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Effects of an ankle-foot orthosis on balance performance in patients with hemiparesis of different durations

Ray-Yau Wang Institute and Faculty of Physical Therapy, National Yang-Ming University, **Lu-Lu Yen** Department of Physical Medicine & Rehabilitation, Cheng Hsin Rehabilitation Medical Center, **Chao-Chung Lee, Pei-Yi Lin, Mei-Fang Wang** and **Yea-Ru Yang** Institute and Faculty of Physical Therapy, National Yang-Ming University, Shih-Pai, Taipei, Taiwan

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Objective: To examine the effects of an ankle-foot orthosis (AFO) on balance performance in patients with hemiparesis of short and long duration.
Design: Within-subject random order of intervention, cross-sectional study design.
Settings: Medical centres and district hospitals.
Subjects: Forty-two subjects with hemiparesis of short duration ($<$ six months) and 61 subjects of long duration ($>$ 12 months).
Measurements: The balance and gait ability of subjects were evaluated both with an AFO and without. The static and dynamic balance activities were evaluated by the Balance Master System, whereas the functional balance was assessed with the Berg Balance Scale. The speed and cadence were also measured during a 10-metre walk. Paired *t*-test was used to determine the effect of the AFO.
Results: In subjects with hemiparesis of short duration, we found that subjects wearing an AFO showed significant improvements in (1) weight-bearing distribution during quiet standing ($p = 0.042$, 95% confidence interval (CI) 0.521, 7.325), (2) body sway during standing on foam surface with eyes open ($p = 0.020$, 95% CI 0.020, 0.680) and eyes closed ($p = 0.041$, 95% CI 0.023, 0.921), (3) movement velocity during limit of stability test (LOS) – toward the affected side ($p = 0.037$, 95% CI -0.978, -0.042) and nonaffected side ($p = 0.008$, 95% CI -2.223, -0.377), (4) maximal excursion toward the affected side ($p = 0.042$, 95% CI -19.546, -0.071), and (5) speed ($p = 0.028$, 95% CI -0.204, -0.017) and cadence ($p = 0.021$, 95% CI -22.983, -1.864). Such effects were not observed in subjects with hemiparesis of long duration.
Conclusions: For the subjects with hemiparesis of short duration, the AFO improves the symmetry in quiet and dynamic standing balances. It also increases speed and cadence. However, its effectiveness is minimal for patients of long duration.

Address for correspondence: Yea-Ru Yang, Institute and Faculty of Physical Therapy, National Yang-Ming University, 155, Sec 2, Li Nong St., Shih-Pai, Taipei, Taiwan. e-mail: yryang@ym.edu.tw

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Introduction

Stroke is an acute onset neurological dysfunction due to an abnormality in cerebral circulation with resultant hemiparesis.[1] Of survivors, 30–40% will have significant disability.[2] Residual neurological impairments may lead to limited balance abilities and functional activities,[3,4] and therefore lead to a decrease in life quality.[2]

Following a stroke, balance is frequently disturbed and results in impairments in steadiness, symmetry and dynamic stability.[5,6] Problems may arise when patients react to a destabilizing external force or perform self-initiated movements. Studies have addressed the deficiencies of dynamic postural stability in hemiplegic patients.[7,8] Pai *et al*.[7] found unsuccessful weight transfer in the frontal plane during transitions from bipedal to single-limb stance in hemiplegic patients. Di Fabio and Badke[8] reported that the greatest instability for hemiplegic patients resulted from a direction of visually cued sway in the sagittal plane.

The value of orthoses used on stroke patients is still a matter of debate.[9–11] To improve functional performance or allow practice of an action, there should be congruence between the goals of training and the rationale behind the design of the orthoses. An ankle-foot orthosis is typically suggested to compensate for the effects of impairments on walking, in particular for inadequate dorsiflexion in swing and mediolateral subtalar instability during stance.[12,13] However, the use of such an orthosis may force adaptive behaviour on the individual by interfering with the ankle plantarflexion that occurs at the balance activity. Few studies have addressed the effects of an AFO on the balance activities of stroke subjects.[14] Moreover, we are not aware of any published information on the effects of AFOs on balance performance of subjects with different post-onset duration. The main objective of the present study was to investigate the effects of AFOs on balance performance of subjects with hemiparesis of short and long duration.

