The Effect of 3 Foot Pads on Plantar Pressure of Pes Planus Foot Type

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Context: Many styles of foot pads are commonly applied to reduce immediate pain and pressure under the foot. Objective: To examine the effect of 3 different foot pads on peak plantar pressure (PPP) and mean plantar pressure (MPP) under the first metatarsophalangeal joint (MTPJ) during slow running. Design: A 4 (pad) × 4 (mask) repeated-measures design. Setting: University athletic training clinic and fitness facility. Participants: 20 physically active participants, 12 men (19.7 ± 1.3 y, 181.5 ± 6.3 cm, 83.6 ± 12.3 kg) and 8 women (20.8 ± 1.5 y, 172.7 ± 11.2 cm, 69.9 ± 14.2 kg) with navicular drop greater than or equal to 10 mm, no history of surgery to the lower extremity, and no history of pain or injury to the first MTPJ in the past 6 months. Interventions: PPP and MPP were evaluated under 4 areas of the foot: the rear foot, lateral forefoot, medial forefoot, and first MTPJ. Four pad conditions (no pad, metatarsal dome, U-shaped pad, and donut-shaped pad) were evaluated during slow running. Main Outcome Measures: PPP and MPP in 4 designated foot masks during slow running. Results: The metatarsal dome produced significant decreases in MPP (163.07 ± 49.46) and PPP (228.73 ± 63.41) when compared with no pad (P < .001). The U-shaped pad significantly decreased MPP (168.68 ± 50.26) when compared with no pad (P < .001). The donut-shaped pad increased PPP compared with no pad (P < .001). Conclusions: The metatarsal dome was most effective in reducing both peak and mean plantar pressure. Other factors such as pad comfort, type of activity, and material availability must also be considered. Further research should be conducted on the applicability to other foot types and symptomatic subjects.

Keywords: peak pressure, mean pressure, metatarsal

The foot is an elaborate system of levers and pulleys that adapts to ground surfaces, aids in shock absorption, and transitions to a rigid lever for propulsion during gait.1,2 Faulty biomechanics or injury to any area of the foot can change
postural-control strategies and muscle-activation patterns, resulting in adverse effects throughout the entire body.\textsuperscript{3–6} The potential for injury to other parts of the kinetic chain has made it necessary to correctly recognize and treat injuries of the foot to restore the efficiency and effectiveness of not only the foot but also the entire lower extremity.\textsuperscript{7,8}

A variety of injuries such as primary metatarsalgia, sesamoiditis, and turf toe cause significant pain and discomfort at the first metatarsophalangeal joint (MTPJ). Primary metatarsalgia at the first MTPJ is related to increased pressures under the metatarsal head and leads to inflammation and pain.\textsuperscript{9–11} This type of metatarsalgia is often linked to conditions such as pes cavus, pes planus, hyperpronated feet, hallux valgus, and claw or hammer toes through a change in the biomechanical properties of the foot.\textsuperscript{10,12} In addition, sesamoiditis is linked to similar conditions and can also be linked to neurological sensory deficits, limits in range of motion, and synovitis.\textsuperscript{13} If an individual sustains an acute injury to the MTPJ, it can be extremely painful and cause a disruption in athletic participation for 2 to 6 weeks or longer.\textsuperscript{14} Once the patient is able to start bearing weight again, foot pads and orthoses can be used to relieve pressure on the joint and make it more comfortable during gait.\textsuperscript{13,15,16} Many variations of pressure-relieving pads such as metatarsal domes, metatarsal bars, donut-shaped pads, and U-shaped pads can be purchased or easily constructed.\textsuperscript{17} These pads are placed just proximal to or around the first MTPJ and can redistribute the plantar pressure to other areas of the foot.\textsuperscript{18–20} Metatarsal tear-drop pads have been shown to also decrease pain in patients with secondary metatarsalgia when placed proximal to the second metatarsal head\textsuperscript{21} and were the preferred pad for reducing pain when combined with a custom orthosis.\textsuperscript{15} Clinicians often apply these types of pads directly to the foot, in the absence of a full orthosis, to immediately relieve associated pain and pressure. However, limited information is available on these types of applications.

