Anterior Ankle-Foot Orthosis Effects on Postural Stability in Hemiplegic Patients

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ABSTRACT. Chen C-L, Yeung K-T, Wang C-H, Chu H-T, Yeh C-Y. Anterior ankle-foot orthosis effects on postural stability in hemiplegic patients. Arch Phys Med Rehabil 1999;80:1587-92.

Objectives: To evaluate the effects of an anterior ankle-foot orthosis (AFO) on static and dynamic postural stability in hemiplegic patients.

Design: A cross-sectional assessment of hemiplegic subjects with and without an AFO.

Setting: Outpatient department of a rehabilitation hospital.

Patients: A convenience sample of 24 subjects who had been prescribed an anterior AFO.

Outcome Measures: Postural sway index and postural symmetry (body weight distribution through the affected leg) when standing were measured as static postural stability. Maximal balance range in anterior-posterior and lateral directions and the affected leg's weight bearing after weight shift to affected side were measured as dynamic postural stability.

Results: When wearing the anterior AFO, there was no significant difference and small effect size ($r < 0.3$) in postural sway index ($p = .35$), postural symmetry ($p = .21$), and maximal balance range in anterior-posterior direction ($p = .46$). There was a significant improvement and large effect size ($r > 0.5$) in lateral weight shifting ($p < .01$) and weight bearing through the affected leg after weight shifted to the affected side ($p < ,01$).

Conclusions: The significant effects of the anterior AFO in long-term hemiplegic patients were on lateral weight shifting and weight bearing through affected leg after weight shifted to the affected side. Postural sway, postural symmetry, and anterior-posterior weight shifting were not significantly affected.

ALTERATIONS IN postural stability or balancing are common among adults with hemiplegia.[1-8] Postural stability is the ability to maintain or control the center of mass in relation to the base of support to maintain static postures and to complete desired movements.[9] Balancing is the process by which postural stability is maintained. The ability to keep the center of mass within the base of support when maintaining static postures is operationally defined as static postural stability. The ability to move the center of mass in relation to the base of support in a controlled manner when engaged in movements is operationally defined as dynamic postural stability.

Studies[1-5] have demonstrated impairments of static postural stability in poststroke patients, including an uneven weight distribution in stance with less weight placed on the affected leg and an increase in sway during quiet standing. Other studies[6-8] have addressed the deficiencies of dynamic postural stability in hemiplegic patients. Pai and colleagues[6] noted unsuccessful weight transfer in the frontal plane during transitions from bipedal to single-limb stance in hemiplegic patients. Di Fabio and coworkers[7] reported that the direction of visually cued sway that resulted in the greatest instability for hemiplegic patients was in the sagittal plane. Turnbull and associates[8] found that even functionally ambulant hemiplegic patients demonstrated marked limitations in the capacity to shift weight and possessed a reduced range of weight shift. The greater the weight borne by the paretic limb, the greater the distance the patient could shift his or her weight, and a significant relation between postural instability and walking performance was found by Dettman and colleagues.[4]

Ankle-foot orthoses (AFOs) are frequently prescribed for hemiplegic patients to correct the ankle joint, increase walking speed, and reduce energy expenditure during ambulation. They allow ambulatory safety by ensuring mediolateral stability during stance and adequate toe clearance during swing.[10-13] There are various AFO designs. Metal orthoses have gradually been replaced by plastic AFOs,[14] because metal orthoses are heavy and have a poor cosmetic appearance.[15,16] Conventional plastic AFOs are designed in posterior leaf type and fabricated by a lamination or vacuum-forming technique over a positive plaster model of the limb.[10] These types of AFOs are not suitable for walking barefoot indoors, as is the custom in Taiwan.

A low-temperature ankle-foot orthosis called an anterior AFO was designed in the anterior leaf type (fig 1); it is suitable for walking barefoot indoors, as well as for walking with a shoe. This low-temperature plastic anterior AFO can be fabricated to a custom fit quickly and easily. It is commonly used for hemiplegia with spasticity in Taiwan.[17] Wong and colleagues[18] reported 46 of 68 (67.6%) patients with short-term hemiplegia could ambulate better with the anterior AFO objectively with no complaints of subjective discomfort. The effect of the AFO on improving hemiplegic gait pattern was noted by Wong in the study. Chen and associates[19] investigated the influence of the anterior AFO on hemiplegic gait and reported that walking velocity was increased and the forefoot's weight bearing at heel strike was decreased in patients wearing the anterior AFO.

