The Effects on Muscle Activation of Flatfoot during Gait According to the Velocity on an Ascending Slope

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Abstract. [Purpose] This study determined the difference between flatfeet and normal feet in humans on an ascending slope using electromyography (EMG). [Subjects] This study was conducted on 30 adults having normal feet (n=15) and flatfeet (n=15), all of whom were 21 to 30 years old. [Methods] A treadmill (AC5000M, SCIFIT,) was used to analyze kinematic features during gait. These features were analyzed at slow, normal, and fast gait velocities on an ascending slope. A surface electromyogram (TeleMyo 2400T, Noraxon Co., USA) was used to measure muscle activity changes. [Results] The activities of most muscles in the subjects with flatfeet were significantly different from the muscle activities in the subjects with normal feet at different gait velocities on an ascending slope. There were significant differences in the vastus medialis and abductor hallucis muscles. [Conclusion] Because muscle activation of the vastus medialis in relation to stability of the lower extremity has a tendency to increase with an increase in gait velocity on an ascending slope, we hypothesized that higher impact transfer to the knee joints occurs in subjects with flatfeet due to the lack of a medial longitudinal arch and that the abductor halluces muscles, which provide dynamic stability to the medial longitudinal arches, do not activate well when they are needed in subjects with flatfeet.
Key words: Flat foot, Electromyography, Ascending slope

INTRODUCTION

Gait is the most natural motion performed by humans in their ordinary life and has the highest frequency in human activities. Numerous musculoskeletal muscles and nerves of the lower extremities respond together during gait[1, 2]. During gait, movement occurs through a series of interactions among the heel bones, the soles, and the ends of the feet. Damages to the feet is associated with impact force, control force, and the distribution of plantar pressure during grounding of the heel bones[3]. Flat-arched feet, in particular, 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[4].

The medial longitudinal arch (MLA) plays an important role in shock absorbance and energy transfer during walking[5]. Although the etiology of this deformity can be arthritic or traumatic in nature[6], it is most commonly associated with posterior tibial tendon dysfunction[7].

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Load during gait increases the number of steps and the double support time, decreases step length, raises energy consumption, and makes the repulsive force against the earth or the lower extremity joints greater[8, 9]. During gait, the kinds or directions of loading change the distribution of pressure delivered to the center of the body and the feet, which may trigger abnormal gait by causing fatigue fracture or affecting muscle activity or postural alignment[9, 10]. Based on the fact that individuals with the flatfeet more easily feel muscle fatigue of the lower extremities and have a higher risk of damages to the musculoskeletal system than individuals with normal feet, the aim of this study was to examine differences between flatfeet and normal feet while subjects walked on an ascending slope like when climbing a mountain.

SUBJECTS AND METHODS

The subjects in the present study, people with normal feet (n=15) or flatfeet (n=15), 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. Flatfoot was confirmed by posture analysis (GPS400, Redbalance, Italy). As described by Clarke[11], Strake's line and Marie's

Table 1. General characteristics of each group (Mean±SE)

	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

line were used to confirm flatfoot. Strake's line is the line that passes between the medial border of the forefoot and the medial border of the hindfoot, and Marie's line is the line that passes between the center of the 3rd toe and the center of the hindfoot. There is also a bisector line between Strake's line and Marie's line. We categorized subjects into the normal foot group if their medial soles passed to the lateral side of Marie's line, and we categorized subjects into the flat foot group if their medial soles passed between the bisector line and Strake's line.

All subjects received a sufficient explanation about the research and provided consent to participation. A treadmill (AC5000M, SCIFIT, UK) was used to examine kinematic features during gait. The average gait velocities of the men at slow, normal, and fast rates are 3, 4, and 5 km/h using a slope of 10%, respectively, and those of women are 2.7, 3.7, 4.7 km/h using a slope of 10%, respectively[12]. Subjects walked for one minute to determine their natural gait velocity before the experiment. Then all subjects walked barefoot for five minutes on the treadmill. Muscle activity data were collected and analyzed using a wireless surface electromyograph (TeleMyo 2400T, Noraxon Co., USA). Active electrodes were used, which consisted of two stainless-steel pads. The electrode diameter was 11.4 mm, and the distance between the electrodes was 20 mm. The sampling rate for the EMG signal was set at 1000 Hz, the bandwidth was set between 20–450 Hz, and the notch filter was set at 60 Hz. EMG was conducted after removing the horny layer with sand paper, and cleansing the areas with an alcohol swab.

To measure muscle activations in the lower extremities during gait, electrodes were attached to the abductor hallucis, tibialis anterior, medial gastrocnemius, lateral gastrocnemius, peroneus longus, vastus medialis, vastus lateralis, and biceps femoris muscles. The frequency range of the EMG signal was band-pass filtered between 20 and 500 Hz, and the sampling frequency was 1024 Hz. We normalized the signals of muscles to the maximal voluntary isometric contraction (MVIC).

