ORIGINAL ARTICLE

Kinematic Features of Rear-Foot Motion Using Anterior and Posterior Ankle-Foot Orthoses in Stroke Patients With Hemiplegic Gait

Chih-Chi Chen, MD, Wei-Hsien Hong, PhD, Chin-Man Wang, MD, Chih-Kuang Chen, MD, Katie Pei-Hsuan Wu, MD, Chao-Fu Kang, MD, Simon F. Tang, MD

ABSTRACT. Chen C-C, Hong W-H, Wang C-M, Chen C-K, Wu KP-H, Kang C-F, Tang SF. Kinematic features of rear-foot motion using anterior and posterior ankle-foot orthoses in stroke patients with hemiplegic gait. Arch Phys Med Rehabil 2010;91:1862-8.

Objective: To evaluate the kinematic features of rear-foot motion during gait in hemiplegic stroke patients, using anterior ankle-foot orthoses (AFOs), posterior AFOs, and no orthotic assistance.

Design: Crossover design with randomization for the interventions.

Setting: A rehabilitation center for adults with neurologic disorders.

Participants: Patients with hemiplegia due to stroke (n=14) and able-bodied subjects (n=11).

Interventions: Subjects with hemiplegia were measured walking under 3 conditions with randomized sequences: (1) with an anterior AFO, (2) with a posterior AFO, and (3) without an AFO. Control subjects were measured walking without an AFO to provide a normative reference.

Main Outcome Measures: Rear-foot kinematic change in the sagittal, coronal, and transverse planes.

Results: In the sagittal plane, compared with walking with an anterior AFO or without an AFO, the posterior AFO significantly decreased plantar flexion to neutral at initial heel contact (P=.001) and the swing phase (P<.001), and increased dorsiflexion at the stance phase (P=.002). In the coronal plane, the anterior AFO significantly increased maximal eversion to neutral (less inversion) at the stance phase (P=.025), and decreased the maximal inversion angle at the swing phase when compared with using no AFO (P=.005). The posterior AFO also decreased the maximal inversion angle at the swing phase as compared with no AFO (P=.005). In the transverse plane, when compared with walking without an AFO, the anterior AFO and posterior AFO decreased the adduction angle significantly at initial heel contact (P=.004).

Conclusions: For poststroke hemiplegic gait, the posterior AFO is better than the anterior AFO in enhancing rear-foot dorsiflexion during a whole gait cycle. The anterior AFO decreases rear-foot inversion in both the stance and swing phases, and the posterior AFO decreases the rear-foot inversion in the swing phase when compared with using no AFO.

Key Words: Biomechanics, Gait, Orthotic devices, Rehabilitation; Stroke.

STROKE PATIENTS OFTEN have upper motor neuron syndrome with a resultant loss of strength and dexterity, impaired motor control, increased spasticity, hyperreflexia, cocontraction, and spastic dystonia in the affected limbs. These conditions result in inappropriate and involuntary posturing and contribute to abnormal gait patterns and impaired walking ability.[1] Clinically, we can identify more than 1 type of gait pattern across stroke patients, such as the equinus and equinovarus gaits, indicating that people who have had strokes need to use different strategies to achieve the goal of walking.[2]

AFOs are often prescribed to stroke patients and are designed to provide mediolateral ankle stability during stance and adequate toe clearance during swing, and to promote heel strike.[3] Conventional plastic AFOs have a posterior leaf-type design, and are fabricated by a lamination or vacuum-forming technique over a positive plaster model of the limb.[4] Anterior AFOs are low-temperature AFOs commonly used in Asian countries for convenience when walking indoors. Several studies evaluated the effects of posterior AFOs on stroke patients and demonstrated improvement in gait parameters including stride length, gait velocity and cadence,[4-6] gait stability,[4] balance control,[7] energy cost of walking,[8,9] and functional status.[5] Some studies evaluated the anterior AFO functions and suggested that anterior AFOs also work effectively for gait parameters,[10] walking ability,[11] and balance control[12] in hemiplegic stroke patients.

Because ankle motor control in stroke patients is variable and the designs of anterior AFOs and posterior AFOs are different, we speculated that different poststroke gait patterns could benefit from different AFO types. We analyzed the shank-calcaneus rotation angle, as representative of rear-foot movement, by means of a 3-dimensional motion analysis system.[13] To our knowledge, this is the first study to compare the kinematic changes in rear-foot movement during gait in hemiplegic stroke patients using either anterior AFOs or posterior AFOs.

METHODS

Participants

For this study, we recruited 14 stroke subjects with hemiplegia. The inclusion criteria for the study group were as

List of Abbreviations

AFO	ankle-foot orthosis

From the Department of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital and Chang Gung University, Linkou, Taiwan (C-C Chen, Wang, C-K Chen, Wu, Kang, Tang); and School of Sports Medicine, China Medical University, Taichung, Taiwan (Hong).

