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Case Report Open Access

Gait Changes in a Hemiplegic Patient Using an Ankle-Foot Orthosis with an Oil Damper: A Case Report

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Abstract

This study utilized a single case design to evaluate the effects of an ankle-foot orthosis with an oil damper (AFO-OD) that was developed to assist heel rocker function during gait. The gait of a single patient with stroke-related hemiplegia was measured by a 3D motion analysis system. Gait without an AFO and then after training with the AFO-OD were compared. Results showed improvement in temporal and spatial parameters when the patient walked with the AFO-OD, and height and progressive velocity of the center of gravity showed the movement as an inverted pendulum as seen in ankle rocker movement during normal gait. Peak plantar flexion moment in late stance was increased despite the AFO-OD not assisting the plantar flexors. These results indicate that assistance of heel rocker function by the AFO-OD improved the gait of the hemiplegic patient.

Keywords: Ankle-foot orthosis; Hemiplegia; Rocker function; Inverted pendulum

Introduction

Hemiplegia is a common symptom seen in stroke survivors, and it causes many problems with walking pattern. Hemiplegic gait is characterized by decreased walking speed, asymmetrical walking pattern, increased energy cost, foot drop, and decreased muscle activity in stance [1-3]. Ankle-foot orthoses (AFOs) are commonly used in clinical practice to overcome these problems. The main purposes of AFOs are to prevent foot drop in swing and to stabilize the ankle joint in stance. Many studies that have shown the positive effect of AFOs were based on insufficient evidence [4]. The low level of evidence in AFO studies is due to variability in patients' conditions and difficulty adjusting AFO functions to individual patients.

The ankle joint of traditional solid AFOs are rigid to stabilize the ankle joint in stance and maintain clearance in swing. However, some AFOs have been developed to actively move the ankle joint during gait. Dynamic AFOs are designed to control alignment of ankle movement for functional range of motion during gait [5]. In a case report, Nolan et al. showed the positive effect of a dynamic AFO on a patient's overall gait, in particular improved hip joint movement during gait [6]. Also, a specially designed carbon fiber AFO that allows ankle joint movement was shown to produce significantly greater push-off in children with hemiplegia [7]. An AFO with an oil dampner (AFO-OD), which was developed to assist the heel rocker function, is another type of AFO that facilitates active ankle joint movement during gait [8]. Previous studies have shown the positive effect of the AFO-OD on the gait of stroke patients [9,10]. These studies found increased walking velocity and increased peak plantar flexor ankle joint moment after short-term use and gait rehabilitation with the AFO-OD. Because the ankle joint of the AFO-OD moves freely to dorsiflexion, it does not assist the activity of the plantar flexors. These results imply a change in muscle activity in patients related to whole body alignment during gait. Heel rocker improvement due to the AFO-OD might improve ankle rocker function.

This case report described an evaluation undertaken with a single stroke patient to determine the effect of an AFO-OD, in terms of the rocker function, during gait.

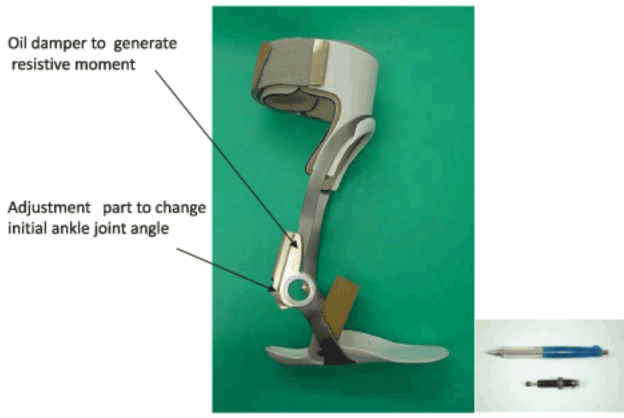

Figure 1: Structure of the ankle foot orthosis using an oil damper (AFO-OD) used in this study.

