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EFFECTS OF THE ANKLE ANGLES OF AN ANKLE FOOT ORTHOSIS ON FOOT PRESSURE DURING SLOPE WALKING IN HEALTHY ADULTS

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ABSTRACT

Objectives: This study was to investigate the effects of the ankle angles of an ankle foot orthosis (AFO) on foot pressure during uphill and downhill slope walking in healthy young adults.

Methods: A total of 16 healthy adults without specific diseases in the musculoskeletal or neurological system participated in this study. Participants performed to walk on the uphill and downhill slope with four different ankle angles (-5°, 0°, 5°, and 10°) of an AFO. The recorded pathway length of the center of pressure (COP) and plantar foot pressures of each pressure sensor was measured using the F-scan system.

Results: The COP lengths of anterior-posterior and medio-lateral directions were significant differences between uphill walking and downhill walking, and the length was long in the ascent slope and less in the descending slope. Also, the medio-lateral trajectory length of the pressure center was longer in the downhill slope. In the foot pressure distribution of each angle when walking the uphill and downhill slope were significantly different in specific areas with different ankle angles of an AFO.

Conclusion: It was found that the ankle angles of an AFO affect the gait pattern and plantar foot pressure distribution when walking on the slope. Therefore, the walking of the slope is affected in the joint angle of AFO, so it is considered that proper angle adjustment is necessary.

INTRODUCTION

Ankle instability due to injuries of the central and peripheral nervous system, muscle weakness, compression of the deep peroneal nerve, proprioceptive deficits of the ankle, and ankle sprain contribute to poor balance control, higher risk of falling, and altered gait patterns [1-3]. Reduced walking capacity has a negative effect on patients' functional ability and participation in social and domestic roles, and patients with reduced velocity and walking quality have restricted daily activities and reduced quality of life [4].

In clinical practice, the ankle foot orthosis (AFO) is prescribed to patients with ankle problems [5, 6]. The AFO contributes medial and lateral stability of the ankle in the stance phase, reduces energy consumption during walking, maintains postural balance, and facilitates toe clearance in the swing phase [6, 7]. Moreover, the ankle angle of AFO affected the static balance during one-leg standing and the foot pressure and gait patterns in level walking [1, 8, 9]. However, ankle movement restriction by AFO may cause difficulties in performing tasks that require moving the ankles, such as ascending and descending slope surfaces or stairs.

Patients can use slopes instead of climbing stairs. Slopes are mainly used to transfer individuals with a physical disability or older people with difficulty using the stairs but have a high risk of falling and slipping [10, 11]. In particular, compared with level walking, slope walking cannot be avoided in performing daily activities, stair walking, and older people or patients with ankle problems who need more effort, exercise, and balance ability [12]. Moreover, in individuals facing increased locomotor challenges, walking in difficult environments such as on slopes needs more concentration and higher balance ability than when walking on the level ground [12, 13].

In previous studies related to slope walking, humans used slow cadences and long strides in ascending slopes and short strides and fast cadences in descending slopes [12, 14, 15]. In addition, slopes have a higher risk fact of falls than stairs in a similar inclination; however, there is a lack of verification data on walking, risk of falling, and balance on slopes [12, 16]. In particular, descending on slopes is at risk of slipping or losing balance [12, 16]. Understanding the gait dynamics while ascending or descending a slope is essential to determine which factors cause falls and make it difficult for patients with AFO to move along the slopes without falling, and understanding adaptation and factors of walking on slopes should help in determining what is causing the fall.

Although there are studies of normal people walking on slopes and stairs [10-12, 15], there is a lack of research on using walking aids such as AFO in patients with ankle problems. In addition, some studies have focused on level walking and balancing using AFO depending on the angle of the ankle joint [1, 8]. However, although moving to uneven places increases the risk of falling, it is not considered sufficiently and no clinical studies have examined walking on uneven slopes during everyday living. Therefore, the purpose was intended to examine the effects of the ankle angles of an AFO on plantar foot pressure during uphill and downhill slope walking in young adults.

