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0894-9115/08/8710-0815/0
American Journal of Physical Medicine & Rehabilitation

DOI: 10.1097/PHM.0b013e31817c150e

ORIGINAL RESEARCH ARTICLE

Effects of an Anterior Ankle–Foot Orthosis on Postural Stability in Stroke Patients with Hemiplegia

ABSTRACT

Chen C-K, Hong W-H, Chu N-K, Lau Y-C, Lew HL, Tang SFT: Effects of an anterior ankle–foot orthosis on postural stability in stroke patients with hemiplegia. Am J Phys Med Rehabil 2008;87:815–820.

Objective: To evaluate the effects of an anterior leaflet ankle–foot orthosis (AFO) on postural stability in stroke patients with hemiplegia.

Design: Twenty-one stroke patients with hemiplegia resulting from new-onset stroke and ten normal subjects were included in this study. The SMART balance master system was used to assess the postural stability by measuring the ankle strategy, maximal stability, and velocity of center-of-gravity (COG) movement under the following six conditions: (1) eyes open and fixed support (EOFS), (2) eyes closed and fixed support (ECFS), (3) sway-referenced vision and fixed support (SVFS), (4) eyes open and sway-referenced support (EOSS), (5) eyes closed and sway-referenced support (ECSS), and (6) sway-referenced vision and support (SVSS). Each patient was tested with and without an anterior AFO as compared with normal subjects.

Results: When wearing an anterior AFO, patients used ankle strategy more than hip strategy to maintain postural stability in all the six sensory conditions ($P < 0.05$). An anterior AFO also provided stroke patients with better maximal stability under relatively challenging conditions such as SVFS, EOSS, and ECSS ($P < 0.05$), but the effect was not apparent in the conditions without external perturbation (EOFS and ECFS) and the most difficult condition (SVSS). The velocity of COG movement was lowered when wearing an anterior AFO in stroke patients, and significant differences existed in the EOFS, ECFS, ECSS, and SVSS conditions ($P < 0.05$).

Conclusions: In the early stage of recovery, the use of an anterior AFO may assist stroke patients with hemiplegia to improve their postural stability.

Key Words: Anterior Ankle–Foot Orthosis, Postural Stability, Stroke, Hemiplegia

Stroke patients are at a high risk for falling because of external environmental factors and also many intrinsic physical factors, such as postural imbalance, muscular weakness, and improper flexibility.[1–3] According to Nyberg and Gustafson,[4] most falls occur during activities in which they change position. Therefore, postural control is of ultimate importance for stroke patients to maintain optimal stability.

Ankle–foot orthoses (AFOs) have been widely used in stroke patients to assist in safe, energy-efficient walking.[5–8] However, very few studies have described the effects of AFOs on postural stability in hemiplegic patients. Mojica et al.[9] investigated the effect of an AFO on body sway in stroke patients. He found that the center of foot pressure shifted toward midposition when patients were wearing AFOs, whereas the center of pressure moved toward the nonaffected foot in patients who were not wearing AFOs. Wang et al.[10] have reported that AFOs improved stance symmetry in static and dynamic standing conditions. These studies used conventional posterior leaf plastic AFOs. Posterior AFOs, however, are not compatible for indoor barefoot walking, as is the custom in some Asian countries. In addition, patients often have to increase their shoe size to accommodate the AFO.

In our previous study, a low-temperature thermoplastic AFO had been designed in anterior leaf type.[11] Anterior AFOs are light, easy to use, and suitable for indoor barefoot walking.[11] An example is shown in Figure 1. Through gait analysis, some authors have shown that anterior AFOs are as effective as posterior AFOs for improving gait in patients with hemiplegia.[12] From the literature review, there is only one article regarding the influence of an anterior AFO on postural stability in stroke patients. Chen et al.[13] report that the effects of an anterior AFO in hemiplegic patients were on lateral weight shifting and weight bearing through the affected leg after weight had shifted to the affected side. Their study, however, did not prove the anterior AFO effects on postural stability under conditions with external perturbation in stroke patients. In this study, we used the SMART balance master system to analyze the effects of an anterior AFO on postural stability in new-onset (within 3 mos) stroke patients with hemiplegia under different perturbed conditions. The validity of this computerized dynamic posturography system has been well documented in previous studies.[14–15] We hypothesized that anterior AFOs may help stroke patients with hemiplegia improve their postural stability.

