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The higher the heel the higher the forefoot-pressure in ten healthy women

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Abstract

Foot pressures were measured in 10 healthy women, while walking in high-heeled (5.91 ± 1.03 cm) and low-heeled (1.95 ± 1.06 cm) shoes. The foot was divided into seven regions. For each region the following parameters were calculated: the peak pressure (PP), pressure time integral (PTI), maximum force (MF), force time integral (FTI), contact time (CT) and contact area (CA). In high heels loading was reduced in the midfoot and under the heel, the CA and MF were decreased significantly. Walking with high-heel shoes caused an increase in peak pressures of 30% in the central forefoot (metatarsals 2–4) in comparison with low heels, whereas PTI increased by 48%. In the medial forefoot (metatarsal 1) these parameters increased by 34% and 47%, respectively. An increasing heel height shows a correlation (>0.70) of PP to PTI in the medial forefoot and to PP in the central forefoot.

Keywords: High-heel shoes; Foot pressures; Insole measurements

1. Introduction

A prevalence of 83% of foot problems in women (aged 50–70) wearing high-heeled shoes is reported by Dawson et al. [1]. It is suggested that wearing high heels leads to changes in load distribution beneath the foot and can be detrimental to foot structure [2]. Research examining changes in loads beneath the foot with different footwear began in the early 1930s [3]. Recently, technology has improved to a point where foot pressures could be measured more precisely and accurately. In-shoe pressure measurement with insoles has the potential to play a crucial role in the screening and management of patients who are at risk from foot problems [4]. In this study we investigated the effect of wearing high heels on plantar pressure.

2. Materials and methods

Ten healthy female subjects participated in the experiment. Women with recent injuries that potentially impair walking, foot deformities, ankle, knee, hip and back problems systemic diseases and neurological defects impairing gait and foot pressure were excluded from the study. All participants normally wore both low and high heels. Physical data of the subjects are listed in Table 1. The study took place at the orthopedic research centre in the academic hospital Maastricht (azM), the Netherlands.

During the experiment all subjects walked in their own low-heeled shoes (1.95 ± 1.06 cm) and their own high-heeled shoes (5.91 ± 1.03 cm) shoes, wearing thin nylon socks. The PEDAR® insole system (Novel Gmbh, München, Germany) was used to measure the pressure and force between the plantar surface of the foot and the shoe. The PEDAR® insole is a pressure distribution measuring device based on the capacitance principle. The insoles are approximately 2.6 mm thick and contain at least 99 sensors. The sensors scan with a speed of 10,000 Hz. The insoles are able to measure pressures up

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Table 1
Physical data of the subjects

Subject	Mean	Range
Age (year)	22	21–24
Weight (kg)	60	52–73
Height (cm)	167	158–175

to 120 N/cm^2. All subjects wore their own shoes on a regular basis in the past. All subjects were given the opportunity to walk around for several minutes on both shoes, so that they could accustom themselves to the PEDAR® insoles.

A number of characteristics of the shoes were measured, such as effective heel height (heel height without basic sole) and surface area of the heel (see Table 2).

Before pressure measurements were started, the subjects were asked to walk straight ahead for about 15 meters at their own pace. The time and number of steps of this walk are recorded, in order to assess the patients' own cadence. This cadence was imposed to the same subject during all measurements, using a metronome [4]. For data collection, subjects were asked to walk five times 15 m in the low-heeled and five times 15 m in the high-heeled shoes [5]. In each walk, data was collected at random from at five left and five right successive footsteps representing the "middle" of the dataset, thus reflecting a "normal" walk pattern, without starting and stepping bias. A total of 25 steps from the low heel walk and 25 steps from the high-heel walk were stored for further evaluation.

