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Original Article

A Three-dimensional Gait Analysis of People with Flat Arched Feet on an Ascending Slope

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Abstract. [Purpose] The purpose of the study was to discover why people who have flat feet show a higher risk of damage to the musculoskeletal system than those who have normal feet. Furthermore, we examined the kinematic differences in the lower extremity between flat feet and normal feet in individuals on an ascending slope using three-dimensional gait analysis. [Subjects] This study was conducted on 30 adults having normal feet (N = 15) and flat feet (N = 15), all of whom were 21 to 30 years old. [Methods] A treadmill (AC5000M, SCIFIT, Berkshire, UK) was used to analyze the kinematic features during gait. These features were analyzed at slow, normal, and fast gait velocities on an ascending slope. Gait data were obtained using a 6-camera motion analysis system (Eagle system, Motion Analysis, Santa Rosa, CA, USA). [Results] Both groups showed significant differences in the sagittal, frontal, and transverse planes according to the speed changes. After comparing the lower extremity kinematics between those with flat feet and those with normal feet, significant differences were found with respect to hip adduction (frontal plane) in the stance phase and hip internal rotation (transverse plane) in the swing phase. [Conclusion] Due to hip adduction, the internal rotation angle of the lower extremity has a tendency to increase according to the increase in gait velocity on an ascending slope, and we can expect that the hip adductor muscles and internal rotator muscles in individuals with flat feet are used much more than would be the case for those with normal feet when they perform actions that require a lot of power, such as walking on an ascending slope and walking quickly.
Key words: Flat foot, Ascending slope, Three-dimensional gait analysis

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INTRODUCTION

The human foot posture is generally characterized by the alignment of the foot skeleton, and it varies considerably between individuals. Variation from a normal foot posture has long been thought to influence the function of the foot and lower limb during gait, thereby predisposing them to injury[1)]. While the link between altered foot posture and injury is still unclear, several studies have demonstrated that foot posture influences lower limb muscle electromyographic (EMG) activity[2)] and joint kinematics[3, 4)] during gait.

Flat feet have been associated with altered foot function, including prolonged calcaneal eversion, increased tibial internal rotation, increased forefoot abduction, reduced efficiency of gait, and reduced shock absorption[5)]. Several kinematic studies have compared subjects with flat feet to those with a normal foot posture[3, 4)].

Based on the fact that those with flat feet more easily feel muscle fatigue of the lower extremities and have a higher risk of damage to the musculoskeletal system than those with normal feet, this study's intent was to examine differences resulting from flat feet in comparison with normal feet while the subjects walked on an ascending slope, such as when climbing a mountain.

SUBJECTS AND METHODS

The subjects who participated in this study were divided into people with normal feet (N=15) and those with flat feet (N=15). All the subjects were between the ages of 21 and 30. Sufficient explanations of this study's intent and the overall purpose were given, and voluntary consent to participate in this study was obtained from all of the subjects. All procedures were reviewed and approved by the Institutional Ethics Committee of Eulji University Hospital. The diagnosis of flatfoot was confirmed by posture analysis (GPS400, Redbalance, Italy). As described by Clarke[6)], Strake's line and Marie's line were used to confirm flatfoot. A treadmill (AC5000M, SCIFIT, Berkshire, UK) was used to see the kinematic features during gait. The average gait velocity of the men at slow, normal, and fast paces were 3, 4, and 5 km/h, respectively, using a slope of 10%, and those of the women were 2.7, 3.7, and 4.7 km/h, respectively, also using a slope of 10%[7)]. The subjects walked for one minute to ensure a natural gait velocity before the experiment, and then

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Table1. General characteristics of each group

	EG (n=15)	CC (n=15)
Number of individuals (Male / Female)	5/10	6/9
Age (years)	21.4±1.3	22.1±0.6
Height (cm)	164.2±1.6	167.4±2.1
Body Weight (kg)	61.±2.3	57.2±2.4
Foot length (mm)	254.2±4.2	257.2±2.7
Ankle width (cm)	5.6±0.3	6.2±1.2

EG: experimental group, CG: control group
Values are expressed as means±SD

Table 2. Comparison of parameters of the lower extremity joints by different velocities on a 10% slope in the sagittal plane

