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FOOT & ANKLE


# A Quantitative Assessment of the Effect of Metatarsal Pads on Plantar Pressures

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## ABSTRACT

**The treatment of metatarsalgia secondary to the plantar prominence of the metatarsal heads has lead to the development of numerous orthotic devices designed to decrease pressures in these areas. In spite of the considerable cost of some of these devices, there has yet to be much objective evidence of their efficacy. This study assessed the effect of a simple metatarsal pad on pressures transmitted to the metatarsal heads. Quantitative measurements of dynamic peak pressures for 10 asymptomatic subjects with and without metatarsal pads were made using the pedobarograph. Female volunteers had a reduction in peak metatarsal pressures from 12% to 60% when a small metatarsal pad was appropriately applied to the foot. In two of five males there was a decrease in metatarsal pressure of 14% to 44%. One male had no change in pressure, while two others had an increase in pressure from 8% to 28%. When properly positioned and appropriately monitored, metatarsal pads can be an inexpensive and effective means of reducing metatarsal pressures.**

## INTRODUCTION

Various conservative measures have been devised to decrease the transmission of pressure to areas of metatarsal prominence. It has been reasoned that by decreasing the forces transmitted to these areas, there will be a reduction in the pain experienced by patients. In addition to wearing shoes with softer insoles or insole excavations, various orthotic devices have been marketed to lessen the forces transmitted to the metatarsal heads. A partial list of such devices includes custom-molded, rigid orthotics, and liners of various materials such as Plastizoate (B.X.L. Plastics Ltd., Croydon, Surrey, England), Spenco (Spenco Medical Corporation, Waco, Texas), felt, or two-way stretch rubber.[3]

One simple and inexpensive device is the soft metatarsal pad. The objective effect of a soft metatarsal pad on metatarsal pressures will be assessed with the use of the pedobarograph, a dynamic real-time visualization device for the quantitative measurement of plantar pressures.

## METHODS

Ten volunteers (five women and five men) were used for data acquisition. The average age of the men was 28 years. The average age of the women was 32 years. None of the patients had a prior history of foot complaints or surgery. All females reported an intermittent history for wearing high-heeled shoes of at least 1 to 2 inches in height. Height, weight, and foot size were also obtained for each volunteer.

Barefoot plantar pressures were recorded for each subject using the Biokinetics Pedobarograph. Technical descriptions of this device have been outlined by previous authors.[1,5] Prior to each trial the pedobarograph was calibrated according the manufacturer's calibration routine. An external calibration using a standardized free-weight was used to check the machine's internal calibration. This procedure demonstrated that the pedobarograph accurately recorded the external standard weight with a variability of less than 0.1%. The pedobarograph was allowed a 30-min warm-up period at the beginning of each session.

A walk-ramp of 11 ft × 3 ft was available for each patient before actual foot contact with the plate of the pedobarograph. The target size of the pedobarograph platform was 15 in × 11 in. Each subject was given time to practice walking on the ramp prior to actual data acquisition. The speed of gait was standarized by the use of both timing lights and a metronome. Each subject walked at a speed of about 1.4 m/sec which was verified by the use of timing lights along the ramp. A metromone was also used to assist the subjects in duplicating the standardized cadence. If the speed was

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not between 1.33 m/sec and 1.50 m/sec for any trial, the subject repeated the trial.

Left foot pressure measurements were initially recorded for all subjects prior to the placement of a metatarsal pad. The data for each subject for 15 trials was then analyzed for peak pressures at the heel, first metatarsal, second metatarsal, combined third and fourth metatarsals, fifth metatarsal, and the great toe (Fig. 1). Due to the size and proximity of the pressures for the third and fourth metatarsals, these areas were combined and measured jointly by one pressure measurement. Each metatarsal area was sampled for peak pressures by using the pedobarograph software, which allowed for the placement of a cursor over the specific area of interest. A specific foot template was drawn for each subject to accurately measure these specific peak pressures for each trial. Areas of increased pressure under the metatarsals were identified for the purposes of placement of metatarsal pads. Various pad sizes from extra-small to large were available. For the purposes of uniformity a small metatarsal pad was chosen for use with all subjects. The pads were placed directly on the foot at a position just proximal to the area or areas of maximal metatarsal pressure (Fig. 2). If prior to the application of the metatarsal pad the pressures were fairly uniform, the pad was placed centrally, just proximal to the second, third, and fourth metatarsals. The placement of the pads was checked by having the subject walk several trials across the pedobarograph prior to actual data collection. In this way the pad could be positioned for the optimal reduction of metatarsal pressure. Fifteen trials were then recorded with the pad correctly positioned on the plantar aspect of the foot.

