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The Effects of Wearing High Heeled Shoes on Pedal Pressure in Women

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ABSTRACT

The purpose of this study was to investigate the effects of increased heel height in women's shoes on foot pressure during walking. An increase in heel height increased the maximum peak pressure under the metatarsal heads in the forefoot, decreased the time to maximum peak pressure under the metatarsal heads, and increased the rate of loading to the metatarsals during early support. The higher pressures noted with increased heel height were accompanied by a more uniform distribution of pressure beneath the forefoot. These findings may denote increased stress to the various tissues in the foot when walking in high heeled shoes, which may contribute to deleterious orthopaedic changes. Quantitative studies need to be conducted to determine whether orthopaedic changes occur with prolonged wearing of high heeled shoes.

LITERATURE REVIEW

Millions of working women spend their entire day standing or walking in high heeled shoes. Clinical relationships have been proposed linking foot ailments or pain to wearing high heels, yet little quantitative research has been done on the relationship between heel heights and pressure beneath the foot. Research examining changes in loads beneath the foot with different footwear began in the early 1930s, but not until recently has the technology improved to a point where pressures could be measured precisely and accurately.

Schwartz et al.[19] used oscillograph records obtained from six galvanometers strapped to the foot to determine that all forces under the forefoot increased with an increase in heel height when walking. Godfrey et al.[8] used a similar approach of placing transducers under various sites on the foot. They found that plantar pressure was concentrated primarily under the head of the first metatarsal in women wearing high heeled shoes, but was generally reduced in a 2 ½-inch heel compared to barefoot. Using more modern strain gauge technology, Soames and Clark[22] reported significant positive correlations between heel height and peak pressures under the first and second metatarsals, and significant negative correlations between heel height and peak pressures under the third, fourth, and fifth metatarsals. These investigations conflict concerning how pressure changes with increased heel height or have methodological limitations.

Data obtained from transducers under the foot may be affected by placement of the transducers and movement of the foot, despite efforts to control or account for these variations. Translation of the plantar skin with gait can cause the transducer to shift from its desired position. The presence of the transducers under the foot may cause alterations in gait or influence the local pressure patterns, particularly if the height or stiffness of the transducers causes unnatural displacement of the bones of the foot.[18]

Relatively little research has been done on the relationship between high heeled shoes and injury. While the medical community has long suspected that high heeled shoes may adversely affect the feet of women who wear them,[7,11-13] there is little quantitative data regarding relationships with injury. In a post hoc analysis of surgical operations for hallux rigidus and hallux valgus, Bonney and Macnab[3] found that women accounted for 90% and 68%, respectively, of a sample of 518 operations. They attributed this gender bias to the difference in typical footwear used by the two sexes.

Studies to date have either not involved high heels directly or can be questioned for technological reasons. A method for measuring pressure under the metatarsal heads, while maintaining the imposed conditions of a standardized heel height and a restrictive toe box, must be employed in order to obtain pressure measures that reflect the true conditions existing when wearing high heeled shoes. The purpose of this study was to investigate the effects of increased heel height on foot pressure.

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METHODS

Subjects and Shoes

Forty-five female subjects were recruited from the University of California community. Age limits for the sample were set at 22 and 55 years to minimize age-correlated changes in flexibility of the ankle.[7] Subjects were required to have worn high heeled shoes at least 4 hrs/day and 3 days/week on a regular basis. This requirement was set to minimize variation in motor control that could result from different levels of habituation.

The shoes used in the study were standard women's heeled shoes purchased at a shoe outlet. All shoe sizes within each heel condition had the same style number. The low (1.91 cm) and medium (5.08 cm) heeled shoes had leather uppers, and the high (8.26 cm) heeled shoe upper was made of vinyl. Although not identical, the shape of the toe box and vamp shape were similar among heel heights. The dimensions (mediolateral × anteroposterior) of the heel of the shoes were as follows: 3.4 × 4.9 cm (low heel height), 1.3 × 1.4 cm (medium), and 0.8 × 0.9 cm (high). To obtain pressures at the surface of the foot, the sole of the forepart of the shoe was completely removed up to the tip of the shank. An experienced cobbler stretched a piece of thin cotton (178 μm) between the edges of the remaining upper and glued it to the sides of the upper. The original shape of the toe box showed minimal or no changes. The strength of the cloth across the sole of the modified shoe was perceived to provide the same toe restriction as the unaltered shoe and, with only fabric separating the bare foot from the walking surface, the pressure beneath each metatarsal head could be measured accurately.