Supported by the National Science Council, Republic of China (grant no. NSC 98-2119-M-009-019).

Correspondence to Simon F. Tang, MD, Dept of Physical Medicine and Rehabilitation, Chang Gung Memorial Hospital & Chang Gung University Taoyuan, Taiwan 5, Fu-Hsin St, Kwei-Shan, Tao-Yuan, 333, Taiwan, e-mail: *simonftang@gmail.com.* Reprints are not available from the author.

0003-9993/10/9112-00494$36.00/0
doi:10.1016/j.apmr.2010.09.013

Fig 1. A piece of thermoplastic was cut in the shape of a bottle cap opener.

follows: (1) diagnosis of unilateral hemiplegia caused by either hemorrhagic or ischemic stroke; (2) ability to follow simple verbal commands or instructions; and (3) ability to ambulate independently. Subjects were excluded if they had any of the following conditions: (1) medical problems other than stroke that would interfere with their gait; or (2) foot-related premorbid or comorbid orthopedic problems. All patients underwent neuroimaging studies, including computed tomography or magnetic resonance imaging of the brain, to confirm the diagnosis of stroke at an early stage. We also recruited 11 healthy subjects, who had no known neurologic and orthopedic impairments, to serve as our control group. This study was approved by the local medical ethics and the human clinical trial committees (Chang Gung Memorial Hospital), and all participants signed the informed consent.

Ankle-Foot Orthosis Design

A-AFOs and P-AFOs for the study were custom-made for each subject by a certified orthotist. Fabrication of an anterior AFO was well documented in our previous study.[11] The anterior AFO was made of a low-temperature, 3.2-mm-thick thermoplastic material, Orfit.[a] A piece of thermoplastic was cut in the shape of a bottle cap opener (fig 1). The pretibial and ankle parts were padded with closed-cell foam, Kushionflex padding.[b] Subjects were asked to sit with their knee in 90° of flexion and their ankle in a neutral position. After softening the thermoplastic in a hot water tank (60°C), the anterior AFO was molded directly to the subject's lower limb, with the foot going through the hole in the bottle cap opener section. The sole part was 6cm in width, with its anterior trim line just behind the metatarsal heads. The foot and ankle portions were folded to form the medial and lateral bars. The upper part was molded onto the ankle and lower half of the tibia without covering the medial and lateral malleoli. Velcro straps[c] were placed at the ankle level and upper part of the orthosis (fig 2). Usually, we can make an anterior AFO within half an hour.

The posterior AFO used in this study was the plastic leaf-spring AFO.[14] We used a leaf-spring AFO in comparison with anterior AFO not only because it is commonly used in clinical situations, but because it does not cover malleoli, which is similar to the anterior AFO. Each posterior AFO was fabricated using polypropylene, with the ankle in a neutral position. The footplate was cut to the metatarsal head. Proximally, it covered the posterior portion of the leg to 5cm below the fibular head. The medial and lateral trim lines over the ankle were posterior to both malleoli. Three straps crossed the proximal end of the shank, the front of the ankle, and the midfoot area (see fig 2). We used 3 straps to hold the posterior AFO instead of the