MATERIALS AND METHODS

Subjects

Sixteen healthy young adults (16 males, mean age: 26.25±2.08 years; height: 174.81±3.39 ㎝; weight: 71.38±5.98 ㎏; foot length: 268.13±2.50 ㎜) without specific disease in the musculoskeletal or neurological system recruited in this study. Participants were healthy and no orthopedic problems that might influence locomotion and their performance. The study was conducted with the Institutional Review Board of Yeungnam University College (YNC IRB201811-03) and conformed to the ethical standards of the Declaration of Helsinki. They understood explanation of the purpose and provided their written informed consent prior to all participations in the study.

Apparatus

Plantar foot pressure was measured using F-scan system (Tekscan, USA) which was placed on the subject’s AFO in shoes during uphill and downhill walking. The film insole containing the resistance pressure sensors was placed in shoes to each subject’s AFO size before insertion. The pathway length and plantar foot pressure were analyzed 7 different plantar areas and the pressure regions were the hallux, 2nd-5th toes, 1st metatarsal head, 2nd and 3rd metatarsal heads, 4th and 5th metatarsal heads, midfoot, and the heel region. And the anterior-posterior and medio-lateral pathway length of the center of mass (COP) was measured. The recorded trajectory length of COP and peak pressures of each pressure sensor was calculated by F-scan program.

The experimental slope walkway was a length of 3 m, a width of 1.2 m, and less than 0.75 m height at either end. The slope was an inclination of 7 degrees designed to prevent slipping according to the standard prescribed by the detailed structure of the facilities and materials.

Procedure

The angles of ankle joint of an AFO were manufactured with four kinds of inclinations: 5° of plantarflexion (-5°), the neutral position (0°), 5° of dorsiflexion (5°), and 10° of dorsiflexion (10°). The same thickness of lightweight overshoes was worn on the opposite foot to eliminate any leg length differences that could be caused by wearing the AFO. The ankle angle and uphill and downhill walking were performed randomly to avoid the effects of learning by the principle of counter-balance. The participants were explained to walk on the slope, and asked to walk the slope several times at a self-selected pace while looking straight ahead. The data of the trajectory length of the COP and the peak plantar foot pressure was measured by each foot region. The data of the 2 gait cycles of uphill and downhill walking was used in the analysis. The subjects had to walk three trials and then the average of three trials was used for data analysis. The rest was provided between measurements to avoid fatigue.

Data Analysis

The Kolmogorov-Smirnov test was used to evaluate the normal distribution. Repeated-measures ANOVA was used to examine plantar foot pressure during uphill and downhill walking, and Tukey's post-hoc test was used for post hoc analysis data using IBM SPSS statistics 22.0 for Windows. The statistical significance level was accepted for values of p<0.05.

RESULTS

Comparison Of COP Length Between Uphill and Downhill Walking

The COP lengths of anterior-posterior and medio-lateral trajectory were significant differences between uphill walking and downhill walking with an AFO (p<0.05) (Table 1). The COP length of anterior-posterior while uphill walking was significantly greater, and the length of medio-lateral was significantly shorter than while downhill walking. The COP length of medio-lateral was significantly decreased with greater joint angles, and the interaction between angle and group in the COP length of anterior-posterior was significant (p<0.05) (Table 1).

In the COP length according to the ankle joint angle, the anterior-posterior pathway length was a significantly different at -5° and other angles of the an AFO (p<0.05) (Table 1), but the medio-lateral pathway length did not show significantly different during uphill walking. And the anterior-posterior and the medio-lateral pathway length was a significant difference at -5° and other angles of the an AFO during downhill walking (p<0.05) (Table 1).