All pressure measurements were made using a Biokinetics Pedobarograph (BTE, Inc., Baltimore, MD) and its accompanying computer software package.[2] Following familiarization with protocols for the Pedobarograph and timing lights, subjects were allowed to practice until they could walk at a steady rate of 1.4 m/sec (±5%) through the experiment area. An acceptable trial was one in which a subject placed the right foot in the center of the pressure plate without hesitating or altering her normal movement patterns and met the speed criterion. Feedback was not provided except to indicate whether the trial met the criteria. Each subject walked across the plate under four conditions: barefoot, and in shoes with low, medium, and high heels. The order of conditions was randomized and data from three acceptable trials for each condition were saved for further analysis.

Data were collected at 30 Hz. Following successful data collection, a visual analog image of the peak pressures under the foot over the total contact time appeared on the computer screen. Analysis software allowed specific areas of the foot to be isolated and pressures within these areas to be quantified over time. Specifically, a circular cursor was placed on the projected image on the computer monitor to isolate each of the following areas: the heads of the first metatarsal (cursor radius 10.3 mm), second metatarsal (7.7 mm), third metatarsal (7.7 mm), and combined fourth and fifth metatarsals (15.4 mm), the hallux (10.3 mm), and the heel (20.6 mm). The cursor placement in the anteroposterior direction was set to encircle the peak pressures in that region (identified by bright colors on the color monitor). Cursor placements along the mediolateral axis were made relative to a line drawn from the center of the heel to the tip of the second toe for the barefoot condition and from the center of the heel to the pointed tip of the shoe to account for a hallux valgus condition caused by the shape of the toe box. The cursor placement for the second metatarsal was positioned so the line bisected the circular cursor. The first metatarsal cursor placement was centered between the medial border of the foot image and the adjacent second metatarsal area. The third metatarsal cursor was placed abutting the second metatarsal area. The fourth/fifth metatarsal cursor was centered between the lateral border of the foot image and the adjacent third metatarsal circle. The cursor placement for the hallux was centered within the image of the hallux and the placement for the heel cursor was centered within the barefoot image of the heel or encircling the shod heel. Figure 1 graphically shows the placement and corresponding size of the cursor.

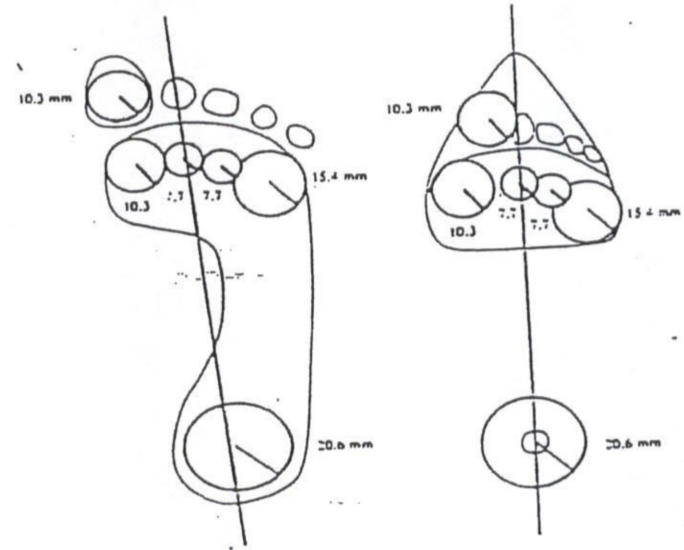

Fig. 1. Diagram indicating the typical cursor placement for a barefoot and shod foot.

Within each designated area at each sampling interval, the peak pressure within the area was obtained. This was analyzed during support to yield: the maximum peak pressure during support, time to maximum peak pressure, support time, and maximum rate of loading (increase in pressure divided by the time interval) for the first half of support (load rate 1) and the second half of support (load rate 2) of the walking cycle.

For each designated area of the foot, the preceding measures were determined for the three trials. The results of the three trials were averaged for each person in each condition and then averaged across subjects to produce mean data. Because the diameter of the heel in contact with the plate progressively decreased from barefoot to high heels, it was expected that pressure under the heel of the shoe would increase with an increase in heel height. Since the pressure under the heel of the shoe was not representative of pressures under the subject's anatomical heel, data from the shoe heel were used only for temporal information indicating the moment at which footstrike occurred.

