Tohoku J. exp. Med., 1988, **156**, 395-401

Effect of Ankle-Foot Orthosis (AFO) on Body Sway and Walking Capacity of Hemiparetic Stroke Patients

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MOJICA, J.A.P., NAKAMURA, R., KOBAYASHI, T., HANDA, T., MOROHASHI, I. and WATANABE, S. *Effect of Ankle-Foot Orthosis (AFO) on Body Sway and Walking Capacity of Hemiparetic Stroke Patients*. Tohoku J. exp. Med., 1988, **156** (4), 395-401 —— Body sway, the total length of the sway of the center of foot pressure (CFP) and maximum walking speed were examined with and without AFO in eight post-stroke hemiparetic patients. Without AFO, the CFP moved towards the non-affected limb and the body sway was large. Wearing AFO, the CFP shifted to the midposition and the body sway became small. Without AFO, the time to walk the prescribed distance was longer, the cadence slower and the steps shorter than with AFO. However, there was no correlation between the improvements in body sway and walking capacity. The AFO compensated only for the instability of the ankle joint but not for the dysfunction of the central nervous system after the stroke. ——— AFO ; body sway ; walking speed ; stroke

Previous studies have shown that in hemiplegic patients the greater the body sway or postural instability the poorer the walking capacity (Dettmann et al. 1987 ; Nakamura and Hosokawa 1988). Bohannon et al. (1984) and Bohannon (1987), measuring the ability to balance with the eyes open or closed and the feet together in normal subjects 20 to 79 years old and in hemiplegic patients, reported that dysfunction of balance correlated strongly with age and the ability to walk, i.e., the balance decreased with age and that as the balance improved, so did gait performance. In stroke, unilateral hemispheric lesions could bring about dysregulation of posture, balance and locomotion, thus producing instability in

Received September 2 1988 ; revision accepted for publication November 15, 1988.

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standing and gait abnormality and peripherally weakness of the affected lower limb muscles as well as mediolateral instability of the ankle joint would increase body sway and hinder walking performance (Perry 1969 ; Nakamura et al. 1985 ; Lehman et al. 1987 ; Nakamura and Hosokawa 1988). The use of ankle-foot orthosis (AFO) promotes ankle and foot stability and improves walking performance in hemiplegic patients (Lehmann 1979). However, the relationship of walking capacity to body sway when wearing AFO is not yet clear. The aims of this study are : 1) to assess quantitatively the effects of AFO on body sway and walking capacity of hemiparetic stroke patients and 2) to determine the relationship of improvement between the two variables when using AFO.

Method

Eight hemiparetic patients due to stroke, five males and three females aged from 46 to 66 years participated in this study. The time from onset of stroke to the examination was 7 to 32 weeks (mean : 20.7 weeks). Five patients presented with right hemiparesis and three with left. The affected lower limb showed mild to moderate muscular hypertonia but passive range of motion was within normal limits in all patients. Based on Brunnstrom's method (1970), the motor recovery stage for the affected lower limb ranged from 2 to 3. All patients could stand alone and have used plastic AFO for everyday ambulation for a mean duration of 7.5 weeks (range : 2 days-18 weeks). The AFO was manufactured by lamination over a positive mold beginning from two fingerbreadths below the fibular head with the sole plate extending to the tip of the toes. The AFO was provided with a rubber outsole and fixed with Velcro straps crossing the metatarsal, malleolar and proximal leg areas.

The body sway is calculated using a force measuring platform (Kistler 9807Y9 system, Kistler, Zurich, Switzerland) and a digital computer (PC-9801F, NEC, Tokyo) (Fig. 1).

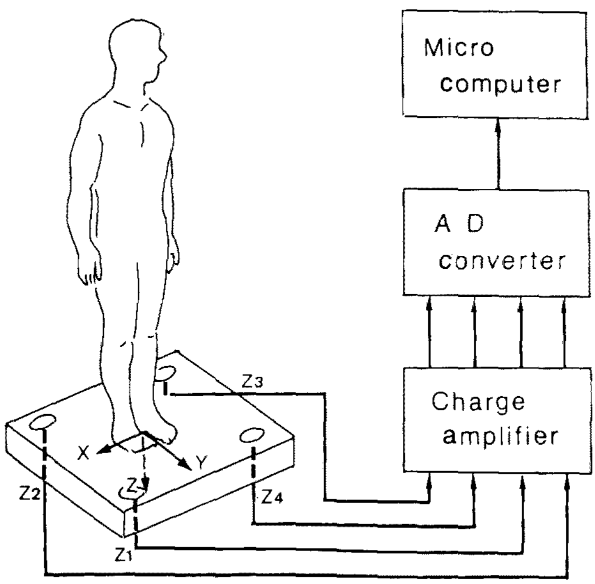
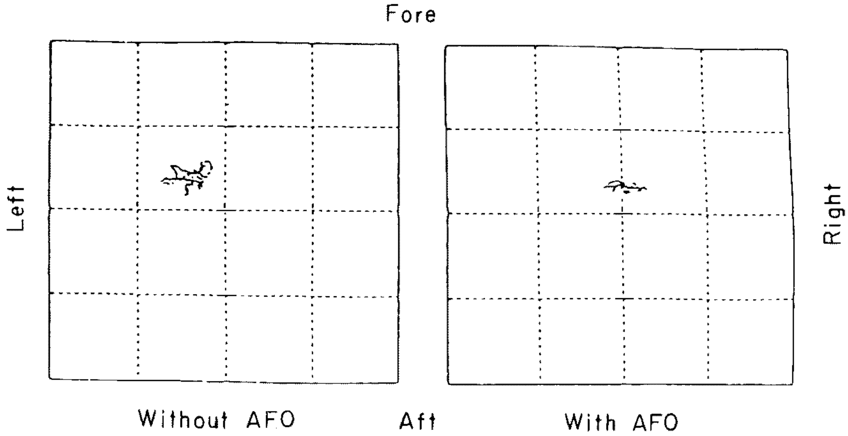


