Foot pressure analysis of adults with flat and normal feet at different gait speeds on an ascending slope

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Abstract. [Purpose] This study was conducted to determine the difference in foot pressures between flat and normal feet at different gait speeds on an ascending slope. [Subjects] This study enrolled 30 adults with normal (n=15) and flat feet (n=15), with ages from 21 to 30 years old, who had no history of neurological disorders or gait problems. A treadmill was used for the analysis of kinematic features during gait, using a slope of 10%, and gait velocities of slow, normal, and fast. [Methods] A foot pressure analyzer was used to measure changes in foot pressure. [Results] Compared to the normal subjects, the foot pressure of the flatfoot subjects showed a significant increase in the 2–3rd metatarsal region with increasing gait speed, whereas there were significant decreases in the 1st toe and 1st metatarsal regions with increasing gait speed. [Conclusion] The body weight of adults with flatfoot was concentrated on the 2–3rd metatarsal region during the stance phase and increased with walking speed on the ascending slope due to weakening of function of the medial longitudinal arch.

Key words: Flatfoot, Foot pressure, Ascending slope

INTRODUCTION

Gait is the most natural motion performed by humans in their daily life and numerous musculoskeletal muscles and nerves of the lower extremity respond together during gait1). In normal gait, pronation of the foot occurs immediately after the initial stance phase and helps to absorb shock received by the foot in contact with the base of support during the stance phase2). In addition, the medial longitudinal arch also serves to distribute the weight of the body and absorb shock3). Damage to the normal biomechanics of the foot, caused by abnormal function of the subtalar joint and medial longitudinal arch, can result in flatfoot4). In general, evaluations of flatfoot can be categorized as visual non-quantitative inspection, anthropometric measurement, footprint and radiation assessments5). Studies of gait range from a basic technological studies of the gait cycle to studies utilizing sophisticated measurement tools and various mathematical measurements5).

Comparison and analysis is needed in order to determine the causes and problematic parts of patients who exhibit pathological gait. In addition, the results from analysis of normal gait and the types of gait of normal adults need to be clarified.

A number of studies have performed kinematic analysis of flatfoot. Kim et al.6) analyzed the features of gait of adults with flatfoot on an ascending slope using a three dimensional gait analysis system, and Kim et al.7) analyzed muscle activity on an ascending slope, level ground, and a descending slope. Lee et al.8) analyzed the muscle activities of the lower extremity during gait by adults with flatfoot on an ascending slope.

The majority of adults with flatfoot exhibit muscle fatigue of the lower extremity during gait on an ascending slope. Accordingly, the present study was conducted to examine the differences between the foot pressures of adults with flat and normal feet at different gait speeds on an ascending slope.

SUBJECTS AND METHODS

Thirty persons with normal (n=15) and flat (n=15) feet with no neurological history, aged between 21 and 30, participated in this study. Age was recorded, and weight and height were measured for evaluation of the body characteristic of the subjects.

Flatfoot was confirmed by posture analysis (GPS400, Redbalance, Italy). As described by Clarke9), Strake’s line and Marie’s line were used to confirm flatfoot.

Strake’s line is the line passing between the medial border of the forefoot and the medial border of the hindfoot, and Marie’s line is the line passing 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. Subjects
were included in the normal foot group if their medial soles passed to the lateral side of Marie’s line, and the flat foot group if their medial soles passed between the bisector line and Strake’s line.

A treadmill (AC5000M, SCIFIT, UK) was used to examine kinematic features during gait. The average gait velocities of the male subjects at slow, normal, and fast walking speeds were 3, 4, and 5 km/h, respectively, on a slope of 10%, and those of women were 2.7, 3.7, and 4.7 km/h respectively, on a slope of 10%(7). Subjects walked for one minute to determine their natural gait velocity before the experiment, and all subjects walked barefoot for five minutes on the treadmill. Foot pressure analysis (FSA, Vista medical, Canada) was performed to measure the changes in foot pressure. The thickness of the pressure measurement pad was 0.88 mm. It held 128 pressure sensors, with a size of 9×16 mm, arranged in an of 8×16 array. Pressure was sampled at 3,072 Hz, and the pressure measurement range was 0–30 psi. The sizes of the pressure measurement pads were 230×100 mm, 250×100 mm, and 270×100 mm, and an appropriately sized pad was chosen according to subjects foot size, and fitted as an insole.

The foot was divided into eight areas for analysis of the pressure differences: two toe regions (1st toe, 2–5th toe regions), three forefoot regions (1st metatarsal, 2–3rd metatarsal, and 4–5th metatarsal regions), midfoot region and two heel region (medial heel, lateral heel). Average pressures of each region were measured during gait trials.

The homogeneity of the general characteristic of subjects (age, height, and weight) was tested using the independent t test. Pressure data in each group were analyzed by one-way repeated measuring analyses using SPSS for Windows (version 17.0) and a post-hoc Duncan test was used to determine the statistical significance of results.

The differences between groups were determined using the independent t test. Statistical significance was accepted for values of p < 0.05.

### RESULTS

A summary of the clinical and demographic features of the sample (n = 30) is shown in Table 1. There were no significant differences in the baseline characteristics of the flat and normal foot groups (p>0.05). Compared to the normal subjects, foot pressure of the flatfoot subjects showed a significant increase in the 2–3rd metatarsal region with increasing gait speed, whereas there were significant decreases in the 1st toe, and 1st metatarsal regions with increasing gait speed (Table 2).

### DISCUSSION

This study was conducted to examine the differences in the foot pressures of adults with flat and normal feet during gait on an ascending slope, a task which they face in daily life.

The center of pressure of a normal foot tends to move to the inside of the forefoot with increase of speed of gait on an ascending slope. The pressure moves particularly in the direction of the big toe.

In contrast, the body weight of adults with flatfoot was concentrated on 2–3rd metatarsal region during the stance phase with increase of walking speed on the ascending slope due to weakening of the function of the medial longitudinal arch, and body weight did not move well to the big toe during the terminal stance phase.

In subjects with flatfoot, evasion of the subtalar joint occurred due to weakening of the function of the medial longitudinal arch during gait. Therefore, the contact area of the medial longitudinal arch with the floor increased. This is consistent with the finding reported by Van Boerum and Sangeorzan(11), that the medial longitudinal arch of the foot descends faster as the load on the center of the body increases, therefore the contact area of the midfoot area increases during the stance phase.

The main reason for the high level of pressure distribution on the 2–3rd metatarsal head of flatfoot subjects may be evasion of the hindfoot. Since the flatfoot subjects showed a higher level of evasion of the hindfoot with increase in
walking speed. From this result, the change in the movement of the hindfoot has been reported to influence the movement of the tibia as well as the knee joint\textsuperscript{12).

Flatfoot exhibited 2° greater of hindfoot eversion than normal foot during 60% of the stance phase of gait. Levinger et al.\textsuperscript{13}) performed kinematic analysis of flatfoot using the Oxford foot model. Flatfoot exhibited a higher level of plantar flexion, abduction of the forefoot, a higher level of internal rotation of the hindfoot, and a higher level of internal rotation of the tibia. The major cause of the higher level of pressure distribution on the 2–3rd metatarsal bone head found in this study would be the influence of the valgus of the hindfoot. In addition, flatfoot subjects exhibited a higher level of hindfoot eversion with increase in walking speed on the ascending slope; therefore, a higher body weight load would be placed on the interior part during the terminal stance.

This study had some limitations. The small sample size may have influenced certain variables and impacted the results. Therefore, these results cannot be generalized to all subjects with flatfoot.

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