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The effects of a short ankle-foot orthosis on gait in patients with post-stroke hemiplegia

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Abstract

Objective: We evaluated the effects of a short ankle-foot orthosis (AFO) in patients with post-stroke hemiplegia by comparing its effectiveness to that of a conventional solid plastic AFO. The calf shells of the long and short AFOs were manufactured in lengths that extended proximally 2.5 cm distal to the fibular head and mid-calf level, respectively. *Methods:* Ten patients with chronic hemiparetic stroke were recruited for the study. Two types of AFOs, short and long, were used, both of which were individually molded and fitted. AFO preference was evaluated using a questionnaire regarding AFO weight, ease of donning and doffing, stability, and comfort. AFO effectiveness was evaluated using gait analysis. *Results:* The short AFO improved gait speed, stride length, and toe clearance as effectively as the long AFO. Additionally, we found that the short AFO had additional merits in terms of its lighter weight and ease of donning and doffing.
Conclusion: The short AFO is a useful treatment option, especially in patients who dislike the heaviness of conventional AFOs or who have difficulty donning and doffing conventional AFOs.

Keywords: Ankle foot orthosis; hemiparesis; chronic stroke; gait analysis

INTRODUCTION

One of major goals of stroke rehabilitation is the restoration of walking ability.[1] Walking is a major component of human mobility and independent walking ability strongly influences activities ranging from those needed for daily living to participation in social activities.[2] Stroke survivors exhibit gait abnormalities due to motor weakness and motor control deficit that results from muscle tone disorder, ataxia, agnosia, and perceptual disorders.[3] Gait characteristics in stroke patients include slow speed, poorly coordinated movements, foot dragging due to weak dorsiflexion of the ankle and extensor spasticity of the leg, circumduction of the leg, pelvic tilting, and hip hiking, as well as a steppage gait to compensate for foot dragging.[4]

In addition to reducing the risk of falling in stroke patients, ankle foot orthoses (AFOs) can modify abnormal gait patterns and restore a safer gait.[5,6] AFOs correct gait abnormalities by supporting dorsiflexion of the ankle and restricting plantar flexion and inversion. AFOs prevents drop foot, improve mediolateral stability of the ankle in the stance phase, and promote heel strike.[7,8] From a kinetics perspective, AFOs can enhance gait speed, cadence, and single and double step length, as well as reduce the energy cost of walking.[9,10] Therefore, in stroke patients, the AFO is the most common orthosis prescribed. Of the various types of AFOs, solid plastic AFOs have commonly been used in recent decades because they are relatively lightweight, adjustable, and flexible.[11] The calf shell of a typical plastic AFO extends proximally 2-4 cm distal to the fibular head on the posterior part of the leg. However, in clinical practice, some patients dislike this type of AFO due to its discomfort, heaviness, and the inconvenience of donning and doffing it. We hypothesized that an AFO with a shorter calf shell length might reduce these problems to some degree, but may result in less stability than a conventional solid plastic AFO.

In the current study, we applied a short AFO with a calf shell extended to the mid-calf level to hemiparetic stroke patients with post-stroke hemiplegia, and investigated the effects of the short AFO in comparison with a conventional solid plastic AFO in terms of efficacy and preference.

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METHODS

Subjects

The ten subjects included in this study were hemiplegic patients who could walk independently with canes and who were admitted to the Department of Rehabilitation Medicine at our hospital. The selection criteria included: (1) diagnosis of unilateral hemiparesis caused by cerebral vascular disease; (2) exhibition of hemiparesis at the time of evaluation; (3) less than fair muscle strength of the ankle; (4) the ability to walk without an AFO for a distance of at least 10 m without physical assistance; and (5) no severe somatosensory problems, apraxia, or cognitive problems. The exclusion criteria included: (1) history of significant orthopedic problems related to the foot; (2) history of having worn an AFO prior to the study; and (3) severe ankle plantar flexor spasticity (above grade 1 on the modified Ashworth scale[12,13]). The local research ethics committee of our hospital approved the study protocol. Written informed consent was obtained from each subject prior to participation.