**Fig. 1.** Areas for the placement of the cursor for pressure measurements on the plantar surface of the foot.

The mean peak pressures were then compared for the various areas of the foot for the 15 trials with and without metatarsal pads.

## RESULTS

The peak pressures with and without metatarsal pads, the standard deviation, the percentage change in pressure and the *P*-value calculations based upon the *t*-distribution formula were determined for both male and female subjects, respectively. Figure 3 graphically demonstrates the mean peak pressures before and after the placement of a metatarsal pad for subject 1 in the female volunteer group. The measurements and calculations for male and female subjects are recorded in Tables 1 and 2.

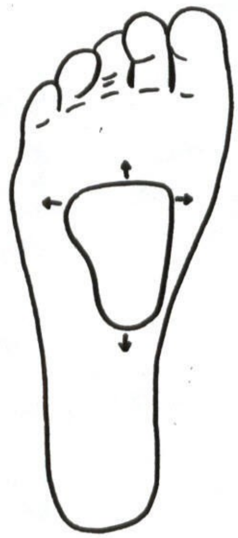

**Fig. 2.** Placement of the metatarsal pad proximal to the metatarsal heads. The pad may be adjusted for maximal effect.

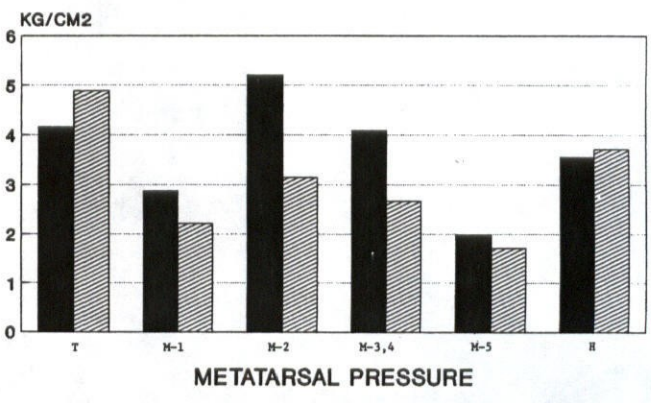


**Fig. 3.** Bar graph representation of the plantar pressures. Female subject (1) before and after placement of metatarsal pad.

