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INFLUENCE OF ARCH INSERTS ON PLANTAR PRESSURE DISTRIBUTION WHEN WALKING IN HIGH-HEELED SHOES: A PRELIMINARY STUDY

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This study investigated the effects of arch inserts on the plantar pressure of adult females standing and walking on shoes with different heel heights. Four healthy adult females between 22 and 24 years old participated in the study. The Novel Pedar insole measurement system (Germany, Munich) was used to determine plantar pressure. Results indicated that during standing, arch inserts reduced the peak plantar pressure in the total foot in both shoes. The arch inserts reduced the peak plantar pressure under the first toe and the metatarsal head regions during normal walking, and increased in the arch regions for both shoes.

KEY WORDS: arch inserts, high-heeled shoes, plantar pressure.

INTRODUCTION: The heel height of shoes is closely associated with plantar pressure distribution. Women wearing high-heeled shoes exhibited redistribution of plantar pressure in which the pressure of the forefoot increased and the pressure of the rear foot decreased. Simultaneously, the center of pressure also moved forward and medially (Cernekova and Hlavacek, 2008). A study on plantar pressure during normal gait conducted among 30 women between 18 and 30 y old wearing shoes of different heel heights. The results showed that heel height remarkably influenced plantar pressure distribution. When heel height exceeded 3.12 cm, the load bearing of the heel started decreasing. Compared with barefoot walking, walking in high heels significantly reduced the peak pressure at the fifth metatarsal head . Peak pressure at the middle part of the heel occurred earliest in barefoot walking and was most delayed as heel height increased (Eisenhardt et al., 1996). Walking with raised heel diminishes the mechanical function of foot arch in cushioning high plantar pressure and intensifies the load of musculature and the fatigue of foot ligaments, resulting in metatarsal head pathology.

Studies on improving peak plantar pressure distribution when walking in high-heeled shoes have been conducted, with some focusing on midsole materials (Kersting and Brueggemann, 2008) as well as materials and contours of inserts (Munedermann, Stefanyshyn, and Nigg, 2001). In particular, modeling of shoe arch has drawn research interest. Witana et al. (2009) found that the geometry of the shoe arch largely influence the perceived sensations of the subjects. (Witana et al., 2009). Shoe inserts are designed such that the foot arch is properly supported and the high peak pressure on the metatarsal head is reduced. To date, studies on this type of inserts and their effect on plantar pressure distribution are rarely reported. In the present study, we measured the plantar pressure and loading area of the foot of young female subjects walking in high-heeled shoes of different heel heights: one with an arch insert and another without an arch insert. This study aimed to provide quantitative information on the functionality of arch inserts on improving plantar pressure distribution.

METHODS: Four young female adults volunteered to participate in the study. All subjects were healthy and had no foot-related disease. Table 1 presents the body weight, body height, and foot size of the subjects. Informed consent was obtained from each subject, and approval of the study by the medical ethics committee of the university was received.

Table 1. Specifications of the subjects

Subjects	Age (years)	Body weight (kg)	Body height (cm)	Foot size
A	23	47.5	166	36
B	23	55	165	36.5
C	24	58	169	37
D	22	62	160	36.5

Specifically designed arch inserts (Figure 1) (MBWalker AO-01, International Biomechanics Limited, Hong Kong) were tested. The inserts were designed based on the arch contour of the normal foot of Chinese adult females. An insole pressure measurement system (Novel Pedar, Munich, Germany) was used to determine the plantar pressure of the subjects wearing high-heeled shoes 8 and 4 cm high, respectively. Plantar pressure for each shoe was measured with an arch insert and without an arch insert. The measuring frequency of the insole system was set at 50 Hz.

Figure 1. The arch insert

The experiments were conducted in the biomechanics laboratory. Prior to the test, the sensor insoles were inserted in the shoes. For each shoe insert, plantar pressure was measured under two mechanical conditions: static and dynamic. Under the static condition, the subjects were requested to stand for 5 sec; under the dynamic condition, three trials were arranged. In each trial, the subjects were asked to walk from the start position along a straight-gait way for 8 m and return to the start position at a comfortable speed. Each subject completed at least three trials. The three trials in which the variation of average walking speed was within 5% were used to attract plantar pressure data. The dynamic tests were arranged in the following order: 4 cm high-heeled shoes without arch inserts, 4 cm high-heeled shoes with arch inserts, 8 cm high-heeled shoes, and 8 cm high-heeled shoes with arch inserts. In each trial, the plantar pressure parameters of three steady-state strides in each walk direction were averaged to obtain the data set for this trial. Finally, for each subject, 16 data sets (2 shoes $\times$ 2 inserts $\times$ 2 mechanical conditions $\times$ 2 feet) were obtained. The data of the Novel Pedar system were converted into the fgt format. The foot sole was divided into 9 regions by the system software. The peak and average regional plantar pressure were calculated. Excel 2003 and SPSS ver. 17.0 software were used to compare the pressure data between the insert and the mechanical conditions.

RESULTS AND ANALYSIS: STANDING CONDITION. Table 2 shows the mean and the standard deviation of the plantar pressure of the foot of each subject when standing for 5 sec with and without the use of arch inserts. The arch inserts significantly reduced the average plantar pressure ($p < 0.01$). Given that the pressure is inversely related to the loading area, the use of inserts is expected to increase the loading area of the foot.