In the literature, however, efficacy studies of AFOs emphasize the effects of gait. Few studies have reported the effects of AFOs on postural stability and balance in hemiplegic patients. Mojica and associates[20] investigated the effect of an AFO on body sway in eight poststroke hemiparetic patients. They

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Submitted for publication November 20, 1998. Accepted in revised form June 1, 1999.

No commercial party having a direct financial interest in the results of the research supporting this article has or will confer a benefit upon the authors or upon any organization with which the authors are associated.

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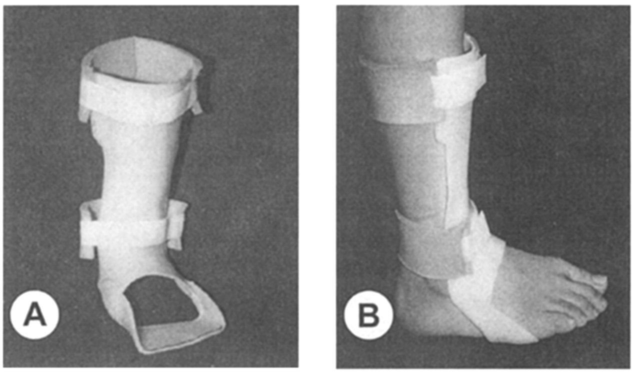

Fig 1. (A) The anterior AFO. (B) The fitting of anterior AFO.

reported that when patients were not wearing an AFO, the center of foot pressure moved toward the nonaffected limb and the body sway was large. With an AFO, the center of foot pressure shifted to the midposition and body sway became small. With respect to these earlier findings, and in light of the overall changes in posture or balance function that commonly accompany strokes in adults, this study examined the effects of the anterior ankle-foot orthosis on postural stability in hemiplegic patients.

METHODS

Subjects

A convenience sample of 24 hemiplegic patients who had been prescribed an anterior AFO was selected from the outpatient department in Taichung Rehabilitation Hospital. Criteria for selection were as follows: (1) diagnosis of unilateral hemiparesis caused by cerebral vascular disease; (2) ability to stand without external support for 60 seconds and perform anterior-posterior (AP) and lateral weight shifting; (3) ability to follow simple verbal command or instruction; and (4) no history of significant orthopedic problems related to the foot.

There were 17 men and 7 women included in the study; 15 (10 men, 5 women) had right and 9 (7 men, 2 women) had left hemiplegia. The mean age of the subjects was 58.9 years (SD, 9.5; range, 43 to 76 yrs) and the median duration of their disabilities was 13 months (range, 3 to 120 mo). All subjects underwent rehabilitation after stroke and were prescribed the anterior AFO during ambulation training. All subjects had asymmetrical hemiplegic gait pattern and most used the AFO for everyday ambulation. Seven subjects used a regular cane, 12 walked with a quad cane, and the remaining 5 subjects did not use walking aids.

Instruments

The Computer Dyno Graphy system,[a] a portable, modular, and programmable system for gait analysis, was used to collect data. It measures the ground reaction force under the feet while subjects walk by using two measuring shoes, each with eight load sensors; it can be worn with or without footwear. The force values are stored in a portable unit. After the measurement, the unit is connected to a computer for data analysis and graphic representation. In this study, the subjects wore the prepared uniform soft slip-on shoes under the measuring shoes. We used the Computer Posturo Graphy[a] program to measure the standing stability and weight shifting. This unit is a modular expansion of the Computer Dyno Graphy system. In addition to the measuring components of the Dyno Graphy, a horizontal adjustable stabiloboard marked with two footprints on the surface was designed to ensure the subjects standing on a horizontal plane and to ensure the consistent foot placement for each test. A stabile analysis program was used to measure results.