Foot Evaluation

In order to specify relationships between foot structure and pressure measurements, foot exams were performed on the right foot of each subject. Following height and weight measurements, subjects were instructed to lie prone on a table with a rolled towel placed under one anterosuperior iliac spine to cause the contralateral lower leg to lie flat. By palpating the talus, the subtalar joint was placed in a neutral position and lines were drawn on the skin of the subject, one longitudinally bisecting the calcaneus and the other longitudinally bisecting the Achilles tendon. The angle of intersection was measured using a goniometer and recorded as the subtalar neutral angle. Stabilizing the subtalar joint in a neutral position, passive range of motion for the following movements were quantitatively measured using a goniometer: calcaneal inversion and eversion; ankle dorsiflexion with the knee in extension and flexion; and ankle plantarflexion. Relaxed standing calcaneal position was also determined by measuring the angle of the line drawn on the heel relative to the vertical. A negative value indicated calcaneal eversion or a subtalar valgus position. The degree of hallux valgus in a nonweightbearing position was measured by placing a goniometer on the dorsal aspect of the foot over the metatarsal-proximal phalanx joint. Passive hallux dorsiflexion during stance and nonweightbearing was measured using a goniometer and recorded. Because these subjects were asymptomatic and for medical and legal reasons, no x-rays of the subjects' feet were obtained.

While the subject stood, length and breadth measurements of both feet were taken using Harpenden-type calipers (Seritex, Inc., Carlstadt, NJ). The length of the foot was measured from the heel to the tip of the first toe and from the heel to the tip of the second toe.

To classify the foot types, bilateral footprints were obtained in single support-full body weight stance. The subject's foot was coated with a clear forensic ink prior to stepping onto a piece of chemically treated paper (Crime Detection Equipment, Faurot, Inc., Elmsford, NY). The ink reacts with the paper and leaves a footprint. The area of the footprint and the relative area of the midfoot were calculated. The proportional area of the midfoot to the whole foot in contact with the surface was recorded as the arch index.[4]

Statistical Analysis

Repeated-measures analysis of variance with no grouping factors and two within factors (heel height and location beneath the foot) was performed on each of the following variables: maximum peak pressure, time to maximum peak pressure, support time, and load rates. Post hoc comparisons on statistically significant main effects were performed. In all cases, the experiment-wise error level of significance was kept at $P < .05$ using a Bonferroni adjustment, which held the P-value necessary for significance to $P < .003$. Significant interactions between area beneath the foot and heel height were evaluated. Unpaired one-tailed t-tests, based on an a priori hypothesis that deviations from the normal foot morphology would have a specific directional effect on the peak pressure beneath the foot, were used to test for associations between variables from the foot evaluation with peak pressure.

RESULTS

Subjects

The mean age of the subjects was 37.9 ± 7.3 years. The average height and weight of the subjects were 162.0 ± 6.3 cm and 62.1 ± 7.9 kg, respectively. The subjects tested were habituated to wearing heeled shoes. Fourteen of them normally wore to work shoes of medium heel height (3.81–5.08 cm) and 31 normally wore high heels (5.33 cm or higher). On average, the subjects wore heeled shoes 9.1 hrs/day for 4.5 days/week and had been wearing heeled shoes for 14.2 years.

Body Weight and Peak Pressure

Maximum peak pressure under the second metatarsal and body weight were slightly correlated ($r = 0.27$, $P < .05$). While this was a significant finding, it should

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TABLE 1
Means ± SD of Maximum Peak Pressures (kPa) for Each Forefoot Area and Heel Height (N = 45)

Area	Barefoot	Low	Medium	High
Hallux	$361.49^{a,v,x,y}$ ± 116.92	$442.31^{a,z}$ ± 127.18	$493.05^{a,b,c,v,x,y}$ ± 147.96	$500.12^{a,b,c,y}$ ± 144.61
Met 1	$235.72^{a,u,w}$ ± 86.29	$332.25^{a,u,y}$ ± 107.80	$432.14^{a,u}$ ± 170.89	480.75^{a} ± 169.20
Met 2	$345.24^{e,a,v,x,y}$ ± 121.78	$340.56^{a,e,u,y}$ ± 125.05	$434.98^{a,y}$ ± 145.28	489.62^{a} ± 150.71
Met 3	$269.19^{e,a,u,w,y}$ ± 83.09	$295.64^{d,e,u,y}$ ± 129.64	$392.33^{a,u}$ ± 120.81	459.23^{a} ± 140.26
Met 4/5	$186.00^{a,u,w,x}$ ± 61.61	$225.29^{a,z}$ ± 100.84	$358.00^{a,u,w}$ ± 131.40	$421.37^{a,u}$ ± 149.53