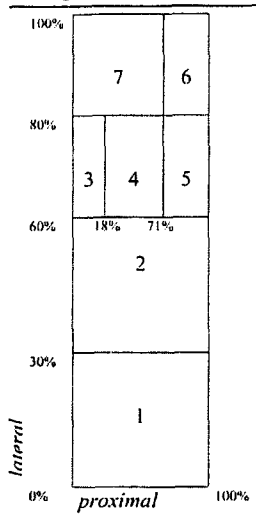
For final analysis, the feet were divided in seven regions of interest (masks): heel, midfoot, lateral forefoot, central forefoot, medial forefoot, hallux and toes 2–5 (see Table 3). For each of these regions the following parameters were assessed: contact area (CA) in cm^2, contact time (CT) in ms, maximum force (MF) in %body weight (BW), peak pressure (PP) in N/cm^2, force time integral (FTI) in %BW s and pressure time integral (PTI) in N/cm^2 s. Both the PTI and the FTI provide an understanding of the load distribution applied over time.

SPSS® 10.0 for Windows was used for statistical analysis (SPSS, IL, USA). Data from clinical evaluation and physical measurements were put into the SPSS program. The differences between results of the right and left feet and between measurements in low and high heels were analyzed using a two-tailed t-test for paired samples. Statistical significance was determined at the $P<0.05$ level. The Pearson correlation was used to assess the relationship heel-height, weight, height, cadence and velocity to the results of the PEDAR measurements (CA, CT, MF, FTI, PP and PTI).

Table 2
Characteristics of the low- and high-heel shoes

	Low-heel	High-heel
Effective height (cm)	1.95 (±1.06)	5.91 (±1.03)
Heel surface (cm^2)	50.7 (±9.7)	32.3 (±4.4)
Shoesize (European)	38 (range 36–41)	

Table 3
Zoning of the foot in several masks for the left foot



mask 1: heel
mask 2: midfoot
mask 3: lateral forefoot
mask 4: central forefoot
mask 5: medial forefoot
mask 6: hallux
mask 7: toes 2-5

3. Results

A difference in stand phase was noted between the right and left feet, resulting in a different CT. The CT differed significantly between the left and right foot in LH for the medial forefoot, lateral forefoot, hallux and toes 2–5 and in HH for the hallux and toes 2–5. The CT difference between the left and right feet could be explained by the natural difference during the standing phase in gait, since there are no complaints or abnormalities within these subjects. In further analysis only the left feet were used.

Several parameters showed significant changes while walking in high-heeled shoes compared to walking in low-heeled shoes in the left foot (Table 4, Figs. 1–2). In the heel, midfoot, lateral forefoot and central forefoot was a decrease of the CA, respectively, −4%, −54%, −5% and −3%. The CT increased in the midfoot (12%) and lateral forefoot (11%). The MF decreased in the heel (−15%), midfoot (−66%), lateral forefoot (−28%) and increases in the medial forefoot (30%) and hallux (14%). In the midfoot the FTI decreased (−76%) and increased in the central forefoot (16%) and medial forefoot (37%). The PP increased in the central forefoot (30%), medial forefoot (34%) and hallux (23%). In the midfoot PTI decreased (−40%) and increased in the heel (12%), central forefoot (48%), medial forefoot (47%) and hallux (20%).

The difference in height between low and high heels was correlated by the observed difference in loading for the individual subjects. Correlations >0.70 were found between increasing heel-height and PP and PTI in the medial forefoot

Table 4
Results of various variables of plantar foot pressure in the high-heel shoes in relation to the low heel shoes (percent change)

	Total	Heel	Midfoot	Lateral forefoot	Central forefoot	Medial forefoot	Hallux	Lateral toes (2–5)
Contact area (cm^2)	−13***	−4*	−54***	−5**	−3**	1	1	−3
Contact time (ms)	1		12**	11**	−8	−8	−1	0
Maximum force (N)	2	−15**	−66**	−28*	−4	30*	14*	−1
Force time integral (N s)	3	0	−76*	−21	16*	37*	14	16
Peak pressure (N/cm^2)	28*	−4	−27	−15	30*	34**	23*	8
Pressure time integral (N/cm^2 s)	21*	12*	−40*	1	48**	47**	20*	35

* Significant change $P<0.05$.
** Significant change $P<0.01$.
*** Significant change $P<0.001$.