Method

Features of the AFO-OD

An AFO-OD (GaitSolution, Kawamura Gishi, Osaka, Japan) that was originally developed to assist heel rocker function was used in this study (Figure 1). Mechanical features of the AFO-OD are described in detail elsewhere [8]. Figure 2 shows a schematic illustration of the gait assistance provided by the AFO-OD. The device assists the heel rocker

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function by the resistive force generated by an oil damper attached to the ankle joint. It assists insufficient eccentric contraction of the dorsiflexors to prevent abrupt landing of the forefoot and to pull the shank forward in the loading response. The mechanical joint of the AFO-OD moves freely to dorsiflexion, which means that the AFO-OD does not assist the plantar flexors in ankle rocker function. The AFO-OD generates resistance to prevent excessive plantar flexion of the ankle joint in the forefoot rocker and swing phases. The amount of resistance to plantar flexion can be changed easily by rotating a small screw at the top of the oil damper.

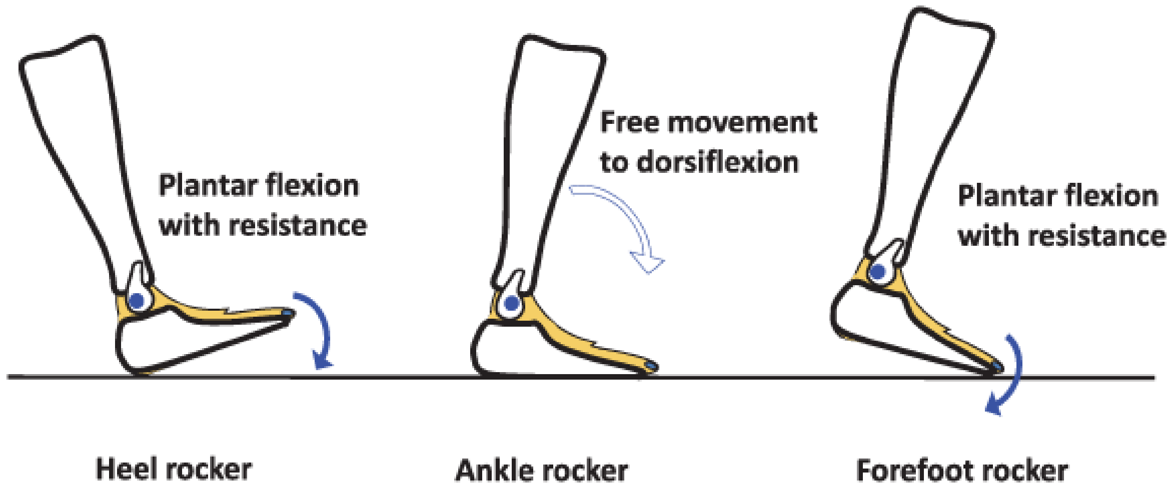

Figure 2: Schematic illustration of the effect of using the AFO-OD.

Patient and study protocol

A 77-year-old right-handed man (height 158 cm, weight 51 kg), 12 months post-stroke with right-sided hemiplegia caused by cerebral infarction, volunteered for participation. His lower limb Brunnstrom stage was IV, and he was independent in walking inside and outside. Range of motion of the joints of the paretic limb was normal. He was prescribed a traditional plastic AFO one month post-onset, and he began to use the AFO-OD 2 weeks before participating in this study. Physiotherapists explained the features of the AFO-OD to him and established gait practice to facilitate smooth heel contact at the beginning of stance phase of the paretic limb. The ankle joint of the AFO-OD moved to plantar flexion with resistance so that he could make heel contact without pushing the shank excessively forward with the AFO-OD. The physiotherapists adjusted the amount of AFO-OD resistance to obtain smooth forefoot contact in the loading response. The knee joint moved excessively forward when resistance was too great, and it remained backward when there was insufficient resistance.

Gait was measured by a 3D motion analysis system (VICON 512 with 8 cameras and 4 Kistler forceplates). A total of 16 reflective markers were attached to patient's body, and the trajectory of markers and forceplate data were measured at a sampling frequency of 100 Hz. The patient wore his own shoes and did not use any assistive devices during the measurements. Gait without an AFO was measured before he started using the AFO-OD. He used the AFO-OD in daily life for 2 weeks, after which a second measurement was taken with the AFO-OD. In both conditions, gait was measured at the patient's preferred walking speed, and measurements were repeated until the paretic limb had made contact with the force plates five times.