[a] Significantly different from all other conditions for the given foot area ($P < .003$).
[b] Significantly different from the barefoot condition for the given foot area ($P < .003$).
[c] Significantly different from the low condition for the given foot area ($P < .003$).
[d] Significantly different from the medium condition for the given foot area ($P < .003$).
[e] Significantly different from the high condition for the given foot area ($P < .003$).
[u] Significantly different from the hallux for the given heel condition ($P < .003$).
[v] Significantly different from Met 1 for the given heel condition ($P < .003$).
[w] Significantly different from Met 2 for the given heel condition ($P < .003$).
[x] Significantly different from Met 3 for the given heel condition ($P < .003$).
[y] Significantly different from Met 4/5 for the given heel condition ($P < .003$).
[z] Significantly different from all other areas of the foot for the given heel condition ($P < .003$).

be noted that there was substantial variability in the correlation coefficients using pressure from other areas of the foot ($r = 0.25$ and $r = 0.23$, for first and third metatarsals, respectively; range r is −0.02 to 0.27). The correlation coefficient of 0.27 indicates that only 7% of the variation in pressure beneath the second metatarsal can be attributed to body weight. This implies that maximum peak pressures under the foot are not greatly influenced by body weight. All pressures were, therefore, analyzed using absolute values (kPa).

Maximum Peak Pressure

On average the maximum peak pressure across all pressure areas increased 22%, 57%, and 76% for the low, medium, and high heels, respectively, compared to barefoot. Maximum peak pressure for each tested area under the forefoot significantly increased with an increase in heel height ($P < .003$), with the exception of the second and third metatarsals barefoot to low condition and the hallux medium to high condition, which were not significantly different. Table 1 lists the mean maximum peak pressures and significance for the study sample and Figures 2 through 5 show changes in maximum peak pressure versus time for all footwear conditions and foot locations for one individual who showed changes similar to those for the group. The pressure under the hallux tended to be the highest followed by the first and second metatarsal, which were similar. Next came the third metatarsal, with the least pressure under the fourth/fifth metatarsals.

Pressure Distribution

The interactions between the main effects (heel height and the area of the foot) are indications of changes in pressure distribution between the barefoot and the three heel conditions. In the barefoot condition, the second metatarsal bore significantly more of the pressure compared with the first, third, and fourth/fifth metatarsals. In the shod conditions, there was no significant difference in pressure among the first, second, or third metatarsals. However, the pattern was slightly different for the fourth/fifth metatarsals. In the low heel

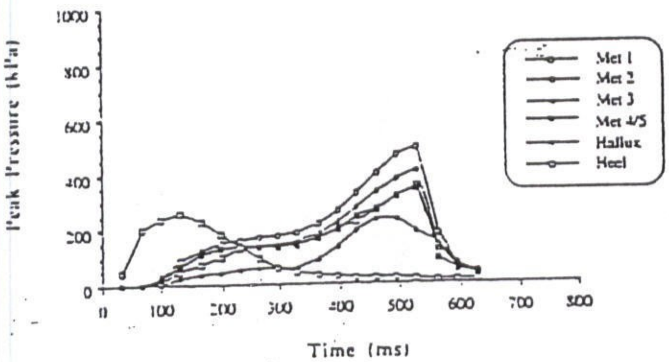

Fig. 2. Maximum peak pressure versus time for the barefoot condition for one subject.