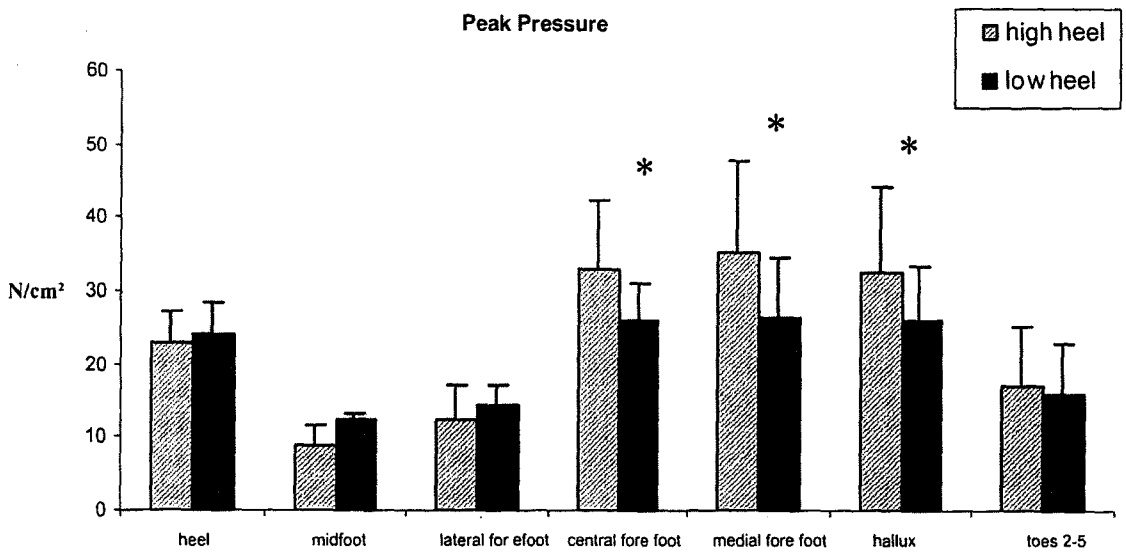


Fig. 1. Peak pressure in high-heel and low-heel walking for the left foot. Significant change $^{*}P<0.05$.

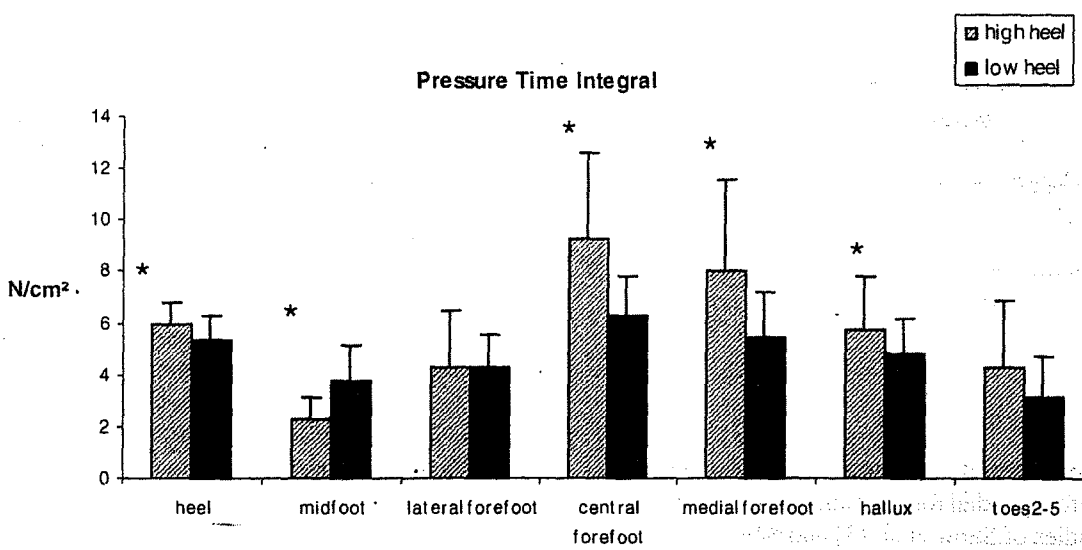


Fig. 2. Pressure time integral in high-heel and low-heel walking for the left foot. Significant change $^{*}P<0.05$.

