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Original Article

Effects of Dynamic Ankle-Foot Orthosis on Postural Balance Control in Hemiparetic Patients

Hong Min Kim, M.D., Min Ho Chun, M.D., Chung Reen Kim, M.D.[1], Ji Young Park, M.D.[2]

Department of Rehabilitation Medicine, Asan Medical Center, University of Ulsan College of Medicine, Seoul 138-736, Department of Rehabilitation Medicine, [1]Eonyang Hospital, Ulsan 689-812, [2]Philip Hospital, Seoul 138-170, Korea

Objective To determine the effects of dynamic ankle foot orthosis (AFO) on balance control by comparing it with conventional plastic AFO and barefoot conditions in hemiparetic patients.

Method Fifteen hemiparetic patients with brain lesions were recruited for this study. All subjects were capable of standing up independently and had a modified Ashworth score of less than two. The postural control capabilities of the subjects were assessed using the timed up and go (TUG) test, and Tetrax® tetra-ataxiametric posturography. The stability index, weight distribution index, and synchronization index were measured at six different head positions with dynamic AFO, conventional AFO and under barefoot conditions.

Results There were nine males and six females, whose average age was 45.1 years. There was a significantly even weight distribution for the dynamic AFO and conventional AFO conditions relative to the barefoot condition in neutral, right-sided head, and left-sided head with eyes closed ($p<0.05$). And there was significantly increased stability in left sided-head, neck flexed positions with eyes closed for dynamic AFO and conventional AFO ($p<0.05$). However, there was no significant difference in weight distribution or stability between dynamic and conventional AFO conditions, except the stability in right-sided head position with eyes closed.

Conclusion In this study, the balance control of hemiparetic patients with dynamic AFO was better than in the barefoot condition, and was similar to conventional AFO. Therefore, we suggest that dynamic AFO may be a useful orthosis for hemiparetic patients with mild to moderate spasticity with poor balance control and foot drop.

Key Words Balance, Hemiplegia, Ankle foot orthosis

INTRODUCTION

Hemiparetic patients, such as stroke patients, have an increased risk of falls.[1,2] According to Nyberg and Gustafson, most falls occur while patients are changing their position, and, so, balance is very important in order for stroke patients to keep optimal stability.[2]

For patients with hemiparesis due to stroke or brain tumor who have weak ankle dorsiflexion, the Ankle-Foot Orthosis (AFO) has been used to help them to walk safely and efficiently.[3,4] However, there are almost no studies on the effect of the AFO on hemiparetic patients' posture stability. Previous studies on AFO effects on the body sway of stroke patients reported that the center of pressure moved from the normal position to the center when patients wore the AFO, and other

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Corresponding author: Min Ho Chun
Department of Rehabilitation Medicine, Asan Medical Center, University of Ulsan College of Medicine, 388-1, Pungnap-2 dong, Songpa-gu, Seoul 138-736, Korea
Tel: +82-2-3010-3800, Fax: +82-2-3010-6964, E-mail: mhchun@amc.seoul.kr

studies have indicated that the AFO affected the symmetry of the lower limbs while the subject was in static and dynamic postures.[5,6]

The conventional plastic AFO has a fixed 90^{o} ankle and covers the leg from the fibular head to the whole sole or the metatarsal head. The problems with this conventional plastic AFO are that it is difficult for patients to wear the AFO consistently because it is uncomfortable, and patients cannot wear shoes because the AFO is thick in order to be stiff and covers half of the foot and calf.[7] Thus, though the AFO is needed, patients do not wear it consistently.[8]

In contrast, the dynamic AFO is smaller and easier to wear than the conventional one, and much research and development is continuing for various types of dynamic AFOs. In addition, it has been reported that the dynamic AFO is flexible for efficient walking and is preferred by patients.[9,10] However, because there are almost no studies examining if the dynamic AFO has a positive effect on hemiparetic patients' postural control to the same extent as the conventional plastic AFOs, this study set out to investigate the effect of the dynamic AFO on postural control by comparing it with the conventional plastic AFO.