Methods

All subjects were referred from three medical centres and three district hospitals. The diagnosis, age, sex, affected side and onset time of hemiparesis were obtained from patient interviews and medical charts. The criteria for subject selection were as follows: (1) diagnosis of unilateral hemiparesis secondary to cerebrovascular accident with symptoms having lasted either less than six months (short duration group) or more than 12 months (long duration group); (2) ability to stand without support for at least 1 min; (3) ability to walk for 10 m with or without assisted device; (4) ability to follow simple verbal commands or instructions; and (5) no history of significant orthopaedic problems that would interfere with performing the balance test. Subjects were placed into two groups according to the duration of hemiparesis. Hemiparesis of short and long duration were defined as symptoms lasting less than six months and more than 12 months, respectively.[15] There were 42 subjects in the short duration group and 61 subjects in the long duration group. All procedures performed in this study were approved by the Human Subject Review Boards of Veterans General Hospital of Republic of China. Subjects gave their informed consent prior to participating.

Each subject performed all measurement tests, both wearing and not wearing an AFO on the affected foot. The testing sequences were randomized. The AFO used in this study is a standard, off-the-shelf, plastic type weighing 125 g, set in neutral position. This orthosis came in three different sizes. The one that best fitted each subject was used.

Static and dynamic standing balance

The Balance Master System was used for static and dynamic standing balance test in the study.[16,17] The Balance Master System is a rehabilitation tool designed to provide quantitative assessment of static and dynamic balance performance and visual feedback of the excursion and position of the centre of gravity. Concurrent validity of the Balance Master data has been established for patients with stroke.[17,18] Test–retest reliability estimates for static and dynamic balance test of Balance Master were found to be moderate to high.[18] The static balance test was performed requiring subjects to look straight ahead while standing as still as possible. The difference of the weight-bearing distribution between two legs was recorded. The degrees of body sway were also recorded when subjects stood on the firm and foam surfaces with eyes open or closed.

Dynamic balance was also recorded to assess subjects' ability to control the movement (maximum excursion), accuracy (directional control) and speed (movement velocity) of their centre of gravity (COG) movements during tasks requiring weight shifts toward different directions (limit of stability – LOS test). Four directions – anterior, posterior, affected side and nonaffected side – were included in the test. Subjects were instructed to stand with their arms at their sides and not to move their feet throughout the testing procedure. Movement velocity is the average speed in degrees per second of the rhythmic movement along the specified direction. Directional control is a comparison of the amount of movement in the intended direction to the amount of extraneous movement. Maximal excursion is the distance of the movement toward the designated target, expressed as a percentage of maximum LOS distance. The other dynamic balance test was the sit-to-stand test. The rising time, weight transfer and COG sway during the sit-to-stand test were recorded.

Berg Balance Scale

The functional balance ability was evaluated using the Berg Balance Scale, rating performance from 0 (cannot perform) to 4 (normal performance) on 14 different tasks.[19] The total highest score of 56 on the Berg Balance Scale indicates excellent balance. The scale has been validated in the subjects with hemiparesis and has very high intra- and interrater reliability.[20]

Gait

Two trials of a 10-metre walk with self-selected speed were performed for the gait ability. The total time (in seconds) and total number of steps during each trial were obtained with a stopwatch and by counting heel-strikes, respectively. To avoid the effects of acceleration and deceleration, measurements were taken from the middle 10 m of a 14-metre walkway. Two minutes of rest was given between the two trials. Gait speed was calculated as the distance divided by the time and cadence was calculated as the number of steps divided by the time. Two trials of data were obtained by the same independent physical therapist and were averaged.

Independent-samples t-test and chi-square test were used to compare demographic data between groups. A between-groups homogeneity evaluation of the balance and gait performance without AFO was carried out using the independent-samples t-test. The paired t-test was used to compare test performance with wearing and without wearing the AFO. A level of $p < 0.05$ was considered statistically significant.

Results

Twenty-three male and 19 female subjects with hemiparesis of short duration participated in the study. Fifteen were left hemiparesis and 27 were right hemiparesis. The mean age of subjects was 59.9 ± 13.0 years and mean onset duration was 101.0 ± 51.3 days. Fifty-one male and 10 female subjects with hemiparesis of long duration participated in the study. Twenty-six were left hemiparesis and 35 were right hemiparesis. The mean age of subjects was 62.3 ± 11.8 years and mean onset duration was 1043.6 ± 1104.9 days. There were no differences between these two groups in hemiparetic side, age, and all variables of the balance and gait performance without AFO. However, results of the chi-square test were significant ($p = 0.002$) for gender between these two groups. Therefore, preliminary statistical analyses for gender were conducted to verify that the observed results were not confounded by gender. The analysis on these data showed no gender differences. We concluded that gender had virtually no effect on the present results.

