

The Changes of COP and Foot Pressure after One Hour's Walking Wearing High-heeled and Flat Shoes

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Abstract. [Purpose] This study aimed to determine the most appropriate height for shoe heels by measuring the displacement of the COP (center of pressure) and changes in the distribution of foot pressure after walking in flat (0.5 cm), middle-heeled (4 cm), and high-heeled (9 cm) shoes for 1 hour. [Methods] A single-subject design was used, with 15 healthy women wearing shoes with heels of each height in a random order. The foot pressure and displacement of COP before and after walking in an ordinary environment for 1 hour were measured using an FDM-S (zebris Medical GmbH, Germany). [Results] The distribution of foot pressure did not change significantly after walking in middle-heeled (4 cm) shoes but did change significantly after walking in either flat (0.5 cm) or high-heeled (9 cm) shoes. Similarly, the COP was not significantly displaced after walking in middle-heeled (4 cm) shoes but was significantly displaced after walking in either flat (0.5 cm) or high-heeled (9 cm) shoes. [Conclusion] Both flat and high-heeled shoes had adverse effects on the body. Middle-heeled (4 cm) shoes are preferable to both flat (0.5 cm) and high-heeled (9 cm) shoes for the health and comfort of the feet.

Key words: Foot pressure distribution, High heel, Flat shoes

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INTRODUCTION

The feet receive some stimulation whenever humans walk¹⁾, and we wear shoes to protect our feet, to absorb impact, and to make human gait natural and comfortable²⁾. Therefore, one guideline for the selection of shoes could be the efficiency of protection from injuries and impacts^{3, 4)}. However, most women consider design and fashion rather than health and comfort as their top priorities when selecting shoes⁵⁾. According to a survey on the wearing of shoes, 37–69% of women prefer to wear a high heel, but high-heeled shoes with an excessive focus on fashion can induce musculoskeletal diseases such as plantar fasciitis, hallux valgus, ankle sprain, and chronic lower back pain^{6–11)}. High heels may contribute to changes in the muscles around the knee joint¹²⁾; they could also increase the risks of developing of patellofemoral pain (PFP) and knee osteoarthritis, by increasing the joint reaction force via the higher knee extensor moments and knee flexion angles induced^{13, 14)}. Furthermore, wearing high heels may increase the risks of back pain and strain injury, as heel height is associated with local muscle activity, fatigue^{8, 15)}, and over-loading of the muscles⁶⁾.

The musculoskeletal disorders and deformities described above are related to increased forefoot pressure^{16, 17)}. Cong et al.¹⁰⁾ reported that peak pressure and shear stress shifted

from the lateral to the medial forefoot as the heel height increased from 30 to 70 mm. Speksnijder et al.¹⁶⁾ found that walking in high-heeled shoes (5.91 cm) increased the peak pressure on the medial forefoot relative to low-heeled (1.95 cm) shoes. Additionally, Song et al.¹⁸⁾ observed that the peak pressures on the forefoot were 4.5–4.8 times and 2.3–2.5 times greater than those on the middle foot and rear foot when women wore high heels and kill heels. Therefore, a study on the distribution of foot pressure is necessary to predict the deformity associated with the wearing of high heels.

Additionally, wearing high-heeled shoes has been associated with increased potential for slips and falls, because the consequent changes in local sensation around the ankle may affect women's postural balance^{19–22)}. Therefore, some studies have suggested that the best heel height for maintaining balance is from 3 to 5 cm^{22–24)}. If the heel height were greater than 5 cm, women would tire easily because it would be more difficult for the feet to balance the body weight²⁰⁾. Lee et al.²⁾ reported that heel thickness and height are related to walking stability, and Oh et al.²⁵⁾ found that high heels may be disadvantageous for the maintenance of balance.

According to previous studies, heel height may have a direct impact on musculoskeletal disorders and body stability. Many research have studied the effects of high heels, but the effect of wearing flat shoes has not been studied. Recently, flat shoes have been recognized as conferring feminine beauty and lauded as the most favorable type of shoe

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Table 1. General characteristics of subjects (n=15) (M(SD))

Gender	Age (year)	Weight (kg)	Height (cm)	Foot Length (mm)
Female (15)	20.9 (1.3)	52.1 (5.0)	160.6 (3.3)	234.3 (7.3)

* M: mean, SD: standard Deviation

for women because of the comfortable, classical elegance that they provide²⁶). Therefore, clinical studies are required to study the effect of wearing flat shoes as well. It is also necessary to verify whether wearing high heels in the short term affects the body. Additionally, there have been few COP studies which have investigated body stability.

The purpose of this study was to determine the most appropriate heel height by measuring the changes in COP and foot pressure produced by walking for 1 hour in shoes with various heel heights: flat (0.5 cm), middle-heeled (4 cm), and high-heeled (9 cm) shoes.