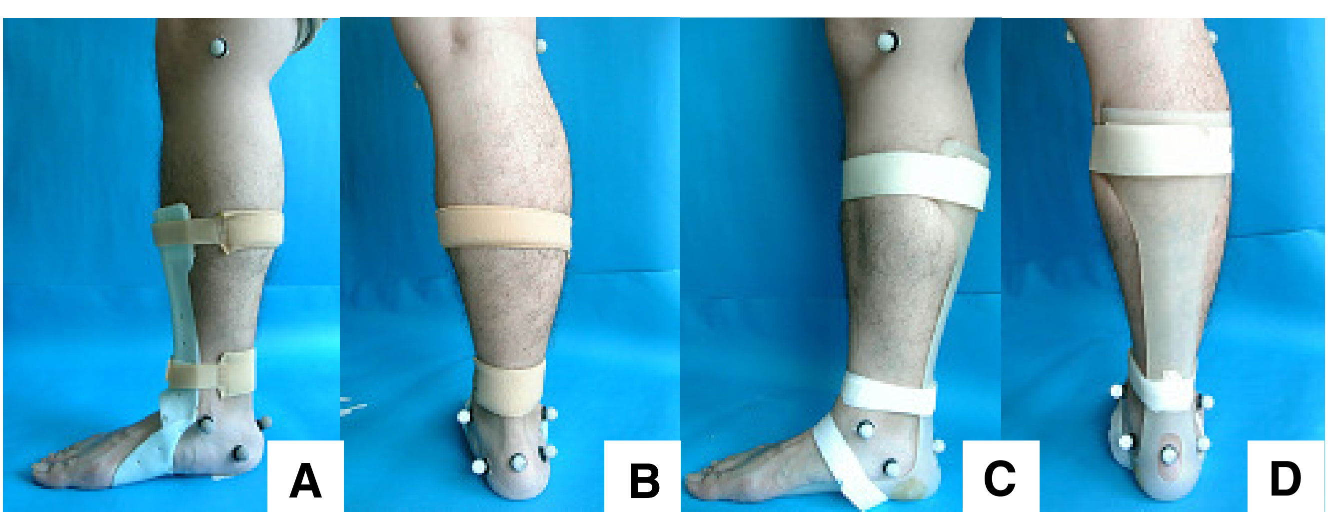

Fig 2. The arrangement of markers on the shank and calcaneus in anterior AFO (A, B) and posterior AFO (C, D) conditions.

standard single strap at the upper shank because we let subjects walk barefoot with the posterior AFO without the assistance of shoes. The decision to analyze subjects walking barefoot with AFOs was based on (1) our needs to know the real function of the AFO without the assistance of a shoe; and (2) our interest in conforming to the custom in Asian countries of walking barefoot indoors.

Equipment

A Vicon motion analysis system[c] was used to collect the kinematic data. The Vicon MS system included 8 infrared cameras for acquiring, at a rate of 100Hz, the kinematic trajectories of the reflective markers attached to the subject's lower limbs. We placed 7 spherical retroreflective markers (diameter, 1.4cm) directly on the subject's affected-side calcaneus and shank. Two markers were placed on the medial and lateral tibial condyles, and 2 markers were also placed on the medial and lateral malleoli of ankle. One marker was placed on the midline of the calcaneal posterior process, and with the subject standing, 2 markers were placed on the medial and lateral sides of the calcaneus in a plane parallel to the ground. We made 1 hole in each posterior AFO to allow placement of the calcaneal markers directly onto the skin (see fig 2). Three-dimensional marker trajectories were used to determine the rear-foot motion angles in the sagittal (dorsiflexion–plantar flexion), coronal (inversion-eversion), and transverse (abduction-adduction) planes.

Data Collection

We evaluated and recorded stroke participants' motor recovery and ankle muscle tone using a Brunnstrom stage[15] and Modified Ashworth Scale,[16] respectively. All subjects practiced walking with and without the orthosis before we performed the gait analysis. Each subject was asked to stand still for 1 second to allow all the cameras to record the markers to analyze the subject's initial anatomic position. Each subject was then measured walking at a self-selected, comfortable speed in each of 3 orthotic trials (barefoot without an AFO, with a posterior AFO, and with an anterior AFO) during the ~~same~~ session. The order of the 3 trials was randomized. Subjects were allowed to rest for 5 minutes between trials. The walkway was carpeted to avoid any discomfort when the subjects walked barefoot without an AFO. To reduce measurement errors during gait analysis, data were collected from 3 successful trials. The data from these 3 trials were averaged, and the results were used for the statistical analysis.

Data Analysis

A LabView software package[d] was designed to analyze rear-foot motion. A joint coordinate system examined the relative rotation matrices of the marker reference frames on the calcaneus with respect to those on the shank. The neutral position was defined as the standing position. The calculated rotation matrices in the neutral position were used to correct the joint. Euler angles were used to define the 3-dimensional relative joint angular motion. From this neutral position, the distal segment was assumed to move through 3 successive finite rotations to attain its new configuration. The first rotation was dorsiflexion–plantar flexion about the z-axis of the proximal segment, followed by inversion-eversion about a rotated floating x-axis. Finally, the third rotation was the abduction-adduction rotation about the distal to proximal direction (y-axis) of the distal segment. The temporal and spatial gait parameters were computed, including walking speed, step length, cycle time, and angles of the rear-foot joint.

Statistical Analysis

We used SPSS version 12 software[e] for the statistical analysis. Group differences in age, body height, and body mass were compared using an independent *t* test. Sex differences between the groups were determined using a chi-square test. The gait parameters were compared by using repeated-measures analysis of variance to determine significant differences among the AFOs and groups. Post hoc Bonferroni tests were used to evaluate the significance of pairwise comparisons between the AFOs. The level of significance used was *P* less than .05.