All procedures were approved by the Ethics Committee of the faculty and were consistent with the Declaration of Helsinki. Informed consent was obtained from the patient prior to his participation.

	w/o AFO	AFO	w/o vs. AFO
Gait velocity(m/s)	0.26 (0.04)	0.51 (0.03)	*
Stride length(m)	0.42 (0.02)	0.69 (0.02)	*
Step length paretic limb(m)	0.15 (0.03)	0.32 (0.02)	*
Step length nonparetic iimb(m)	0.27 (0.04)	0.37 (0.03)	*
Gait cycle(s)	1.60 (0.10)	1.35 (0.08)	*
Loading response of paretic limb(s)	0.47 (0.02)	0.23 (0.01)	*
Single stance of paretic limb(s)	0.34 (0.08)	0.37 (0.06)	ns
Preswing of paretic limb(s)	0.27 (0.04)	0.25 (0.03)	ns
Swing phase of paretic limb(s)	0.54 (0.05)	0.51 (0.03)	ns
			*p<0.05

Table 1: Temporal-spatial gait parameters, without an AFO and with the AFO-OD mean (SD).

Data analysis

The trajectory of markers and the forceplate data were low-pass filtered by a second-order Butterworth filter with a cut-off of 6 Hz. A link-segment model was used to calculate the center of gravity (COG), and an inverse dynamic model was employed to obtain the joint moment [9]. In this study, the height and progressive velocity of the COG and the vertical and fore-and-aft components of floor reaction force were evaluated because these parameters showed the rocker function was achieved. Temporal and spatial parameters without an AFO and with the AFO-OD were compared using the Mann-Whitney U test. Statistical analysis was not used for other parameters such as

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movement of the COG, floor reaction forces, joint angle, and joint moment because of the limited number of steps for the floor reaction forces and joint moment data.

Results

Temporal and spatial parameters

Table 1 shows temporal and spatial parameters in both conditions and the results of statistical analysis. With the AFO-OD, gait speed was increased by 0.26 m/s (p=0.001) and stride length, paretic and nonparetic step lengths increased 0.27 m (p=0.032), 0.17 m (p=0.024), and 0.10 m (p=0.040), respectively, when compared with the condition without an AFO. The patient showed shorter step length in the paretic limb than in the nonparetic limb, which remained unchanged with the AFO-OD. However step-length asymmetry was improved from 46% to 73%. The gait cycle was decreased by 0.25 s (p=0.037), and an especially remarkable decrease in the loading response was found by 0.24 s (p=0.018). Single stance, preswing, and swing phases did not change significantly with the AFO-OD.

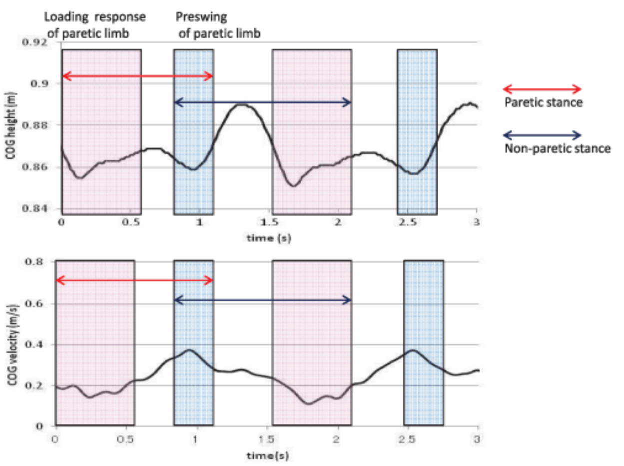

Figure 3: Center of gravity (COG) movement during gait; Upper: Height; Lower: Progressive velocity; (a) without an AFO; (b) with the AFO-OD.