In the group with hemiparesis of short duration, the weight bearing was more evenly distributed ($p = 0.042$, 95% confidence interval (CI) 0.521, 7.325) and the body sway was less when subjects stood on the foam surface ($p = 0.020$, 95% CI 0.020, 0.680 with eyes open; $p = 0.041$, 95% CI 0.023, 0.921 with eye closed) with an AFO than without (Table 1). The movement velocity was faster toward the non-affected ($p = 0.008$, 95% CI -2.223, -0.377) and affected side ($p = 0.037$, 95% CI -0.978, -0.042) during the LOS test with an AFO than

Table 1 Comparisons of static standing balance in subjects with hemiparesis of short duration (≤six months) between wearing and not wearing an AFO ($n = 42$)

	Without AFO	With AFO	*p*-value	95% Confidence interval
Weight-bearing difference in standing (%)	16.83±10.94	12.83±8.13	0.042*	0.521, 7.325
Body sway (deg/s)				
Standing on firm surface				
Eyes open	0.31±0.16	0.29±0.20	0.647	−0.058, 0.091
Eyes closed	0.36±0.21	0.45±0.40	0.235	−0.225, 0.058
Standing on foam surface				
Eyes open	1.40±1.01	1.05±0.90	0.020*	0.020, 0.680
Eyes closed	4.16±1.98	3.69±0.99	0.041*	0.023, 0.921

Data are expressed as mean±SD.
*$p < 0.05$ versus with AFO.

without (Table 2). Also, the maximal excursion toward the affected side was increased with wearing an AFO ($p = 0.042$, 95% CI −19.546, −0.071) (Table 2). However, the performance of the sit-to-stand test or the Berg Balance Score was not different between wearing an AFO and without (Table 3). The self-selected speed ($p = 0.028$, 95% CI −0.204, −0.017) and cadence ($p = 0.021$, 95% CI −22.983, −1.864) were increased when subjects wore an AFO in a 10-metre walk test (Table 3). All the recorded and analysed data are presented in Tables 1–3. By contrast, in the group with hemiparesis of long duration, an AFO did not have an appreciable effect in improving static and dynamic balance (Tables 4 and 5), gait speed and cadence (Table 6), or Berg Balance Score (Table 6). All the recorded and analysed data are presented in Tables 4–6.

Table 2 Comparisons of dynamic standing balance (limit of stability test) in subjects with hemiparesis of short duration (≤six months) between wearing and not wearing an AFO ($n = 42$)

	Without AFO	With AFO	*p*-value	95% Confidence interval
Movement velocity (deg/s)				
Anterior	1.91±1.48	2.10±0.96	0.545	−0.819, 0.444
Posterior	1.31±0.91	1.66±1.47	0.311	−1.037, 0.345
Sound side	2.84±1.53	4.14±2.14	0.008**	−2.223, −0.377
Affected side	3.15±2.18	3.66±1.41	0.037*	−0.978, −0.042
Maximum excursion (%)				
Anterior	51.29±25.91	55.54±20.17	0.277	−12.141, 3.641
Posterior	40.04±22.26	44.00±25.93	0.499	−15.885, 7.968
Sound side	75.50±21.42	68.54±33.37	0.317	−7.124, 21.041
Affected side	56.17±30.02	66.04±34.83	0.042*	−19.546, −0.071
Directional control (%)				
Anterior	51.17±30.66	54.63±24.49	0.059	−7.180, 0.335
Posterior	24.42±29.64	26.75±29.96	0.731	−16.215, 11.549
Sound side	73.33±17.69	62.25±30.35	0.130	−3.513, 25.680
Affected side	58.13±30.27	56.83±32.48	0.856	−13.267, 15.851

Data are expressed as mean±SD.
*, **$p < 0.05$, $p < 0.01$ versus with AFO.