		Group	Slow	Normal	Fast
Hip (°)	D1	EG	26.6±2.1	36.0±2.6	42.8±4.1
		CG	25.3±1.6	34.9±2.4	45.4±4.4
	D2	EG	−21.2±1.1	−19.6±1.2	−10.9±1.2
		CG	−21.6±0.8	−18.4±0.7	−11.4±0.7
	D3	EG	−20.3±1.7	−17.4±1.3	−9.9±2.2
		CG	−20.9±1.4	−17.7±0.9	−10.7±1.2
	D4	EG	26.0±2.2	36.6±2.6	43.7±3.9
		CG	26.3±1.6	36.7±2.3	46.5±4.0
Knee (°)	D1	EG	7.6±1.6	9.5±1.0	8.0±1.7
		CG	7.8±1.5	8.0±1.5	7.0±1.1
	D2	EG	6.7±1.4	10.6±2.5	11.3±2.6
		CG	7.2±1.1	11.9±1.2	12.0±3.9
	D3	EG	24.7±3.1	34.1±3.1	40.6±5.6
		CG	23.9±2.4	33.6±3.8	42.8±5.7
	D4	EG	43.7±3.4	62.2±2.5	75.6±1.5
		CG	47.1±6.7	61.6±3.4	73.8±0.9
Ankle (°)	D1	EG	−2.3±0.8	−2.7±1.0	−2.7±0.8
		CG	−2.4±0.7	−2.4±1.0	−2.9±0.9
	D2	EG	10.5±2.0	12.6±2.3	13.5±3.5
		CG	10.2±1.0	13.0±1.0	14.1±1.0
	D3	EG	10.1±2.2	12.3±1.1	17.2±1.6
		CG	10.3±2.0	13.2±2.0	13.7±1.0
	D4	EG	14.0±2.4	20.3±1.1	27.8±2.5
		CG	14.2±2.0	21.1±3.8	23.9±2.2

*$p<0.05$, D1: flexion at initial contact, D2: max. ext. in stance phase, D3: flexion at preswing, D4: max. flex. in swing phase, EG: experimental group, CG: control group

subsequently all subjects walked barefoot for five minutes on the treadmill.

Gait data were obtained using a 6-camera motion analysis system (Eagle system, Motion Analysis, Santa Rosa, CA, USA) and sampling at 120 Hz. Hemispherical reflective markers (25 mm in diameter) were applied to the following sites on both sides of the body: anterior superior iliac spine, superior aspect of the L5-sacral interface, thigh (lower thigh below the midpoint), medial femoral condyle, lateral femoral condyle, shank (lower shank below the midpoint), medial malleolus, lateral malleolus, posterior calcaneus, and the center of the foot between the 2nd and 3rd metatarsals. To facilitate application and visualization of the markers, the subjects wore a pair of skin-tight cycling shorts and a sleeveless top. The EvaRt and Orthotrak software (Motion Analysis, Santa Rosa, CA, USA) were used for processing the data. After a test walk to become accustomed to the experimental procedure, the subjects were asked to walk for 30 seconds at each speed on the treadmill, and the average values of the data were used.

The general subject characteristics were tested for homogeneity using the independent t-test. Data were analyzed by repeated ANOVA in SPSS for Windows (Version 17.0), and the differences between groups at the different gait veloci-

Table 3. Comparison of parameter of the lower extremity joints by different velocities on a 10% slope in the frontal plane

		Group	Slow	Normal	Fast
Hip (°)	D5	EG	0.6±0.2	0.4±0.2	0.6±0.3
		CG	0.6±0.3	0.6±0.4	0.7±0.4
	D6*	EG	5.5±1.1	6.8±1.2	8.9±1.4
		CG	4.3±0.5	5.9±0.3	8.8±0.8
	D7	EG	−4.2±0.9	−5.6±1.2	−6.6±1.1
		CG	−2.9±0.7	−6.2±1.1	−7.7±0.9
	D8	EG	−4.1±0.6	−6.0±1.0	−7.0±0.9
		CG	−3.2±0.9	−6.8±0.6	−8.1±0.6
Knee (°)	D5	EG	−1.6±1.3	−1.8±1.9	−1.9±2.0
		CG	−0.8±1.5	−2.1±1.8	−2.0±1.7
	D6	EG	1.8±0.2	2.5±0.5	3.8±0.5
		CG	1.9±0.0	2.8±0.7	4.2±0.7
	D7	EG	0.5±0.4	2.7±0.6	3.0±0.7
		CG	0.4±0.3	2.2±0.9	2.9±0.9
	D8	EG	−2.0±0.5	−3.4±0.7	−3.6±0.7
		CG	−2.5±0.4	−3.4±0.6	−3.7±0.8
Ankle (°)	D5	EG	1.6±0.6	1.8±0.7	2.4±0.5
		CG	2.0±0.7	2.4±0.6	2.0±1.1
	D6	EG	3.9±1.1	3.2±0.4	2.0±0.7
		CG	3.4±0.7	2.4±0.8	2.6±1.2
	D7	EG	1.6±0.6	1.9±0.9	2.4±0.4
		CG	1.8±0.6	2.4±0.7	2.2±0.9
	D8	EG	3.2±0.7	3.5±0.8	3.5±1.0
		CG	3.5±0.4	3.8±0.7	3.9±0.5

*p<0.05, D5: adduction at initial contact, D6: max. add. in stance phase, D7: adduction at preswing, D8: max. abd. in swing, EG: experimental group, CG: control group

ties were examined with the independent t-test. Statistical significance was accepted for p values less than 0.05.

