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Differences in Plantar Foot Pressure and COP between Flat and Normal Feet During Walking

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Abstract. [Purpose] The purpose of this study was to compare the peak plantar foot pressure and the pathway of the center of pressure (COP) between normal and flat feet. [Subjects and Methods] Nineteen subjects (10 normal feet, 9 flat feet) participated in this study. Plantar foot pressure was recorded by the Matscan system (Tekscan, Boston, USA) while walking upright. Plantar foot surface was divided into seven regions for pressure measurement: two toe regions, three forefoot regions, one midfoot region, and one heel region. The independent t-test was used to compare plantar foot pressures between normal adults and patients with flat feet. The pathway of COP in normal and flat feet was observed macroscopically. [Results] The plantar foot pressures of the 4th-5th metatarsal head and heel regions in the flat feet group were less than those of the normal feet group. The pathway of COP of normal feet group had a tendency to shift medially in the forefoot but the pathway of COP in the flat feet group had a tendency to be straight in the forefoot. [Conclusion] The results indicate that the plantar foot pressure of a flat foot was lower than that of a normal foot and the pathway of COP of a flat foot may be different from that of a normal foot. We believe that reduction of the longitudinal arch of foot in flat feet explains these results.

Key words: Plantar foot pressure, Center of pressure, Flat foot

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INTRODUCTION

Flat foot, one of the most common deformities of the feet, affects about 5% of the total population[1)]. Flat feet are an acquired or developmental deformity that is progressive and is characterized by supination and abduction of the fore foot and decrease in the longitudinal arch height[2)]. Generally, flat feet are defined as a feet with an abnormally low medial arch height as measured during weight-bearing stance[3)]. As the condition progresses, someone with flat feet exhibit a distinctive flat-footed gait and experience discomfort while walking for long times[4)] which if not treated, will produce pain and disability[5)]. Flat peoples have complaints related to loss of functions and changes in the shape of the foot. In the late stages, arthritic changes, rigidity, and ankle valgus may also be observed[6)].

Many maintain that most asymptomatic flat feet do not need any treatment[7,8)]; however, there may are many possible results of neglected flat feet[9)]. Staheli[10)] mentioned that flat feet were normal or physiological in infants, children, and some adults. On the other hand, some peoples have hypothesized that flat feet in children, in many cases, can lead to disability in adulthood[11,12)]. Increased plantar foot pressures caused by deformity are closely associated with tissue injury and ulceration[13)], and as a source of pain[14,15)].

Plantar pressure measurements are used to quantify dynamic and static pressures as a measure of foot activity during walking[16)]. They are also broadly used as a screening tool for diabetic patients to establish the risk of ulceration[17,18)]. Plantar pressure evaluation is also used to assess the effectiveness of footwear[19,20)] and orthotic interventions[21,22)]. Despite the growing use of plantar foot pressure assessments for research and clinical purposes, the factors that contribute to loading patterns of the foot remain poorly understood[23)]. Therefore, the aim of this study was to evaluate plantar foot pressure and the pathway of COP, and to utilize the evidence from this study during gait training for patients with flat feet.

SUBJECTS AND METHODS

In this study, a total of 19 subjects (10 normal feet, 9 flat feet) were recruited from the surrounding community and they were classified as having flat or normal feet. The exclusion criteria were orthopedic maladies that would prevent normal a stance phase, e.g. limb length discrepancy, partial foot amputation or severe deformity[24)]. Subjects with a navicular height of less than 37 mm and a rear foot angle of more than 9° of valgus were considered to have a flat foot in this study. Each subject had his/her feet marked at the following bony landmarks: a mark on the midline of the posterior calcaneal tuberosity, and a mark on the midline of the Achilles tendon, plantar tip of the navicular tuberosity[25)]. We measured the navicular height and the rear foot angle of the subjects with a goniometer and tape measure. Navicular height was defined as the distance between the lower border of the navicular and the floor[26)]. The rear foot angle was defined as the angle between the mid-Achilles line and the mid-calcaneal line[27,28)]. Subjects were included in the study if they had either bilaterally flat or normal feet and foot type was determined by examining the above-indicated variables. All subjects read and signed consent forms approved by our institutional review board.

Plantar foot pressure data were recorded using the Matscan system (Tekscan, USA). The width of the pressure mat 702.579 mm and the sensors comprise a 44 × 52 matrix. The data of pressure distribution were collected 60 times/sec using the Tekscan and Tekscan Pressure Measurement System Version 5.23 to analyze plantar foot pressure. Although a complex ad hoc calibration was necessary, high accuracy was also found for the resistive technology by TEKSCAN[29)]. For each pressure measurement trial, seven plantar regions on the foot were identified: two toe regions, three forefoot regions, one midfoot region, and one heel region. The toe region was subdivided into two regions consisting of the hallux and the lesser toes. The three forefoot regions underneath the area of the metatarsal heads were divided into equal thirds. The medial forefoot region was underneath the first metatarsal head, the central region was underneath the second and third metatarsal heads, and the lateral region was underneath the fourth and fifth metatarsal heads.

All subjects were asked to walk on the Matscan mat with bare feet and the pressure of the right foot was recorded. The trials were performed two times and the averages of trials were used to analyze the data. We measured peak pressure values of the seven plantar foot regions and the tendency of the pathway of COP.