RESULTS

Descriptive information regarding the 14 participants with hemiplegia is listed in table 1. Comparisons of demographic data, including age, sex, body height, and body weight between the stroke and normative subjects are listed in table 2. The hemiplegic stroke subjects walked at a significantly slower, self-selected, comfortable walking speed and had decreased step length and longer cycle times than the control group. When comparing the anterior AFO, posterior AFO, and barefoot conditions in the hemiplegic stroke subjects, there was no

Table 1: Information About Stroke Subjects With Hemiplegia

Subject No.	Sex	Age (y)	Time Since Stroke	Involved Side	Brunnstrom Stage of Involved Lower Limb	Ankle MAS	Use of Assistive Device	Prior AFO Use
1	M	47	5y, 6mo	L	V	3	N	Y (A-AFO)
2	M	51	3y, 8mo	L	IV	3	N	Y (A-AFO)
3	M	47	3y, 9mo	R	V	1+	N	N
4	M	67	2y, 5mo	L	IV	1+	N	N
5	M	60	7mo	R	III–IV	3	N	Y (A-AFO)
6	M	53	5y, 4mo	R	V	2	N	N
7	M	53	8mo	L	III	2	N	N
8	M	51	3y, 4mo	R	III	3	N	Y (A-AFO)
9	M	43	10mo	L	V	2	N	Y (A-AFO)
10	F	70	5mo	R	V	1+	N	N
11	F	49	2mo	R	IV	2	N	Y (A-AFO)
12	F	56	2y, 2mo	R	IV	2	N	Y (A-AFO)
13	F	72	1y	R	V	2	N	N
14	F	71	4y, 4mo	L	IV	1+	N	Y (A-AFO)

Abbreviations: A-AFO, anterior ankle-foot orthosis; F, female; L, left; M, male; MAS, Modified Ashworth Scale; N, no; R, right; Y, yes.

Table 2: Comparisons of Demographic Data Between Stroke and Normative Subjects

Demographic Variables	Stroke Subjects (n=14)	Healthy subjects (n=11)	*P*
Age (y)	56.4±9.8	55.6±8.2	.842
Sex (men/women)	9/5	5/6	.435
Body height (cm)	161.0±9.5	158.3±5.6	.415
Body mass (kg)	64.0±9.7	60.9±9.9	.439

NOTE. Values are mean ± SD or as otherwise indicated.

significant difference in the self-selected, comfortable walking speeds, step lengths, and cycle times (table 3).

Rear-foot kinematic changes during gait in both the stroke and normal subjects when barefoot are shown in table 4 and figure 3. At initial heel contact, the rear-foot movement of the stroke patients showed increased inversion and adduction in comparison with the healthy control subjects. During the stance phase, the stroke patients showed less dorsiflexion and more inversion in the rear-foot angle. During the swing phase, the rear foot of the stroke patients showed less maximal plantar flexion and less dorsiflexion than the healthy control group. Actually, they all showed the gait pattern as equinovarus gait.

Comparisons of the rear-foot angular motions in hemiplegic stroke subjects in the anterior AFO, posterior AFO, and without AFO conditions are shown in figures 3 and 4. In the sagittal plane, as compared with walking with an anterior AFO or without an AFO, the posterior AFO significantly decreased plantar flexion to neutral at initial heel contact and the swing phase, and increased dorsiflexion at the stance phase. In the coronal plane, the anterior AFO significantly increased maximal eversion to neutral (less inversion) at the stance phase and decreased the maximal inversion angle at the swing phase when compared with not using an AFO. The posterior AFO also decreased the maximal inversion angle at the swing phase when compared with not using an AFO. In the transverse plane, as compared with walking without an AFO, the anterior AFO and posterior AFO conditions decreased the adduction angle significantly at initial heel contact. There were no significant differences in maximal adduction and the maximal abduction angles among the 3 AFO conditions during the stance and swing phases, respectively.

DISCUSSION

The incidence of equinovarus foot in stabilized vascular hemiplegia was reported to be about 18%.[17] The equinovarus foot shifts weight-bearing from the heel to the lateral plantar surface, which can cause loss of balance and reduce walking safety. This condition also has a strong correlation to the presence of claw toes.[18,19] An AFO has often been prescribed to facilitate ankle control for the equinus foot, the varus foot, or both. This study investigated the kinematic change in rear-foot joint control during gait in hemiplegic stroke patients using anterior AFOs, posterior AFOs, and no AFO assistance. As compared with using no AFO, the anterior AFO decreased rear-foot inversion at the stance and swing phases. The posterior AFO increased rear-foot dorsiflexion during the whole gait cycle in comparison with the anterior AFO and posterior AFO. The posterior AFO also decreased rear-foot inversion at the swing phase as compared with using no AFO.

In comparison with the normative controls in our study, the stroke subjects showed significantly decreased gait parameters including walking speed, step lengths, and cycle times. After wearing either the anterior AFOs or posterior AFOs, we noted no significant differences in the walking speed, step lengths, and cycle times after statistical analysis. Such results were not compatible with those of the previously mentioned studies,[4-6] but were similar to the results of other studies.[1,20,21] The relatively small number of cases and the variable improvement in patients wearing different types of AFOs (improvement in gait speed when wearing anterior AFOs as opposed to decreases in gait speed when wearing posterior AFOs, or vice versa) may explain the insignificant statistical results. According to the study of Perry et al,[22] a difference of 20cm/s in walking speed was defined as clinically significant. Even though some studies showed an improvement in gait speed in