FIGURE 1 *Anterior ankle–foot orthosis (AFO).*

METHODS

Subjects

Subjects were recruited from a university-affiliated medical center. The inclusion criteria for the study group were as follows: (1) diagnosis of unilateral hemiplegia caused by either hemorrhagic or ischemic stroke, (2) first-ever stroke within the previous 3 mos, (3) ability to stand without external support for at least 60 secs, and (4) ability to follow simple verbal commands or instructions. Subjects were excluded if they had any of the following conditions: (1) neurological problems other than stroke that would interfere with balance control, (2) premorbid or comorbid orthopedic problems related to the foot, (3) uncorrectable visual impairment, and (4) experience of using an AFO before this stroke event. All patients underwent neuroimaging studies, including computed tomography and magnetic resonance imaging of the brain to confirm the diagnosis of stroke in the early stage. We also recruited normal subjects without any known neurological and orthopedic impairments to serve as the control group.

Local research ethics committee approved this study, and informed consent was obtained from all the subjects.

Equipment and Measurement

The SMART Balance Master (NeuroCom International, Inc., Clackamas, OR) was used to acquire postural stability measurements in this study.

Briefly, this device used two 9 × 18-inch forceplates with rotation capabilities to measure vertical and horizontal shear forces at different points on the platform on which the patient stands. There is a movable visual enclosure surrounding the subject on three sides. It provides objective assessment of the sensory and motor control balance with visual biofeedback on either a stable or unstable support surface, as well as in a stable or dynamic visual environment. There are several standard assessment protocols, of which we used a sensory organization test (SOT) as the test for postural stability.

The SOT protocol (Fig. 2) comprised six different conditions, including (1) eyes open and fixed support (EOFS), (2) eyes closed and fixed support (ECFS), (3) sway-referenced vision and fixed support (SVFS), (4) eyes open and sway-referenced support (EOSS), (5) eyes closed and sway-referenced support (ECSS), and (6) sway-referenced vision and support (SVSS). The six conditions were designed to be increasingly challenging on the sensory feedback system. A complete protocol consisted of three consecutive trials for each condition, and the average of three consecutive trials was used for the subsequent data analysis. The subject was informed of the conditions (eyes open or eyes closed; surrounding walls will move; platform floor will move) before the beginning of each trial.

The SOT measured sway while the subject stood on the platform for the six sequential conditions mentioned above. The measured parameters were (1) ankle strategy, (2) maximal stability, and (3) velocity of center-of-gravity (COG) movement. Ankle strategy was quantified as the relative amount of movement about the ankles and about the hips that the patient used to maintain postural stability during each trial. Normally, individuals move primarily about the ankle joints when the surface is stable, and they will shift to hip movements as they begin to lose balance. The greater the percentage of ankle strategy, the better the stability the patient has. Maximal stability is the indicator of COG stability. One hundred percent of maximal stability means the subject has remained in a stable stance position, and 0% means the subject has fallen. Velocity of COG movement is also a quantification of the stability control. The larger the COG velocity, the greater the likelihood that the subject has lost balance and is in the process of falling.

During data collection, the subject stood barefoot on the platform with the medial malleolus at

