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Case Report Open Access

Gait Change Using an Ankle-Foot Orthosis with an Oil Damper in a Stroke Patient with Hyperextension of the Knee Joint in Late Stance

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Abstract

The gait of a stroke patient who showed hyperextension of the knee joint in late stance was measured and compared with and without an ankle-foot orthosis. When the patient walked using an ankle-foot orthosis with an oil damper that assisted the heel rocker, the center of pressure was kept at the heel in loading response and the start of the plantarflexion moment was delayed. Forward inclination of the shank in early midstance was obtained, and the hyperextension of the knee joint in late midstance was reduced. The orthosis was able to control the shank inclination, and the shank vertical angle was found to be an important parameter for understanding the gait of stroke patients with and without ankle-foot orthoses.

Keywords: Stroke patient; Ankle-foot orthosis; Shank vertical angle; Hyperextension

Abbreviations

AFO: Ankle-foot Orthosis; AFO-OD: AFO with an Oil Damper; AFO-PF: AFO with a Plantarflexion stop; COG: Center of Gravity

Introduction

Ankle-foot orthoses (AFOs) are commonly used to improve gait in stroke patients. Gait analysis of stroke patients has shown the increased velocity, cadence, and step length, improved ankle joint angle throughout the gait cycle when patients used the AFOs [1-3]. In general, AFOs are used to facilitate foot clearance during swing phase, to improve the initial contact in early stance, to maintain mediolateral stability in stance [4]. For these purposes traditional AFOs have solid ankle joint or joint with plantar flexion stop. However, the ankle joint has an important role to achieve three rocker functions in stance phase [5]. In normal gait, the heel contacts the floor and the eccentric contraction of the dorsiflexors prevents the abrupt foot drop and pulls the shank forward in loading response. This mechanism is called the heel rocker function. Previous studies have shown the importance of plantarflexion resistive moment of AFOs in improving heel rocker function during gait of stroke patients [6-10]. We previously developed an AFO with an oil damper (AFO-OD) to assist the eccentric contraction of the dorsiflexors in loading response of the paretic limb [11], which was found in later studies to improve the gait of stroke patients [12,13]. These studies found that the AFO-OD provided assistance in loading response of the paretic limb, but the improvement was found in mid-to late stance. However, how improvement of heel rocker function improves the later phases of gait has not been clarified.

The gait of stroke patients shows some typical problems. The previous study to classify the gait of stroke patients using cluster analysis found that the velocity and the knee joint angle were key factors [14]. De quervain et al. showed three specific gait patterns for stroke patients with slow gait speed [15]. One of these patterns was the extension thrust pattern which meant the hyperextension of the knee joint in stance of paretic limb. Previous studies including a case report showed the effect of AFOs on the knee joint angle in early stance [1,3,16], however the effect of AFOs on the knee joint angle in late stance has not been shown. The purpose of this case report was to show the effect of the AFO-OD, which assists the heel rocker function, on the gait of a stroke patient with hyperextension of the knee joint in late stance.

Method

A 75-year-old man (height, 160 cm; weight, 57 kg), 23 years post-stroke with left-sided hemiparesis caused by cerebral hemorrhage 23 years prior, participated in this study. He had no other physical or cognitive conditions that negatively affected gait. The impairment of the lower limb was Brunnstrom stage IV. He could walk independently and did not require the use of assistive devices or AFOs. The patient was prescribed a solid plastic AFO when he stayed at the hospital, but he felt uncomfortable with it. After that he had refused to use any types of AFO. Consequently he had not used any AFOs for over 20 years.

The AFO-OD, which generates plantarflexion resistance to assist heel rocker function, was used in this study (Figure 1). Because the ankle joint of the AFO-OD moves to dorsiflexion without any resistance, the AFO-OD does not assist plantarflexor activity in mid-to late stance. The degree of plantarflexion resistance was tuned so that smooth foot contact was obtained after initial contact of the paretic limb and initial ankle joint angle was adjusted so that the resistive moment began to be generated from the ankle joint angle at initial contact.

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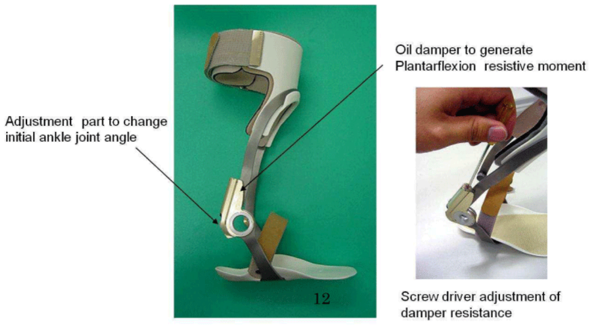

Figure 1: The ankle foot orthosis with an oil damper. The amount of plantarflexion resistance is changed by rotating a screw at the top of the oil damper. The initial ankle angle is changed by inserting a part at the ankle joint. The ankle joint moves freely to dorsiflexion without any resistance.