SUBJECTS AND METHODS

Fifteen healthy women participated in this experiment after providing their informed consent. Subjects were excluded if they had experienced foot pain within the previous 6 months, had any history of previous foot surgery, or had congenital or acquired foot deformities, blisters or corn on the feet, or problems with the feet and the legs at the time of the study¹⁶). We also excluded women who had worn high-heeled shoes (higher than 7 cm) more than 3 times per week for 2 years to minimize the differences in the levels of habituation.

The mean age of the participants was 20.9 years, their mean height was 161 cm, and their mean foot length was 234.3 mm (Table 1).

We used the FDM-S (zebris Medical GmbH, Germany) to measure the plantar foot pressure and displacement of COP of all subjects. This system uses a pressure board, with 2,560 embedded sensors and the pressure is recorded by each sensor. The styles of shoes used in our study were the same. We chose only 3 different heel heights, 0.5 cm, 4 cm, and 9 cm. We used a single-subject design in which each subject wore all 3 types of shoe in a random order in order to minimize the effects caused by cumulative muscle fatigue. The subjects rested for 1 day between tests to ensure adequate rest²⁷). The subjects walked along a directed route for 60 minutes with a guide. The walking route included an uphill road, a downhill road, a flat section, and stairs to faithfully simulate the types of walking that people perform daily life. In order to control the walking speed, we gave each subject a metronome. This was set according to the scientific results of 2 different studies that determined the average stride length and walking pace of typical women in Korea to be 0.66 m/step and 1.17 m/s, respectively²⁰). We measured the foot pressure after having each subject walk barefoot for 10 to 20 seconds in order to minimize the resistance. We drew an outline of the foot on the force plate in order to control the foot position and directed the subjects to stand above the outline and look at a line in front of them at approximately eye level. The data were recorded before and after walking. The paired t-tests was used to compare the

results obtained before and after walking for 1 hour wearing each type of shoe. Analysis of variance (ANOVA) with the posthoc Scheffe test was used to identify the differences in the changes among the heel heights. The statistical significance level was 0.05, and SPSS 18.0 was used for the analysis.

RESULTS

The distributions of foot pressure of both feet shifted from the forefoot to the hindfoot after walking for 1 hour in flat (0.5 cm) shoes, and the difference between the distributions before and after walking was significant ($p < 0.05$). For high-heeled shoes (9 cm), the distributions of pressure in both feet shifted from the hindfoot to the forefoot after walking for 1 hour, and the difference between the distributions before and after walking was significant ($p < 0.05$). However, there was no significant difference between the pressure distributions before and after walking in either foot when the subjects walked wearing 4-cm heels ($p > 0.05$) (Table 2).

The COP was significantly displaced ($p < 0.05$) after walking while wearing either flat shoes (0.5 cm) or high heels (9 cm), but not after walking while wearing middle height heels (4 cm) (Table 3).

DISCUSSION

We investigated the relationships of the distribution of foot pressure and the displacement of COP with the height of the shoe heel worn by women, and found that both the distribution of foot pressure and the displacement of COP altered after walking for 1 hour wearing either flat (0.5 cm) or high-heeled (9 cm) shoes. The distributions of foot pressure shifted toward the hindfoot and the forefoot after walking in flat (0.5 cm) and high-heeled (9 cm) shoes, respectively, for 1 hour. The distribution of foot pressure moved from the hindfoot to the forefoot as the heel height increased. Consistent with our findings, Hong et al.²⁸) reported that increasing the heel height shifted the distribution of foot pressure toward the forefoot and altered the biomechanics. Cong et al.¹⁰) and Speksnijder et al.¹⁶) suggested that 7-cm- and 6-cm-heeled shoes increased the peak pressure in the medial forefoot. In addition, Song et al.¹⁸) reported that the peak pressures of the forefoot were 4.5–4.8 times and 2.3–2.5 times greater than those of the middle foot and rear foot, respectively, in subjects wearing high heels or kill heels. One possible reason for this change in the distribution of foot pressure may be related to the walking pattern. Because of the heel height, walking while wearing high heels involves more contact of the forefoot than of the hindfoot, and walking in flat shoes involves more contact of the hindfoot than of the forefoot. In running, the running pattern is more im-