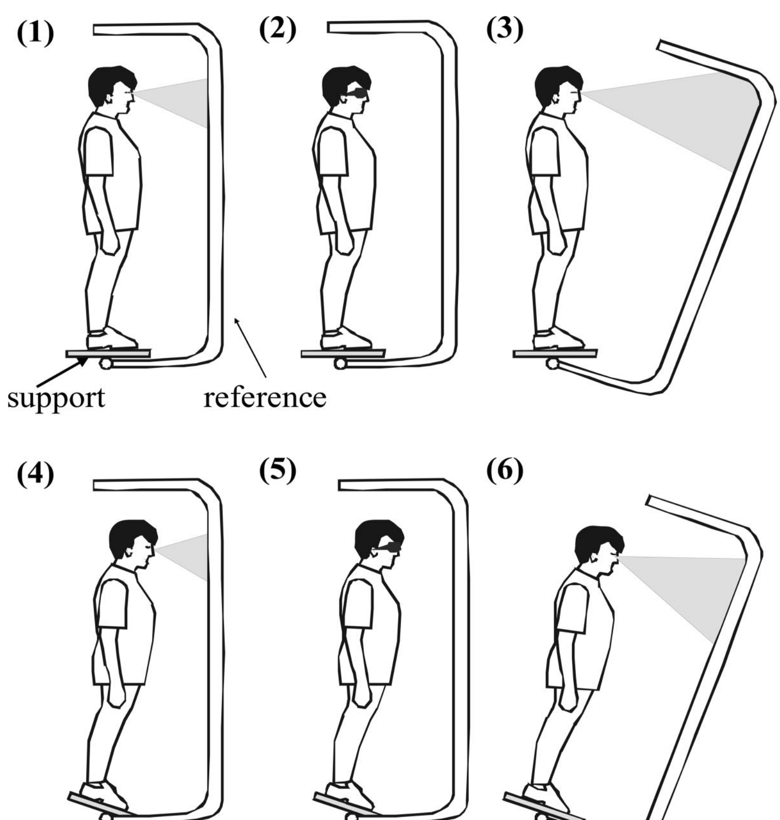

FIGURE 2 *Sensory organization test (SOT) included six sensory conditions: (1) eyes open and fixed support (EOFS), (2) eyes closed and fixed support (ECFS), (3) sway-referenced vision and fixed support (SVFS), (4) eyes open and sway-referenced support (EOSS), (5) eyes closed and sway-referenced support (ECSS), and (6) sway-referenced vision and support (SVSS).*

the rotation's axis, as indicated by a line on the forceplate. The feet were pointed slightly outward to provide each subject with a stable foot position. To prevent the subjects from falling down and injuring themselves, a harness was secured with straps to an overhead bar. The tests were performed both with and without an anterior AFO on the affected foot in stroke patients with hemiplegia and on a randomized foot (either right or left) in normal subjects. The testing sequence was randomized and completed within the same 1-hr session.

Data Analysis

Statistical analysis was performed using SPSS 10.0 (SPSS Inc., Chicago, IL). Differences in age, body height, and body weight between normal subjects and stroke patients with hemiplegia were compared using the Student's *t* test, and differences in gender distribution were determined with the Forward Exact test. Two-way analyses of variance (ANOVA) for repeated measures (two subject groups and AFO conditions) were used to examine the differences of groups and AFO conditions within postural stability variables. Paired *t* tests were used to compare test performance with an AFO against test performance without an AFO for each group. The level of significance was set at $P < 0.05$.

RESULTS

A total of 31 participants (21 stroke patients with hemiplegia resulting from new-onset stroke, 10 normal subjects) were recruited for this study. No significant difference was present regarding the gender, age, body height, and body weight between the study and control groups (Table 1).

Eleven of the 21 stroke patients had left hemiplegia, and 10 had right hemiplegia. Right-hemisphere lesion is assumed to be associated with visuospatial impairment theoretically. To test the influence of side of lesion on the postural stability measurement, we compared the SOT of 11 left-hemisphere stroke patients with that of 10 right-hemisphere stroke patients. The results showed no significant difference between these two groups. On the other hand, the determining factor for prescription of an AFO in stroke patients is the existence of ankle plantar flexion in the hemiplegic leg rather than on the side of hemiplegia. Therefore, we combined the left- and right-hemisphere stroke patients into one group for comparison with normal subjects.

Comparison of the effects of anterior AFOs on the postural stability in stroke patients with hemiplegia and normal subjects are shown on Table 2. The obtained values for ankle strategy and maximal stability declined, whereas the COG velocity elevated sequentially from the EOFS condition to the SVSS condition, which is expected because the SOT protocol was designed to be a progressively harder task from condition 1 to condition 6. When wearing an anterior AFO, stroke patients with hemiplegia used more ankle strategy than hip strategy to keep their balance in all the six sensory conditions (as compared with that without an anterior AFO [$P < 0.05$]), but the difference between wearing *vs.* not wearing an AFO was not significant in the normal subjects.