COG movement

Figure 3a shows COG height and progressive velocity of the COG without an AFO. The COG did not move upward in stance phase of the paretic limb, and it moved excessively upward in stance phase of the nonparetic limb. The excessive upward movement of the COG in stance phase of the nonparetic limb was caused by hip hiking to achieve clearance of the paretic limb. Progressive velocity of the COG did not increase in the loading response of the paretic limb, and it slightly increased in the loading response of the nonparetic limb. Figure 3b shows the same graphs for the AFO-OD condition. There were upward movement of the COG in stance of the paretic limb and an increase in progressive velocity of the COG in the loading response of the paretic limb. However, the amounts of these parameters were still lower than those of the nonparetic limb.

Floor reaction force and center of pressure

Figure 4a shows the results of the floor reaction forces (vertical component in the upper graph and fore-and-aft component in the lower graph) without an AFO. The vertical component increased gradually in the loading response of the paretic limb, and it took a long time to move weight to the paretic limb. The amount of the fore-and-aft component was very small, signifying that the patient did not push the floor backward and forward with the paretic or nonparetic limb. Figure 4b shows the same graphs for the AFO-OD condition. The vertical component of the floor reaction force increased rapidly in the loading response of the paretic limb, and it shortened the duration of the loading response. The fore-and-aft component of the floor reaction force showed a negative value in the first part of stance and a positive value in the latter part of stance in both the paretic and nonparetic limbs. The amount of the peak value of the fore-and-aft component was still small; however the pattern of the graph resembled that of normal data.

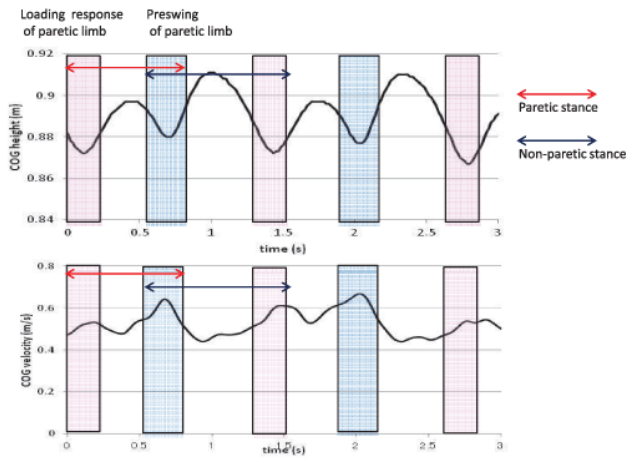

Figure 4: Floor reaction force during gait; Upper: Vertical component; Lower: Fore-and-aft component; (a) without an AFO; (b) with the AFO-OD.

Figure 5 shows representative results for the trajectory of the center of pressure (COP) in the paretic limb. COP started in the midfoot and did not move forward in the condition without an AFO. When he walked with the AFO-OD, COP started at the heel and moved forward during stance phase.

Joint angle and joint moment

The upper graphs of Figures 6a and 6b show representative results for the joint angle of the paretic limb in both conditions. The horizontal axis shows the percent gait cycle beginning with initial contact of the paretic limb. In the condition without an AFO (Figure 6a), the patient's foot touched the floor in a plantar-flexed position and exhibited an excessively planter-flexed position during swing phase, which signified foot drop when walked without an AFO. The knee joint showed hyperextension during stance phase. Hip extension at the end of stance phase was small. When the patient walked with the AFO-OD (Figure 6b), foot contact was made with the ankle joint in a neutral position and the ankle joint angle remained neutral during swing phase. This occurred as a direct effect of the AFO-OD.

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Hyperextension of the knee joint was decreased in stance, and hip extension in late stance was increased. These changes were related to increased step length when the patient walked with the AFO-OD.

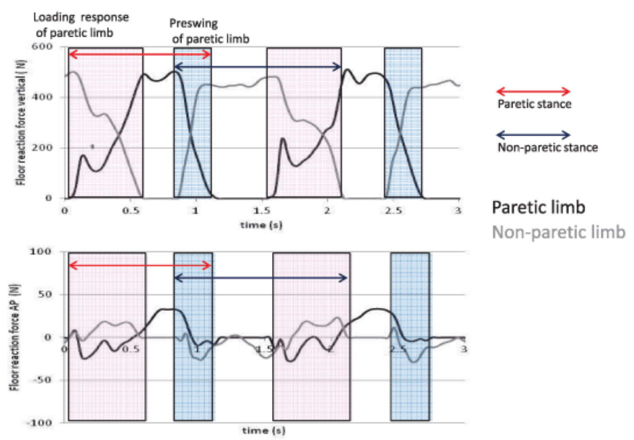

Figure 5: Trajectory of the center of pressure; a) without an AFO; b) with the AFO-OD.