Pes planus foot type is more commonly seen in the general population and is associated with flatfoot and pronated foot types of greater than or equal to 10 mm.\textsuperscript{3,22} Plantar-pressure analysis of pes planus feet revealed higher loading in the subhallucal area than in neutrally aligned feet\textsuperscript{23}; however, pes planus foot type does not affect impact forces from single-leg landing.\textsuperscript{24} The relationship of pes planus to increased pressures in the subhallucal area may provide an explanation for pathologies in the first-MTPJ area and warrants further investigation as related to the application of treatment devices. Although simple pad devices are a common treatment for first-MTPJ pain, the comparative effectiveness of pressure distribution of some of these pads has not yet been studied in the pes planus foot type. No information is available to date on the effects of applying a donut-shaped pad to this area. Investigation of the pressure distribution through the use of sensor technology could provide clinicians with the necessary distribution effects throughout the foot when typical foot pads are applied for a painful MTPJ area. The purpose of this study was to determine the effect of metatarsal domes, U-shaped pads, and donut-shaped pads on plantar pressure under the first MTPJ in pes planus foot type during slow running. We hypothesized that application of any pad would decrease plantar pressure (mean and peak) under the first MTPJ during slow running when compared with no pad application. Finally, we hypothesized that foot pressures would be redistributed throughout the foot for all pad conditions.
Methods

Design

We used a repeated-measures design to assess slow running under 4 different pad conditions—metatarsal dome, U-shaped pad, donut-shaped pad, and no pad—for 4 areas of the foot (rear foot, lateral forefoot, medial forefoot excluding the area under the first MTPJ, and the first MTPJ; Figure 1). The dependent variables were the peak and mean plantar pressures measured in kilopascals by the Pedar in-shoe pressure-measurement system (Novel GMBH, St Paul, MN, USA).

Subject Characteristics

Twenty subjects, 12 men (19.7 ± 1.3 years, 181.5 ± 6.3 cm, and 83.6 ± 12.3 kg) and 8 women (20.8 ± 1.5 years, 172.7 ± 11.2 cm, and 69.9 ± 14.2 kg) with no history of pain or injury to the first MTPJ in the past 6 months, participated in the study. Subjects wore standardized men’s shoes (Nike Air Max Glide, Beaverton, OR, USA) with the size ranging between 6 and 12, had no history of surgery to the lower

Figure 1 — Four masks of the foot.
extremity, had a navicular drop greater than or equal to 10 mm on the dominant foot, and participated in physical activity for at least 30 minutes, 4 to 6 times per week, for at least the past 2 months. They were instructed to refrain from activity the day of testing. Each subject signed an informed consent before participating in this study, which was approved by the university institutional review board.

Instrumentation

The Pedar in-shoe pressure-measurement system (Novel GMBH, St Paul, MN, USA) was used to collect plantar-pressure data during all trials. A pair of pressure-sensing insoles was placed in a standardized pair of shoes (Nike Air Max Glide, Beaverton, OR, USA) and connected directly to an A/D converter with a Bluetooth communication system (Novel GMBH) that was worn in a camelback backpack securely strapped to the subject’s back. The A/D converter was connected to a laptop computer (Sony Vaio, Tokyo, Japan) on which data from each trial were viewed and recorded. Each insole was 2 mm thick and contained 99 individual sensors dispersed evenly throughout. Insoles were calibrated using the Trublu (Novel GMBH) calibration device at the beginning of each subject’s session. A sampling rate of 100 Hz was used, and pressure was recorded in the range of 0 to 600 kPa. We evaluated information for the dominant foot only. The Pedar in-shoe system had been previously determined to be a reliable instrument in measuring plantar pressure during gait, with $r$ values calculated at .84 to .99\textsuperscript{25} and .98\textsuperscript{26}.