MATERIALS AND METHODS

Subjects

Among hemiparetic patients transferred to the Department of Rehabilitation Medicine, those who needed an AFO due to weak dorsiflexion and who had a Modified Ashworth Scale (MAS) score of II or less were recruited for this study. The subjects had a lesion on the right or left cerebral hemisphere and were able to follow more than two instructions and stand up independently. Excluded were those who had severe ataxia due to a lesion in the cerebellum and brain stem, those who could not stand up for more than one minute due to postural hypotension, those who had weak lower limbs and severe hypoesthesia due to disorders in the peripheral nervous system, and those who had musculoskeletal problems that may lower their postural control capability. In addition, only those who agreed to participate in this study after listening to a sufficient explanation of the study were selected.

Methods

Before the experiment, all subjects' heights and weights were measured, and their postural control capability was assessed. In order to eliminate the carry-over effect and period effect due to the wearing order of the AFO, the subjects were randomly divided into two groups. In the first group, the subjects wore the conventional plastic AFO first and then the dynamic

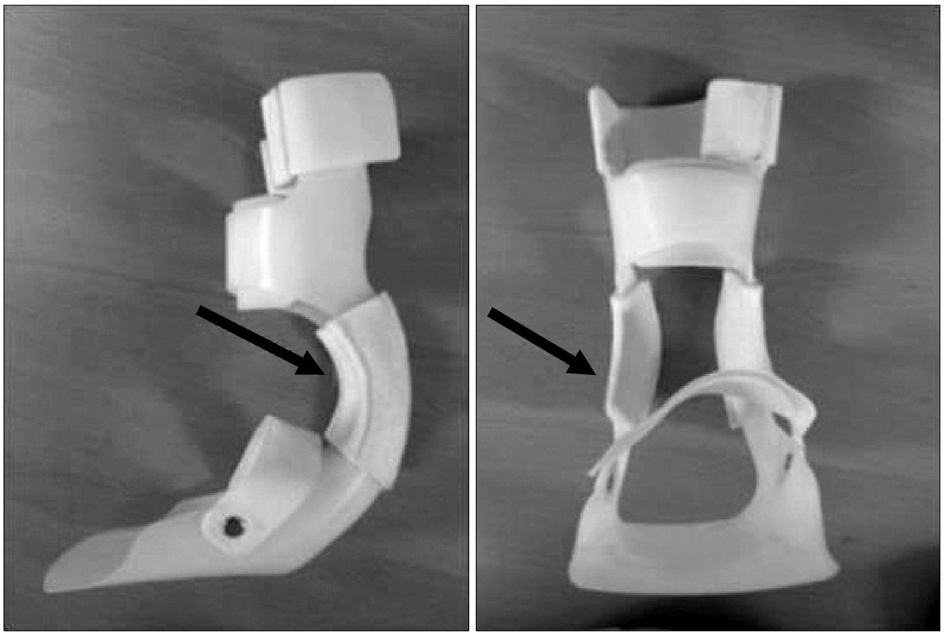

Fig. 1. Photographs of Dynamic AFO®. The arrows indicate elastic components of Dynamic AFO®.

one. The second group had a reverse wearing order. The postural control capability was assessed using the Timed Up and Go (TUG) test and Tetrax® posturography.

Ankle-Foot Orthosis (AFO): The conventional plastic AFO has a 90° fixed ankle, a calf shell up to 2 Finger Breaths (FB) below the fibular head, a foot shell covering the metatarsal head, three velcro closures and D-rings, and a thickness of 4.5 mm. Conventional AFOs were custom built for each subject.

Though the ankle is fixed at 90° in the dynamic AFO like the conventional one, the dynamic AFO has two ellipsis bars on both sides which make the dynamic AFO more flexible than the conventional one. It has two velcro closures, a calf shell up to the ankle, a foot shell covering the metatarsal head, and a thickness of 3 mm. The subject wore one of three prefabricated dynamic AFOs (Fig. 1).