**TABLE 1**
**Summation of Data for Females for 15 Trials With and Without Metatarsal Pads (Peak Pressure, Kg/cm²)**

| | Patient no. | Great toe | | Metatarsal 1 | | Metatarsal 2 | | Metatarsals 3, 4 | | Metatarsal 5 | | Heel | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | −Pad | +Pad | −Pad | +Pad | −Pad | +Pad | −Pad | +Pad | −Pad | +Pad | −Pad | +Pad |
| Peak pressure | 1 | 4.16 | 4.89 | 2.78 | 2.21 | 5.21 | 3.15 | 4.09 | 2.67 | 1.91 | 1.17 | 3.55 | 3.71 |
| SD | | 0.45 | 0.44 | 0.66 | 0.42 | 0.47 | 0.33 | 0.5 | 0.29 | 0.38 | 0.28 | 0.67 | 0.35 |
| % Change | | +18 | | −23 | | −40 | | −35 | | −39 | | −50 | |
| *P*-value | | <.0001 | | <.005 | | <.0001 | | <.0001 | | <.0001 | | ns | |
| Peak pressure | 2 | 4.32 | 4.91 | 1.72 | 1.43 | 3.29 | 2.6 | 2.65 | 1.94 | 1.42 | 1.31 | 2.36 | 2.33 |
| SD | | 1.05 | 0.58 | 0.31 | 0.18 | 0.52 | 0.34 | 0.41 | 0.13 | 0.51 | 0.14 | 0.2 | 0.21 |
| % Change | | +14 | | −17 | | −21 | | −27 | | −8 | | −1 | |
| *P*-value | | ns | | <.005 | | <.001 | | <.0001 | | ns | | ns | |
| Peak pressure | 3 | 4.53 | 4.98 | 2.27 | 2.58 | 4.49 | 2.75 | 2.67 | 2.35 | 0.97 | 0.76 | 1.97 | 2.07 |
| SD | | 0.56 | 1.1 | 0.98 | 0.85 | 0.85 | 0.38 | 0.66 | 0.5 | 0.24 | 0.16 | 0.22 | 0.15 |
| % Change | | +10 | | +14 | | −39 | | −12 | | −22 | | +5 | |
| *P*-value | | ns | | ns | | <.0001 | | ns | | <.01 | | ns | |
| Peak pressure | 4 | 4.8 | 4.51 | 3.05 | 2.71 | 3.8 | 2.93 | 2.77 | 2.21 | 2.19 | 0.83 | 2.82 | 2.69 |
| SD | | 0.55 | 0.52 | 0.69 | 0.68 | 0.37 | 0.36 | 0.32 | 0.31 | 0.54 | 0.33 | 0.2 | 0.17 |
| % Change | | −6 | | −11 | | −23 | | −20 | | −62 | | −5 | |
| *P*-value | | ns | | ns | | <.0001 | | <.0001 | | <.0001 | | ns | |
| Peak pressure | 5 | 4.87 | 5.11 | 2.31 | 1.87 | 4.78 | 4.17 | 2.35 | 2.09 | 3.09 | 1.95 | 2.87 | 2.98 |
| SD | | 1.14 | 0.61 | 0.72 | 0.4 | 0.72 | 0.58 | 0.43 | 0.37 | 0.65 | 0.45 | 0.21 | 0.32 |
| % Change | | +5 | | −19 | | −13 | | −11 | | −37 | | −4 | |
| *P*-value | | ns | | ns | | <.01 | | ns | | <.0001 | | ns | |

For female subjects there was a broadly ranged statistically significant decrease in metatarsal pressures. Metatarsal pressures were most consistently reduced for lesser metatarsals 2, 3, 4, and 5. There was no statistical change in the pressures transmitted to the heel by placement of the metatarsal pad. In no instance did any of the female subjects have a statistically significant increase in pressure under the metatarsal heads as a result of the placement of metatarsal pads. For all metatarsal areas sampled for the five female subjects, placement of the pads resulted in a reduction of pressure 60% of the time. The overall success rate for lowering lesser metatarsal pressures was 80%. The area with the highest rate of lowered pressure was the second metatarsal with all subjects having a reduction of pressure with the proper positioning of a pad.

The data for the male patients is summarized in Table 2.

For male volunteers 20% of all metatarsal areas sampled had a decrease in pressure as a result of pad placement. On the other hand, 65% had no change in pressure and 15% had an increase in pressure with pad placement.

There was no significant difference between the peak pressures of the female patients and the male patients. The placement of a metatarsal pad did not appear to have a consistent effect, one way or the other, on the pressures transmitted to the great toe or first metatarsal head. Pressures were generally greatest at the second metatarsal for both female and male subjects. With metatarsal pads in place, all females had a reduction in pressure transmitted to the second metatarsal while only the male with the highest pressure had a reduction.

A typical or normal distribution of pressures was demonstrated for the separate and combined pressures of the men and women. Such a profile of pressure distribution is shown in Figure 4. Typically, the pressure of the first metatarsal was less than that of the great toe or the second metatarsal. The pressure distributed to the great toe was usually less than that under the second metatarsal. Within the lesser metatarsals there was usually a descending cascade of pressure from the second to the fifth metatarsal.

No female reported pain during the trials using the metatarsal pad. Even though all subjects were symptom-free at the time of this study, three reported a dramatic improvement in plantar comfort with the pads. One subject has since started to use the pads on a regular basis.

Within the 10 asymptomatic patients sampled, the females had the greatest reports of an improved comfort on the plantar aspect of the foot. The male with a reduction in pressure under all the lesser metatarsals stated that the pads did not enhance the comfort appreciated on the plantar aspect of his feet. The other male with a reduction in pressure under the fifth metatarsal felt better with the pad in place. All males with an increase in pressure found the pads to be uncom-