Regions (masks) of the foot were defined using the area of 99 sensors on the pressure-sensing insoles (Figure 1). The rear-foot region was defined as sensors 1 to 54 on the Pedar pressure-sensing insoles. This area on the plantar aspect of the foot spanned from the posterior aspect of the calcaneus to the proximal aspect of the metatarsal bones. The lateral forefoot region was defined as sensors 59 to 61, 66 to 68, 73 to 75, 80 to 82, 87 to 89, 94, 95, and 99. This area on the plantar aspect of the foot covered the shaft of the third, fourth, and fifth metatarsals to the distal aspect of the third, fourth, and fifth toes. The medial forefoot was defined as sensors 55 to 58, 62 to 65, 69, 72, 76, 79, 83 to 86, 90 to 93, and 96 to 98. This area on the plantar aspect of the foot covered the shaft of the first and second metatarsal to the distal aspect of the first and second toes but excluded the area under the first MTPJ. The first MTPJ was defined as sensors 70, 71, 77, and 78. This area on the plantar aspect of the foot covered the area directly under the first MTPJ. The size of the sensor elements in the insoles change with each insole size and are therefore proportional.

All slow running trials for each subject were performed on a Life Fitness 9500HRT treadmill (Life Fitness, Schiller Park, IL, USA) in a university fitness center. This treadmill was calibrated to ensure accuracy of speed before testing.

Testing Procedures

Subjects reported to the athletic training clinic wearing a T-shirt and athletic shorts for 1 session. Each subject’s navicular drop, height, age, and weight were recorded. Subjects were given a standard pair of socks (Russell Corp Brand, Alexander City, AL, USA) to wear during testing. The pair of insoles was secured between the shoe and the pad using double-sided carpet tape in a pair of Nike Air Max Glide shoes.
Wiring from the insoles to the A/D converter was secured to each leg using hook-and-loop tape around the ankle and just below the knee. The A/D converter was worn in a camelback backpack that was tightened to prevent excessive bouncing yet allow the subject to breathe comfortably. Subjects were allowed a 2-minute period to warm up at a self-selected pace and become familiar and comfortable with the Pedar system. The insoles were then initialized to 0 by having the subject lift his or her foot off the ground to remove pressure from the insole while the computer recorded the 0 setting. The order of pad testing was counterbalanced. The condition of no pad was always tested first. Each trial was performed 3 times, and the average of 5 dominant foot strikes was recorded and used for statistical analyses. A 5-minute rest period was allowed between pad conditions to allow the subject to rest and the researcher to change pads and initialize the insoles to 0. The insoles were calibrated at the beginning of each testing day, and all data were recorded using the Pedar-X Expert software package (Novel, St Paul, MN, USA).

**Navicular Drop.** Pes planus was defined using weight-bearing navicular drop, which has been found to adequately represent subtalar motion during gait. A single examiner performed all tests using a modification of the Brody technique (ICC₂,1 = .90, SEM = 1.02), and the values were used solely as determining inclusionary status for the study. Subjects stood in a comfortable position with feet shoulder width apart. They were then instructed to sit down without moving or lifting their feet off the ground. The dominant foot (foot used to kick a ball) was placed in partial-weight bearing subtalar neutral. This subtalar-neutral position was found by having the examiner passively invert and evert the rear foot, palpating the talus equally on both sides. When congruency of the talus was found the subject was asked to hold this position while a mark was placed at the navicular tuberosity and an index card was placed at the medial aspect of the rear foot. The index card was backed with a solid object, so that the card would not bend during testing. A line was placed on the index card at the corresponding mark on the navicular, and this measurement was recorded as the baseline for navicular drop. Subjects were then asked to stand, bearing weight equally on both feet, and a second line was marked on the index card to correspond with navicular height. The difference between the first and second measurements was determined and recorded. This process was repeated 3 times, and the average of the 3 measurements was used as the subject’s navicular drop. A subject was considered to have pes planus foot type if the average difference between the first and second measurement was greater than or equal to 10 mm.

**Metatarsophalangeal Pads.** The 3 different pads that were used during this investigation included a metatarsal dome (Figure 2), a U-shaped pad (Figure 3), and a donut-shaped pad (Figure 4). The prefabricated metatarsal dome was made of self-adhesive, 0.635-cm orthopedic felt and had tapered edges all the way around (My Foot Shop, Granville, OH, USA). The U-shaped pad was also prefabricated and made of self-adhesive 0.3175-cm orthopedic felt. To control for pad height, 2 U-shaped pads were placed one on top of the other to make the pad 0.635 cm in height. This pad was shaped to contact the skin proximal, lateral, and medial to the metatarsal head but left the area distal to and under the metatarsal head open (My Foot Shop). The donut-shaped pad was fabricated by the researcher. Self-adhesive felt (0.635 cm) was cut into circles that measured...
Figure 2 — Metatarsal pad.