Procedure

Informed consent was obtained from subjects eligible for the study. For static postural stability test, subjects were asked to stand on the stabiloboard quietly for 30 seconds,[21] keeping the feet still and the arms relaxed at both sides. To consider the subjects' tolerance, a 10-second period was chosen for each of the following weight shifting task. For AP weight shifting, patients were asked to lean forward from the ankles, without moving the feet, as far as possible to where they could just retain balance for 10 seconds. They were then asked to lean back as far as possible. For the lateral weight shifting test, patients were asked to shift as much weight as possible to the left for 10 seconds then to the right. They kept their trunk in an upright position without leaning to one side during the weight shift. The subjects were guarded for safety during the test. The Computer Dyno Graphy unit monitored the pressure at a frequency of 100Hz for 40 seconds for the weight shifting task and 30 seconds for standing stability. Patients were randomly assigned to wearing or not wearing the anterior AFO and the order of the two postural stability tests. They were permitted to rest between tests.

Data Processing

Postural sway index and body weight distribution through the affected leg were derived from data as indicators of static postural stability. Maximal balance range in AP and lateral dimension and body weight distribution through the affected leg after weight shifting to the affected side were calculated as indicators of dynamic postural stability.

In the Computer Posturo Graphy program, the center of pressure was calculated by multiplying the force on each sensor by the position of the sensor and averaging the results. As a consequence, the center of pressure is dependent not only on the value of the force, but also on the location of the sensors. In the Computer Posturo Graphy program, the sensor positions were normalized to obtain a picture that was visually the same for all shoes sizes. The sensor positions were such that the feet, as displayed, fit into a square with the range of -1000 to $+1000$. So the arbitrary instantaneous X-Y coordinate of the center of pressure was calculated. The maximal balance range of weight shift was measured by calculating the distances between the furthermost limit of the position of the center of pressure attained laterally and anteroposteriorly. The mean position of the center of pressure during the 30 seconds was recorded as Xm, Ym coordinate. The software calculated the standard deviation of the X array (Xsd) and Y array (Ysd) as the offset X-Y coordinate from the mean center of pressure (Xm, Ym). The average offset value was determined as the postural sway index according to the following equation: postural sway index $= \sqrt{Xsd^2 + Ysd^2}$. The total mean force value for each sensor under the affected foot was calculated and displayed as a percentage of the total mean force under two feet. It was shown as body weight distribution through the affected leg.

Paired t test was used to compare test performance with use of the AFO to performance without the AFO. Because of the multiple statistical comparison being run, a level of significance of $p < .01$ was accepted as the minimum for a significant finding. To demonstrate the degree to which the anterior AFO has an influence on postural stability, the effect size r was