Assessment method

1) TUG test: In order to assess the subjects' mobility and postural control, each subject sat on a general armchair and made themselves comfortable with their arms on the armrest. When a start signal was given, they stood up and walked 3 m at their normal pace, and then they returned to the armchair and sat down. The researcher timed how long it took for the subjects to stand up, walk, and sit down again. In general, this took less than 10 seconds. If it took more than 14 seconds, it was concluded that the subject had lost their postural control capability.

2) Postural control test with Tetrax®

(1) Assessment tool: Tetra-ataxiametric posturography (Tetrax®; Ramat Gan and Sunlight Medical Ltd., Tel-Aviv, Israel) consisted of four separate plates, which measured the vertical pressure of the toes and heels of both feet. The toe plate measured 12×19 cm (Width×Height), and the heel plate measured 12×12 cm (Width×Height). When the subject stood on the plates, the pressure data was amplified and filtered in order to be transferred to the computer and then the data was analyzed by Tetrax® software (Fig. 2).

(2) Assessment method: Assessment was conducted in a quiet and small room with little external stimulation. The subject stood on the plates barefoot and held the support bar. A total of eight postures were tested. For each posture, the test time was 32 seconds. In order to exclude data during the initial stabilization period, the subject was allowed to find a posture for 10 seconds. Without holding the support bar, the subject stood straight. The following tests were conducted: NO, which consisted of a test where the subject stood upright with eyes open; NC, which consisted of a test where the subject stood with eyes closed; HR, where the subject turned his/her head to the right with eyes closed; HL, where the subject turned his/her head to the left with eyes closed; HB, where the subject tilted his/her head back; and HF, where the subject lowered his/her head with eyes closed. After these tests, a flexible plate (31×12 cm) was placed under the subjects' feet in order to create an unstable environment. Then, tests were conducted for PO, where the subject stood upright with eyes open and PC, where the subject stood upright with eyes closed. If a subject moved his/her foot from the plate or could not hold a posture, the subject was tested again. When a subject closed their eyes or stood on the flexible plate, the researcher stood next to the subject in order to prevent the subject from falling.

(3) Assessment index: The stability index measured the agitation on the four plates in order to measure the overall stability and assess how well the subject could control and compensate for postural changes. The higher the stability index was, the more unstable the subject was.[11]

The weight distribution index indicated the weight distribution on the four plates, and its normal range

Fig. 2. Tetra-ataxiametric posturography (Tetrax®, Ramat Gan and Sunlight Medical Ltd., Tel-Aviv, Israel) using two paired force plates that measured vertical pressure fluctuations over both heels and forefeet.

was 4-6. The ideal posture was when 25% of the subjects' weight was placed on each plate. When a deviation from 25% was small, the index was closer to 0. If not, the index became bigger. If the weight distribution index was too high, the subject was thought to have a disorder. If it was too low, the subject was too stiff.

The synchronization index compared the vibration waves measured from two out of the four plates. A total of six combinations were possible. The index ranged from −1,000 to 1,000. A normal person has an index of 700 or higher. If the index was lower than 200, it meant that the subject had a lack of fine pedal postural control. If the index was negative, then two waves were in mirror-image synchronization, and a positive index indicated that the two waves were in parallel synchronization. A negative compensatory synchronization in the form of a mirror-image synchronization was observed between the toe and the heel, and a positive co-active synchronization in the same form was observed between the toes or between the heels.

Statistical methods

For statistical analyses, SPSS version 14.0 (SPSS, Inc., Chicago, IL, USA) was used. For the subjects without any AFO, with the conventional plastic AFO, or with the dynamic AFO on, their TUG time, stability index, weight distribution index, and synchronization index were analyzed. The significance between the two groups when subjects were not wearing any AFO was tested with a Mann-Whitney test. In addition, when the subjects wore the conventional AFO or dynamic one, their carryover effect and period effect caused by wearing order was tested with a Mann-Whitney test. For each posture, when the subjects did not wear a AFO, wore the conventional one, or wore the dynamic one, that data was analyzed with the Wilcoxon signed-rank test. In addition, in order to compare the subjects with the conventional AFO on and the subjects with the dynamic AFO on, the data was compared with the Mann-Whitney test. Differences were considered statistically significant with p-values < 0.05.