Table 4: Rear-Foot Kinematics During Gait for the Involved Limb of Stroke Subjects and Control Subjects Walking Barefoot With Their Self-Selected, Comfortable Walking Speed

Gait Phase	Initial Heel Contact	Stance Phase	Swing Phase
Sagittal Plane	Plantar Flexion	Maximal Dorsiflexion	Maximal Plantar Flexion
Angle (deg)			
Control	6.3±4.7	–8.6±2.9	8.4±3.6
Stroke	8.5±5.7	–2.4±6.4	5.4±4.0
P	.307	.018*	.048*
Coronal Plane	Inversion	Maximal Eversion	Maximal Inversion
Angle (deg)			
Control	−1.4±2.8	−4.6±3.0	7.7±2.6
Stroke	8.2±4.5	4.4±5.0	10.5±4.7
P	<.001†	<.001†	.177
Transverse Plane	Adduction	Maximal Adduction	Maximal Abduction
Angle (deg)			
Control	1.2±3.6	11.3±4.5	7.7±2.6
Stroke	8.9±4.3	11.5±5.5	3.7±5.4
P	<.001†	.850	.118

NOTE. Values are mean ± SD or as otherwise indicated.
Plantar flexion (+), dorsiflexion (–); inversion (+), eversion (–); adduction (+), abduction (–). *$P<.05$; †$P<.01$.

Table 3: Gait Parameters of AFO Conditions in Stroke Subjects and Normative Subjects

	Stroke Subjects			Normative Subjects
Plane	A-AFO	P-AFO	Barefoot	Barefoot
Speed (%BH/s)	32.8±11.1	31.6±10.9	31.9±11.6	66.5±3.9
Step length (%BH)	9.6±6.2	9.2±5.9	9.8±6.6	29.4±4.1
Cycle time (s)	4.0±1.4	4.2±1.4	3.9±1.5	2.2±0.3

NOTE. Values are mean ± SD.
Abbreviations: A-AFO, anterior ankle-foot orthosis; BH, body height; P-AFO, posterior ankle-foot orthosis.

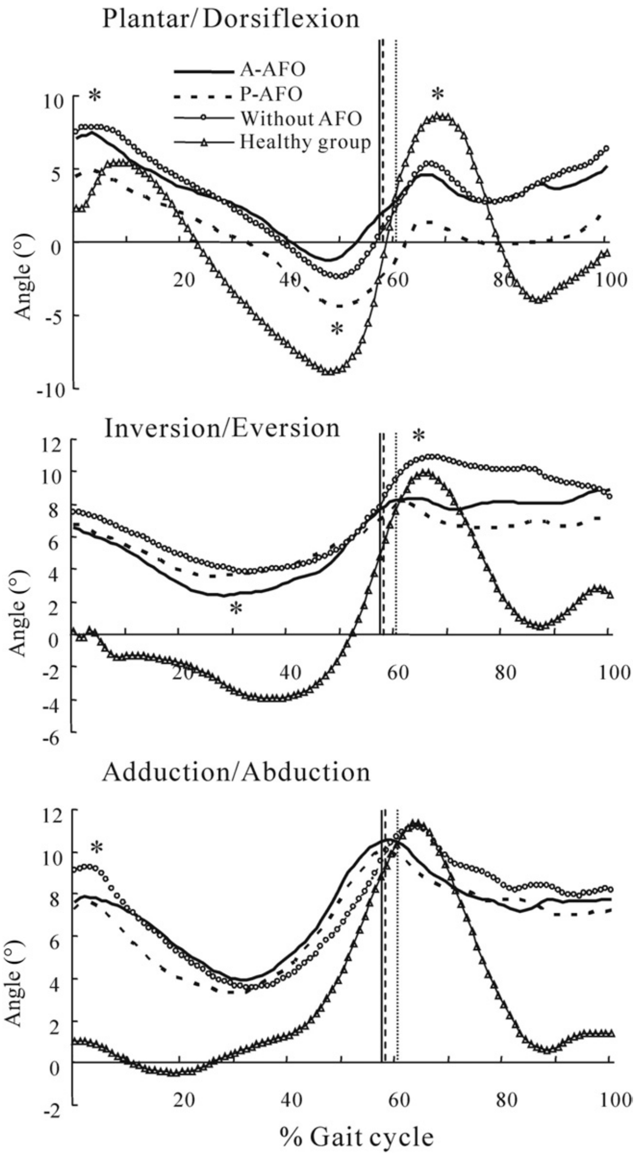

Fig 3. Angular motion of rear foot in both groups: plantar flexion (+), dorsiflexion (–); inversion (+), eversion (–); adduction (+), abduction (–). Vertical lines indicate mean toe-off for each cycle with and without AFOs. The solid line shows toe-off for the A-AFO trial, the dashed line for the P-AFO trial, and the dotted line for toe-off without an AFO. *Points in the gait cycle where the difference in angles with and without AFOs was significantly different. Abbreviations: A-AFO, anterior ankle-foot orthosis; P-AFO, posterior ankle-foot orthosis.