The general subject characteristics (age, height, and weight) were tested for homogeneity using the independent t-test. Data were analyzed by repeated measures ANOVA in SPSS for Windows (Version 17.0), and the differences between groups at the different gait velocities 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. Muscle activities of the flat-footed subjects were significantly different from those of the normal-footed subjects at all of the different gait velocities ($p < 0.05$) (Table 2), especially those of the vastus medialis and abductor hallucis muscles ($p < 0.05$) (Table 3).

DISCUSSION

In the subjects with the flatfeet, the function of their feet may did not activate properly as a result of overuse when conducting activities that put repetitive loads on the feet[13]. When the subtalar joints are excessively pronated, the medial tibia areas of the knees slip backward at a rapid speed, rotate and enter under the medial femoral condyles, which may cause damage to the medial side of the knees[6]. The results of analysis of the muscle activities of the subjects during gait on an ascending slope showed that overall, their muscle activities increased according to the rise in gait speed, and there were significant differences between the two groups in the vastus medialis and abductor hallucis muscles. In the subjects with flatfeet, the muscle activity of the vastus medialis was high on an ascending slope. Extensor muscles, in particular, the vastus medialis, play a role in lowering speed and absorbing impact through eccentric contraction. The subjects with flatfeet received more loads on the vastus medialis than those with normal feet due to weakened plantar flexion muscles. Drawing in a slant line of the patellas by the vastus medialis muscles has an important meaning in stabilization and direction of the patellas when they pass or slip through the intercondylar areas of the femurs[14]. The abductor hallucis muscles, which are situated below the medial longitudinal arches of the feet, stop at the sesamoid bones of the distal phalanxes from the heel bones and provide dynamic stability to the medial longitudinal arches[15]. In this study, the changes in activity of the abductor hallucis muscles according to the changes in speed and gradient were smaller in the subjects with flatfeet than those with normal feet. This indicates that the abductor halluces muscles of individuals with flatfeet do not properly function as muscles for dynamic stability of the medial longitudinal arches. The present study verified that in individuals with flatfeet, the abductor hallucis muscles affected descent of the navicular bones by inducing blockage[16] and fatigue of the tibial nerves[17].

Table 2. Comparison of variable with different velocity on a 10% slope (%MVC)

	Group	Slow	Normal	Fast
Rectus femoris	EG*	20.8±3.2	24.1±3.2	30.6±3.7
	CG*	21.4±2.5	23.7±3.9	29.9±4.7
Vastus medialis	EG*	19.9±2.3	25.1±5.8	38.0±6.2
	CG*	21.7±1.6	24.2±1.4	31.8±4.1
Vastus lateralis	EG*	20.5±1.8	23.8±1.6	29.5±3.6
	CG*	20.7±2.4	24.3±1.9	29.1±3.7
Tibialis anterior	EG*	23.4±0.7	24.8±1.4	30.2±4.5
	CG*	22.5±1.8	25.2±2.1	30.0±3.4
Peroneus longus	EG*	20.8±3.1	27.0±2.0	31.0±0.7
	CG*	22.1±1.3	27.6±3.4	32.9±4.3
Medial gastrocnemius	EG*	32.2±4.5	34.2±4.6	35.8±3.2
	CG*	33.3±1.0	34.6±1.3	37.1±1.5
Lateral gastrocnemius	EG*	33.4±1.7	34.4±1.6	36.2±2.3
	CG*	32.7±1.2	34.1±1.3	38.7±1.7
Abductor hallucis	EG*	14.6±4.2	17.3±4.0	20.2±3.6
	CG*	15.2±3.4	21.4±5.0	26.4±3.2

*$p<0.05$, EG: experimental group; CG: control group

Table 3. Results of between-subject comparisons of the effects of muscle activation during treadmill gait on a 10% slope

		Type III SS	df	MS
Rectus femoris	Group	0.2	1	0.2
	Error	225.2	28	8.0
Vastus medialis*	Group	23.9	1	23.9
	Error	155.7	28	5.5
Vastus lateralis	Group	0.0	1	0.0
	Error	68.4	28	2.4
Tibialis anterior	Group	0.4	1	0.4
	Error	70.7	28	2.5
Peroneus longus	Group	11.6	1	11.6
	Error	111.7	28	3.9
Medial gastrocnemius	Group	6.3	1	6.3
	Error	311.1	28	11.1
Lateral gastrocnemius	Group	1.7	1	1.7
	Error	63.5	28	2.2
Abductor hallucis*	Group	98.2	1	98.2
	Error	381.1	28	13.6

*$p<0.05$

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