The lower graphs of Figures 6a and 6b show representative results for joint moment of the paretic limb in both conditions. The internal moment and the extension and plantar flexion moments are shown to be positive. When the patient walked without an AFO (Figure 6a), the ankle joint moment was always positive, the knee joint moment negative, and the hip joint moment positive. These results indicate that the same muscles were activated throughout stance phase of the paretic limb. The flexion moment around the knee joint might be caused by the passive component behind the knee joint because the patient showed hyperextension of the knee joint during stance. The peak plantar flexion moment in late stance was approximately 30 Nm. In the AFO-OD condition (Figure 6b), small dorsiflexion moment was found in the loading response of the paretic limb due to resistance of the AFO-OD's oil damper. The peak planter flexor moment in late stance was increased to 50 Nm and the joint moments around the knee and hip showed positive values in the first part of stance phase. These results indicate that the activities of the muscles around the ankle, knee, and hip joints of the paretic limb changed in stance phase.

Whole body alignment

Figure 7 shows whole body alignment and floor reaction force vectors of the paretic limb in stance under both conditions. These figures were clipped from data derived by the 3D motion analysis system. In the condition without an AFO, the patient inclined the trunk slightly forward. The floor reaction force vector went in front of the ankle, knee, and hip joints throughout stance phase, which meant that he maintained the same alignment in stance of the paretic limb to prevent buckling of the knee joint. When walking with the AFO-OD, the trunk was in a more upright position and the relative position of the floor reaction force vector to each joint changed during stance phase.

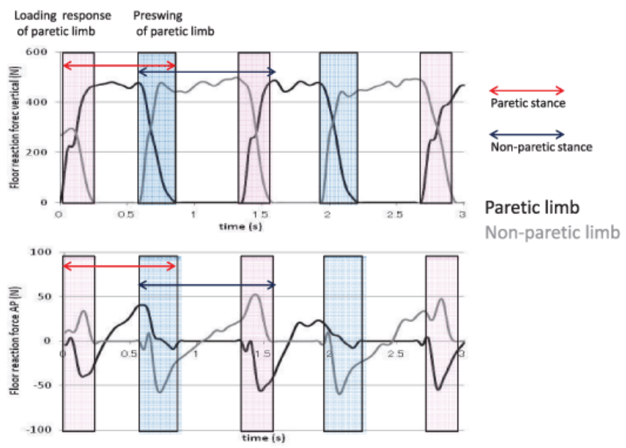

Figure 6: Joint angle and joint moment; Upper: Joint angle, flexion and dorsiflexion in positive Lower: Internal joint moment, extension and plantar flexion in positive; (a) Without an AFO; (b) With the AFO-OD.

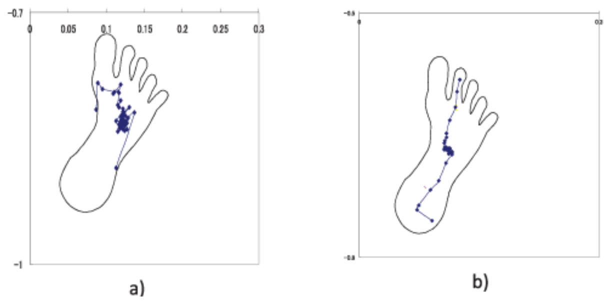

Figure 7: Stick figures and floor reaction force vectors in stance phase of the paretic limb; (a) Without an AFO; (b) With the AFO-OD.