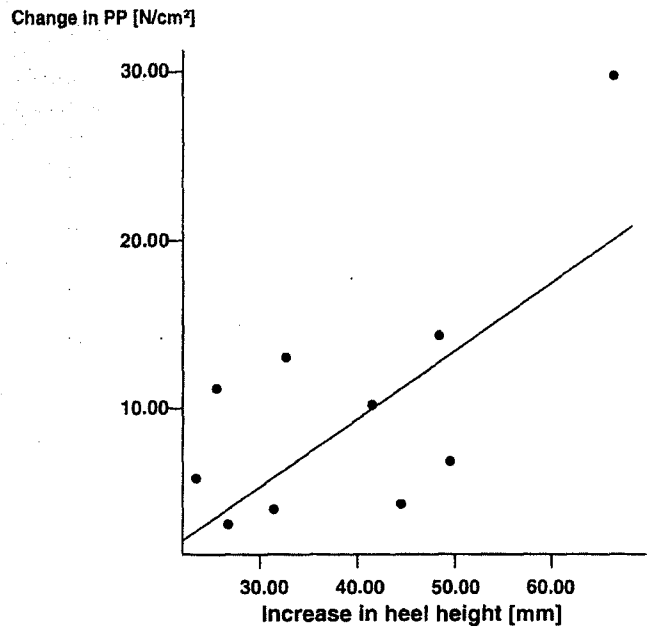


Fig. 3. Correlation between increase in heel height and change PP in the central forefoot.

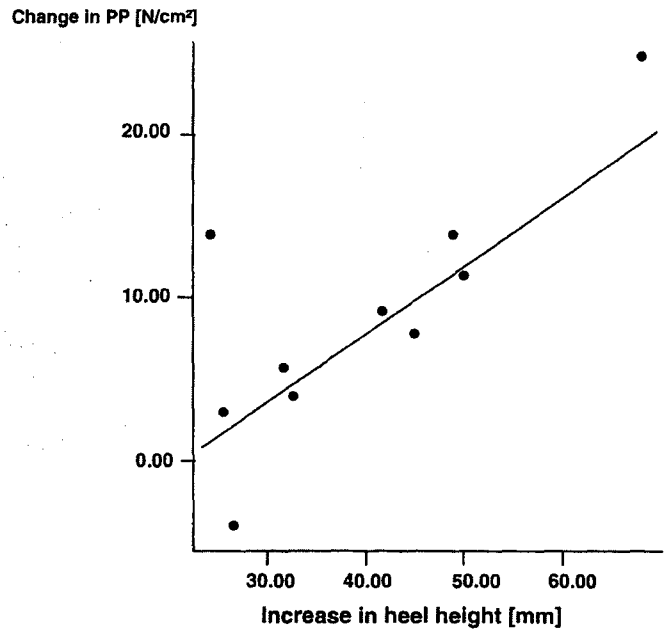


Fig. 4. Correlation between increase in heel height and change PP in the medial forefoot.

and PP in the central forefoot (Figs. 3–5). All other calculated correlations were <0.70.

4. Discussion

This study demonstrates an increased PP and PTI under the central forefoot, medial forefoot and hallux when wearing high heels. Studies of Snow et al. [3] and Soames and Clark [6] used outdated method for pressure measurement with a scanspeed of, respectively, 30 Hz and 200 Hz. In this study,