Figure 3 — U-shaped pad.

Figure 4 — Donut-shaped pad.
5.08 cm in diameter. A smaller circle measuring 2.54 cm in diameter was cut directly in the center of this circle. This pad formed a complete circle around the joint, leaving a space between the shoe and the joint itself. Each pad was secured directly to the dominant foot, worn underneath the sock, and discarded after 1 use.

**Pad Placement.** The metatarsal dome was placed immediately proximal to the head of the first metatarsal, where it has been found to be most effective. This placement was expected to transfer pressure proximal to the first MTPJ. The U-shaped pad was also placed proximal to the first MTPJ, with the joint itself in the open area of the pad. This placement was expected to transfer pressure proximally, medially, and laterally away from the joint. The donut-shaped pad was placed with the first MTPJ in the center of the cutout circle. This placement was expected to transfer pressure to tissues that surround the first MTPJ.

**Pressure Measurements.** To obtain plantar pressure while jogging, the subject was positioned on a treadmill in the university’s fitness facility. The subject was allowed to warm up at a self-selected pace for 2 minutes. After the warm-up period, the subject jogged at a self-selected pace between 8.85 and 10.46 km/h for 2 minutes. Data were collected at 3 separate 10-second intervals at 30, 60, and 90 seconds under each condition. To prevent the subjects from altering their gait during data collection, they were not notified when the data-collection intervals took place.

The midstance phase was defined as the moment in time when the contact area was the greatest during the stance phase. The middle 45% values within the midstance phase were used for analysis. The actual measurements were taken as follows: For each foot strike analyzed, the first frame that noted any kind of foot contact marked the beginning of the foot strike, this frame number was subtracted from the final frame that contained foot pressure, and the middle 45% of the frames were used in data analysis. Thus, if the foot strike contained information from frames 100 to 200, frames 127 to 172 were analyzed.

Peak pressure was defined as the highest pressure value within that mask during the midstance phase. Mean pressure was defined as the average of all pressure values within each mask during the midstance phase. Averages of the peak and mean pressure values for the 5 foot strikes were calculated and recorded for use in statistical comparison. This method was repeated under each of the 4 conditions. After all trials under all conditions were completed, subjects were allowed to perform a self-determined cool-down.

**Data Analysis**

Mean and peak pressures from each of 4 areas of the foot were exported from the Pedar-X Expert software package into an Excel spreadsheet. Data were then reduced to average peak and mean pressures and imported into SPSS 15.0 for Windows (SPSS, Inc, Chicago, IL, USA) for statistical analysis.

Descriptive statistics were used to calculate the means and standard deviations. Separate 4 (pad) × 4 (area of the foot) repeated-measures ANOVAs were used to determine any significant differences in peak and mean pressure for all masks between pad conditions during slow running. Results were considered statistically significant at an alpha level of .05 or less. Tukey’s post hoc analysis was performed to determine where the significant relationships existed.
Results

Descriptive statistics (mean ± SD) for MPP and PPP are located in Tables 1 and 2, respectively.

Peak-Pressure Slow Running

There was a main effect for pad ($P = .033$), with the no-pad condition (246.45 ± 47.13 kPa) producing higher peak pressure in running than the metatarsal dome (238.00 ± 53.66 kPa) and the U-shaped pad (239.08 ± 47.56 kPa), $P < .05$.

There was a main effect for mask ($P < .001$), with the rear-foot area (166.39 ± 44.81 kPa) experiencing significantly lower peak pressures than the lateral forefoot (251.83 ± 71.82 kPa), medial forefoot (306.07 ± 70.63 kPa), and the first-MTPJ area (244.4 ± 66.35 kPa), $P < .05$. Moreover, the medial forefoot was significantly higher than all the other masks, $P < .05$.

There was a statistically significant interaction between pad and mask ($P < .001$). Tukey post hoc comparisons revealed that the metatarsal dome (228.73 ± 63.41) significantly decreased peak pressure during running under the first MTPJ when compared with the no-pad condition (249.75 ± 67.01) and donut-shaped pad (258.53 ± 72.31), $P < .05$ (Figure 5). The distribution of the masks for each pad condition is demonstrated in Figure 6.

