Muscle Activation Analysis of Flatfoot According to the Slope of a Treadmill

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Abstract. [Purpose] The purpose of this study was to determine the difference between the flatfoot and normal foot on slopes using electromyography. [Subjects] This study was conducted on 30 adults having normal feet (N=15) and flatfeet (N=15) from who were 21 to 30 years old and no neurological history or gait problems. [Methods] A treadmill (AC5000M, SCIFIT, UK) was used to analyze kinematic features during walking, using slopes of -10, 0, and 10% and normal gait velocities. A surface electromyogram (TeleMyo 2400T, Noraxon Co., USA) was used to measure muscle activity changes. [Results] Muscle activity of the flatfoot was significantly different at most muscles, and muscle activity in the normal foot was significantly different in the vastus medialis, vastus lateralis, tibialis anterior, peroneus longus, medial gastrocnemius, and lateral gastrocnemius. Comparison of muscle activity between the flatfoot and normal foot showed significant differences in the tibialis anterior and abductor hallucis muscle. [Conclusion] In the gait of people with flatfoot while walking on slopes, muscle activation of the tibialis anterior is higher than for normal feet and muscle activation of the abductor hallucis muscle is relatively lower than for normal feet in the gait while walking on slopes. This is due to lack of the ability to absorb shock on the ground as a result of the weakened function of the medial longitudinal arch.

Key words: Gait, Slope, Electromyography

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INTRODUCTION

Flatfoot is a congenital or acquired disease and shows features such as medial rotation of the talus, decrease of the medial longitudinal arch, supination, and abduction of the forefoot¹⁾. Mechanical causes of flatfoot have been explained by many researchers. Firstly, flatfoot can be generated because of dysfunction of the posterior tibial tendon. This increases the load on the ligament supporting the joint of the first metatarsal bone and medial longitudinal arch. This reduces the height of the medial longitudinal arch, and it gradually becomes flat^{2, 3)}. It can also be generated by injury, such as to the spring ligament⁴⁾ and plantar fascia⁵⁾, which supports a stability of the medial longitudinal arch. Overweight also raises the incidence of flatfoot⁶⁾. Recently, there have been many studies relating to gait. Flatfoot has been studied with basic technology using various complex methods⁷⁾. The study of flatfoot is constantly evolving, developing from visual quantitative examination to mathematical analysis and modeling through to more complex measurement methods with the development of computer and electronics technologies⁸⁾. The causes and abnormal features of patients with a pathological gait need to be determined through analysis and accumulation of analysis results. We then need to identify objective gait types for normal adults. Therefore, this study was conducted to determine the

difference between the flatfoot and the normal foot by gait velocity and slopes using electromyography.

SUBJECTS AND METHODS

This study was conducted on 30 adults having normal feet (N=15) and flatfeet (N=15) who were 21 to 30 years old and had no neurological history or gait problems. A treadmill (AC5000M, SCIFIT, UK) was used to analyze kinematic features during walking, using slopes of -10, 0, and 10% with normal gait velocities. A surface electromyogram (TeleMyo 2400T, Noraxon Co., USA) was used to measure muscle activity changes. Flatfoot was diagnosed by postural analysis with a foot pressure analysis device (GPS400, Redbalance, Italy). Flatfoot was evaluated using Strake's line and Marie's line as explained by Clarke⁹⁾. Strake's line passes through the medial border of the forefoot and hindfoot, and Marie's line passes through the center of the 3rd metatarsal bones and hindfoot. Diagnosis of flatfoot was made based on Strake's line and Marie's line. In the normal foot, the line of the medial arch passes lateral to Marie's line. In the flatfoot, the line of the medial arch passes medial to Marie's line. In this study, the laboratory environment was made comfortable and had a pleasant indoor temperature, and we obtained the consent of the subjects for participation in the study. A treadmill (AC5000M, SCIFIT, UK) was used