In this study, the peak pressure and the pathway of COP were measured of subjects with normal and flat feet during walking. The independent t-test was used to examine the differences in peak plantar pressure between normal and flat feet. Macroscopic observation was used to compare the pathways of COP between normal and flat feet. An alpha level of 0.05 was used to test for significance. All data were analyzed using SPSS 18.0 statistical software.

Table 1. Characteristics of subjects (Means ± SD)

Variables	Normal feet	Flat feet
Years	20.6 ± 0.69	22.1 ± 1.64
Height (cm)	164.6 ± 9.70	165.3 ± 6.80
Weight (kg)	55.53 ± 9.11	58.75 ± 8.64
Foot sides (cm)	247.5 ± 14.57	246.87 ± 14.12
Navicular height (cm) *	4.17 ± 0.31	2.98 ± 0.26
Rear foot angle (°) *	2.78 ± 1.12	9.27 ± 0.34

* Significant difference ($p<0.05$) between normal and flat feet. SD: Standard deviations.

Table 2. Comparison of plantar foot pressure between normal and flat feet subjects (Mean ± SD)

Regions	Normal feet	Flat feet
Hallux	212.78 ± 100.70	270.77 ± 74.67
Lesser toe	55.29 ± 28.07	78.63 ± 45.54
1st metatarsal head	156.41 ± 79.14	154.46 ± 41.76
2nd~3rd metatarsal head	272.58 ± 51.10	295.22 ± 73.75
4th~5th metatarsal head*	130.34 ± 68.37	83.65 ± 32.05
Midfoot	55.13 ± 28.67	54.19 ± 44.20
Heel*	247.81 ± 38.48	198.54 ± 30.77

Unit: kPa. * Significant difference ($p<0.05$) between normal and flat feet. SD: Standard deviations.

RESULTS

Table 1 shows the characteristics of the subjects. The subjects were divided into two groups (normal feet group and flat feet group) by their navicular height and rear foot angle. The pathway of the normal feet group had a normal pathway that started from the lateral heel and moved medially in the forefoot ending at the in big toe. The pathway of COP of the flat feet group tended to be abnormal, moving straight from the heel to the toe without medial shifting in the forefoot.

Table 2 shows the comparison of the peak plantar pressures of each foot plantar region during walking. In the big toe area and the small toe area, peak plantar pressure of the flat feet group was higher than in the normal feet group, but without significant difference (Table 2). Peak plantar pressure of the 1st metatarsal head region was similar between the normal and flat feet group. In the 2nd-3rd metatarsal head regions, peak plantar pressure of the flat feet group increased slightly more than in the normal feet group, but without significant difference (Table 2). In the 4th-5th metatarsal head region, peak plantar pressure of the flat feet group was lower than in the normal feet group and the difference was statistically significant ($p <0.05$) (Table 2). In the midfoot region, peak plantar pressure was similar between the normal and flat feet group. In the heel region, the peak plantar pressure of the flat feet group was lower than in the normal feet group and the difference was statistically significant ($p <0.05$) (Table 2).

DISCUSSION

The purpose of this study was to determine the differences between foot types of peak plantar pressures and the pathway of COP during walking. The longitudinal plantar arch is a very important structure which is responsible for static and dynamic functional stabilization.

A low longitudinal arch may be a predictor of peak pressures under the midfoot and due to this it is important to evaluate if a flat foot causes abnormal forces and pressures during walking[28]. The results of this study demonstrate that the pathway of COP of the flat feet group tended to be abnormal, moving straight from the heel to the toe without medial shifting in the forefoot and the flat feet group had slightly increased pressures at the hallux and the lesser toe, 2nd -3rd metatarsal heads relative to the normal group. In the flat feet group the pressure was significantly decreased at the 4-5th metatarsal head and heel regions relative to the normal group. In the midfoot region, there was no difference in pressures between the normal and flat feet groups.

The pathway of COP of normal subjects generally tends to start from the lateral heel and end at the hallux, and shift medially in forefoot region[23,30]. The results of our study are in agreement with those of previous studies and we could identify the difference between the pathways of COP for the normal and flat feet groups. Plantar loading beneath the medial midfoot is higher in subjects with a flat foot than in subjects with a normal foot[28] and this increase in medial midfoot loading in individuals with a flat foot is in agreement with other reports which have examined plantar loading difference based on foot type during walking[31,32]. The results of our study are a little different from previous studies. In our study, the plantar pressure of the midfoot was not different between the normal and flat feet groups while the plantar pressure of the 4-5th metatarsal head and heel regions in the flat feet group was decreased compared to the normal feet group. We believe that these results arise from the center of mass (COM) being shifted medially in flat feet because of loss of longitudinal arch height. In conclusion, we believe that the increase of plantar pressure in flat feet does not arise from the increase of plantar pressure on the medial side of the foot, but from a decrease in plantar pressure on the lateral side of foot by movement of the COM and a relative increase in plantar pressure on the medial side. Therefore, we think that the plantar pressure of individuals with flat feet may increase on the medial side of the foot during walking.

This study was conducted to examine the peak plantar pressure and the pathway of COP of subjects with normal and flat feet during walking. The pathway of COP of the flat feet group tended to be abnormal, moving straight from the heel to the toe without medial shifting in forefoot. At the 4-5th metatarsal head and heel regions, peak plantar pressure of flat feet group was lower than in the normal group. We believe that the center of mass shifts medially because the longitudinal arch height is reduced in flat feet.

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