Wearing an anterior AFO resulted in significant improvements in maximal stability under more complicated sensory conditions such as SVFS, EOSS, and ECSS ($P < 0.05$), but the effect was not obvious in the conditions without external perturbation (EOFS and ECFS) or in the most challenging condition (SVSS).

The velocity of COG movement was lower when wearing an anterior AFO in stroke patients with hemiplegia in all six sensory conditions as compared with that without an anterior AFO, and the effect was significant in the EOFS, ECFS, ECSS, and SVSS conditions ($P < 0.05$). Contrary to the insignificant effect of the anterior AFO on the velocity of COG movement in moderately difficult sensory conditions of SVFS and EOSS in stroke patients, significant difference existed in these two conditions in normal subjects.

TABLE 1 Characteristics of the subjects

	Stroke Patients	Normal Subjects	*P* Value
Gender, female/male	11/10	5/5	0.602
Age, yrs	58.2 ± 8.4	63.0 ± 8.3	0.139
Body height, cm	158.6 ± 8.2	161.7 ± 4.5	0.270
Body weight, kg	61.2 ± 11.4	64.8 ± 5.7	0.359
Hemiplegic side	Left/right: 11/10		

DISCUSSION

Postural control is a complex process involving both sensory and motor components. An ideal stance postural control is accomplished by coordinated sensorimotor strategies to keep the COG within the base of support.[16] The motor output to maintain COG within stability limits are ankle strategy and hip strategy. Ankle strategy restores the COG to a position of stability by rotation about the ankle joint. It is more commonly used to accommodate the perturbation of equilibrium, particularly when the perturbation is small. However, use of ankle strategy requires intact

TABLE 2 Sensory organization test with different sensory conditions for the subjects without and with anterior ankle–foot orthoses (AFO)

	EOFS	ECFS	SVFS	EOSS	ECSS	SVSS
Ankle strategy (%)						
Patients						
Non-AFO	95.1 (2.8)	92.7 (3.6)	91.9 (6.2)	83.0 (4.4)	75.2 (6.0)	74.5 (7.6)
AFO	96.4 (1.8)[a]	94.5 (3.7)[a]	93.9 (3.7)[a]	84.5 (4.0)[a]	81.4 (3.9)[b]	78.6 (5.0)[a]
Normal subjects						
Non-AFO	98.8 (0.6)	97.9 (1.4)	97.9 (1.0)	90.2 (3.5)	81.6 (2.8)	81.0 (2.4)
AFO	99.2 (1.0)	97.9 (2.2)	98.4 (1.1)	90.3 (2.2)	82.2 (4.0)	78.8 (6.7)
Between-subjects effect	$P < 0.001$[d]	$P < 0.001$[d]	$P = 0.002$[d]	$P < 0.001$[d]	$P = 0.02$[c]	$P = 0.087$
Maximal stability (%)						
Patients						
Non-AFO	90.4 (3.0)	86.6 (3.5)	83.4 (6.3)	69.8 (10.7)	53.1 (12.7)	54.8 (12.0)
AFO	91.0 (3.1)	88.8 (4.0)	85.0 (4.9)[b]	75.0 (11.2)[b]	60.4 (9.4)[b]	58.7 (9.7)
Normal subjects						
Non-AFO	94.1 (1.4)	90.0 (2.4)	89.0 (3.2)	82.0 (7.8)	60.4 (9.5)	55.5 (9.3)
AFO	94.3 (1.9)	90.0 (4.5)	90.2 (3.0)	80.9 (5.2)	61.5 (5.8)	54.5 (12.0)
Between-subjects effect	$P < 0.001$[d]	$P = 0.177$	$P = 0.008$[d]	$P = 0.021$[c]	$P = 0.242$	$P = 0.645$
Velocity of center-of-gravity movement (degrees/sec)						
Patients						
Non-AFO	0.36 (0.11)	0.55 (0.14)	0.83 (0.35)	1.00 (0.29)	1.50 (0.38)	1.56 (0.39)
AFO	0.33 (0.10)[a]	0.49 (0.13)[a]	0.79 (0.38)	0.98 (0.33)	1.33 (0.39)[b]	1.34 (0.44)[b]
Normal subjects						
Non-AFO	0.31 (0.11)	0.45 (0.17)	0.48 (0.17)	0.84 (0.30)	1.37 (0.32)	1.23 (0.33)
AFO	0.32 (0.10)	0.40 (0.14)	0.41 (0.14)[a]	0.82 (0.31)[a]	1.34 (0.30)	1.20 (0.36)
Between-subjects effect	$P = 0.253$	$P = 0.020$[c]	$P = 0.231$	$P = 009$[d]	$P = 0.056$	$P = 0.045$[c]

