gait stability, thereby increasing the step length for both limbs [27]. In their study, however, the participants used two types of AFO, namely a hinged AFO and a shoehorn brace, which demonstrated the dual effects of ankle mobility and stability. This suggests that the E-AFO could improve the ankle flexibility and stability in the affected limb, thereby increasing the step length of the less-affected limb further. In addition, minimizing any interruption in tactile sensory input arising from the foot might help improve the body scheme [22]. Based on the very strong decrease in stance time and swing time in the present study, it was concluded that the treatment of foot-drop could play an important role in improving the walking pattern of stroke patients. On the other hand, the E-AFO could not provide sufficient medio-lateral stability to increase the walking velocity and step length of the less-affected side based on research using an elastic band as an assistive device [19].

This study had some limitations. First, it included a small sample, which was also limited to stroke patients only. Nevertheless, it appears that the use of the E-AFO by patients with chronic stroke has clinical benefit. Second, no other AFOs were evaluated. In future studies, it will be necessary to investigate whether the E-AFO can be applied to patients with a spinal cord injury, multiple sclerosis, peroneus nervous palsy, and other conditions, as well as to compare the gait patterns associated with use of the E-AFO versus other types of AFO. This could help improve the E-AFO design and clinical applicability. In addition, this study did not measure the kinematic data and weight-bearing ratios of the less-affected and affected sides when wearing the E-AFO. In the future, however, it would be necessary to assess these variables according to the gait phase using 3D motion analysis and a force plate.

Ⅴ. Conclusion

The E-AFO showed a tendency to increase the gait velocity and could decrease the stance and swing time of both limbs strongly and effectively, particularly the less-affected limb. Although it could not be effective in improving the step length of the affected limb, it could strongly increase the less-affected step length. This study demonstrated that E-AFO could be a useful assistive device for gait training in stroke patients.

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