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Studying the Plantar Pressure Patterns in Women Adapted to High-Heel Shoes during Barefoot Walking

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Abstract

Introduction: The feet are the only anatomical structures of the body which are in touch with the ground and complete the lower limb chain to bear the ground reaction forces (GRFs). Inappropriate distribution of the GRF as a result of the long-term use of high-heeled shoes causes an excessive stress which results in a wide-range of musculo-skeletal disorders mainly in feet and leg areas. Due to the increased rate of using high-heeled shoes in the world and because of the lack of knowledge about feet pressure patterns in this condition, the current study focused on studying the pressure in different parts of the foot in barefoot women who used to(were accustomed to wearing) wear high-heeled shoes for a long time. **Materials & Methods:** In this observational analytical case-control study, two groups of 35 subjects, were recruited. The feet pressure indexes of the experimental group of women who were habituated to wearing high-heeled shoes for the last 2 years were compared with women in the control group who wore shoes with normal heel height. A Zebris pedobarograph (Zebris Company, Germany) system was used to study the subjects' feet planter pressure during the static (double stance) and the dynamic (walking with self-selected speed) conditions. All tests were run amog subjects with their feet bare. **Results:** The statistical analysis showed a significantly stronger pressure on feet in participants with high-heeled shoes than the ones in the control group (P<0.001). **Conclusion**: The finding of this study suggested that long-term use of high-heeled shoes results in some changes on the distribution of body weight on feet even during barefoot standing and walking positions. In other words, individuals wearing high-heeled shoes involuntarily press a greater percentage of their body weight on the front part of their feet, which may results in pathological conditions of their feet such as callosity, corns or ulcers beneath their forefoot.

Keywords: High-Heel Shoes, Foot Pressure, Pedobarography, Women

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Introduction

The feet are the only structures of the body connecting human body to the ground. It is the most important part of the skeletal system bearing significant weight during standing and walking positions. There are very few studies regarding the pressure applied on the plantar part of the feet (1).The American Podiatric Association (APA) has pointed out that 72% of women wear high-heeled shoes and 40% of them use these shoes every day in America (2). In Iran, however, no reliable data is available on the extent of the high-heeled shoes use among Iranian women. The shoes design including stiffness, heel width, heel height and the flexibility of the heel may affect walking mechanics (3). The previous studies showed that high-heedel shoes might impose changes on feet pressure as these shoes could raise plantar pressure on the front of the feet and could transfer them from the third, fourth and fifth metatarsals toward the first and second metatarsal heads (4). A series of accommodation changes has been reported in subjects accustomed to wear high-heeled shoes. It varies from shortening of the gastrosoleus muscles, increase in Achilles tendon stiffness, stretching of the feet dorsiflexors and evertor muscles and changes beneath the feet. Too much shortening or lengthening of the muscles may make them alter neuromuscular activation patterns. These changes, in (long) turn result in the reduction in muscle-tendon motor unit quality

(5, 6). Peroneus longus fatigue has frequently been mentioned by the users because of the long-term use of high-heel shoes (7). In fact, high-heeled shoes affect the base of support, center of pressure, changes of the center of gravity and lead to the decrease in balance, which may cause the the reduction in body balance (8). Frequent bone fractures have been reported after the subjects wearing high-heeled shoes had fall, particularly the elderly people. Research has showed that the fall risk in the elderly when they wear shoes with heels higher than 2.5 cm is two times more than younger individuals. In addition, higher heel height decreases the preferred speed, shortens the step length, increases knee flexion and ankle plantar flexion angles and increases pelvic anterior tilt and trunk extension (9).

The longer women use high-heeled shoes, the worst kinematics and kinetic changes occur which finally will result in inflammatory or degeneration changes of the Achilles tendon. According to the studies, one can conclude that high-heeled shoes may lead to changes in the skeletal systems of the body and can have considerably negative effects on the kinematics and kinetics during walking, standing and balance positions in peoples' distribution of plantar pressure. In all studies related to this topic, the immediate effects of walking with high-heeled shoes have been studied. To the best of the authors' knowledge, the long-term effects of wearing high- heeled shoes via its plantar pressure measurement have not yet been examined. The current study aimed to find out if the plantar pressure pattern of the subjects who accustomed to wear high-heel shoes are different from subjects accustomed to wear shoes with normal height during walking bare foot.

MATRIALS AND METHODS

In this observational-analytical case-control study 70 subjects were recruited and divided into two groups each of which had 35 subjects. The mean age of subjects was 23 years old and all were students of the school of rehabilitation in Shahid Beheshti University of Medical Sciences. The experimental group included 35 young women with an experience of wearing shoes with heels higher than 5 cm at least 3 days per week (6 hours per day) for at least 2 years. The control group contained 35 healthy young women with an average age of 23 years old, who were using normal shoes with heels of up to 2 cm. pregnancy, any apparent lower limb muscle weakness, previous fracture of the lower limb bones and pain in the lower limbs were considered as the main exclusion criteria.