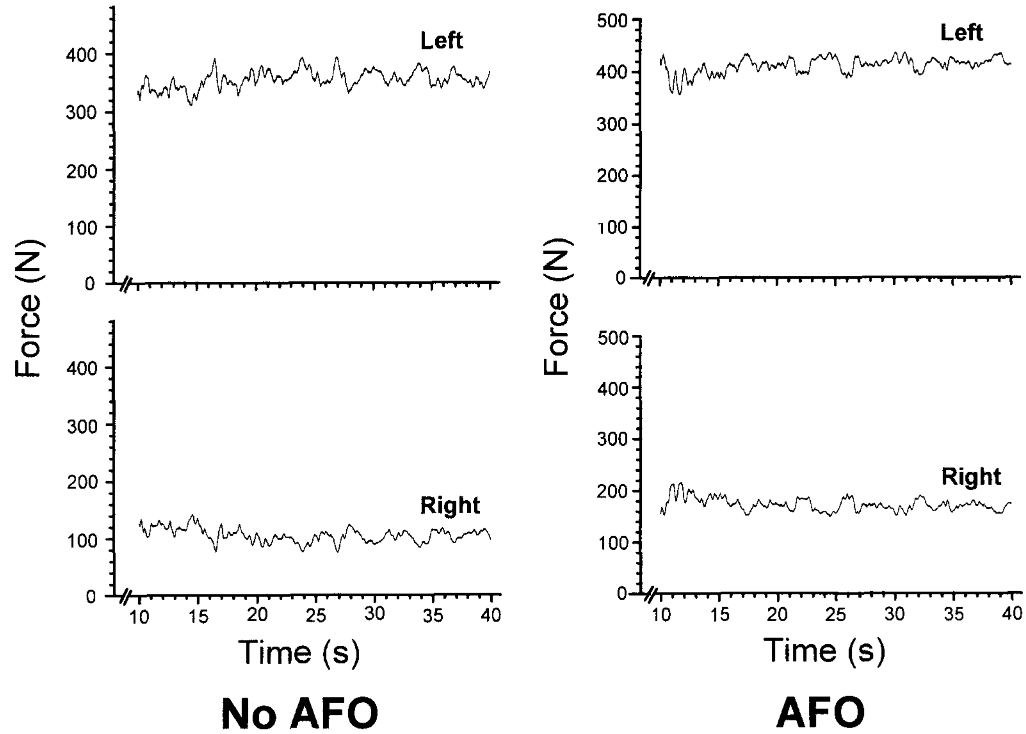

Fig 2. Vertical force diagrams during quiet standing for a right hemiplegic subject. The forces under the foot are summed and displayed as a function of time.

calculated for each dependent variable using procedures described by Rosenthal and Rosnow.[22]

RESULTS

The vertical force diagrams (forcegraph), the mean force value for each sensor (histogram), and the changing points of center of pressure (stabilogram) under both feet are shown in figures 2, 3, and 4, respectively, for a subject during quiet standing without and with the anterior AFO. The means and standard deviations of the postural stability variables for the subjects with and without the anterior AFO are presented in table 1. Wearing the anterior AFO resulted in no significant difference and small effect in postural sway index ($t = -.96$, $r = .20$, $p = .35$) or body weight distribution through the affected leg ($t = 1.28$, $r = .26$, $p = .21$). Four phases were found using the vertical force diagrams of both lower limbs without and with the anterior AFO after the start of the weight shift procedure (fig 5). Changing points of center of pressure are shown in figure 6. There was a significant improvement and large effect in lateral weight shifting ($t = 2.90$, $r = .52$, $p = .008$) and weight bearing through affected leg after weight shifting to the affected side ($t = 3.36$, $r = .57$, $p = .003$), but there was no significant difference and small effect in AP weight shifting when wearing the anterior AFO ($t = -.75$, $r = .15$, $p = .46$).

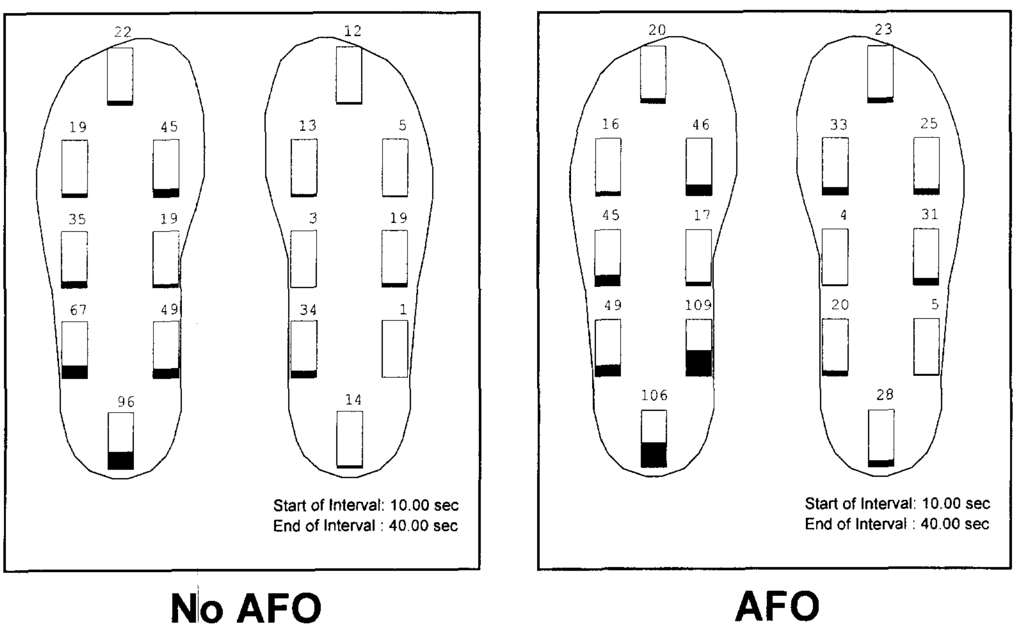

Fig 3. Mean force value for each sensor during quiet standing for a right hemiplegic subject. The graph represents the mean forces on each of the sensors in the form of two footprints in which the position of the sensors are displayed as rectangles. The exerted force is represented by a proportional black part of the rectangle and its value.