**TABLE 2**
**Summation of Data for Males for 15 Trials With and Without Metatarsal Pads (Peak Pressure, Kg/cm²)**

| | Patient no. | Great toe | | Metatarsal 1 | | Metatarsal 2 | | Metatarsals 3, 4 | | Metatarsal 5 | | Heel | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | −Pad | +Pad | −Pad | +Pad | −Pad | +Pad | −Pad | +Pad | −Pad | +Pad | −Pad | +Pad |
| Peak pressure | 1 | 3.31 | 3.98 | 2.13 | 2.35 | 3.41 | 3.71 | 2.79 | 2.53 | 1.96 | 1.87 | 2.9 | 2.73 |
| SD | | 1.08 | 0.54 | 0.52 | 0.35 | 0.36 | 0.32 | 0.51 | 0.48 | 1 | 0.76 | 0.53 | 0.76 |
| % Change | | +20 | | +10 | | +9 | | −9 | | −5 | | −6 | |
| *P*-value | | ns | | ns | | ns | | ns | | ns | | ns | |
| Peak pressure | 2 | 4.6 | 4.63 | 2.5 | 2.51 | 2.94 | 2.96 | 2.6 | 2.55 | 2.87 | 1.62 | 4.07 | 3.73 |
| SD | | 0.4 | 0.52 | 0.5 | 0.44 | 0.22 | 0.19 | 0.19 | 0.2 | 0.55 | 0.43 | 0.46 | 0.3 |
| % Change | | −1 | | 1 | | 1 | | −2 | | −44 | | −8 | |
| *P*-value | | ns | | ns | | ns | | ns | | <.0001 | | ns | |
| Peak pressure | 3 | 3.81 | 2.26 | 2.25 | 1.93 | 3.33 | 3.74 | 2.81 | 3.11 | 1.7 | 1.95 | 3.15 | 2.96 |
| SD | | 0.86 | 0.63 | 0.38 | 0.41 | 0.28 | 0.33 | 0.22 | 0.21 | 0.32 | 0.39 | 0.2 | 0.14 |
| % Change | | −40 | | −14 | | +12 | | +11 | | +15 | | −6 | |
| *P*-value | | <.0001 | | ns | | <.001 | | <.001 | | ns | | <.001 | |
| Peak pressure | 4 | 2.09 | 2.96 | 2.43 | 2.7 | 4.75 | 3.7 | 3.93 | 2.61 | 1.77 | 1.07 | 2.43 | 2.28 |
| SD | | 0.54 | 0.27 | 0.4 | 0.36 | 0.52 | 0.38 | 0.47 | 0.39 | 0.3 | 0.19 | 0.16 | 0.27 |
| % Change | | +42 | | +11 | | −22 | | −34 | | −40 | | −6 | |
| *P*-value | | <.0001 | | ns | | <.0001 | | <.0001 | | <.0001 | | ns | |
| Peak pressure | 5 | 6.04 | 4.22 | 2.01 | 2.21 | 3.94 | 4.63 | 3.47 | 3.97 | 1.7 | 2.18 | 2.62 | 3.11 |
| SD | | 1.18 | 1.87 | 0.52 | 0.69 | 0.7 | 0.33 | 0.63 | 0.48 | 0.5 | 0.73 | 0.16 | 0.34 |
| % Change | | −30 | | +10 | | +18 | | +14 | | +28 | | +19 | |
| *P*-value | | <.005 | | ns | | <.005 | | ns | | ns | | <.0001 | |

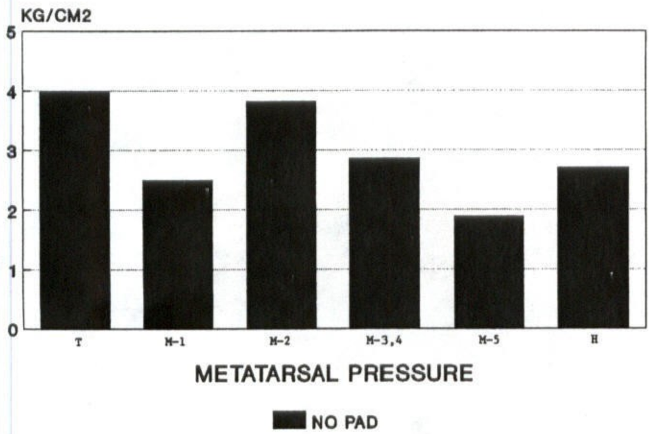


**Fig. 4.** Composite graph of peak pressures for both males and females without a metatarsal pad.

fortable. All patients reported an increased awareness of pressure in the arch of the foot with placement of the pads. This "awareness" did not cause discomfort in any of the patients, male or female, who had a measureable reduction in pressures as a result of the pads.