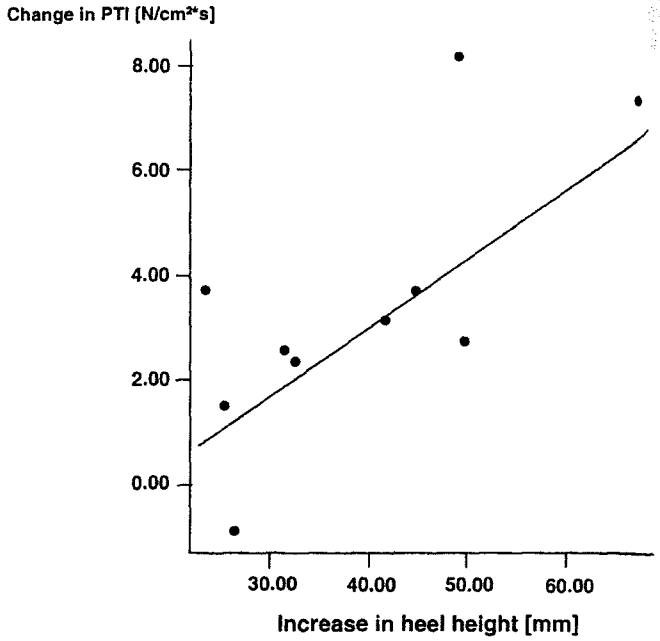


Fig. 5. Correlation between increase in heel height and change PTI in the medial forefoot.

in-shoe pressure measurements were taken by a system with a high resolution by the PEDAR® insole system (see Section 2). Nyska et al. [7] measured subjects, while walking on a treadmill at a regulated speed. They noted that 'using a treadmill for the different walks may alter normal gait patterns'. Therefore, in this study the subjects walked their own pace, on a smooth linoleum surface, mimicking normal gait as closely as possible.

Several studies [3,6–8] found that an increase in heel height increases the maximum peak pressure under the metatarsal heads of the forefoot. In the forefoot, parameters most likely to change were studied: PTI, PP, FTI and MF. In this study a correlation >0.70 between increasing heel height and PP in the central and medial forefoot was found. Also a correlation >0.70 was found between heel height and PTI in the medial forefoot. The increasing load in the forefoot is in congruence with findings of other investigations. Nyska et al. [7] reported an increase of 40% in PP in the medial forefoot, and an increase up to 35% of the PP under the hallux. Mandato and Nester [8] reported an increase of 63% in (medial) forefoot PP when sneakers were compared to 2-in. heels, and an increase of 30% when 2-in. and 3-in. heels were compared with one another. McBride et al. [2] implied that wearing high-heeled shoes tends to shift the course of the ground reaction forces closer to the first metatarsal than walking barefoot, thereby allowing a greater proportion of the total force to act directly on this bone. The main difference between this study and others as mentioned in this paragraph is the finding of linear correlation >0.70 between an increase of heel-height and an increase of PP and PTI in the medial forefoot and PP in the central forefoot.

Under the midfoot the most important changes were seen in CA, MF, FTI and PTI. All these parameters decreased sig-

nificantly with a major difference for the FTI. This could be explained by a decreased roll forward over the midfoot in high-heeled shoes which gave a significant decreasing of the above mentioned parameters [2]. In high-heeled shoes, the midfoot is held off the ground, which may prevent this dissipation or high pressures. In this study CA decreases under the midfoot, this can be explained by the "windlass effect". This phenomenon is likened to the winding of a cable (plantar aponeurosis) around the drum of a windlass (first metatarsophalangeal joint) by pulling a handle (proximal phalanx of the hallux). Passive dorsiflexion of the hallux caused the medial longitudinal arch to rise [9].

Most of the data are in line with earlier studies in which the effect of high heels were investigated. This study differed from other studies on a number of relevant points; the subjects walked at their own pace, the used instrument was more precise and had a higher resolution and all measures were taken five times.

Each female wore her own shoes, to assure comfortable walking and to approach normal gait. However, different footwear can flaw the results. Footwear materials (outer soles, inner soles, linings and uppers) vary and may influence the results of the foot pressure measurements. Standard shoes with variable heel height could solve this problem, but such shoes might be uncomfortable and affect the results.

The type of feet can influence the results of foot pressure measurements. The number of feet in this study did not permit sub-analysis.

This study demonstrates that wearing high-heeled shoes results in load shifting from the heel region towards the central and medial forefoot. Increases of pressures up to 40% are common in the forefoot. These findings implicate that subjects who are vulnerable for high pressures such as diabetics and rheumatoid arthritis should be discouraged from wearing high-heeled shoes.

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