Discussion

The AFO-OD was developed to assist insufficient activity of the dorsiflexors during gait. In normal gait, the dorsiflexors are activated in the loading response and preswing and swing phases. Activity in the loading response is largest to prevent abrupt landing of the forefoot [11]. It is well known that hemiplegic patients have difficulty activating the dorsiflexors, and insufficient activity of the dorsiflexors causes foot drop during swing phase. Many AFOs have been developed to prevent foot drop because the foot drop is a visible event. However, activity of the dorsiflexors in loading response is also important for initiating adequate rocker functions in stance phase.

In normal gait, COG movement in stance phase is compared to the movement of an inverted pendulum. The COG starts to rise in the heel rocker and continues to rise during the first half of the ankle rocker. The COG descends due to gravity during the latter half of the ankle rocker. Progressive velocity of the COG increases in the loading response and decreases in mid to late stance. This phenomenon indicates the effective exchange of kinetic and potential energy during gait [12]. The upward movement of the COG in the heel rocker is caused by eccentric contraction of the dorsiflexors and knee extensors. Activating these muscles requires contacting the floor with the heel and having the backward component of the floor reaction force, which goes behind the ankle and knee joints. In this study, the patient did not make contact with the heel, and the fore-and-aft component of the floor reaction force was very small when he walked without an AFO. Because the function for moving the COG was lost, COG did not rise in stance phase of the paretic limb. Consequently, he exhibited a loss of heel and ankle rocker functions.

When walking with the AFO-OD, the patient's heel touched the floor at the beginning of stance phase and the backward component of the floor reaction force was observed. A small amount of dorsiflexor moment and knee extensor moment in the loading response of the paretic limb were observed. These activities facilitated the upward movement of the COG, and the height of the COG was increased in stance phase of the paretic limb when walking with the AFO-OD.

Previous studies on hemiplegic gait have shown that decreased activity of the plantar flexors during late stance was closely related to decreased walking velocity [13,14]. Plastic AFOs cause resistance to dorsiflexion, with the resistance assisting the insufficient activity of the plantar flexors. However, Bregmen et al. measured the amount of resistance of an AFO during gait in hemiplegic patients and found that the amount of resistive moment was small compared to the moment generated by the plantar flexors, although the AFO did improve gait [15]. In the present study, the peak plantar flexor moment in terminal stance was 30 Nm when the patient walked without an AFO and was 50 Nm when he walked with the AFO-OD. The ankle joint of the AFO-OD moved freely to dorsiflexion and did not assist the plantar flexors. These results imply that the functions of the AFO include not only mechanical assistance but also improvement of alignment so that muscles can be easily activated.

In terms of the rocker function, although the AFO-OD assisted the heel rocker function, changes were also observed in the ankle rocker. Improvement of the ankle rocker increased step length of the nonparetic limb and consequently there was a marked increase in gait velocity. These results indicate the importance of evaluating gait as a sequential movement. These findings obtained in this study were similar to the results shown in the previous study [9]. However any time sequential graphs including the COG movement and discussion about COG movement were not shown in the previous study. The COG movement is important to understand the rocker function considering the movement of an inverted pendulum. This case report showed the importance of investigating the COG movement to evaluate the effect of an AFO from the viewpoint of the rocker function.

This study was limited by its focus on a single participant. Although other studies have reported gait analysis results with the AFO-OD, they included an insufficient number of patients [9,10]. Therefore, further research should include more participants of different ages and sex. Furthermore, the AFO-OD has a larger degree of freedom compared to traditional AFOs, so it is necessary to show contraindications for AFO-OD use considering the level of spasticity and gait pattern of patients.

Conclusion

Quantitative gait analysis is a good assessment tool for objectively determining what happens during a patient's gait. In this single case report, gait without an AFO and with the AFO-OD were compared using 3D gait analysis. Although the AFO-OD was developed to assist the heel rocker function during gait, we found that the AFO-OD improved whole body alignment including the ankle rocker function. When the patient walked with the AFO-OD, the height and progressive velocity of the COG showed the movement as an inverted pendulum, which is seen in the ankle rocker in normal gait. The peak plantar flexion moment in late stance was increased despite the AFO-OD not assisting the plantar flexors. These results indicate that, by assisting the heel rocker, the AFO-OD improved the ankle rocker function during gait in a hemiplegic patient.

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