## DISCUSSION

At the 1989 winter meeting of the AOFAS the President's Symposium on "The Use and Abuse of Orthotics" concluded that the medical community lacked the objective data to support the rational use of most orthotics prescribed to patients. Some of these devices have been used to treat specific areas of pain or deformity while others have been used strictly on a prophylactic basis. Some of these devices may cost hundreds of dollars. In this age of cost containment it becomes incumbent upon us as orthopaedists to seek information and data to support the appropriate use of orthotics. This study was undertaken to look at the specific issue of the effectiveness of metatarsal pads for the reduction of metatarsal pressures.

The diagnosis and treatment of metatarsalgia is by no means a simple process. Pain may stem not only from prominence of the metatarsal heads but also from abnormalities of soft tissue and biomechanics. Diagnostic possibilities include those of abnormal gait, painful plantar incisions, postsurgical scarring, neuroma, hallux rigidus, or osteonecrosis such as in Frieberg's disease. Metatarsalgia may be result of prominence of the metatarsals which may be due increased plantarflexion, prominent condyles, or adaptive soft-tissue changes on the plantar aspect of the foot. The use of metatarsal pads has been viewed as one modality of treatment when various mechanical alterations are suspected of causing metatarsal pain. To investigate the effectiveness of metatarsal pads in reducing plantar pressures without the interference of various biomechanical abnormalities or subjective pain, asymptomatic subjects were chosen for analysis with the pedobarograph.

Normative data for metatarsal pressures using the pedobaragraph has been generated in a previous study of Cavanaugh.[2] Peak metatarsal pressures were demonstrated to be maximal at the second metatarsal head.

This was contrary to a previous study which indicated that metatarsal pressures were preferentially concentrated under the first metatarsal.[4] The data from our study is consistent with the findings of Cavanaugh showing the preferential weight-bearing under the second metatarsal rather than the first metatarsal.

The most consistent reduction in metatarsal pressures were noted in the female subjects. Various factors could be invoked to explain this observation. The reduction in pressures in females may have been due to soft-tissue and bony adaptive changes secondary to the wearing of high-heeled shoes. Even though a small pad was used for all subjects, this pad may have been relatively more effective for the smaller foot of the female subjects. In a series with a small sample size one must consider the possibility of bony variations not fully appreciated in the absence of a complete radiographic survey of the foot and ankle.

The use of metatarsal pads appears to be highly effective in the reduction of metatarsal pressure in female subjects. In all, 100% of the females demonstrated a diminution of metatarsal pressure with a metatarsal pad. A variable response was noted for males. Three of five males had either a decrease or no change in metatarsal pressures, while two in five had an increase in metatarsal pressure. The increase in pressure in these two subjects may ultimately have been due to improper placement of the metatarsal pad. Alternatively, for some subjects, particularly those who are asymptomatic, there may be a threshold of plantar pressures below which a metatarsal pad may be ineffective in lowering pressures. It should be possible to use the technique described in this study to investigate the effect of metatarsal pads on patients with metatarsalgia due to any of several causes. It may also be possible to correlate pressure reduction with diminution of symptoms.

The information presented in this study has practical benefit for the clinician today. A simple, soft metatarsal pad may be of benefit in the reduction of metatarsal pressure. This benefit may be maximal for female patients. Clinicians should take the time and effort to ensure that the pad is appropriately positioned in the shoe. The pedobarograph offers one means by which to assess each patient individually in order to determine if the metatarsal pad is actually achieving the desired effect of pressure reduction under the metatarsals. The means to quantitatively demonstrate a reduction of pressure is a crucial step in the overall assessment of the efficacy of any form of orthotic intervention. In cases where no diminution of pressure has actually been accomplished, one can not be surprised if there is a failure to achieve symptomatic relief of pain. With increased experience and data collection we may find that there is an overall lower threshold of pressure below which it will not be practical to expect a reduction of pressure with the use of a metatarsal pad. Due to its low cost, the metatarsal pad or similar device may be the preferred initial choice of shoe-insert to lower metatarsal pressures. All current orthotics should be subjected to a quantitative measure of their ability to reduce plantar pressures. Correlation with subjective improvement will then be the next step in the design and use of the most appropriate and cost effective inserts and orthotics.

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