stroke patients after wearing AFOs, most of the improvements were too small to reach clinical significance.[5]

In healthy subjects, the rear foot tended to plantar flex at initial heel contact, and then dorsiflex during the stance phase and midswing phase in the sagittal plane. In the coronal plane, the rear foot inverted at initial heel contact and then everted until terminal stance when it inverted. These findings are compatible with those of previous studies.[12,15] Liu et al[23] evaluated rear-foot kinematic changes in healthy subjects and found that repeatable patterns between subjects can be observed in dorsiflexion/plantar flexion and inversion/eversion, suggesting that these characteristic changes are essential for efficient level walking. The inconsistent kinematic changes in the abduction/adduction angle between the studies may be explained by the angle's secondary importance to level walking. Each subject may adopt his/her own strategy and specific motion characteristics.

We noted that hemiplegic stroke subjects have altered rear-foot kinematics during gait, such as rear-foot inversion and adduction at initial heel contact. It has been suggested that foot eversion during the stance phase provides shock absorption on floor impact.[24] Increased rear-foot inversion at initial heel contact only offers shock absorption from the toe and lateral border of the foot, but increases the stress on the contact area.[25]

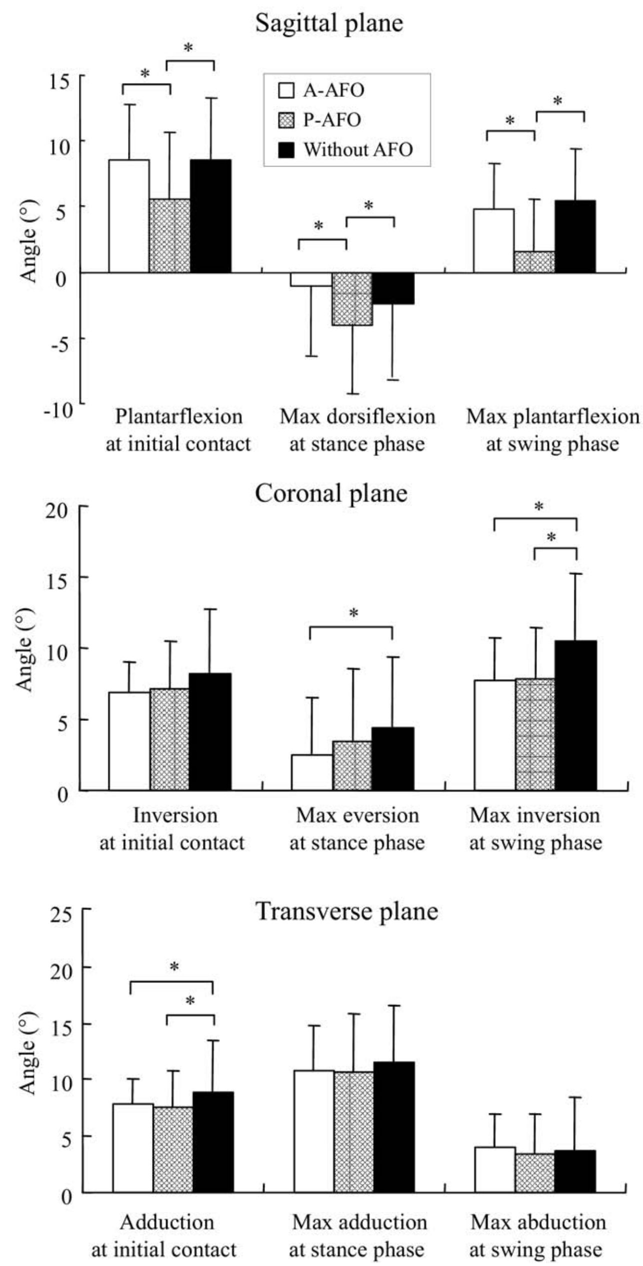

Fig 4. Angular comparisons of rear foot with and without AFOs Plantar flexion (+), dorsiflexion (–); inversion (+), eversion (–); adduction (+), abduction (–). *$P<.05$. Abbreviations: A-AFO, anterior ankle-foot orthosis; P-AFO, posterior ankle-foot orthosis.

During the stance phase, rear-foot control in the hemiplegic stroke patients became more plantar-flexed and still inverted. This plantar flexion and rear-foot inversion may interfere with adequate pushing motion generation during propulsion.[26] During the swing phase of stroke subjects, the rear foot remained in the plantar flexion position and could not accomplish dorsiflexion well. Inadequate dorsiflexion may interfere with foot clearance. Perry[27] found that the hemiplegic stroke patients had inadequate shock absorption at heel strike, poor control of momentum during stance, and inadequate excursion of the paretic limb during swing. Our study suggests that these observations may be explained by the abnormal kinematic changes in rear-foot control in our stroke patients.