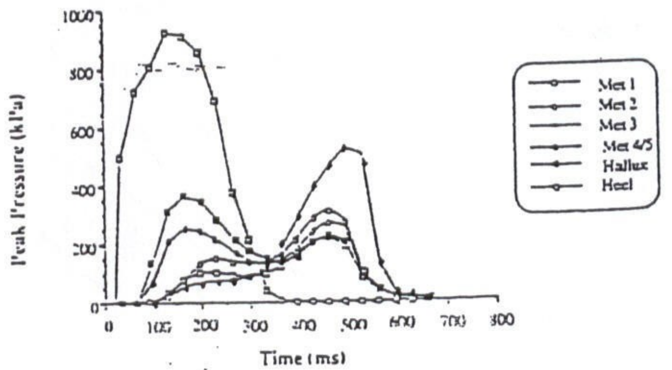

Fig. 3. Maximum peak pressure versus time for the low heel condition for one subject.

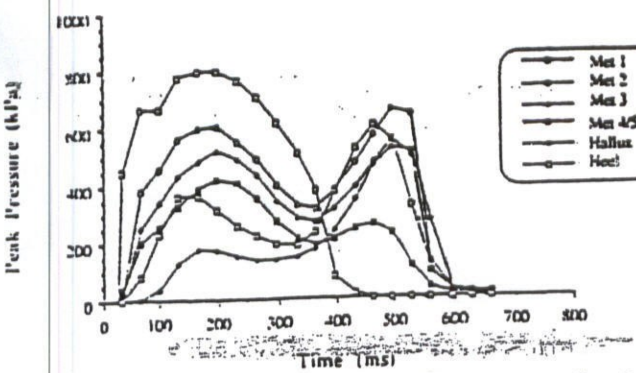

Fig. 4. Maximum peak pressure versus time for the medium heel condition for one subject.

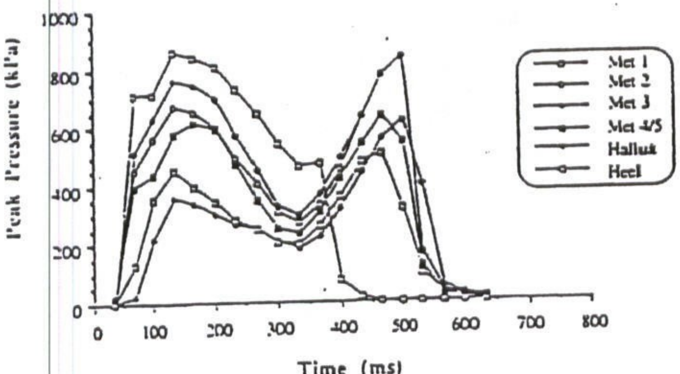

Fig. 5. Maximum peak pressure versus time for the high heel condition for one subject.

condition, the pressure under the fourth/fifth metatarsal was significantly less than that for all other areas of the foot. In the medium heeled condition, the pressure under the fourth/fifth metatarsal was significantly less than the pressure under the second metatarsal and the hallux, and in the high heeled condition, it was only significantly less than the hallux. Overall, the pressure distribution among metatarsals became more uniform with an increase in heel height. (Table 1 documents these changes quantitatively and they can be qualitatively viewed in Fig. 6.)

Time to Maximum Peak Pressure

The time to maximum peak pressure under the metatarsal heads was significantly reduced with an increase in heel height ($P < .003$), (Table 2). On average, the time to maximum peak pressure across all metatarsal heads decreased 8%, 30%, and 51% for the low, medium, and high heels, respectively, compared with barefoot. Generally, the time to maximum peak pressure under each of the metatarsals was significantly different from each of the other areas, with the exception of metatarsals one and two, which were not significantly different from each other. The time to maximum

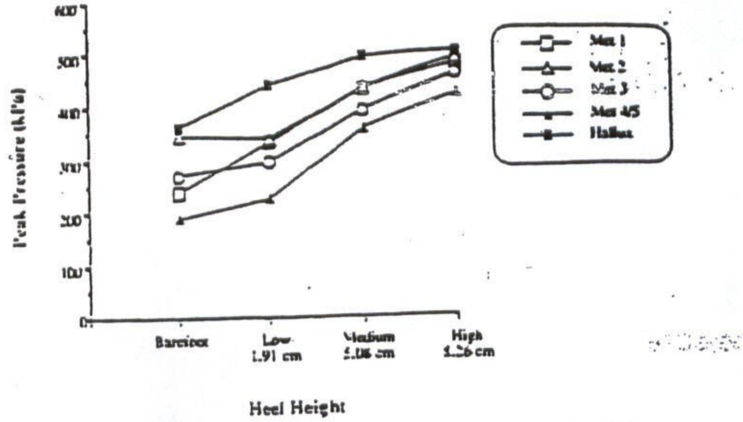

Fig. 6. Maximum peak pressure versus shoe condition for different areas of the foot for the mean from all subjects (N = 45).

peak pressure for the hallux actually increased in going from the barefoot to all three shod conditions.