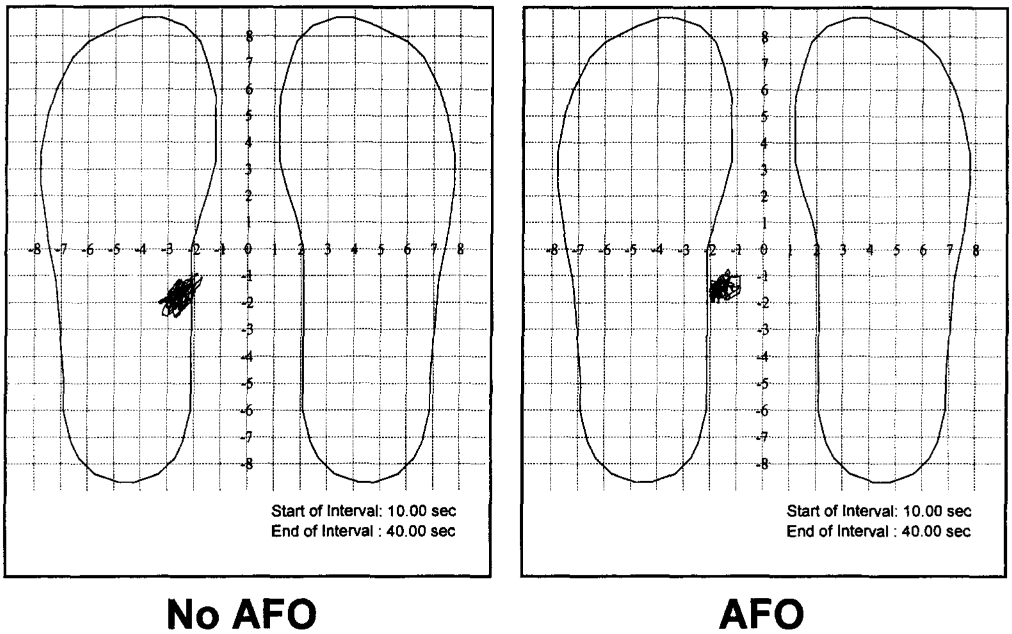

Fig 4. Changing points of center of pressure during quiet standing for a right hemiplegic subject. The trajectory is formed by the changing position of the application point of the resultant normal force on a virtual supporting horizontal plane during standing. The position of both feet displayed in the graph is standardized.

DISCUSSION

Nearly all of the patients in our study had long-term hemiplegia; the median duration postonset was 13 months. Our results show that their standing asymmetry was not obvious. Their mean body weight distribution through the affected leg was 44.21% while wearing the AFO and 41.72% without the AFO, a difference in body weight distribution that was not significant. In the system model, balance is a complex process involving the integration of mechanical, sensory, and motor processing strategies that permit upright standing. It has been hypothesized that the central nervous system also has an internal map or "unconscious perception" of stability limits that in pathologic or unusual circumstances may be inconsistent with the actual mechanical limits of stability.[23] Though the anterior AFO might improve ankle stability, the hemiparetic subjects still had a "habitual" postural alignment. Also, quiet standing is normally a highly automatic activity. Further research is needed to examine the effects of the AFO on postural stability in short-term hemiplegic patients.