AFO, Non-AFO, not wearing an anterior AFO; AFO, wearing an anterior AFO; [a] $P < 0.05$, [b] $P < 0.01$ compared between subjects without and with AFOs; [c] $P < 0.05$, [d] $P < 0.01$ compared between patients and normal subjects; EOFS, eyes open and fixed support; ECFS, eyes close and fixed support; SVFS, sway-referenced vision and fixed support; EOSS, eyes opened and sway-referenced support; ECSS, eye closed and sway-referenced support; SVSS, sway-referenced vision and support.

range of motion and strength in the ankles. In the conditions of limited ankle motion, or when the perturbation to balance is too large, hip strategy will be employed.[17] One of the disadvantages to using a posterior leaflet AFO is that it will prevent the use of ankle strategy. In our study, stroke patients with hemiplegia were still able to use more ankle strategy by wearing anterior AFOs in all six sensory conditions than when they did not wear AFOs. The design of an anterior AFO does not sacrifice the degrees of freedom through which a patient still has some movement space around his ankle. Therefore, we recommend that anterior AFOs be applied in patients who need more ankle movement to adjust upright posture.

In the EOFS and ECFS conditions, the platform on which the stroke patient with hemiplegia stood was stationary, and the presence or absence of an anterior AFO had no significant influence on the maximal stability. However, an anterior AFO provided better maximal stability in the more challenging conditions with external perturbation from either sway-referenced vision or sway-referenced support (SVFS, EOSS, and ECSS), though the effect was not obvious in the most difficult condition of simultaneously sway-referenced vision and support (SVSS). The results suggest that anterior AFOs have greater effectiveness in providing postural stability when stroke patients with hemiplegia stand on an unstable surface.

In all six sensory conditions of SOT, the velocity of COG movement was lowered by wearing an anterior AFO in stroke patients with hemiplegia, though the difference was statistically insignificant in the moderately difficult conditions of SVFS and EOSS. The slower the COG movement is in a disturbed environment, the less likely the subject is to lose balance and fall. The results imply that anterior AFOs can improve postural stability by reducing the sway of the trunk in stroke patients with hemiplegia.

Three sensory systems are responsible for the maintenance of upright posture, including somatosensory, visual, and vestibular systems. The somatosensory and visual systems gather information from the environment, whereas the vestibular system provides information about the head's position in space.[18] Generally, the somatosensory system is processed in the fastest mode, followed by the visual and vestibular systems.[19] Research performed by Dietz and colleagues[20] suggests that somatosensory inputs play a major role in the control of perturbed stance. In this study, stroke patients with hemiplegia have better stance postural control to accommodate disequilibrium by wearing an anterior AFO. When a person stands, the peripheral somatosensory input comes primarily from the feet. An anterior AFO provides adequate contact surface between the foot and ground, which can relay more somatosensory inputs to the central nervous system for sensory organization. On the contrary, conventional posterior AFOs used in stroke patients tend to prevent the affected foot from making contact with the ground.[21] The different effects of somatosensory inputs in anterior AFOs *vs.* posterior AFOs need to be investigated in future studies.

CONCLUSIONS

When wearing an anterior AFO, stroke patients with hemiplegia used ankle strategy more than hip strategy to confront perturbed conditions. An anterior AFO also provides hemiplegic stroke patients with better maximal stability under more complicated challenges with external perturbation from either sway-referenced vision or sway-referenced support, but the effect was not apparent in relatively simple conditions without external perturbation (EOFS and ECFS) or in the most challenging sensory condition of sway-referenced vision and support (SVSS). The velocity of COG movement was lowered by wearing an anterior AFO in stroke patients with hemiplegia, though the difference was not obvious in the moderately difficult sensory conditions of SVFS and EOSS. We recommend that in the early stages of recovery, anterior AFOs may be used to assist stroke patients with hemiplegia to improve their postural stability.

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