Support Time

The mean ± SD values for support time for the barefoot, low, medium, and high conditions were as follows: 607 ± 35 ms, 629 ± 40 ms, 627 ± 38 ms, and 625 ± 37 ms, respectively. Pairwise comparisons showed that support time for the barefoot condition was significantly less than that for any of the shod conditions ($P < .003$), but there were no significant differences among any of the heeled conditions.

Rate of Loading

Table 3 lists the mean values and significant levels for load rate 1 for all subjects for each area of the foot and heel height. In Figures 2 through 5, the changes in loading are seen by the increased slope of the pressure-time curves in going from the barefoot to high heeled conditions. Each area of the forefoot showed a significant increase in load rate 1 with an increase in heel height. Similar significant results were found for load rate 2 (Table 4). Within a given footwear condition, the rate of loading was similar for all of the metatarsals.

Interactions of Foot Morphology

No variables of foot size, rearfoot or forefoot position, or range of motion were significantly correlated with pressures under the metatarsals for either the barefoot or high heeled condition. There was no relationship between the length of time high heels were worn by an individual (hr/day, days/week, hr/year, years) and the maximum amount of ankle dorsiflexion. Means ± SD of variables from the foot evaluation are presented in Table 5.

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TABLE 2
Means ± SD of Time to Maximum Peak Pressures (ms) for Each Forefoot Area and Heel Height (N = 45)

Area	Barefoot	Low	Medium	High
Hallux	$421^{a,v,y} \pm 27.0$	$459^{v,x,y} \pm 37.0$	$457^{z} \pm 49.0$	$461^{z} \pm 34.0$
Met 1	$389^{d,e,z} \pm 55.0$	$376^{d,e,u,w,y} \pm 102.0$	$302^{a,u,x,y} \pm 132.0$	$241^{a,u,x,y} \pm 117.0$
Met 2	$431^{d,e,v,y} \pm 34.0$	$430^{d,e,v,y} \pm 49.0$	$310^{a,u,x,y} \pm 130.0$	$206^{a,u,y} \pm 104.0$
Met 3	$419^{d,e,v,y} \pm 34.0$	$391^{d,e,u,y} \pm 94.0$	$214^{b,c,z} \pm 114.0$	$169^{b,c,u,v} \pm 89.0$
Met 4/5	$351^{a,z} \pm 89.0$	$210^{a,z} \pm 97.0$	$142^{b,c,z} \pm 56.0$	$143^{b,c,u,v,w} \pm 48.0$

Note. See Table 1 for a key to the symbols.

TABLE 3
Means ± SD for Rate of Loading (kPa/ms) during the First Half of Support of the Walking Cycle for Each Forefoot Area and Heel Height (N = 45)

Area	Barefoot	Low	Medium	High
Hallux	$1.82^{a,*} \pm 1.38$	$2.38^{a,e,v,y} \pm 1.59$	$3.88^{b,c,z} \pm 2.62$	$3.86^{b,c,z} \pm 1.93$
Met 1	$1.36^{*} \pm 0.90$	$3.59^{a,w} \pm 1.74$	$6.22^{a,w} \pm 3.21$	$7.51^{a,w} \pm 3.76$
Met 2	$1.64^{*} \pm 0.69$	$2.86^{*} \pm 1.37$	$6.42^{a,w} \pm 2.57$	$8.09^{a,w} \pm 3.01$
Met 3	$1.49^{*} \pm 0.64$	$3.17^{*} \pm 1.83$	$6.18^{a,w} \pm 2.27$	$7.55^{a,w} \pm 2.90$
Met 4/5	$1.49^{*} \pm 0.81$	$3.43^{a,w} \pm 1.75$	$6.21^{a,c,w} \pm 3.26$	$7.30^{a,c,w} \pm 4.03$

Note. See Table 1 for a key to the symbols.

DISCUSSION

The present study utilized technology that obtained and calculated discrete measures of pressure, that was reliable,[1] and that lacked the problematic aspects of transducers commonly used in previous studies. The heel height and style of the shoes were controlled and data from a large number of subjects allowed proper statistical analyses to be performed.