After hemiplegic stroke subjects wore the 2 types of AFOs, their rear-foot control at initial heel contact was in a more dorsiflexed position with posterior AFOs as compared with the anterior AFOs and no AFO, and was less adducted with both the anterior AFOs and posterior AFOs when compared with using no AFO. During the stance phase, the posterior AFO increased the dorsiflexion angle when compared with the anterior AFO and no AFO, while the anterior AFO corrected an inverted rear foot more effectively when compared with not using an AFO. At the swing phase, the posterior AFO kept the rear foot in the dorsiflexion position in comparison with the anterior AFO and no AFO, and both the anterior AFO and posterior AFO decreased the inverted angle as compared with using no AFO. The kinematic findings for the posterior AFO in the sagittal plane were compatible with the findings of Fatone et al,[1] who showed that all patients with hemiplegic gait patterns tested with posterior AFOs with different AFO alignments and footplate lengths were able to decrease their plantar flexion of the ankle at initial contact and midswing. Our study further suggested that anterior AFOs decreased rear-foot inversion in both the stance and swing phases, and posterior AFOs decreased the rear-foot inversion in swing phase when compared with going barefoot.

We speculated that the different effects of AFO type on the rear-foot kinematic change may relate to the design differences. The posterior AFO, with its sole extending the length from heel to sulcus and its posterior reinforcement to stiffen its plantar flexion resistance feature, may prevent ankle plantar flexion effectively. Its medial and lateral trim lines posterior to both malleoli allowed sufficient flexibility and helped dorsiflexion effectively. The anterior AFO, with its small sole band just under the metatarsal and lack of posterior reinforcement, may have limited its ability to prevent plantar flexion. However, its continuous coverage from the metatarsal and tarsal to the shank may fix the subtalar joint and prevent rear-foot inversion effectively. Although the rear-foot kinematics of hemiplegic stroke subjects were still different from those of the healthy subjects after AFO correction, the anterior AFO and posterior AFO did play a role in correcting and normalizing the rear-foot angle of hemiplegic subjects after statistical analysis. Such change may contribute to the functional improvement noted in previously mentioned studies in gait stability, balance control, energy cost, and patients' function. Other integrated strategies are still needed to improve stroke patients' gait pattern.[28]

Study Limitations

There are some limitations in this study. First, a relatively small number of cases were recruited for this study. Second, the healthy control group did not walk as slowly as the stroke subjects, given that forcing such a slow speed on a healthy person would result in unnatural gait patterns and thereby increase the variables. Third, we studied the rear-foot kinematic change as representative of the ankle joint, because it can be easily marked and compared well with the typical ankle gait analysis.[13] Fourth, we only analyzed the posterior leaf-spring AFO, which cannot represent all posterior AFO designs. Further study should evaluate the rear foot, midfoot, and forefoot motions under different AFO designs and conditions.

CONCLUSIONS

The results of our study suggest that for poststroke hemiplegic gait, the posterior AFO is better than the anterior AFO in enhancing rear-foot dorsiflexion during the whole gait cycle. The anterior AFO decreases rear-foot inversion in both the stance and swing phases, and the posterior AFO decreases the rear-foot inversion in the swing phase as compared with using no AFO. The choice between an anterior AFO and a posterior AFO should be made by considering not only the patients' preference and the practitioners' expertise, but also should be based on the patients' motor control and resultant gait characteristics. We report our results here in anticipation that they will be applied to AFO selection in hemiplegic stroke patients.