Fig. 1. Schematic presentation of CFP measurement.
X, force X ; Y, force Y ; Z, momentary center of foot pressure.



CFP (cm):	CFP (cm):
L: 1.97	R: 0.14
F: 1.98	F: 1.59
BS (cm): 38.38	BS (cm): 22.27

Fig. 2. Computer dislay of body sway in a right hemiparetic patient without and with AFO. Distance between divisions is 2.5 cm.
L, left; R, right; F, fore; BS, body sway; CFP, center of foot pressure.

The patient stands on the rectangular force platform equipped with strain gauges at its four corners, which measures the center of foot pressure (CFP). The midposition of the force platform is taken as the zero point. The CFP is the center of distribution of the total force to the supporting surface. The momentary position of CFP is described by x and y coordinates calculated from the component vertical forces (z1, z2, z3, z4) being recorded by each strain gauge: $CFPx = 4Dx \ \{(z1+z2)-(z3+z4)\}/(z1+z2+z3+z4)$; $CFPy = 4Dy \ \{(z1+z4)-(z2+z3)\}/(z1+z2+z3+z4)$ where Dx and Dy indicate the distance between strain gauges on the left and right columns as well as the fore and aft rows, respectively. The position of the CFP is determined every 10 msec for 10 sec and quantified as to its x and y values. The body sway reflects the total length of the sway of CFP approximated by the sum of the distances between successive instantaneous two sampling points: Body sway $= \sum\sqrt{(x_{i+1}-x_i)^2+(y_{i+1}-y_i)^2}$. The body sway is recorded by the computer via A/D converter with a sampling frequency of 100 Hz and is graphically displayed on the computer screen (Fig. 2).

Wearing AFO (AFO (+)) and without AFO (AFO (−)), i.e., barefoot, the patient was instructed to stand on the force platform with the head upright, eyes open and looking forward, arms at the sides and the feet together equidistant from the platform edges in the fore-aft and lateral positions, respectively. After assuming the position, the patient was asked to maintain the posture for at least 10 sec during which data were gathered. Then the patient was asked to assume his comfortable position or to rest as needed prior to proceeding to the next measurement.

To determine the effects of AFO use on the walking capacity, the patient was asked to walk 10 m as fast as possible on a level floor with and without AFO. The time (sec) and the number of steps taken to walk the 10-m distance were recorded. Three to five trials were performed and the fastest trial was chosen as the datum. The data were fed into the computer which was programmed to calculate the following gait variables: 1) walking speed (m/min), 2) walking rate or cadence (steps/min) and 3) stride length (m/stride).

Body sway and gait measurements, with and without AFO, were done in a single experimental session lasting about 30 min. The order of measurement, i.e., body sway AFO (+), body sway AFO (−), gait AFO (+) and gait AFO (−), was randomly assigned among the patients. No practice trials were necessary prior to the experimental procedure.

RESULTS

Fig. 2 shows a computer display of the body sway in a right hemiparetic patient without and with AFO. When barefoot, the CFP moves forward (1.98 cm) and left (1.97 cm) of the midposition towards the non-affected side. Wearing AFO, the CFP maintains its forward position (1.59 cm) but moves laterally close to the midposition and slightly to the right (0.14 cm), i.e., towards the paretic limb. Without AFO, the movement of CFP occupies a large area and the corresponding body sway is 38.38 cm/10 sec. Using AFO, small excursions of CFP are seen and the corresponding body sway is 22.27 cm/10 sec.