Table 1. Cop Length with The Ankle Angles of An AFO During Uphill and Downhill Walking

		-5°	0°	5°	10°	Angle	group	Interaction
AP (㎝)	Uphill	12.82±2.06[a]	14.58±1.24[b]	15.45±1.07[b]	15.84±1.22[b]	0.32	0.02*	0.00*
	Down hill	15.73±1.45[a]	12.66±2.83[b]	12.55±2.65[b]	12.12±2.63[b]			
ML (㎝)	Uphill	1.69±0.23	1.52±0.27	1.46±0.29	1.43±0.25	0.00*	0.00*	0.17
	Down hill	2.09±0.45[a]	1.70±0.32[b]	1.61±0.30[b]	1.59±0.24[b]			

Mean±SD. The Same Columns (A, B) Are Significantly Different According To Post Hoc Test. COP: Center of Pressure, AP: Anterior-Posterior, ML: Medio-Lateral. *P<0.05.

Comparison Of Foot Pressure During Uphill Walking

The peak plantar foot pressures of all regions were significantly different among the angles during uphill walking ($p<0.05$) (Table 2). The post-hoc test showed that the peak plantar pressures of the 2nd-5th toes, 1st metatarsal head, 2nd and 3rd metatarsal heads and heel were significantly different at -5° and other angles of the an AFO, the peak plantar pressure of the 4th and 5th metatarsal heads significantly different between 10° and other angles ($p<0.05$) (Table 2). And the peak pressure of -5° and 0° differed from 5° and 10° in hallux and heel ($p<0.05$) (Table 2).

Table 2 Comparison Of Foot Pressure with The Ankle Angles of An AFO During Uphill Walking

		-5°	0°	5°	10°
Foot pressure (kPa)	Hallux*	303.63 ±63.72[a]	252.38±41.63[a]	189.75±50.12[b]	196.44±47.10[b]
	2nd~5th toes*	183.94 ±39.75[a]	154.81±41.63[b]	121.25±30.45 [b]	141.63±29.03[b]
	1st metatarsal head*	235.25 ±52.52[a]	299.06±53.82[b]	276.50±52.74[b]	314.19±48.40[b]
	2nd & 3rd metatarsal heads*	205.81 ±25.43[a]	276.75±46.87[b]	269.81±37.12[b]	307.81±42.22[c]
	4th & 5th metatarsal heads*	117.13 ±47.58[a]	114.75±14.97[a]	100.00±27.58[b]	127.56±25.38[a]
	midfoot*	82.50±14.36[a]	69.88±17.23[b]	65.13±15.17[b]	97.56±21.50[a]
	Heel*	312.81 ±68.75[a]	336.00±57.25[a]	262.31±45.75[b]	267.13±46.65[b]

Mean±SD. The Same Columns (A, B, C) Are Significantly Different According To Post Hoc Test. *P<0.05.

Table 3. Comparison Of Foot Pressure with The Ankle Angles of An AFO During Downhill Walking

		-5°	0°	5°	10°
Foot pressure (kPa)	Hallux	260.50±63.02	261.81±86.95	224.75 ±63.21	242.31±76.59
	2nd~5th toes*	226.19±41.84[a]	158.63±37.00[b]	171.31 ±52.21[b]	164.25±51.57[b]
	1st metatarsal head	443.56±75.49	463.50±151.64	426.44 ±117.31	473.94±74.18

	2nd & 3rd metatarsal heads	419.88±53.34	453.25±135.04	430.13±84.98	459.50±77.53
	4th & 5th metatarsal heads*	62.88±14.18^{a}	95.31±24.81^{b}	94.44±19.01^{b}	107.56±22.72^{b}
	midfoot	67.63±15.91	65.44±18.30	70.44±19.12	71.63±19.08
	Heel*	215.69±33.13^{a}	145.31±33.57^{b}	171.44±37.40^{b}	160.63±33.89^{b}

Mean±SD. The same columns (a, b) are significantly different according to post hoc test. *p<0.05.

Comparison Of Foot Pressure During Downhill Walking

The peak plantar foot pressures of the 2nd-5th toes, 4th and 5th metatarsal heads, and the heel were significantly different according to the angles during downhill walking (p<0.05) (Table 3). The post-hoc test showed that the pressures of 2nd-5th toes, 4th and 5th metatarsal heads, and heel were significantly different at -5° and other angles of the an AFO (p<0.05) (Table 3). In contrast, the peak plantar foot pressures of the hallux, 1st metatarsal head, 2nd and 3rd metatarsal heads, and midfoot revealed no statistically significantly different among the ankle angles of the an AFO (p>0.05) (Table 3).