References

1. Fatone S, Gard SA, Malas BS. Effect of ankle-foot orthosis alignment and foot-plate length on the gait of adults with poststroke hemiplegia. Arch Phys Med Rehabil 2009;90:810-8.
2. Kim CM, Eng JJ. Magnitude and pattern of 3D kinematic and kinetic gait profiles in persons with stroke: relationship to walking speed. Gait Posture 2004;20:140-6.
3. Lehmann JF, Condon SM, Price R, deLateur BJ. Gait abnormalities in hemiplegia: their correction by ankle-foot orthoses. Arch Phys Med Rehabil 1987;68:763-71.
4. Abe H, Michimata A, Sugawara K, Sugaya N, Izumi S. Improving gait stability in stroke hemiplegic patients with a plastic ankle-foot orthosis. Tohoku J Exp Med 2009;218:193-9.
5. de Wit DC, Buurke JH, Nijlant JM, Ijzerman MJ, Hermens HJ. The effect of an ankle-foot orthosis on walking ability in chronic stroke patients: a randomized controlled trial. Clin Rehabil 2004; 18:550-7.
6. Tyson SF, Thornton HA. The effect of a hinged ankle foot orthosis on hemiplegic gait: objective measures and users' opinions. Clin Rehabil 2001;15:53-8.
7. Wang RY, Lin PY, Lee CC, Yang YR. Gait and balance performance improvements attributable to ankle-foot orthosis in subjects with hemiparesis. Am J Phys Med Rehabil 2007;86:556-62.
8. Corcoran PJ, Jebsen RH, Brengelmann GL, Simons BC. Effects of plastic and metal leg braces on speed and energy cost of hemiparetic ambulation. Arch Phys Med Rehabil 1970;51:69-77.
9. Bleyenheuft C, Caty G, Lejeune T, Detrembleur C. Assessment of the Chignon dynamic ankle-foot orthosis using instrumented gait analysis in hemiparetic adults. Ann Readapt Med Phys 2008;51: 154-60.
10. Park JH, Chun MH, Ahn JS, Yu JY, Kang SH. Comparison of gait analysis between anterior and posterior ankle foot orthosis in hemiplegic patients. Am J Phys Med Rehabil 2009;88:630-4.
11. Wong AM, Tang FT, Wu SH, Chen CM. Clinical trial of a low-temperature plastic anterior ankle foot orthosis. Am J Phys Med Rehabil 1992;71:41-3.
12. Chen CK, Hong WH, Chu NK, Lau YC, Lew HL, Tang SF. Effects of an anterior ankle-foot orthosis on postural stability in stroke patients with hemiplegia. Am J Phys Med Rehabil 2008; 87:815-20.
13. Leardini A, Benedetti MG, Berti L, Bettinelli D, Nativo R, Giannini S. Rear-foot, mid-foot and fore-foot motion during the stance phase of gait. Gait Posture 2007;25:453-62.
14. Ragnarsson KT. Lower extremity orthotics, shoes, and gait aids. In: Delisa JA, editor. Physical medicine & rehabilitation: princi-

ples and practice. 4th ed. Philadelphia: Lippincott, Williams & Wilkins; 2005. p 1383-5.
15. Brunnstrom S. Motor testing procedures in hemiplegia: based on sequential recovery stages. Phys Ther 1966;46:357-75.
16. Bohannon RW, Smith MB. Interrater reliability of a modified Ashworth scale of muscle spasticity. Phys Ther 1987;67:206-7.
17. Verdie C, Daviet JC, Borie MJ, et al. [Epidemiology of pes varus and/or equinus one year after a first cerebral hemisphere stroke: apropos of a cohort of 86 patients] [French]. Ann Readapt Med Phys 2004;47:81-6.
18. Reiter F, Danni M, Lagalla G, Ceravolo G, Provinciali L. Low-dose botulinum toxin with ankle taping for the treatment of spastic equinovarus foot after stroke. Arch Phys Med Rehabil 1998;79:532-5.
19. Laurent G, Valentini F, Loiseau K, Hennebelle D, Robain G. Claw toes in hemiplegic patients after stroke. Ann Phys Rehabil Med 2010;53:77-85.
20. Beckerman H, Becher J, Lankhorst GJ, Verbeek AL. Walking ability of stroke patients: efficacy of tibial nerve blocking and a polypropylene ankle-foot orthosis. Arch Phys Med Rehabil 1996;77:1144-51.
21. Cruz TH, Dhaher YY. Impact of ankle-foot-orthosis on frontal plane behaviors post-stroke. Gait Posture 2009;30:312-6.
22. Perry J, Garrett M, Gronley JK, Mulroy SJ. Classification of walking handicap in the stroke population. Stroke 1995;26:982-9.
23. Liu W, Siegler S, Hillstrom H, Whitney K. Three-dimensional, six-degrees-of-freedom kinematics of the human hindfoot during the stance phase of level walking. Hum Mov Sci 1997;16:283-98.
24. Perry J. Gait analysis: normal and pathological function. Thorofare: SLACK; 1992.
25. Condie DN, Turner MS. An atlas of lower limb orthotic practice. London: Chapman & Hall; 1997.
26. Levinger P, Gilleard W. Tibia and rearfoot motion and ground reaction forces in subjects with patellofemoral pain syndrome during walking. Gait Posture 2007;25:2-8.
27. Perry J. The mechanics of walking in hemiplegia. Clin Orthop Relat Res 1969;63:23-31.
28. Dickstein R. Rehabilitation of gait speed after stroke: a critical review of intervention approaches. Neurorehabil Neural Repair 2008;22:649-60.

Suppliers

a. Orfit Industries NV, Vosveld 9a, B-2110 Wijnegem, Belgium.
b. Sammons Preston, PO Box 93040, Chicago, IL 60673-3040.
c. VICON, Oxford Metrics Ltd, 14 Minns Estate, West Way, Oxford, OX2 OJB UK.
d. National Instruments, 11500 N Mopac Expwy, Austin, TX 78759-3504.
e. SPSS Inc, 233 S Wacker Dr, 11th Fl, Chicago, IL 60606.