Table 2 Average plantar pressure of the foot with and without arch inserts (kpa) when standing

Subject	Use arch inserts	4 cm left	4 cm right	8 cm left	8 cm right
A	Without	51.23 ± 17.61	56.67 ± 1.39	59.15 ± 16.47	54.72 ± 10.17
	With	49.94 ± 2.60*	44.70 ± 4.84	58.0 ± 16.39**	53.61 ± 0.80
B	Without	59.08 ± 17.16	55.70 ± 3.93	64.65 ± 4.11	61.01 ± 16.39
	With	53.10 ± 25.41*	55.15 ± 1.36	46.43 ± 9.45**	51.97 ± 3.17
C	Without	67.38 ± 5.57	67.00 ± 19.51	60.46 ± 20	68.11 ± 25.46
	With	53.20 ± 9.73*	61.38 ± 24.65	47.1 ± 13.65**	54.74 ± 8.33
D	Without	76.96 ± 25.28	86.84 ± 9.62	65.2 ± 32.95	73.87 ± 9.49
	With	66.04 ± 2.77*	60.80 ± 11.92	54.3 ± 10.61	57.49 ± 3.1**

Note: *p < 0.05，**p < 0.01 with arch inserts vs. without arch inserts. No difference between both shoes.

Table 2 shows that the plantar pressure in both feet were not significantly different. The use of inserts significantly reduced the plantar pressure (p < 0.05) in 4 cm high-heeled shoes (p < 0.05). The significance in the 8 cm high-heeled shoes was more remarkable (p < 0.001). No significant difference in plantar pressure was indicated between heel heights.

WALKING CONDITIONS: By using the system software, the foot sole was divided into eight regions: (1) first toe (T1), (2) second to fifth toes (T2 to T5), (3) first metatarsal head (M1), (4) second to third metatarsal heads (M2 to M3), 5) fourth to fifth metatarsal heads (M4 to M5), (6) medial arch (MA), (7) lateral arch (LA) and (8) heel (H). The data are shown in Table 3. Peak plantar pressure indicates the load on the foot. The magnitude and the position of the peak plantar pressure influence fatigue and cumulative injury of the foot during locomotion.

Table 3. Peak plantar pressure at foot regions when walking in high-heeled shoes of different heel heights with and without arch inserts (kpa)

	Shoes with 4 cm heels		Shoes with 8 cm heels	
Foot regions	Without insert	With insert	Without insert	With insert
T1	277.5 ± 46.73	181.8 ± 13.29*	248.13 ± 77.25	207.5 ± 15.81
T2 to T5	73.75 ± 3.23	117.5 ± 15.14	75.63 ± 5.91	89.38 ± 6.57
M1	131.88 ± 8.01	113.1 ± 12.48 **	468.75 ± 48.07##	124.38 ± 49.39**
M2 to M3	326.2 ± 134.02	294.3 ± 21.73*	541.25 ± 140.36##	118.75 ± 9.46**
M4 to M5	163.75 ± 13.62	51.25 ± 21.46	106.88 ± 16.88	79.38 ± 16.63**
MA	70.63 ± 16.63	92.5 ± 17.80**	29.38 ± 14.05	32.5 ± 25.41**
LA	70.63 ± 15.99	54.38 ± 22.95**	28.13 ± 6.88#	40.63 ± 16.38**
H	24.38 ± 5.91	16.88 ± 12.48	8.75 ± 5.91	15 ± 1.25

Note: *p < 0.05, **p < 0.01 with insert vs. without insert；#p < 0.05，##p < 0.01 8 cm vs. 4 cm

The results show that the peak plantar pressure at the first toe as well as the second to the third metatarsal heads were relatively higher than that at the other regions when wearing 4 cm high-heeled shoes. These higher plantar pressure regions when wearing 8 cm high-heeled shoes extended to the first metatarsal head. Comparing the two shoes, The peak plantar pressure of the first and the second to the third metatarsal heads was relatively higher in 8 cm high-heeled shoes than in 4 cm high-heeled shoes, whereas the first toe, heel, and both arches showed opposite results. Wearing both shoes, the lowest peak plantar pressure

occurred in the heel regions, indicating that high-heeled shoes anteriorly shifted the center of pressure during walking. In the forefoot, the medial and mid-metatarsal heads and the first toe were the regions that bore the higher peak plantar pressure. Finally, the use of arch inserts in both shoes resulted in a significant decrease in peak plantar pressure in metatarsal regions: the first metatarsal head ($p < 0.01$), the second to the third metatarsal heads ($p < 0.01$), and the fourth to the fifth metatarsal heads ($p < 0.01$).

SUMMARY: The heel height of shoes and the use of arch inserts were associated with the change in peak plantar pressure. During standing, arch inserts reduced the peak plantar pressure of the total foot. During normal walking, the arch inserts changed the plantar pressure distribution. The peak plantar pressure in the medial part and the anterior part of the foot such as the first toe as well as the first and the second to the third metatarsal heads decreased, whereas the peak plantar pressure in the arch regions increased. The 8 cm shoes were associated with higher peak plantar pressure at the first metatarsal head as well as the second to the third metatarsal heads, whereas the peak plantar pressure at the arch regions was lower than that in the 4 cm shoes. The reduced plantar pressure in high-heeled shoes further indicates the anterior shift of the center of pressure at the foot.

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