RESULTS

A total of 15 subjects (9 male, 6 female) participated in this study. Their average age was 45.7±20.1, and the period between onset of the hemiparesis and their assessment was 3.5±2.5 months. Eight of them had ischemic stroke, three had hemorrhagic stroke, and four had brain tumors. Ten of them were right-hemiparetic, and five were left-hemiparetic. For all of them, their dominant hand before the disorder was their right (Table 1).

TUG test results

For the subjects without any AFO on, their average time on the TUG test was 9.3 seconds, with the conventional AFO on, their average time was 9 seconds, and with the dynamic AFO on, their average time was 9.1 seconds. A carryover effect or period effect caused by the wearing order was not observed. No meaningful differences between no AFO, the conventional AFO, or the dynamic AFO were found. In addition, there was no meaningful difference between the conventional AFO and the dynamic one.

Test with Tetrax®

No AFO vs. Conventional plastic AFO: As for the stability index, in the HL and HF postures, the subjects with the conventional plastic AFO on were more stable. As for the weight distribution index, except in the NO posture, the subjects with the conventional plastic AFO on had more even weight distribution. As for the synchronization index, except in the HF posture, movement between the toe and the heel on the abnormal side was more synchronized when the subject wore the conventional plastic AFO. In addition, movement between the toe and the heel on the healthy side was more synchronized when the subjects were in the HR and HF postures. Although the two groups had no significant differences in the synchronization of movements

Table 1. General Characteristics of Subjects

Variables	Values
Age (years)	45.1±20.1
Duration since onset (months)	3.5±2.5
Brain lesion	
Ischemic stroke	8
Hemorrhagic stroke	3
Brain tumor	4
Affected side	
Right	10
Left	5
Dominant hand	
Right	15
Left	0

Values are means±standard deviation.

Table 2. Comparison of Posturographic Results between Barefoot and Conventional plastic AFO Conditions

		STI	WDI	S1	S2	S3	S4
NO	Z	−1.02	−1.81	−2.04*	−1.81	−1.02	−0.94
NC	Z	−0.63	−2.51*	−2.83	−1.89	−1.02	−2.67*
HR	Z	−1.57	−3.06*	−2.83*	−2.59*	−0.31	−2.67*
HL	Z	−2.20*	−2.83*	−2.83*	−0.39	−0.71	−0.71
HB	Z	−1.89	−3.07*	−2.83*	−1.81	−1.18	−3.07*
HF	Z	−2.99*	−2.53*	−0.94	−2.20*	−1.65	−0.16

NO: Neutral position with eyes open, NC: Neutral position with eyes closed, HR: Head to the right side with eyes closed, HL: Head to the left side with eyes closed, HB: Neck extended with eyes closed, HF: Neck flexed with eyes closed, STI: Stability index, WDI: Weight distribution index, S1: Synchronization index between hemiparetic toe and heel, S2: Synchronization index between non-hemiparetic toe and heel, S3: Synchronization index between both toes, S4: Synchronization index between both heels, Z: Test statistics by Wilcoxon signed-rank test
*p-value < 0.05 by Wilcoxon signed-rank test

Table 3. Comparison of Posturographic Results between Barefoot and Dynamic AFO Conditions

		STI	WDI	S1	S2	S3	S4
NO	Z	−0.0	−1.72	−0.94	−0.55	−0.71	−0.08
NC	Z	−0.87	−2.81*	−2.83*	−1.26	−1.57	−1.81
HR	Z	−1.02	−2.36*	−1.49	−1.02	−2.67*	−1.34
HL	Z	−2.28*	−2.36*	−2.36*	−0.71	−1.34	−0.08
HB	Z	−1.02	−1.73	−1.18	−0.16	−1.88	−1.89
HF	Z	−2.20*	−0.71	−2.75*	−0.86	−1.10	−1.02