A 3D motion analysis system comprising 10 cameras (VICON Mx) and 4 force plates (AMTI) were used in this study. Forty-three reflective markers were attached to the patient following the Helen Hayes marker set, and marker trajectory and force plate data were recorded at a sampling frequency of 100 Hz. At first, the gait without an AFO was measured, after which the patient began to use the AFO-OD. After a short acclimatization period the gait with the AFO-OD was measured. In both conditions, the patient walked at a self-selected speed. The measurement was repeated until five steps of the affected limb on the force plates were obtained. After measurement, the trajectories of markers were low-pass filtered with a cut-off frequency of 6 Hz and force plate data with 18 Hz. A link segment model with 13 segments, the head, thorax, pelvis, both of upper and lower arms, thighs, shanks, and feet, was defied and the center of gravity (COG), the joint angle, and the joint moment were calculated by inverse dynamic analysis. Comparing the temporal and distance parameters in both conditions, Mann-Whitney U test was used. Values of $p<0.05$ were considered significant. Visual 3D software (C-motion Inc.) and SPSS ver.21 were used for calculation.

All procedures were approved by the Ethics Committee of International University of Health and Welfare and were consistent with the Declaration of Helsinki. Informed consent was obtained from the patient prior to his participation in the study.

Results

The temporal and distance parameters from gait analysis are shown in Table 1. The period of loading response and preswing were long and midstance was short. The step length of the non-paretic limb was shorter than that of the paretic limb. The velocity, single stance, swing phase, and both of step lengths were improved by use of the AFO-OD ($p<0.05$).

Figure 2 shows stick figures and floor reaction force vectors of the patient in stance phase of the paretic limb. In these figures the paretic limbs are shown in pink. When the patient did not use an AFO, a significant hyperextension of the knee joint was found at the time of non-paretic initial contact, but this was reduced when the patient used the AFO-OD.

	Without an AFO	With AFO-OD
Velocity (m/s)	0.71 (0.12)	0.93 (0.10)*
Gait cycle (s)	1.22 (0.09)	1.10(0.07)
Loading response(%)	13.1	11.8
Single stance (%)	21.3	28.2*
Preswing (%)	17.2	16.4
Swing phase (%)	48.4	43.6*
Paretic step (m)	0.52 (0.06)	0.62 (0.04)*
Non-paretic step (m)	0.35 (0.08)	0.41 (0.03) *

Table 1: Temporal and distance parameters in gait with and without use of the AFO. Mean (SD) m/s: meter per second; %: percent of gait cycle, *$p<0.05$.

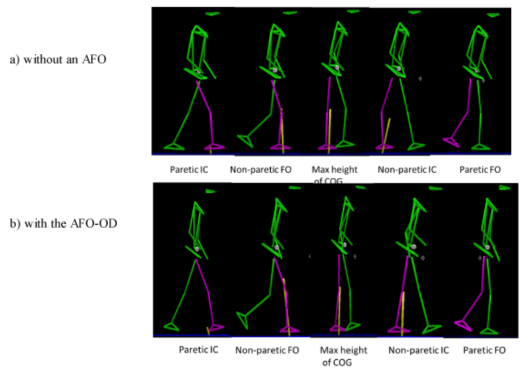

Figure 2: Stick figures and floor reaction force vectors during gait of the patient. The paretic limb is shown in pink. IC: Initial Contact; FO: Foot Off.

Figures 3-6 shows the height of the COG, the joint angle, shank vertical angle (SVA) and thigh vertical angle, and the joint moment during one gait cycle starting at the initial contact of the paretic limb, respectively. Joint angle, joint moment, and SVA are parameters shown in the previous studies [1,2,17], and COG height was additionally used to show whole-body movement. All graphs shown here are the result of a typical one-gait cycle to show the exact time sequence of each parameter. The neutral angle of the ankle joint was the angle in which the shank was vertical to the floor. In Figure 4, dorsiflexion and flexion are shown as positive values. Figure 5 shows SVA and thigh vertical angle, with forward inclination shown as positive values. Figure 6 shows joint moment as the internal moment, with plantar flexion and extension are shown in positive.

When the patient walked without an AFO, the time of maximum height of the COG coincided with the time of hyperextension of the knee joint as shown in Figures 3a and 4a. The shank did not incline forward but moved slightly backward from the initial contact to the time of maximum COG height (Figure 5a). When the patient used the AFO-OD, gradual forward inclination of the shank was found in the loading response and early midstance as shown in Figure 5b, and the COG raised more slowly compared when the patient did not use the AFO-OD (Figure 3).

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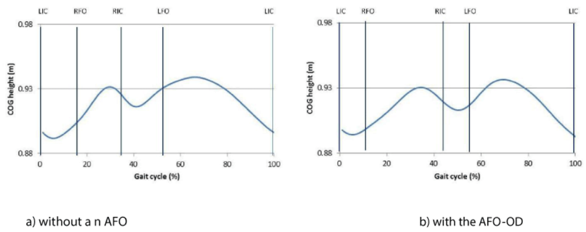

Figure 3: Height of the COG Left means the paretic side. LIC: Left Initial Contact; RFO: Right Foot Off RIC: Right Initial Contact; LFO: Left Foot Off.