Procedure

All subjects completed gait cycles, defined as walking back and forth one time between two points located 7 m apart, under various AFO conditions. Three-dimensional gait analysis for each subject was performed using a motion analysis system (Motion Analysis Corporation, Santa Rosa, CA). This system included six Eagle infrared cameras, two force plates (Advanced Mechanical Technology, Watertown, MA), an Eagle-Hub (100 Mbps), and a personal computer. Gait was measured while each subject walked with a conventional solid plastic AFO (long AFO), a short solid plastic AFO (short AFO), and while barefoot. Subjects rested for 5 minutes between tests.

All subjects were initially assessed and measured by the same orthotist for their custom-molded polypropylene AFOs. AFOs, which were individually molded and fitted, were made in two different calf lengths and were constructed from 4 mm thick polypropylene with a 90° plantar flexion stop, free dorsiflexion, and a metatarsal head-length foot plate (Figure 1). The calf shells of the long and short AFOs were manufactured in lengths that extended proximally 2.5 cm distal to the fibular head and mid-calf level, respectively. Prior to measuring gait performance, subjects were given a short period of time to familiarize themselves with their new AFOs. Gait speed was set at a comfortable level for each subject. To reduce measurement errors during the gait

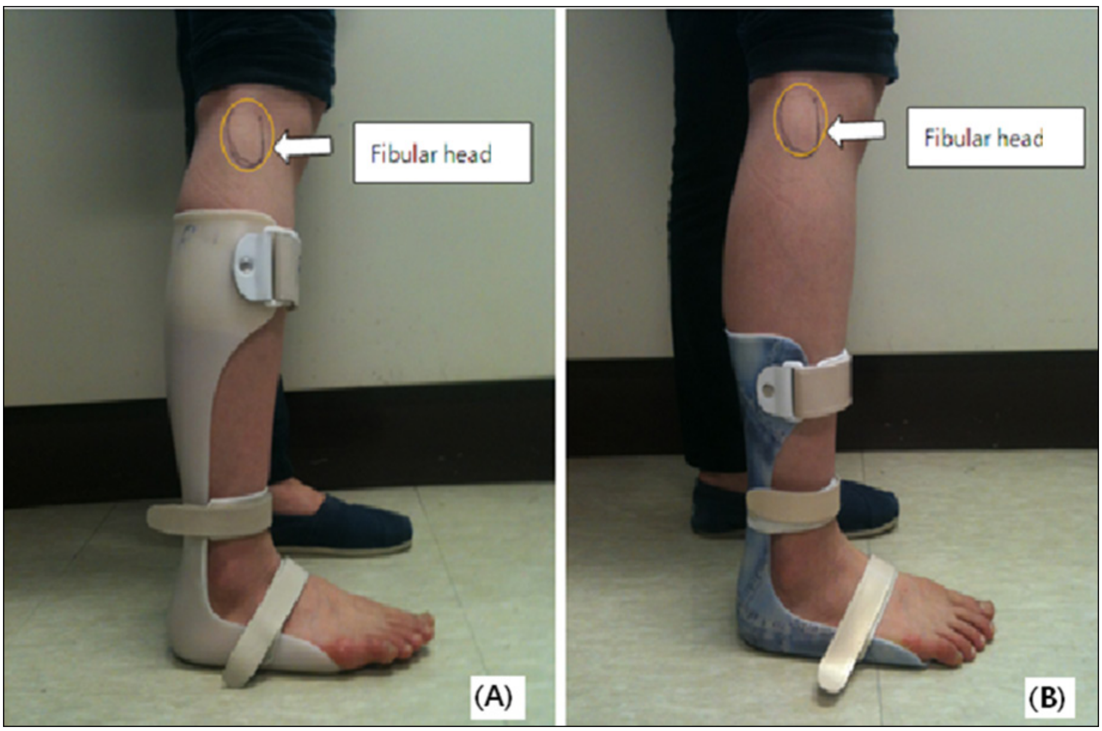

Figure 1. Photograph of (A) long and (B) short ankle foot orthoses.

analysis, we calculated the mean of three repeated measurements. The spatiotemporal parameters included gait speed, stride length, and single and double support time. Additionally, ankle, knee, and hip joint kinematic parameters were assessed. In order to determine the kinematic parameters, 19 specific markers were placed bilaterally on the second web spaces of the feet, on the heels and medial and lateral malleoli (or medial and lateral orthotic ankle joints), anteriorly on the shanks and thighs, and on the medial and lateral femoral epicondyles. Markers were also placed on the anterior superior iliac spine and sacrum.