NO: Neutral position with eyes open, NC: Neutral position with eyes closed, HR: Head to the right side with eyes closed, HL: Head to the left side with eyes closed, HB: Neck extended with eyes closed, HF: Neck flexed with eyes closed, STI: Stability index, WDI: Weight distribution index, S1: Synchronization index between hemiparetic toe and heel, S2: Synchronization index between non-hemiparetic toe and heel, S3: Synchronization index between both toes, S4: Synchronization index between both heels, Z: Test statistics by Wilcoxon signed-rank test
*p-value < 0.05 by Wilcoxon signed-rank test

between their heels, the movement between their toes was well synchronized when the subjects were in the NC, HR, and HB postures with the conventional plastic AFO on (Table 2).

No AFO vs. Dynamic AFO: As for the stability index, in the HL and HF postures, the subjects with the dynamic AFO on were more stable in a statistically significant way. As for the weight distribution index, in the NC, HR, and HL postures, the subjects with the dynamic AFO on had more even weight distribution. As for the synchronization index, movement between the toe and the heel on the abnormal side was more synchronized when the subjects were in the NC, HL, and HF postures with the dynamic AFO on. In addition, movement between the heels was more synchronized when the subjects were in the HF postures with the dynamic AFO on. However, the synchronization of the movement between the toe and the heel on the healthy side and the movement between toes had no significant difference (Table 3).

Conventional plastic AFO vs. Dynamic AFO: A carry-over effect or period effect caused by wearing order was not observed. As for the stability index, the conventional plastic AFO was more stable than the dynamic one only in the HR posture. As for the weight distribution index, there was no difference between the two groups. As for the synchronization index, the synchronization of movement between the toe and heel on the abnormal side was more synchronized when the subjects were in the HL posture with the dynamic AFO on. Synchronization of movement between the toe and heel on the healthy side was more synchronized when the subjects were in the NC and HR posture with the dynamic AFO on. There was no difference between the

Table 4. Comparison of Posturographic Results between Conventional plastic AFO and Dynamic AFO Conditions

		WDI	STI	S1	S2	S3	S4
NO	P2	5.4±1.5	35.8±18.2	−598.8±426.4	−211.7±358.4	−106.2±393.9	338.0±315.3
	P3	5.6±1.7	37.4±18.3	−656.4±434.5	−264.0±404.3	−51.4±419.3	411.3±284.5
NC	P2	5.3±2.0	42.3±19.3	−779.4±241.0	−393.1±275.8	−103.4±256.9	412.3±219.2
	P3	5.7±1.9	44.9±18.8	−767.3±246.9	−422.8±309.0*	−12.4±268.4	477.1±224.3
HR	P2	6.0±1.8	40.0±13.7	−684.9±185.9	−412.5±423.1	−88.0±298.7	385.1±260.2
	P3	6.2±1.8	40.4±13.8*	−661.0±235.1	−453.7±452.2*	−17.1±385.9	462.6±298.0
HL	P2	6.7±1.9	42.7±17.1	−686.4±268.7	−278.6±392.6	−58.5±287.6	11.7±458.5
	P3	6.6±2.1	44.1±15.8	−702.8±280.0*	−250.8±426.4	15.1±288.4	114.9±508.4
HB	P2	6.5±3.4	48.5±10.8	−755.4±275.8	−336.0±388.8	−12.0±141.8	358.4±249.2
	P3	6.8±3.4	50.1±9.2	−740.4±281.0	−347.2±405.4	7.4±170.0	414.9±281.2
HF	P2	7.5±3.4	43.5±15.4	−489.9±335.0	−344.4±487.9	−155.2±228.3	101.0±451.4
	P3	7.5±3.4	44.0±15.3	−510.6±350.2	−331.0±510.4	−84.5±281.2	230.4±484.4

Values are means±standard deviation.
P2: Conventional plastic AFO condition, P3: Dynamic AFO condition, NO: Neutral position with eyes open, NC: Neutral position with eyes closed, HR: Head to the right side with eyes closed, HL: Head to the left side with eyes closed, HB: Neck extended with eyes closed, HF: Neck flexed with eyes closed, STI: Stability index, WDI: Weight distribution index, S1: Synchronization index between hemiparetic toe and heel, S2: Synchronization index between non-hemiparetic toe and heel, S3: Synchronization index between both toes, S4: Synchronization index between both heels
*p-value<0.05 by Mann-Whitney U test (cross-over study)

two groups regarding the synchronization of movement between the toes or between the heels (Table 4).