for walking, and -10, 0, 10% slopes were used based on the study of Leroux et al. Gait velocity for the subjects was 1.20 m/s which represents the normal gait velocity of young people in their 20s in Korea. Most of the subjects walked on the treadmill set at the three different slopes for 5 minutes. The subjects walked barefoot and looked towards the front while walking. Each subject walked for one minute to ensure a natural gait before the experiment. We collected the data by wireless surface electromyography (TeleMyo 2400T, Noraxon co., USA). The active electrode was composed of two stainless steel pads; the diameter of the electrode was 11.4 mm, and the distance of the electrode was 20 mm. The signal was stored and analyzed using the software of the TeleMyo 2400T system (Noraxon U.S.A Inc.). The sampling rate for the electromyography signal was set to 1000 Hz, the bandwidth was set to 20–450 Hz, and the notch filter was set to 60 Hz. Electromyography (EMG) was performed after depilating the electrode attachment areas with a razor, removing the horny layer with sand paper, and cleansing with an alcohol swab. To measure muscle activations in the lower extremity during walking, electrodes were attached to the abductor hallucis muscle, tibialis anterior muscle, peroneus longus muscle, medial gastrocnemius muscle, lateral gastrocnemius muscle, vastus medialis, vastus lateralis, and biceps femoris muscle. The surface electrodes used were composed of three electrodes. The frequency range of the EMG signal was between 20 and 500 Hz, and the sampling frequency was 1024 Hz. We normalized the signal of each muscle with %MVC which compare with RMS and maximal voluntary isometric contraction. Analysis of homogeneous data for general characteristics of the subjects, age, height, and weight was conducted with the independent t-test. Measured data were analyzed by repeated measures ANOVA in SPSS for Windows (version 17.0). The differences between groups according to slopes were measured with the independent t-test. Statistical significance was accepted for p values of < 0.05.

RESULTS

The general characteristic of the subjects are showed in Table 1. Muscle activity for the flatfoot was significantly different in most muscles, and muscle activity for the normal foot was significantly different in the vastus medialis, vastus lateralis, tibialis anterior, peroneus longus, medial gastrocnemius and lateral gastrocnemius ($p < 0.05$). Comparison of muscle activity between the flatfoot and normal foot showed significant difference in the tibialis anterior and abductor hallucis muscle ($p < 0.05$) (Table 2).

DISCUSSION

Electromyography can evaluate nerve root injury and can be used as a tool for evaluating nerve conduction velocity, and so it can be used to confirm the position of a peripheral nerve injury¹⁰). It can also be useful when we analyze a limb segment kinematically and perform clinical analysis of functional activities such as walking, stair climbing and so on. Ground reaction force of a lower extremity supporting

Table 1. General characteristics of each group

	EG (n=15)	CC (n=15)
Number of individuals (male / female)	5/10	7/8
Age (years)	21.7 ± 1.5	22.0 ± 2.1
Height (cm)	165.1 ± 0.7	164.2 ± 6.5
Body weight (kg)	55.8 ± 6.2	54.2 ± 4.2
Foot length (mm)	255.4 ± 10.7	252.8 ± 5.1
Ankle width (cm)	7.89 ± 0.37	7.60 ± 0.53
Navicular drop (mm)*	11.6 ± 0.3	6.0 ± 0.1

(Mean ± SD) * $p < 0.05$, EG : Experimental group, CC : Control group

weight and flexion angle of the knee joint could control the amount of power applied to the body during walking. But lower extremities could be injured when it cannot be controlled well.