Table 1 presents the means and S. Ds. of the mean positions of the lateral and fore-aft components of CFP as well as the body sway without and with AFO. Compared to without AFO, a significant reduction was observed in the lateral component of CFP when using AFO ($p<0.05$) but not in the fore-aft component. The CFP laterally shifted toward the midposition when wearing AFO but tended to maintain its initial fore-aft position. Also, the body sway was significantly different between AFO (−) and AFO (+) ($p<0.01$), pointing out that with AFO

TABLE 1. *Means and standard deviations (in parenthesis) of the mean positions of the lateral and fore-aft components of CFP and the body sway without and with AFO*

	CFP (cm)		Body sway (cm/10 sec)
	Lateral (paretic/ non-paretic)	Fore-aft	
AFO (−)	2.42 (1.37)	2.36 (1.07)	37.93 (14.48)
AFO (+)	1.56 (1.08)	2.08 (0.90)	28.96 (9.77)
Difference	0.86 (0.96)	0.28 (0.66)	

AFO (−), without AFO ; AFO (+), with AFO.
$n=8$.

TABLE 2. *Means and standard deviations (in parenthesis) of the variables of gait cycle without and with AFO*

	Walking speed (m/min)	Walking rate (steps/min)	Stride length (m)
AFO (−)	32.80 (24.94)	91.78 (25.42)	0.64 (0.35)
AFO (+)	41.58 (30.57)	102.56 (25.77)	0.74 (0.39)

AFO (−), without AFO ; AFO (+), with AFO.

TABLE 3. *Correlation coefficients and the intercept and slope in the regression equation ($y=a+bx$) between AFO (−) and AFO (+) for body sway, walking speed, walking rate and stride length*

	r	a	b
Body sway	0.901	5.90	0.61
Walking speed	0.997	1.51	1.22
Walking rate	0.992	10.27	1.01
Stride length	0.996	0.03	1.10

r=0.834, $p<0.01$.
$n=8$.

the body sway decreased with improved standing balance.

Table 2 shows the means and S.DS. of gait measurements of the patients without and with AFO. There were significant differences in maximum walking speed, walking rate and stride length, between wearing and not wearing AFO ($p<0.01$, respectively). With AFO, the maximum walking speed, walking rate and stride length improved compared to without AFO.

Table 3 presents the correlation coefficient and the intercept (a) and slope (b) in the regression equation between AFO (−) and AFO (+) of body sway and the gait variables. Within the limits of the present study, the slope of the regression line for body sway was low (b=0.61) suggesting that the larger the body sway without AFO, the greater the decrease in body sway with AFO. As for walking speed, the slope was steep (b=1.22) indicating that the faster the walking speed without AFO, the more the increase of walking speed when using AFO.

The mean ratio AFO (+)/AFO (−) of each variable was calculated. The mean ratio of body sway relative to the mean ratio of maximum walking speed, walking rate and stride length showed no correlation, respectively. The reduction in body sway was independent of the improvement of the gait variables when wearing AFO. There were significant correlations of the mean ratio of stride length and walking rate relative to maximum walking speed ($p<0.01$, respectively).

DISCUSSION

The main findings of the study are: 1) wearing AFO significantly reduced body sway and increased the maximum walking speed and 2) there was no correlation between the reduction of body sway and the improvement in the gait variables when using AFO.

When the subject was barefoot, the CFP moved towards the non-affected lower limb and the body sway was large indicating unsteadiness of station. Similar findings have been reported by Murray et al. (1975) and Detmann et al. (1987). The movement of CFP towards the non-paretic lower limb pointed out a greater weight supporting activity borne by the non-paretic compared to the paretic lower limb. Wearing AFO compensated for the instability of the ankle joint, promoted steadiness when standing and allowed shifting of part of the body weight on the affected lower limb. Thus, the CFP with AFO (+) moved slightly towards the paretic limb and the body sway became small.

When walking barefoot the patient was unsteady during the stance phase on the affected limb and also had some difficulty clearing the floor because of foot drop during the swing phase. Consequently, the patient took fewer and shorter steps and the time needed to walk the 10 meter distance was longer. Wearing AFO significantly increased the maximum walking speed. The AFO compensated for the mediolateral instability of the ankle joint, prevented the foot drop and decreased the degree of hip-hiking during the swing phase, which resulted in the reduction of the minimum amount of energy required to cover the distance (Corcoran et al. 1970). Thus, the improvement of functional walking capacity brought about by the use of AFO was due to the stabilization of the ankle joint as well as the decrease in the energy consumption required for ambulation.

The use of AFO significantly decreased body sway and improved walking capacity but the degree of reduction in body sway was not related to the degree of improvement in walking capacity. There are two possibilities to explain what appears to be a discrepant finding. Firstly, because of the small sample size and heterogeneity of the patients in this study we could not obtain a clear correlation between the improvements in body sway and gait variables. Secondly, the disturbances in balance and gait due to stroke reflect a disorder of both central and peripheral mechanisms. The AFO compensated for the weakness and imbalance of the muscles around the affected ankle and foot thereby improving peripheral stability, but did not correct the dysfunction of the central nervous system. The present results suggest that the contribution of either central or peripheral factor to the postural and gait disturbances is different for each patient.

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