Reliability of cursor placement was ensured through the use of distinct methodology outlined in the Methods section of this paper. The major limitation to the technology used in this study was the lack of precision in controlling the size of the cursor used to identify the area of interest. This prevented these researchers from scaling the size of the cursor to foot size. In all cases, the cursor encircled the area of highest pressure for the given area of the foot so consistent cursor size for each designated area, regardless of foot size, did not appreciably influence the results.

In the barefoot condition, the second and third metatarsals bore more pressure than the first metatarsal. This finding concurs with Rodgers and Cavanagh[17] and Grieve and Rashdi,[9] who all reported that the greatest pressure was under the second metatarsal.

The results of the current study show that an increase in heel height leads to an increase in peak pressure beneath the metatarsal heads. This is in accord with Schwartz et al.,[19] who showed that 2-inch high heels decrease the load under the heel and shift the load to the metatarsal heads. Furthermore, the pressures under the lateral three metatarsals increased with an increase in heel height, but were consistently the lowest pressures under the ball of the foot, regardless of heel height. This agrees with the findings by Soames and Clark.[22] However, the present study found the difference in peak pressure between the two medial and three lateral metatarsal heads to consistently decrease with an increase in heel height, while Soames and Clark found the difference to increase. Soames and Clark did not report the shape of the toe box of their experimental shoes. A different pattern of forefoot pressure may have resulted if the forefoot was allowed to splay with an increase in heel height, rather than remain constricted as in the present study. Based on the results of this study, it appears that wearing high heeled shoes with a narrow toe box does not cause a transfer of pressure from the lateral aspect of the forefoot to the medial aspect, but instead results in a more uniform distribution and higher overall pressure across the metatarsal heads.

It is likely that the shape of the toe box has an important influence on the distribution and magnitude of the maximum peak pressures. In a closed toe box, particularly if the toe box is very narrow, the relative positions of the metatarsal heads will change compared to the barefoot condition. A narrow toe box may put a laterally directed force on the hallux and first metatarsal, and a medially directed force on the fifth toe and fifth metatarsal. This results in a hallux valgus deformation and what could be termed a fifth toe varus. The lateral force on the first ray may subsequently put force on the second ray, causing it to move laterally and elevate.[14] Furthermore, Hutton and Dhanendran[10] found that a hallux deformation resulted in increased pressure under the lateral three metatarsal heads. These changes may account for the more evenly distributed pressures under the forefoot when shoes were worn. Further research needs to be conducted on the influence of the toe box on the pressures beneath the foot.

The timing variables were also affected by shoe conditions. The results of the present research agree with a study by Soames,[21] who found a significant increase in contact time between barefoot and shod conditions. The time to maximum peak pressure decreased and the load rate increased with an increase

TABLE 4
Means ± SD for Rate of Loading (kPa/ms) during the Second Half of Support of the Walking Cycle for Each Forefoot Area and Heel Height (N = 45)

Area	Barefoot	Low	Medium	High
Hallux	$2.11^{a,z} \pm 0.95$	$2.72^{b,e,z} \pm 1.23$	$3.06^{e,z} \pm 1.25$	$3.19^{b,c,z} \pm 1.31$
Met 1	$1.17^{d,e,u,w,x,y} \pm 0.74$	$1.46^{d,e,u,y} \pm 0.73$	$2.02^{b,c,u,x,y} \pm 0.96$	$2.10^{b,c,u,y} \pm 0.98$
Met 2	$1.73^{e,z} \pm 0.93$	$1.51^{d,e,u,y} \pm 0.72$	$1.94^{c,u,y} \pm 0.88$	$2.17^{a,b,u,y} \pm 1.10$
Met 3	$1.22^{e,u,w,y} \pm 0.55$	$1.16^{d,e,u,y} \pm 0.63$	$1.51^{c,u,v,y} \pm 0.84$	$1.82^{b,c,u,y} \pm 1.06$
Met 4/5	$0.69^{e,z} \pm 0.35$	$0.55^{e,z} \pm 0.40$	$0.75^{e,z} \pm 0.61$	$1.21^{a,z} \pm 0.74$

Note. See Table 1 for a key to the symbols.