RESULTS

The general characteristics of the subjects are shown in Table 1. Both groups showed significant differences in the sagittal, frontal, and transverse planes according to the changes in speed ($p<0.05$). After comparing the lower extremity kinematics between the subjects with flat feet and those with normal feet, significant differences were found with respect to hip adduction (frontal plane) in the stance phase and hip internal rotation (transverse plane) in the swing phase ($p<0.05$) (Tables 2–4).

DISCUSSION

This study was conducted to investigate the kinematic difference between people with flat feet and those with normal feet according to changes in walking speed on an ascending slope. Three-dimensional gait analysis is now commonly used in research and as a tool in guiding the treatment of gait disorders[8]. The results for the lower extremity kinematic features of the subjects during gait on an ascending slope showed that overall, their joint angles increased according to the increase in gait speed, and there were significant differences between the two groups with respect to hip adduction and the hip internal rotation angle. Because hip adduction and the internal rotation angle on the lower extremity have a tendency to increase in response to an increase in gait velocity on an ascending slope, we can expect that the hip adductor muscles and internal rotator muscles of a subject with flat feet would be used much more than those of a subject with normal feet when they perform actions which require a lot of power, such as walking on an ascending slope and walking quickly. The hip internal rotation in the stance phase is increased in subjects with flat feet compared with subjects with normal feet, this causes the patellofemoral joint's internal pressure to increase, and the deformity of the patella increases in accordance with the increase in the angle of the knee joint[9]. Increased pressure on the lower extremity is related to tibia shock, and the internal rotation of the tibia in subjects with flat feet[10].

The present study has some limitations. First, the small sample size may have influenced certain variables and impacted on the results. Therefore, these results cannot be generalized to all people with flatfoot.

Table 4. Comparison of parameters of the lower extremity joints by different velocities on a 10% slope in the transverse plane

		Group	Slow	Normal	Fast
Hip (°)	D9	EG	−5.9±2.2	−5.2±1.5	−4.2±1.1
		CG	−6.3±2.1	−5.5±1.6	−4.2±1.4
	D10	EG	−10.1±1.7	−12.1±1.6	−13.8±2.7
		CG	−10.1±1.7	−12.4±1.8	−13.3±2.7
	D11	EG	3.1±0.7	3.8±0.9	2.3±0.8
		CG	3.4±0.8	3.6±0.8	2.6±0.7
	D12*	EG	10.1±1.6	14.9±0.7	16.0±0.9
		CG	10.4±1.8	12.6±1.5	14.9±1.7
Knee (°)	D9	EG	−3.7±1.8	−4.4±2.7	−4.9±2.8
		CG	−4.9±1.0	−5.1±2.0	−5.5±3.1
	D10	EG	3.6±1.2	5.9±1.9	7.9±2.5
		CG	5.2±1.4	6.4±1.7	8.9±2.2
	D11	EG	−1.6±1.2	−1.7±1.5	−2.3±1.5
		CG	−2.2±0.6	−2.3±1.5	−2.4±1.6
	D12	EG	8.9±1.3	9.8±0.9	14.9±2.6
		CG	9.3±1.1	10.3±1.0	16.0±1.4
Ankle (°)	D9	EG	−2.7±1.2	−4.1±1.4	−4.2±1.2
		CG	−3.2±1.4	−3.8±1.0	−4.1±1.3
	D10	EG	10.3±1.5	11.8±1.3	14.0±2.5
		CG	10.4±1.9	12.5±1.5	15.0±1.8
	D11	EG	−8.0±0.5	−5.4±0.9	−7.3±0.6
		CG	−7.9±1.1	−6.2±0.5	−7.1±0.4
	D12	EG	0.3±0.3	1.2±0.9	1.7±1.4
		CG	0.3±0.4	1.4±0.8	2.4±1.3

*$p<0.05$, D9: int. rot. at initial contact, D10: max. ext. rot. in stance phase, D11: int. rot. at preswing, D12: max. int. rot. in swing phase, EG: experimental group, CG: control group

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