Table 1: Comparison of Static and Dynamic Postural Stability in Hemiplegic Subjects Without and With AFO

Outcome Measure	Without AFO	With AFO	*p* Value
Static postural stability			
Postural sway index	48.40 ± 13.80	44.18 ± 21.24	.346*
Body weight on affected leg (%)	41.72 ± 10.47	44.21 ± 10.53	.213*
Dynamic postural stability			
Maximal balance range			
Anterior-posterior	483.46 ± 182.76	462.88 ± 157.49	.46*
Left-right	571.71 ± 172.61	654.58 ± 168.74	.008†
Body weight on affected leg (%)	53.99 ± 13.12	61.42 ± 12.34	.003†

Values are reported as mean ± standard deviation.
* Not significant by the paired *t* test.
† Significant at $p < .01$ by the paired *t* test.

All the visual, proprioceptive, and vestibular systems are critical sources of afferent information that influence the control of stability.[24] By eliminating visual input, it is possible to investigate stability in a more challenging situation. Geurts and colleagues[25] suggested that visual deprivation during quiet standing appears to be a simple, sensitive test for postural instability related to sensory integration deficit. In our study, the subjects were not tested with their eyes closed while quietly 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 cutaneous receptors.[26] It is unclear whether the effect of the AFO on static postural stability would be revealed when standing with eyes closed.

Weight bearing through affected leg after weight shifting improved while wearing the AFO, which can be explained since the AFO provides ankle stability by keeping the ankle joint in good alignment and giving external support[17]; thus, it is beneficial for weight bearing. The result that the maximal lateral balance range increased with the AFO supports a previous study in finding that the greater the weight borne by the affected leg, the greater the range the subject could shift his or her weight.[4] The transference of weight to the hemiplegic leg is essential in gait pattern because it allows the opposite leg to be moved and, consequently, a step to be taken. It was assumed that the improved weight bearing on the affected leg contributed to the improved walking velocity with the AFO as shown in a previous study.[19]

The maximal balance range in AP direction did not improve as expected; the mean of the AP balance range was less while wearing the AFO. In our study, the test of AP weight shift was devised within the inverted pendulum model of the upright body stance.[27] The AFO limits the movement of the ankle joint, so it influences the AP weight shifting performed by moving the body as a relatively rigid mass about the ankle joints. The most common response to subtle perturbations involves an ankle

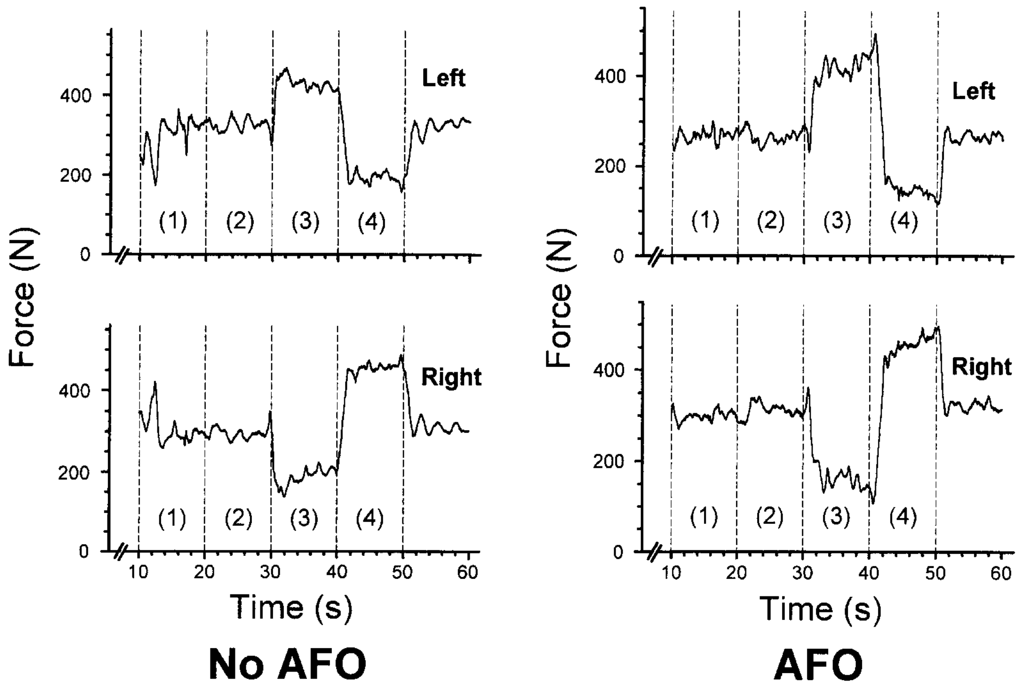

Fig 5. Vertical force diagrams during weight shift for a right hemiplegic subject. The forces under the foot are summed and displayed as a function of time. Phases of the weight shift are marked by (1) shift to anterior, (2) posterior, (3) left, (4) right.