Table 3 Comparisons of balance and gait in subjects with hemiparesis of short duration ($\leq$ six months) between wearing and not wearing an AFO ($n = 42$)

	Without AFO	With AFO	*p*-value	95% Confidence interval
Sit to standing[a]				
Rising time (%)	13.48 ± 7.52	12.43 ± 7.45	0.257	− 0.816, 2.903
Weight transfer (s)	0.79 ± 0.65	0.99 ± 0.85	0.068	− 0.422, 0.017
COG sway (deg/s)	3.21 ± 1.29	3.23 ± 1.23	0.921	− 0.473, 0.430
Berg Balance Scale[b]	51(37 ~ 56)	51(37 ~ 56)	0.862	− 0.556, 0.470
Gait[c]				
Speed (m/s)	0.58 ± 0.29	0.69 ± 0.41	0.028*	− 0.204, − 0.017
Cadence (step/min)	75.06 ± 27.47	87.26 ± 26.93	0.021*	− 22.983, − 1.864

[a,c]Mean ± SD; [b]median (range).
*$p < 0.05$ versus with AFO.

Discussion

In the present study, we found the weight bearing was more evenly distributed when subjects wore an AFO than subjects did not. This finding agrees with the findings reported by Chen *et al*.[21] It has been found that the centre of pressure is shifted to a more lateral position with the use of an AFO.[22] Balmaseda *et al*. speculated that this effect is probably an attempt of the body to increase the base of support for stability.[22] It is reasonable to conclude that weight bearing through the affected leg improved with wearing an AFO because the AFO provided ankle stability by keeping the ankle joint in good alignment and giving external support. Our results showed that the maximal excursion toward the affected side increased with wearing an AFO in subjects with shorter duration. This also supports a previous finding that the greater the weight borne by the affected leg, the greater the range through which the subject could shift his or her weight.[23] The maximal excursion means the farthermost distance travelled by the COG during trial. The maximum excursion score may indicate the 'true' physical distance limitation (due to joint contracture, weakness, muscle tightness or increased muscle tone), or the 'perceived' distance limitation (due to inexperience, fear or perceptual difficulty).[24] The increased maximal excursion and movement velocity in our subjects with shorter onset duration may result from improvement of both the 'true' and 'perceived' limitations when wearing an AFO. The directional

Table 4 Comparisons of static standing balance in subjects with hemiparesis of long duration ($\geq$12 months) between wearing and not wearing an AFO ($n = 61$)

	Without AFO	With AFO	*p*-value	95% Confidence interval
Weight-bearing difference in standing (%)	13.93 ± 12.18	12.31 ± 12.36	0.256	− 1.21, 4.465
Body sway (deg/s)				
Standing on firm surface				
Eyes open	0.31 ± 0.24	0.31 ± 0.25	0.955	− 0.066, 0.062
Eyes closed	0.33 ± 0.31	0.37 ± 0.62	0.550	− 0.205, 0.110
Standing on foam surface				
Eyes open	1.31 ± 0.95	1.16 ± 0.50	0.096	− 0.028, 0.329
Eyes closed	4.45 ± 1.69	4.61 ± 1.63	0.488	− 0.628, 0.305

Data are expressed as mean ± SD.

Table 5 Comparisons of dynamic standing balance (limit of stability test) in subjects with hemiparesis of long duration ($\geq$12 months) between wearing and not wearing an AFO ($n = 61$)

	Without AFO	With AFO	*p*-value	95% Confidence interval
Movement velocity (deg/s)				
Anterior	1.88 ± 1.19	2.05 ± 1.35	0.310	−0.512, 0.166
Posterior	1.08 ± 1.12	1.32 ± 1.35	0.062	−0.498, 0.019
Sound side	3.05 ± 1.99	3.43 ± 2.13	0.071	−0.797, 0.034
Affected side	2.91 ± 1.88	2.81 ± 1.88	0.672	−0.365, 0.561
Maximum excursion (%)				
Anterior	52.85 ± 23.45	53.42 ± 23.18	0.764	−4.322, 3.189
Posterior	34.32 ± 21.70	34.92 ± 21.18	0.827	−6.061, 4.861
Sound side	73.93 ± 18.52	71.62 ± 23.55	0.392	−3.064, 7.697
Affected side	60.12 ± 23.99	61.12 ± 26.17	0.712	−6.402, 4.402
Directional control (%)				
Anterior	55.30 ± 32.69	55.93 ± 32.37	0.825	−6.341, 5.074
Posterior	26.43 ± 29.59	25.48 ± 29.38	0.811	−6.971, 8.871
Sound side	73.40 ± 16.84	71.22 ± 21.34	0.414	−3.124, 7.491
Affected side	67.08 ± 21.07	65.07 ± 29.14	0.497	−3.890, 7.924

Data were expressed as mean ± SD.

control that indicates the movement co-ordination, did not change with wearing an AFO in both groups.