The ratio of load and power applied to the lower extremity could affect the amount of stress in tissues, and injury could result from repetitive stress. Lower extremities could also be injured more easily in a sloped environment than on ground¹¹). The vastus medialis and tibialis anterior muscle showed higher muscle activation in the flatfoot group than in the normal foot group on the slopes. Vastus medialis oblique muscle has an important meaning as stability and direction of patella¹²). Cheung⁵) confirmed that loading in the vastus medialis is different according to the foot position in patients with patellofemoral pain syndrome. It was also identified that in the case of the flatfoot, the activity of the tibialis anterior muscle increased during the stance phase of the gait cycle compared with the normal foot as a way to absorb the impact delivered to the foot while the pronation of the subtalar joint progresses. The tibialis anterior muscle is an agonist of the ankle joint dorsiflexion and plays an important role in eccentric control to achieve appropriate toe clearance during walking. The tibialis anterior muscle shows the maximum muscle activity in the initial swing phase and terminal swing phase and responds sensitively to walking speeds during the terminal swing phase. The tibialis anterior muscle serves the role of a dorsiflexor during the initial swing phase in order to achieve toe clearance and performs eccentric control during the terminal swing phase for anticipatory responses to the loads imposed during the initial stance phase¹³). In a study that compared the activity of the tibialis anterior muscle during walking on a flat land with that during walking on sloped roads¹⁴), Lay et al.¹⁵) could not find any significant difference. However, in that study, the activity of the tibialis anterior muscle was shown to be higher on descending sloped roads or ascending sloped roads compared with roads on flat land and in particular, higher muscle activity was shown in the case of flat feet compared to normal feet.

Relatively higher muscle activation of the tibialis anterior muscle is caused to compensate for shock absorption of the foot. The abductor hallucis muscle is positioned below the medial longitudinal arch of the foot and inserted from the calcaneus into the sesamoid of the distal phalanx. Its function is to provide dynamic stability to the medial longi-

Table 2. Comparison according to velocity on various slopes

	Group	–10%	0%	10%
Rectus femoris	EG*	22.5 ± 3.7	21.6 ± 3.2	24.1 ± 3.2
	CC	23.2 ± 1.5	21.6 ± 1.0	23.7 ± 3.9
Vastus medialis	EG*	26.2 ± 6.0	21.8 ± 3.9	25.1 ± 5.8
	CC*	25.8 ± 1.2	21.6 ± 1.1	24.2 ± 1.4
Vastus lateralis	EG*	22.1 ± 2.5	20.8 ± 1.0	23.8 ± 1.6
	CC*	23.0 ± 1.0	21.8 ± 1.3	24.3 ± 1.9
Tibialis anterior	EG*	23.8 ± 1.2 ^a	22.0 ± 0.9	24.8 ± 1.4
	CC*	22.1 ± 0.9 ^a	20.8 ± 1.8	25.2 ± 2.1
Peroneus longus	EG*	20.7 ± 1.4	22.1 ± 1.0	27.0 ± 2.0
	CC*	22.0 ± 1.8	23.3 ± 2.1	27.6 ± 3.4
Medial gastrocnemius	EG*	32.6 ± 4.1	33.5 ± 4.5	34.2 ± 4.6
	CC*	34.2 ± 1.8	33.6 ± 1.3	34.6 ± 1.3
Lateral gastrocnemius	EG*	34.6 ± 1.4	33.1 ± 1.4	34.4 ± 1.6
	CC*	34.4 ± 1.4	33.1 ± 0.6	34.1 ± 1.3
Abductor hallucis	EG*	14.6 ± 1.5 ^a	16.0 ± 4.0	17.3 ± 4.0 ^a
	CC	17.4 ± 4.3 ^a	18.9 ± 6.4	21.4 ± 5.0 ^a

(%MVC) *p<0.05, EG: Experimental group, CC: Control group. ^asignificant difference (p<0.05) between the groups according the slope

tudinal arch¹⁶). In this study, changes in the activity of the abductor hallucis muscle of the flatfoot in relation to changes in the degree of slope were not large compared with those of the normal foot. This result can be seen as meaning that the abductor hallucis muscle does not properly perform the function of a muscle for the stability of the medial longitudinal arch. By blocking the tibia nerve that controls the abductor hallucis muscle¹⁷) and inducing fatigue, it was identified that the abductor hallucis muscle affected the drop of the navicular bone¹⁸). Metatarsophalangeal joint bending exercises have been shown to be helpful for strengthening intrinsic muscles such as the abductor hallucis muscle^{19, 20}).

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