strategy. In this strategy, equilibrium is restored by moving the body primary around the ankle joint. Further research is needed to investigate the effect of the AFO on postural reaction by ankle strategy.

The effect of an ankle brace on balance in subjects with ankle sprain has been investigated; these studies reported that ankle brace use had positive effects on balance.[28,29] Bennell and Goldie,[30] however, reported that for 24 healthy individuals, the use of ankle braces had a significant detrimental effect on postural control. They suggested restriction of ankle movement as a possible explanation for the results, because postural control was impaired only by the ankle supports, which limited ankle motion. In their study, postural control was determined by the variability of mediolateral ground reaction force and frequency of foot touch-downs by the nonsupporting leg while the subjects attempted to maintain one-legged stance posture with the eyes closed. They proposed two explanations for the finding that restrictive ankle support impairs 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 from being used to maintain one-legged stance. It is important to realize that the results obtained from their study can only be generalized to normal, healthy, and young athletic subjects with one-legged stance. Further research is needed to clarify the effects of the restrictive AFO on postural control in hemiplegic patients.

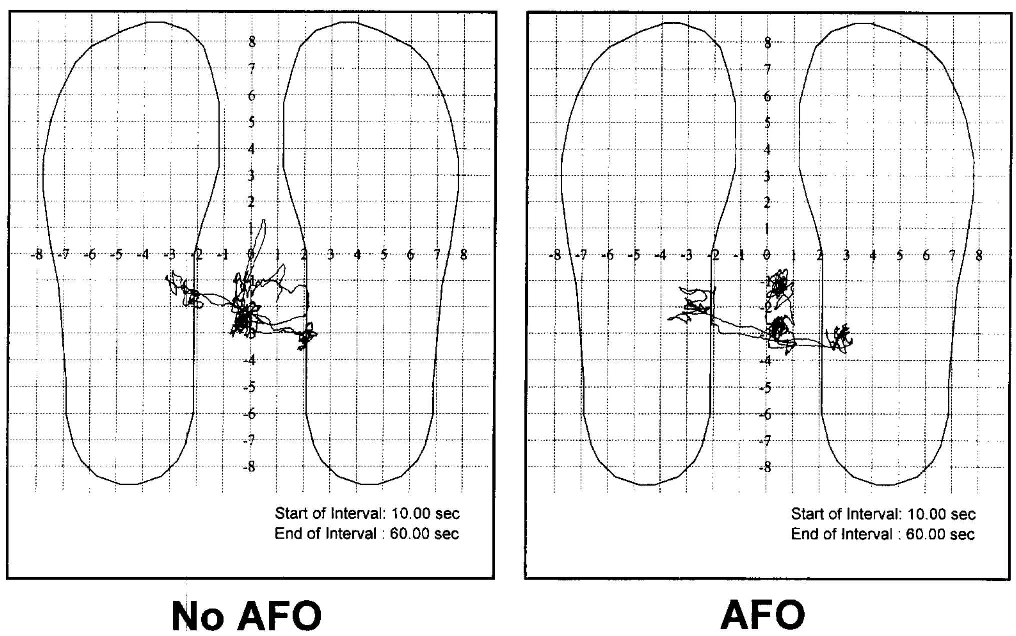

Fig 6. Changing points of center of pressure during weight shift for a right hemiplegic subject. The trajectory is formed by the changing position of the application point of the resultant normal force on a virtual supporting horizontal plane during weight shift. The position of both feet displayed in the graph is standardized.

CONCLUSIONS

The results of this study showed that there was no negative effect of the anterior AFO on postural stability. When wearing the AFO, the dynamic stability of lateral weight shifting improved.

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