### Table 1 Running Mean Pressure (Mean ± SD) Measured in kPa

<table>
<thead>
<tr>
<th></th>
<th>Rear foot</th>
<th>Lateral FF</th>
<th>Medial FF</th>
<th>First MTPJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pad</td>
<td>32.86 ± 9.39</td>
<td>111.12 ± 29.99</td>
<td>120.19 ± 30.84</td>
<td>180.44 ± 53.77*</td>
</tr>
<tr>
<td>Metatarsal dome</td>
<td>35.20 ± 7.70</td>
<td>112.37 ± 30.97</td>
<td>119.63 ± 31.58</td>
<td>163.07 ± 49.46</td>
</tr>
<tr>
<td>U-shaped pad</td>
<td>32.10 ± 8.41</td>
<td>110.62 ± 28.46</td>
<td>120.85 ± 28.88</td>
<td>168.68 ± 50.26</td>
</tr>
<tr>
<td>Donut-shaped pad</td>
<td>32.30 ± 11.57</td>
<td>110.14 ± 31.19</td>
<td>117.50 ± 28.94</td>
<td>178.85 ± 53.25*</td>
</tr>
</tbody>
</table>

FF, forefoot; MTPJ, metatarsophalangeal joint.

*Significantly higher than the metatarsal dome and U-shaped pad under the first MTPJ, $P < .05$.

### Table 2 Running Peak Pressure (Mean ± SD) Measured in kPa

<table>
<thead>
<tr>
<th></th>
<th>Rear foot</th>
<th>Lateral FF</th>
<th>Medial FF</th>
<th>First MTPJ</th>
</tr>
</thead>
<tbody>
<tr>
<td>No pad</td>
<td>160.95 ± 48.35</td>
<td>257.53 ± 71.21</td>
<td>317.60 ± 69.11</td>
<td>249.75 ± 67.01*</td>
</tr>
<tr>
<td>Metatarsal dome</td>
<td>169.18 ± 44.16</td>
<td>252.70 ± 77.40</td>
<td>301.40 ± 74.13</td>
<td>228.73 ± 63.41</td>
</tr>
<tr>
<td>U-shaped pad</td>
<td>169.28 ± 44.22</td>
<td>249.38 ± 67.77</td>
<td>297.03 ± 74.40</td>
<td>240.63 ± 68.89</td>
</tr>
<tr>
<td>Donut-shaped pad</td>
<td>166.18 ± 50.23</td>
<td>247.73 ± 73.57</td>
<td>308.25 ± 75.03</td>
<td>258.53 ± 72.31*</td>
</tr>
</tbody>
</table>

FF, forefoot; MTPJ, metatarsophalangeal joint.

*Significantly higher than the metatarsal dome under the first MTPJ, $P < .05$. 

**Figure 5** — Running peak pressure, metatarsophalangeal joint. *The metatarsal dome produced a significant decrease in peak pressure compared with no pad and the donut-shaped pad. †The U-shaped pad produced a significant decrease in peak pressure compared with the donut-shaped pad.

**Figure 6** — Running peak pressure distribution. Rear-foot (RF) masks for all conditions were lower than all other masks and conditions; medial forefoot (MFF) masks for all conditions were higher than all other masks and conditions; first metatarsophalangeal joint (MTP) mask with dome lower than lateral forefoot (LFF) mask with no pad, lower than first MTP mask with donut pad, and lower than first MTP mask with no pad.
Mean-Pressure Running

There was no statistically significant main effect for pad ($P = .242$). There was a statistically significant main effect for mask ($P < .001$). The first-MTPJ area (172.75 ± 50.72 kPa) had significantly higher mean pressure than the rear foot (33.11 ± 8.46 kPa), lateral forefoot (111.06 ± 29.41 kPa), and medial forefoot (119.54 ± 29.41 kPa), $P < .05$. The rear foot had significantly lower mean pressure than all the other regions of the foot ($P < .05$).