DISCUSSION

Improvement of hemiparetic patients' postural control capability is important in walking training.[12,13] In addition, postural control is related to falling, which is a risk factor in the rehabilitation of hemiparetic patients.[14] Thus, in order to improve hemiparetic patients' postural control capability, an AFO is applied to the injured ankle. Several studies have reported that an AFO had a positive influence on postural control capability and walking.[5,15] However, though the conventional plastic AFO is lighter and more convenient than the metal one, it is not used consistently because patients prefer it less.[8] Recently, in order to overcome this weak point, the anterior AFO and dynamic AFO were developed and applied to some hemiparetic patients.

Different from the conventional plastic AFO, the anterior AFO holds the ankle anteriorly. It is easy to wear and can be worn indoors.[16] According to a 2008 study of Chen et al.,[17] when hemiparetic stroke patients' postural control capability with the anterior AFO on was assessed with the SMART system (NeuroCom International, Inc., Clackamas, OR, USA), their postural control capability was significantly improved in a fixed posture regardless of visual compensation. However, in an unfixed posture, the effect was not significant. Because this study compared subjects with an AFO on and those without any AFO on, it was difficult to compare the anterior AFO with the conventional plastic one.

The dynamic AFO was designed to provide bounce. When the user stands up, the force is stored in the ankle. Then, when the user moves off his/her toes, the stored force is released in order to improve walking efficiency. In addition, the dynamic AFO controls the proximal lower limb. Bleyenheuft et al.[10] studied the effect of the dynamic AFO on hemiparetic patients' walking and reported that the walking speed and kinematic factor of the ankles were improved. Currently, various dynamic AFOs are used. However, their operating principles are similar. As for the dynamic AFO used in this study, its flexible side stores the force while standing up and releases the stored force when the toes are off the ground. In addition, compared to the conventional plastic AFO, it is light and easy to wear like the anterior AFO. The dynamic AFO is better than the conventional plastic one and the anterior one.

However, there are not many studies on the effect of the dynamic AFO on hemiparetic patients. In particular, there is no study on postural control capability. In addition, though the anterior AFO was studied previously, it was not compared with the conventional plastic AFO. This makes it difficult to assess the effect on the postural control capability accurately. Thus, in this study, the objective assessment tool, Tetrax®, was used to assess the effect of the dynamic AFO on postural control capability and compare it with the conventional plastic AFO. As a result, if was found that when the subjects wore the dynamic AFO, their postural control capability was improved compared to when they did not wear it. This was more vividly observed when there was no visual compensation. In addition, when the subjects wore the dynamic AFO, their postural control capability was improved compared to when they did not wear one and when they wore the conventional plastic AFO. In addition, the result was better if there was no visual compensation. Thus, it was found that the AFO was more effective in a situation with limited visual stimulation because visual stimulation plays an important role in postural control.

As for the limitations of this study, the number of subjects was small, and we cannot rule out the possibility that the result was affected by the fact that all subjects were right dominant, and ten of them had right hemiparesis. In addition, while the conventional plastic AFOs were tailored to each subject, prefabricated dynamic ones were applied to the subjects in this study. This may have affected the results.

CONCLUSION

In this study, when hemiparetic patients with mild to moderate spasticity wore the dynamic AFO, their postural control capability improved significantly compared to when they did not wear it. This result was similar when compared to the conventional plastic AFO.

Therefore, it is concluded that the dynamic AFO can be effectively applied to hemiparetic patients with mild to moderate spasticity.

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