DISCUSSION

An AFO is worn to restore insufficient heel strike and toe clearance in patients with ankle instability or muscle weakness during walking [4]. This study investigated the effects of the ankle angles of an AFO on foot pressure during uphill and downhill slope walking in healthy adults. In this study, the anterior–posterior trajectory length was significantly different between the uphill and downhill slopes, and the anterior–posterior trajectory length was longer in the ascending slope than in the descending slope. Moreover, the medio-lateral trajectory length of the pressure center was longer in the downhill slope, and the medio-lateral sway was greater. In the foot pressure distribution of each angle when walking on an uphill slope, the −5° ankle angle revealed high distribution in the 2nd–5th toes, midfoot, and heel. Moreover, the −5° and 0° ankle angles revealed high-pressure distribution in the big toe and heel, and the 10° ankle angle showed high distribution in the 2nd-5th metatarsal heads, and midfoot. During walking on a downhill slope, the foot pressure distribution in each region revealed similar patterns to walking on an uphill slope. Compared with other angles, the 5° and 10° ankle angles revealed that the foot pressure was well distributed and pressure distribution was low in a specific area.

In normal gait, the initial contact could transfer weight from the heel to the toes using eccentric contractions of ankle dorsiflexors for shock absorption by

the heel–rocker mechanism [5]. The ankle in patients with abnormal conditions, such as stroke or ankle instability, does not properly absorb the shock and causes a higher ground reaction force than with normal walking [1]. In particular, the problem can worsen when walking on a ramp. The results of this study revealed that walking on an uphill slope showed longer anterior–posterior COP movement than walking on a downhill slope, and the anterior–posterior COP movement became longer in the uphill slope and shorter in the downhill slope as the dorsiflexion angle was increased. Moreover, the magnitude of the medio-lateral sway was greater on the downhill slope than on the uphill slope. This means that if the ankle dorsiflexion angle is properly maintained by the AFO during uphill slope walking, the COP pathway can be sufficiently moved, and the medio-lateral stability of the ankle is increased. During downhill walking, COP movement is reduced, except with −5° angle, and the medio-lateral stability of the ankle is decreased. In the studies of Kim and Park [8], and Chang [1], the ankle angles of the AFO affected balance performances by changing the foot pressure, muscle activation, or gait pattern during level walking. In this study, an ankle angle of −5° causes difficulty in daily living, and weight transfer is appropriate in an ankle angle of 5°–10°.
Concerning peak plantar pressure when walking on an uphill slope, high plantar pressure was observed in the big toe, 2nd–5th toes, and heel at −5° and similar patterns were found at 0°. Furthermore, the peak plantar pressure was distributed into the whole metatarsal head and midfoot at 5° and 10°, especially at 10°. The peak plantar pressure distribution with the downhill slope is similar to that of the foot pressure when ascending the slope; however, the toe and heel revealed a large plantar pressure at −5°. This means that the foot pressure was concentrated on the forefoot and rearfoot for shock absorption, and the weight of movement occurs quickly; thus, the pressure distribution is lower in the midfoot. By contrast, a slight deviation was observed, but the foot pressure was distributed over the entire foot from 0° to 10°, and the pattern was similar at three angles. This finding has been consistent with those in previous studies suggesting that an appropriate ankle angle of the AFO results in efficient walking patterns and energy consumption and that the angle should be appropriate dorsiflexion to improve balance ability and walking [1, 8, 17-9]. The results also suggest that slope walking affected the joint angles of an AFO; thus, proper angle adjustment is necessary.

As the study only enrolled normal adults, there were limitations to generalization; however, the study observed that the ankle angles of the AFO affect the gait pattern and foot pressure distribution when walking on a sloped surface. When clinicians prescribe an AFO, it is important to determine the angle appropriate for various daily activities, such as walking on a level surface, slope, and stairs. Further studies are needed in patients with stroke and ankle instability.

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