After gait analysis, the patients were asked to complete a questionnaire on AFO preference in terms of weight, ease of donning and doffing, stability, and comfort.

Statistical analysis

All statistical analyses were performed using SPSS version 17.0 for Windows (SPSS Inc., Chicago, IL). The Kruskal-Wallis test was used for comparing mean data from the gait analysis among the three different test conditions. When the result of the Kruskal-Wallis test was significant ($p < 0.05$), a Mann-Whitney U test with a Bonferroni correction (significance level, $p < 0.017$) was used to evaluate which test conditions were significantly different from one another.

RESULTS

A total of 10 subjects, including 3 individuals with right hemiplegia and 7 with left hemiplegia, were enrolled. Subject demographic information is summarized in Table 1.

The spatiotemporal results of the gait analysis are presented in Table 2. Gait speed and stride length were significantly greater with the long or short AFO than in the barefoot test (Mann-Whitney U test, gait speed: $p < 0.001$; stride length: $p < 0.001$). However, there was no significant difference in the spatiotemporal results of gait analysis between the long and short AFOs (Mann-Whitney U test, gait speed: $p = 0.631$; stride length: $p = 0.481$). The test times for the single support and double support were not significantly different between long or short AFO and barefoot walking (Kruskal-Wallis test, single support time: $p = 0.297$; double support time: $p = 0.204$).

The kinematic results from the gait analysis showed that the peak ankle dorsiflexion angle during the swing phase when subjects walked with the long or short AFO was significantly greater than with barefoot walking (Mann-Whitney U test, $p < 0.001$) (Table 2). However, no significant differences were observed between the long and short AFOs (Mann-Whitney U test, $p = 0.280$). The peak knee flexion angle during the standing phase was significantly greater with the long or short AFO than with barefoot walking (Mann-Whitney U test, $p < 0.001$). However, no significant differences were observed between the long and short AFOs (Mann-Whitney U test, $p = 0.481$). For the parameters other than peak ankle dorsiflexion during the swing phase and peak knee flexion angle during the standing phase, there were no significant differences between the three different test conditions (Kruskal-Wallis test, peak knee extension angle during stance phase: $p = 0.120$; peak hip flexion angle during stance

Table 1: Patient characteristics

Subject	Sex	Age	Days from	Affected onset	Stroke type hemisphere
1	F	46	65	Lt	Ischemic
2	M	45	20	Lt	Ischemic
3	M	17	109	Lt	Ischemic
4	M	37	37	Rt	Hemorrhagic
5	F	53	47	Rt	Hemorrhagic
6	F	59	38	Rt	Ischemic
7	M	35	14	Rt	Ischemic
8	F	25	271	Rt	Ischemic
9	M	22	215	Rt	Ischemic
10	M	64	29	Rt	Ischemic

Lt, left; Rt, right.

Table 2: Spatiotemporal and kinematic test results

	Barefoot	Long AFO	Short AFO
Gait speed, cm/sec	32.48±10.10	**38.83±10.34**	**39.38±10.80**
Stride length, cm	59.08±10.98	**66.28±11.88**	**65.91±11.02**
Single support, % cycle	22.91±7.82	24.14±8.01	25.89±8.12
Double support, % cycle	39.27±9.87	38.10±8.56	40.14±9.14
Peak ankle dorsiflexion angle during swing phase	-13.69±5.80	**2.38±7.00**	**3.21±7.04**
Peak knee flexion angle during stance phase	16.86±5.76	**20.76±6.98**	**22.90±7.82**
Peak knee extension angle during stance phase	-8.21±6.47	-5.58±5.59	-7.07±5.78
Peak hip flexion angle during stance phase	23.83±4.36	26.93±5.73	26.55±6.47
Peak hip extension angle during stance phase	-1.34±5.30	0.24±6.40	-3.11±7.25

Values are presented as mean ± standard deviation. Bold values are significantly different from the mean of the barefoot results (Mann-Whitney U test, $p < 0.017$).

phase: p = 0.134; peak hip extension angle during stance phase: p = 0.120).