To examine the plantar pressure distribution test, a platform pedobargraph device (Zebris, Zebris Company, Germany) was used in this study. The device has a pressure sensitive platform that changes feet images to the visible pressure data. The test was conducted at two stages;the static and dynamic.

Prior to the test, the subjects were asked to walk many times freely and with a normal rhythm to get accustomed to the tool. Then, after a few minutes rest, the main test began. During the test, the subjects were asked to walk routinely and to adopt comfortable posture with normal swinging arms while walking. The subject had to keep their head up and could not look down during the test. The test would have been rejected if the subjects had planted his/her feet incompletely on the platform. During the static test, while subjects had to stand on the platform bare feet with legs open about the width of his/her shoulder in order to create balance and to prevent too much pressure on one limb (foot), the subjects were asked to look at a fixed point in front of the wall in the distance of five meters. The data were recorded as the subjects were standing on the platform calmly and comfortably (10). Data collection was repeated three times. The average of the results of three tests was calculated and saved for the data analysis. Then, the dynamic tests were performed. As the subjects were standing four meters far from the platform, they looked forward and passed the platform with a self-selected (preferred) speed. The subjects planted his/her dominant foot on the platform. They had to prevent the other foot from touching the platform. The dynamic data collocation was also repeated until three acceptable records were kept. When subjects showed a targeting gait (*i.e.* stopping in front of the force plate to adjust their footsteps on land on the force plate correctly), the test was repeated. The foam was used to equalize the height between the ground surface and the platform to reduce the error before the test. Finally, the data were processed by using the device software. All data were graphed by the Excel program at dynamic and static stages. All statistical analysis were carried out by the SPSS software version (16).

In this study, the parametric analysis formula were used for the data distributed normally and Non-parametric formula for the data not distributed normally.

A 360 degrees goniometer was used to manually measure the ankle Rom in long-sitting position. Ankle ROM (total and peak), foot contact time during walking, foot peak pressure (total and peak t different parts) and balance parameters including confidence ellipse and CP line were all measured.

Table 1. The demographic table of the subjects who participated in this study

Groups	Number	Age (years)	Height (meter)	Weight (kg)
High heel shoes	35	23.8±3.2	162.17±4.63	59.2±6.3
Normal heel shoes	35	22.9±2.6	163.57±5.97	59.7±8.2

Table 2. The results of the variables between two groups (N=35 in each group)

Variables	Average	SD	P-value
Total ROM in HHS	63.37	3.86	0.02*
Total ROM in NHS	61.20	3.95	
Peak Ankle Dorsi-flexion in HHS	16.54	2.81	0.72
Peak Ankle Dorsi-flexion in NHS	16.45	2.39	
Peak Ankle Plantar-flexion in HHS	46.82	3.38	0.004*
Peak Ankle Plantar-flexion in NHS	44.74	2.79	
Foot contact time in HHS	0.86	0.14	0.08
Foot contact time in NHS	0.80	0.07	
Peak Pressure at Walking in HHS	32.52	6.78	0.2
Peak Pressure at Walking in NHS	31.27	8.2	

The results showed a significant difference between two groups only in total ROM and in peak plantar flexion angles.

Table 3. Percentage of foot pressures on the front and hind foot between right and left feet

Percentage of foot pressure	Average	SD	*P*-value
Total Pressure on the right foot in HHS	52.83	10.61	0.576
Total Pressure on the right foot in NHS	54.1	8.5	
Pressures on right forefoot in HHS	48.5	11.5	0.001*
Pressures on right forefoot in NHS	31.1	9.2	
Pressures at right hindfoot in HHS	51.5	11.5	0.001*
Pressures on right hindfoot in NHS	68.9	9.2	
Total Pressure on the left foot in HHS	47.3	10.7	0.559
Total Pressure on the left foot in NHS	45.8	8.5	
Pressures on left forefoot in HHS	51.0	10.6	0.001*
Pressures on left forefoot in NHS	30.1	8.8	
Pressures on left hind foot in HHS	49.0	10.6	0.001*
Pressures on left hindfoot in NHS	69.9	8.8	
Confidence Ellipse in HHS	68.3	3.15	0.3
Confidence Ellipse in NHS	59.1	7.45	
CoP line length in HHS	119.4	6.36	0.4
CoP line length in NHS	115.9	4.30	

HHS: High-heeled shoes; NHS: Normal heeled shoes

Results

Table 1 shows that two groups were compatible and had no obvious difference in terms of age, height and weight. Therefore, the results could be applicable for both groups.

To find out if data were normally distributed, a K-S test was used and according to the results obtained, for variables of the maximum range of ankle flexion plantar, range of ankle motion, initial contact of the heel and the maximum pressure of the foot during walking the normality of data distribution was not achieved; therefore, a non-parametric Mann-Whitney test was applied to compare two groups for the variables mentioned above. For other variables of the study, an independent sample t-test was used. A Mann-Whitney test showed that two groups ha statistically meaningful difference in terms of the maximum range of ankle flexion plantar and range of ankle motion so that the maximum range in plantar flexion of experimental group had a higher average than the control group (*P*=0.002). Also, the range of ankle motion in the experimental group was higher than the control group (*P*=0.004). No significant differences were noticed regarding the other variables of the current study.