There was a statistically significant interaction between pad and mask ($P < .001$). Multiple comparisons were conducted to further investigate the interaction effect, and it was demonstrated that the metatarsal dome (163.07 ± 49.46) under the first MTPJ significantly decreases mean pressure during running when compared with no pad (180.44 ± 53.77) and donut-shaped pad (178.85 ± 53.25), $P < .05$. However, there was no significant difference between the metatarsal dome and the U-shaped pad (168.68 ± 50.26). The U-shaped pad also significantly decreased mean pressure under the first MTPJ during running when compared with the donut-shaped- and no-pad conditions, $P < .05$ (Figure 7). The distribution of the masks for each pad condition is demonstrated in Figure 8.

![Figure 7](image-url) — Running mean pressure, metatarsophalangeal joint. *The metatarsal dome produced a significant decrease in mean pressure compared with all other pad conditions. †The U-shaped pad produced a significant decrease in mean pressure compared with no pad and donut-shaped pad.
Discussion

We hypothesized that application of any pad would decrease plantar pressure under the first MTPJ during slow running when compared with no pad application. Of the 3 pads, the metatarsal dome was found to be most effective in reducing peak plantar pressure. The metatarsal dome and U-shaped pad significantly decreased mean pressure during running when compared with the donut-shaped- and no-pad conditions. In contrast, the donut-shaped pad showed no significant difference in mean and peak pressure under the first MTPJ compared with no pad application.

The results of this study are similar to other research on the use of foot orthoses (orthoses in combination with foot pads) in reducing plantar pressure. Previous research has proven the effectiveness of both the metatarsal dome\textsuperscript{15,28,29} and...
orthotic-based U-shaped orthosis\textsuperscript{20} in reducing plantar pressure at areas of illness or injury, whereas there is no evidence to support the use of donut-shaped pads in reducing plantar pressure. Hodge et al\textsuperscript{15} demonstrated that a custom-molded orthosis with a metatarsal dome was the most effective of 4 different orthosis conditions in reducing pain and pressure in subjects with rheumatoid arthritis, and Poon and Love\textsuperscript{29} found that a similar custom-made metatarsal dome reduced mean plantar pressure under the metatarsal head by 13\%. Another study on the use of custom-made U-shaped orthoses in subjects with diabetic foot ulceration demonstrated a significant but variable reduction in peak pressures when comparing the insole group with a noninsole control group.\textsuperscript{30} We were interested in examining the outcomes of using a simple pad application without the time constraints of making or ordering a full custom orthosis. Clinicians are often faced with pathologies that an athlete will continue to play through, and immediate solutions are implemented to treat discomfort. Although we did not examine symptomatic patients, the effects of using a metatarsal dome to decrease pressures at the first MTPJ are evident from our results (9.6\% decrease in mean plantar pressure and 8.4\% decrease in peak plantar pressure). Although our decreases are smaller than those found in other studies (range of 22\%\textsuperscript{14} to 29\%\textsuperscript{31}), the placement (first or second MTPJ) and type of the pads varied (full orthosis with pads compared with only a pad),\textsuperscript{15,28,31} as did the defined masks, the movement condition (walking or running), and the patient population (symptomatic vs asymptomatic). Further research is warranted to determine if these pressure decreases with a simple pad also correspond to decreases in pain for all of the conditions used when applied to a specific patient population.

Despite the lack of research on donut-shaped pads, they are used fairly often in clinical practice to reduce areas of friction and pressure (blisters, medial calcaneal pressures, etc). Previous clinical use of the donut-shaped pads in reducing areas of high friction and pressure at various areas of the foot formulated the need to question the effectiveness of this pad at the first MTPJ. We therefore based our hypothesis on its clinical success. However, the results of this study suggest that our clinical practice may not be accomplishing its intended purpose, and other types of foot pads should be considered before the donut-shaped pad is used for this intended result.

There are a few limiting factors to consider when comparing this study with previous studies on foot orthoses. First, the orthoses used in this study were prefabricated and isolated pads without full orthoses, and individual foot variations were not taken into consideration in their construction. Second, the orthosis materials used in each study varied in density, and the ability for each material to absorb shock may negate our ability to compare them across studies. Third, researchers from each study developed their own masks specific to the needs of their study, and very few studies actually use the same masks in evaluating plantar pressure.