The subjects were asked to choose the AFO that they felt was: 1) the most lightweight; 2) easiest to don and doff; 3) the most stable; and 4) the most comfortable. The subjects' responses are shown in Table 3. All subjects felt that the short AFO was lighter than the long AFO. Although 4 of 10 patients reported that the ease of donning and doffing was similar between the two types of AFO, 5 patients indicated that the short AFO was easier to don and doff and only 1 patient indicated that the long AFO was easier to don and doff. Additionally, whereas 6 subjects reported no AFO preference in terms of gait stability, 4 subjects preferred the long AFO in regards to stability, and none preferred the short AFO to the long AFO. There was a similar preference for the two AFOs in terms of comfort.

DISCUSSION

Using gait analysis, this study evaluated the effects of a short solid plastic AFO with a mid-calf shell length on gait in hemiparetic stroke patients by comparing its effectiveness with that of barefoot walking and the longer solid plastic AFO conventionally used in clinical practice. Additionally, we assessed subject preference for the different AFOs using a questionnaire.

In terms of the gait analysis parameters, the long and short AFOs were better for gait speed, stride length, and peak ankle dorsiflexion angle during the swing phase than barefoot walking, though the parameters were not different between the two types of AFOs. These results indicate that the short AFO was as effective as the long AFO in terms of improving gait speed and stabilization. Increased ankle dorsiflexion angle during the swing phase improves toe clearance, which reduces foot dragging and leads to an increase in stride length. These results are consistent with the results of several previous studies on the effects of AFOs.[3,9,14-16] In the current study, we found that the short AFO had positive effects on gait in hemiparetic stroke patients that were comparable to those found with conventional AFOs.

In our study, we used AFOs with a plantar stop at 90 degrees. In stroke patients, the dorsiflexors cannot activate to permit the foot to make contact with the ground, so the ground reactive force remains posterior to the knee after the heel strike, which induces a knee flexion moment at the knee.[11] In our subjects, an increased peak knee flexion

Table 3: Weight, ease of donning and doffing, stability, and comfort preference between the long and short ankle foot orthoses (AFOs)

	Long AFO	Short AFO	No preference
Lightness	0	10	0
Don and doff	1	5	4
Stability	4	0	6
Comfort	4	4	2

angle was observed during the stance phase with both the short and long AFOs compared with barefoot walking.

With regard to preference, the subjects indicated that the short AFO was lighter than the long AFO and was easier to don and doff. However, the long AFO was superior to the short AFO in terms of stability. Consequently, in hemiparetic stroke patients who place a high level of importance on the lightness and ease of donning and doffing, the short AFO might be better than the long AFO.

In conclusion, the short AFO, which had a mid-calf level length calf-shell, may be useful for improving gait performance in hemiparetic stroke patients. The short AFO improved gait speed, stride length, and toe clearance as effectively as the long AFO. In addition, we found that the short AFO had additional merits in terms of its lighter weight and ease of donning and doffing. Therefore, the short AFO may be a useful option, especially for patients who dislike the heaviness of a conventional AFO or who have difficulties donning and doffing a conventional AFO. However, our study had some limitations. First, our study had a small sample size. Second, we only evaluated the effect of the AFOs immediately after the subjects wore the AFO, and did not continue to examine the effects on gait after continuous wearing of the AFO. Third, we recruited only patients with mild or no ankle plantar flexor spasticity (modified Ashworth scale ≤ 1). Therefore, our results indicating that the effects of a short AFO are similar to that of a long AFO in hemiparetic stroke patients cannot be extrapolated to patients with moderate to severe spasticity. Future studies that examine these limitations are warranted.

DISCLOSURE

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Conflict of interest: None

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