The results demonstrated no significant difference between the total pressure of the right and left foot in two groups. However, the pressure on the forefoot and hind foot of the right and left foot were significantly different. The results approved there was always a stronger pressure on the forefoot of the participants who were habituated to wearing high-heeled shoes on both right and left sides.

The balance factors showed no significant difference between two groups (P>0.05).

Discussion

This study aimed to investigate the distribution of plantar pressure patterns in healthy young women who were accustomed to using high- heeled shoes for at least two years. The study was conducted in both static and dynamic situations on the pedobarograph tool. The ankle ROM was measured by a goniometer.

The results of this study showed that there was a significant increase in the whole ankle ROM and the maximum ankle plantar flexion angles in the experimental group compared to the control group. According to the De Lateur and colleagues, the most compensation for heel height occurs at the knees and ankles (11). The findings of the current study were in line with the previously conducted one. In fact, the previous studies have shown that women who routinely use the high-heeled shoes, have shortened Achilles tendon. All the subjects of this study showed significant decrease in ankle dorsiflexion angle that approved the findings of the previous studies.

The plantar pressure distribution pattern of the subjects adapted to frequent use high-heeled shoes showed a significantly more forefoot pressure occurring on their forefeet even when they did not use high-heeled shoes during standing position. In addition, they imposed greater percentage of their body weight on their forefeet in normal walking. For this reason, these people are usually expected to have pain, corns and callosity on their anterior region of their feet.

Some researchers have carried out many studies in this field. The results of this study were in agreement with some of them and in disagreement with some others. Snow and colleagues studied the immediate effects of different high-heeled shoes on women's' plantar pressure using a foot print pedobarograph device (12). The results showed that in short, medium and high heeled shoes, the maximum pressure measured increased in all pressure points compared to the normal heeled shoes. During walking with feet bare, pressures on the second and third metatarsal heads were stronger than the pressure under the first one. This finding was in accordance with the views of Morag and Cavanagh (13) who reported the most intense pressures under the second metatarsal head. The study showed that the increase in the heel height may cause an increase in the pressure under the metatarsal heads. This finding corresponds to the results of Schwartz *et al*. (14) that pointed out an increase of 2-inch heel height, reduces burden under heel and shifts it to the metatarsal heads. Also the pressures will increase via the increase in the heel of the shoes beneath the three lateral metatarsals.

Another study was carried out by Mandato & Naster in 1999 who studied the effects of the increase in the height of the shoe heels on forefoot pressures. The results showed that the pressure on the anterior part of the foot significantly increased when the height of the heels increased. This occured when the maximum pressure was shifted toward the first metatarsal and hallux finger (15). Lee *et al*. investigated the effects of the increase in the heel heighton plantar pressures, compact force and comfortable walking with 3 types of shoes with different heel height (16). They concluded that the increase in the shoes heelincreased the compact force, pressures on the anterior & medial part of the foot and produced pain during walking. They also found that by the increase in the height of the heel, the pressures of the heel and mid-foot areas shifted to the front area of the foot, which was in consistent with the results of the previous studies (16). Besides this study, Hong *et al.* conducted a study that investigated the impact of heel height and shoes insert on comfort and the biomechanical performance during walking in young adult women. The results showed that the problems occurred during walking increased by the increase in the heel height of the shoes, in which the plantar pressure shifted from the heel and mid-foot to the internal part of the anterior segment of the foot (17).

Speksnijder *et al.* showed that the maximum pressure in anterior part of the foot and hallux increased mutually when the height of shoes heels increased. However, all parameters significantly reduced in the mid-part of the foot (18).Ko *et al.*, investigated the relationship between the plantar pressure and soft tissue strains under the metatarsal heads with different heel heights. The results showed that the pressure beneath the metatarsal heads significantly increasedvia the increase in the heel height from 2 cm to 4 cm. In fact, it shifted weight to the first and second metatarsal heads. A change of soft tissue occurred on the antero-medial part of the foot when the height of the heels increased more than 2 cm (19). Another study of the effects of high heels on foot plantar pressure was carried out by Gu *et al.* (20). They examined the plantar pressure distribution using 3 standard heeled shoes with 3 different heights and found that the pressure on the forefoot in high-heeled shoes increased significantly in comparison with the flat shoes. All of these studies measured the immediate effects of wearing high - heeled shoes and the subjects did not have any experience of wearing high-heeled shoes. Barton et al assumed their subjects marked changes following wearing high-heel shoes as a feed forward phenomenon (21).

Conclusion

With regards to the results of this study, those with a background of long-term use of high-heeled shoes tend to have more pressure on their forefoot which may result in cone, callosity, etc. in this area. This is very important in subjects with diabetes who are very susceptible to foot ulcers.

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All authors made substantial contributions to conception, design, acquisition, analysis and interpretation of data.

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