Few studies have reported the effects of AFOs on postural stability and balance in hemiplegic patients. Mojica *et al*. investigated the effect of AFO on body sway in eight post-stroke hemiparetic patients.[25] They reported that when patients were not wearing an AFO, the centre of foot pressure moved toward the nonaffected limb and the body sway was large. With an AFO, the centre of foot pressure shifted to the mid-position and body sway became small. In our study, for subjects with short and long onset duration, the effect of AFO on body sway was not significant when they stood on the firm surfaces. However, for subjects with short onset duration, the body sway was significantly decreased when they stood on the foam surface with eyes either open or closed. In our study, the subjects were tested with their eyes closed while quiet standing, a situation that would force them to rely more on somatosensory inputs. Brace use has been reported to increase proprioception, that is, increased afferent feedback from

Table 6 Comparisons of balance and gait in subjects with hemiparesis of long duration ($\geq$12 months) between wearing and not wearing an AFO ($n = 61$)

	Without AFO	With AFO	*p*-value	95% Confidence interval
Sit to standing[a]				
Ring time (%)	13.76 ± 6.58	13.83 ± 7.21	0.895	−1.091, 0.955
Weight transfer (s)	0.96 ± 1.23	0.94 ± 1.26	0.572	−0.068, 0.122
COG sway (deg/s)	3.19 ± 1.09	3.23 ± 1.28	0.724	−0.248, 0.173
Berg Balance Scale[b]	51(36 ∼ 56)	52(36 ∼ 56)	0.553	−0.437, 0.237
Gait[c]				
Speed (m/s)	0.61 ± 0.27	0.71 ± 0.34	0.095	−0.214, 0.019
Cadence (step/min)	75.81 ± 31.21	88.82 ± 27.77	0.068	−27.071, 1.042

[a,c]Mean ± SD; [b]median (range).

cutaneous receptors.[26] The positive effect of AFO on a static postural stability was significant when standing on a foam surface with eyes open or eyes closed in subjects with hemiparesis of short duration. Such findings were not noted in subjects with long post-onset duration that may be attributable to the chronicity of the stroke. Moreover, it was noted that loss of alignment occurs early in recovery, whereas loss of range and muscle shortening occur over time.[13] Structural change of the ankle joint perhaps contributes to no immediate improvement with AFO in subjects with hemiparesis of long duration.[27]

In our subjects, especially those with shorter onset duration, we found they walked faster with increased cadence when wearing an AFO. Chen *et al*. investigated the influence of AFOs on hemiplegic gait and reported that walking velocity was increased and the forefoot's weight bearing at heel-strike was decreased in patients wearing an AFO.[28] With the use of AFOs, a significant decrease in the mean total duration of the stance phase was noted.[28] The reduction in the mean total duration is primarily due to the reduction in the time between the peaks of heel-strike and push-off. The AFO being semirigid does not allow for the smooth translation of forces across the foot. Therefore, it progresses more rapidly through the midstance period.[22] Walking speed and cadence usually decrease in hemiparetic gait pattern. The mean walking speed of healthy men aged over 60 is 1.18 m/s and that of healthy women 64 years of age and older is 0.96 m/s.[29] Although AFOs increased the walking speed of our subjects, the mean value was still low compared with that of healthy people.

Two proposed explanations for restrictive ankle support may impair postural control: either the proprioceptive input important for postural control that is normally induced by ankle motion was decreased as a result of ankle supports with restrictive properties, or the brace, by limiting ankle joint movement, physically prevented normal ankle strategy.[30] However, the results of our study showed that there was no influence of AFO on postural control. When wearing an AFO, the dynamic stability of lateral weight shifting improved in subjects with short onset duration. We also found the movement velocity increased during the LOS test toward the direction of affected and nonaffected side with wearing AFO.

In summary, for the subjects with hemiparesis of less than six-month duration, the AFO improved the symmetry in quiet standing and improved the dynamic standing balance. The increase of speed and cadence were also noted in our subjects. For the subjects of long duration over 12 months, an AFO has only a weak effect on balance and gait. The effects of AFOs that resulted from better weight transference to the affected side or from the relative rigidity of the AFOs require further investigation.

Clinical messages

- This study indicates that an ankle-foot orthosis (AFO) improves the symmetry in quiet standing and the dynamic standing balance for the subjects with hemiparesis of less than six months duration. The increase of speed and cadence were also noted.
- For the subjects with hemiparesis of duration over 12 months, AFOs have a weak effect on balance and gait.

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