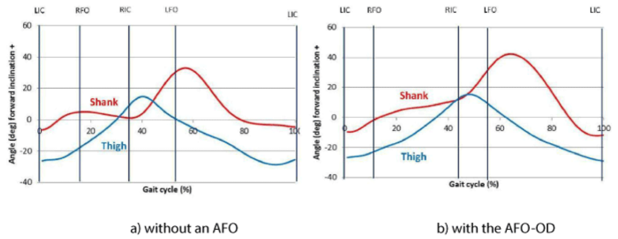

Figure 5: Shank and thigh vertical angles left means the paretic side. LIC: Left Initial Contact; RFO: Right Foot Off; RIC: right Initial Contact; LFO: Left Foot Off.

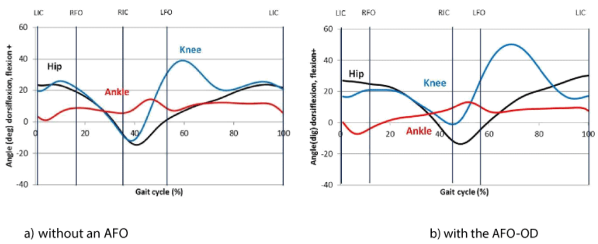

Figure 4: Joint angle left means the paretic side. LIC: Left Initial Contact; RFO: Right Foot Off; RIC: Right Initial Contact; LFO: Left Foot Off.

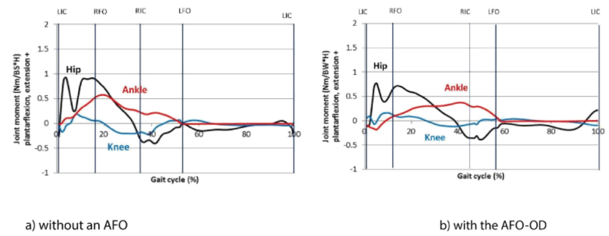

Figure 6: Joint moment left means the paretic side. LIC: Left Initial Contact; RFO: Right Foot Off; RIC: Right Initial Contact; LFO: Left Foot Off.

The major difference in joint moment was found in the ankle joint moment (Figure 6). No dorsiflexion moment was found in loading response when the patient walked without an AFO, but small dorsiflexion moments were apparent in the gait with the AFO-OD. The peak plantarflexion moments were small in both conditions, but the start of the plantar flexion moment was delayed when the patient walked with the AFO-OD.

Discussion

In normal gait, the eccentric contractions of dorsiflexors as well as the knee extensors move the COG forward and upward in loading response and early midstance [5]. In this period, the shank continues to incline forward. The gait of the patient when not using an AFO showed upward movement of the COG in early midstance; however, the shank did not incline forward in this period.

The COG moved upward due to the inclination of the thigh, rather than the shank. After point corresponding to maximum height of the COG, the shank moved slightly backward and the thigh continued to incline forward, thus resulting in hyperextension of the knee joint. The plantarflexio moment started just after initial contact. plantarflexion activity pulls the shank backward, which is effective in late midstance, but prevents smooth forward inclination of the shank in early midstance. Small dorsiflexion moment was found when the patient walked with the AFO-OD. Dorsiflexion moment indicated that the center of pressure was kept at the heel in loading response and delayed the start of plantarflexion moment. The delayed activity of the plantarflexors did not prevent the smooth inclination of the shank in early midstance and resulted in reduced hyperextension of the knee joint.

The slow upward movement of the COG prolonged single stance and lengthened the step length of the non-paretic limb. In general, AFOs which prevent backward inclination of the shank during gait are used to prevent hyperextension of the knee joint. Such AFOs have plantarflexion stop. However, the result in this study showed that the AFO-OD, which allows plantarflexion with resistance, allowed gradual forward inclination of the shank and reduced the hyperextention of the knee joint. Ohata et al. [18] measured plantarflexor activity of stroke patients using an AFO with plantarflexion stop (AFO-PF) and the AFO-OD. Their results indicated that the excessive activity of the gastrocnemius in the loading response found in the gait with AFO-PF was not found when patients walked with the AFO-OD. The present study did not make use of the AFO-PF or electromyography, but the gait features with the AFO-OD were similar to the results of the previous study.

In Japan the AFO-OD is covered by national insurance. About 4,000 AFO-ODs are manufactured a year. A questionnaire survey about the prescription of AFOs was answered by physical therapists in 226 hospitals [19]. The result showed that 10.1% of prescriptions were the AFO-OD. In order to show the advantage of the AFO-OD in contrast with traditional AFOs, the future study with a large number of patients considering the cost performance is necessary.

Conclusion

The AFO-OD, which moved plantarflexion with resistance, maintained center of pressure at the heel in loading response and delayed the start of plantarflexion moment. This function allowed the gradual inclination of the shank in early midstance and resulted in the reduced hyperextension of the knee joint in late midstance. The AFO-

OD was able to control shank inclination, and SVA was found to be an important parameter for understanding the gait of stroke patients with and without AFOs.

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