Table 2. The foot pressure distribution before and after walking

	Heel height	Part	Pre	Post
Left	0.5	Fore foot	48.9 (10.5)	36.5 (9.5) **
		Hind foot	51.1 (10.5)	63.5 (9.5) **
	4	Fore foot	40.8 (7.3)	41.0 (6.5)
		Hind foot	59.2 (7.3)	59.0 (6.6)
	9	Fore foot	41.0 (8.0)	56.4 (12.9) ***
		Hind foot	59.0 (8.0)	43.6 (12.9) ***
Right	0.5	Fore foot	47.8 (11.5)	36.6 (11.0) ***
		Hind foot	52.2 (11.5)	63.4 (11.0) ***
	4	Fore foot	42.6 (9.1)	43.7 (9.8)
		Hind foot	57.4 (9.1)	56.3 (9.8)
	9	Fore foot	39.5 (8.0)	55.7 (11.9) ***
		Hind foot	60.5 (8.0)	44.3 (11.9) ***

p<0.01, *p<0.001

Table 3. The displacement of COP before and after walking

Heel height	Pre (M ± SD)	Post (M ± SD)
0.5 cm	72.5 ± 14.2	104.3 ± 19.6***
4 cm	81.7 ± 13.2	89.7 ± 15.6
9 cm	76.8 ± 17.7	102.7 ± 25.4***

*** p<0.001

portant than whether the subject is barefoot or shod. Running barefoot while maintaining the usual heel strike pattern may predispose to injury²⁹. In contrast, the use of a forefoot heel-strike pattern in barefoot running reduces the impact load and stride length³⁰. The walking pattern while wearing flat shoes may resemble the barefoot running pattern in that the heel strike pattern is maintained despite the change in footwear. According to Hatala et al.³¹, factors such as running speed, training level, substrate mechanical properties, running distance, and running frequency, influence the selection of foot strike patterns. We suggest heel height is an additional factor influencing the selection of foot strike pattern. The second possible reason for the observed changes may be the over use of specific muscles. High heels induce greater plantar flexion, whereas flat heels induced greater dorsiflexion of the ankle. This means that compared to high-heeled shoes, women wearing flat shoes use specific muscles more heavily than others and shift their bodies anteriorly. The overuse of specific muscles during walking may also cause musculoskeletal disorders.

In our study, wearing either flat or high-heeled shoes altered the distribution of foot pressure. The body was measurably affected even though each type of shoe was worn for only 1 hour. Therefore, both flat shoes and high-heeled shoes may increase the risk of musculoskeletal disorders. However, wearing middle-heeled (4 cm) shoes did not change the distribution of foot pressure, suggesting that a middle height heel (4 cm) is the optimal height for preventing musculoskeletal disorders. Notably, we studied the effect of heel height after walking for just 1 hour rather than for a long period. Therefore, our results cannot predict the

effects of wearing these types of shoes long-term.

The COP is the point on a body at which the total sum of the pressure acts, causing a force with no moment about that point. The COP has been used for several years as an index of standing postural stability. The COP can also predict the dynamic balance ability^{32, 33}.

Paik and Im³² suggested that COP parameters quantitatively reflect biomechanical alternations of the foot, and that walking in high-heeled shoes displaced the COP medially and anteriorly relative to walking in low heels. Some studies have recommended a heel height of between from 3 cm to 5 cm as the best for maintaining balance^{20, 22, 23}. Oh et al.²⁵ reported that high-heeled shoes induced extra-muscular effort in the ankle joint. The compensatory reactions of the musculoskeletal system then caused problems with balance control. In the present study, walking in middle-heeled (4 cm) shoes did not cause significant COP displacement ($p>0.05$), but both flat shoes (0.5 cm heel) and high-heeled (9 cm) shoes caused significant displacements.

As suggested by the above studies, wearing either high-heeled or flat shoes may induce biomechanical alternation and compensatory movement. These changes may in turn decrease the ability to balance, explaining why the displacement of COP was greater for flat and high-heeled shoes. We conclude that both flat shoes and high-heeled shoes cause bodily instability that could lead to falls.

This study addressed the effects of wearing shoes for relatively brief periods of time. Although the subjects wore the shoes for just 1 hour, we observed significant effects on the displacement of COP as well as the distribution of foot pressure. In a study by Kim, subjects walked in high-heeled shoes for 50 hours (5 hours per day)²⁴. Hyun and Kim⁸ examined the effect of high heels on back muscle fatigue after walking on a treadmill for 1 hour, and found that even short-term wearing of high heels could affect the body. Their results resemble our findings that both high-heeled and flat shoes change the COP and distribution of foot pressure after walking for 1 hour. This means that even brief walking in inappropriate shoes may negatively affect the body's function.

Our study found that both high-heeled and flat shoes could have adverse functional effects on the body. However, we did not consider the subjects' walking habits, enrolled only college students in their 20s rather than subjects of various ages, and examined only the short-term effects of wearing.

In conclusion, we suggest that it would be better to choose shoes not for style alone, but also for whether they have positive or negative effects on the feet. Our results indicate that middle-heeled (4 cm) shoes are the most suitable for women.

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