TABLE 5
Means ± SD for Foot Morphology of the Right Foot (N = 45)

Measurement	
Leg length (cm)	77.5 ± 13.2
Foot length—end of the 1st toe (cm)	23.8 ± 0.8
Foot length—end of the 2nd toe (cm)	23.4 ± 0.9
Foot breadth (cm)	9.0 ± 0.4
Foot area (cm²)	85.5 ± 16.4
Arch index[4]	22.4 ± 5.1
Max. dorsiflexion—knee extended (deg)	14.3 ± 5.2
Max. dorsiflexion—knee flexed (deg)	23.4 ± 6.0
Max. plantarflexion (deg)	55.3 ± 10.8
Subtalar neutral position (deg)	−1.4 ± 4.5
Max. calcaneal inversion (deg)	18.5 ± 4.4
Max. calcaneal eversion (deg)	−9.0 ± 4.0
Calcaneal stance	−5.8 ± 4.0
Max. hallux flexion—nonweightbearing (deg)	56.1 ± 11.5
Max. hallux flexion—weightbearing (deg)	26.5 ± 11.6
Resting hallux valgus position	17.2 ± 6.7

in heel height. As Figures 2 through 5 illustrate, when wearing shoes, the curves are bimodal, showing two high pressure points for each metatarsal in the heeled shoes, one during the first half of support and one during the second half of support. In all of the conditions, maximum peak pressure generally occurred during the second half of support, but in the medium and high heeled conditions, a high peak pressure was also noted during the first half of support. These results may be primarily due to the position of the foot as a result of the shape of the shoe shank. In the barefoot and low heeled shoes, the foot is allowed to roll forward over the midfoot, thus dissipating some of the high pressure. In the medium and high heeled shoes, the midfoot is held off the ground, which may prevent this dissipation of high pressures, resulting in two periods of rapid applications of pressure compared with the one period experienced during barefoot walking.

It is reasonable to expect that body weight would correlate highly with maximum peak pressure beneath the foot. However, this was not the case in the present study. Cavanagh et al.[5] contrasted their low correlations between body weight and standing pressure (r = 0.05 for women) with the reportedly strong correlations (although correlation coefficients were not reported) for dynamic pressures found by Grieve and Rashdi[9] and suggested that the differences in correlations might be due to the difference between pressure measurements obtained in standing versus those recorded during walking. The data from the present study support the premise that body weight and pedal pressures for the areas measured are not highly correlated for dynamic measures. This difference in findings between the present study and those of Grieve and Rashdi[9] could be due to the difference in methods. They used a foil pedobarography system that was later filmed for comparison to a standard calibration imprint.

Only two of the subjects had previously seen a physician for foot problems. The lack of significant correlations between the foot evaluation measures and peak pressure may be explained by the asymptomatic nature of the study population. If many of the subjects had had an abnormal foot structure that required medical intervention, the pressure patterns may have been more affected.

IMPLICATIONS

Much has been written by clinicians describing the long-term changes in foot morphology attributed to extended wear of high heeled shoes.[7,12,13] However, few research studies have been conducted to quantify the extent of resulting joint changes. Furthermore, few studies have investigated the change in rate of loading with an increase in heel height or the implications this might have for foot health.

Studies in orthopaedics have examined the initial effects of repetitive loading and increased rate of loading on the joints of animals. Some studies have reported that repetitive loading may have a significant effect on the architecture of the bone by changing trabeculae orientation[15] or resulting in microfractures of the bone.[16,20] Other studies have found loading rate to be a significant factor in the initiation of joint deterioration, suggesting that a high rate of loading may damage cartilaginous tissue[23] and increased bone mass,[6] which may eventually lead to osteoarthrosis. Comparable work has not been done with human subjects.

The present study showed higher foot pressures, less variability of the pressure distribution, and greater rate of loading when wearing a high heeled shoe compared with lower heels or barefoot. Furthermore, two periods of high pressure for each support period were noted under the metatarsals in the shod conditions compared with barefoot. The high peak pressures and greater rate of loading evident in the high heeled shoes and the repetitive nature of the application of pressures when wearing shoes may make the individual more susceptible to damaging stress to the bones in the foot and ankle. Additional work is needed in the form of longitudinal studies and clinical investigations to examine the relationship between wearing high heeled shoes and degenerative bone and joint disease.

ACKNOWLEDGMENTS

This research was supported in part by a Biomedical Research Support Grant, Department of Orthopaedics, Davis, California.

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