We also hypothesized that the pressures within the 4 masks would change after the application of the foot pads. Significant differences in first-MTPJ pressure were expected between pad conditions, and therefore we expected to see pressure-distribution changes throughout the foot. Our data suggest that when a pad is placed near the first MTPJ, the pressures are dispersed throughout the foot and do not simply lateralize to the lateral forefoot.
Limitations

Several limiting factors were also observed in this study. Although shoe type was standardized, the results may still have been affected by it. All subjects had a pes planus foot type, but individual variations in foot structure and function, as well as the fit of the shoe, may have affected the results. The quality and flexibility of the shoes used in this study may not be realistic for an individual with first-MTPJ pain or injury. As has been demonstrated in another study, broad-lasted shoes with a firm insole are commonly used to prevent extension at the first MTPJ,\textsuperscript{14} and the test shoes we used allowed a rather significant amount of MTPJ extension. We also did not assess mobility of the first ray, and this could have affected our outcomes.

Individual running form was another factor that may have affected the results of the slow running activity. Subjects were instructed to perform a slow run at a comfortable pace, but we did not standardize the pace other than to keep it within a range, and we had all subjects complete each of the conditions at the same speed. We examined components of midstance and postulate that we may need to consider evaluating the toe-off phase of the stance phase, as well as to assess pressures. Patients with an injury to the first MTPJ would need the most protection during the toe-off phase because of the increased pressure under the joint, as well as the increased range of motion experienced at the first MTPJ as the body is propelled forward. Additional research is indicated to examine whether these pads can relieve pressure during the phase of the gait cycle that experiences the highest plantar pressures.\textsuperscript{32}

The size of the sensors was the final factor that may have affected the results, particularly for the donut-shaped pads. Only 1 set of masks was developed and used for all subjects, regardless of individual foot variations, and these masks may not have been sufficient in representing the area directly under the first MTPJ in all subjects. The donut-shaped pad was designed to distribute pressure around the joint, and if the pad infringed on the sensor area, that may have caused an increase in pressure under those sensors, even though the pad may have been doing what it was designed to do.

Clinical Application and Further Research

The results of this study contribute to the increasing breadth of knowledge that is being applied to clinical practice in sports medicine, and they support the use of foot pads as an effective method of reducing plantar pressure during physical activity. The results agree with those of previous research that the metatarsal dome and U-shaped pads are effective in reducing plantar pressure under the first MTPJ, but other factors must still be taken into consideration when choosing or constructing the proper pad. Location and intensity of foot pain; shoe type, quality, and fit; duration and type of activity being performed; comfort of the pad; and the availability of materials used in pad construction will play a role in the clinician’s choice.

Because of the variations in biomechanics and plantar-pressure patterns of different foot types, the results of this study can only be applied to individuals with pes planus foot type. This study should be repeated for pes cavus and neutral
foot types to determine if the pads are equally effective for all foot types. Other phases of the gait cycle and more sport-specific skills such as sprinting and cutting could also be analyzed to further determine the effectiveness of each of these pads. Different styles of foot pads and types of materials that are used to construct them could also be examined for relative effectiveness. Different types of shoes that offer different levels of support for the foot, as well as shoes for different athletic activities, such as football cleats and track spikes, and their interaction with the pads could also be observed.

Further research is also warranted to determine the applicability of studies on asymptomatic individuals to symptomatic cases. Results of previous studies have shown a significant positive correlation between pain-scale ratings and average and peak plantar-pressure measurements,\textsuperscript{15,30} indicating that the results from studies with asymptomatic individuals may be applicable to symptomatic cases. Anecdotal evidence on comfort from the current study also supports this theory. Fourteen out of 20 subjects stated that the metatarsal dome was the most comfortable of the 3 foot pads.

**Conclusions**

We found that application of a foot pad for conditions related to first-MTPJ pain was effective in reducing mean and peak pressures in that area in relation to use of a metatarsal dome or U-shaped pad for asymptomatic individuals. In addition, application of a donut-shaped pad will increase pressures in the first MTPJ. These foot pads (dome and U-shaped) are effective for immediate pressure decreases and distribute the pressures from the MTPJ throughout the foot.

**References**