The Effect of Padded Hosiery in Reducing Forefoot Plantar Pressures

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Abstract: The purpose of this study was to determine if the use of padded hosiery caused a significant reduction in plantar pressures measured at the sock-shoe interface compared to a control sock, when initially fitted and after 8 weeks of continuous wear. Testing was conducted on eight healthy subjects under the following conditions: a nonpadded control sock, a wash-only padded sock, and a padded test sock. Pressure data were collected within the shoe for the three conditions using the EMED Mikro system (NOVEL Gmbh, Munich, Germany) on the initial day of fitting and after 8 weeks of wear. Data were also collected on the test sock at the time of initial donning and again after 4 hours of activity. The results indicate that padded hosiery can significantly decrease forefoot plantar pressures when initially donned, after wearing for 4 hours of activity, and over a period of 8 weeks of wear. The pressure reductions that were found, however, were not uniform across the entire forefoot. **Key words:** plantar pressures, padded hosiery, walking.

A common treatment approach in the management of numerous disorders affecting the lower extremity and foot is the use of nonmolded insole materials to reduce plantar pressures. In severe cases, the use of an external metatarsal bar or specially designed shoes, in addition to insole materials, may be required to effectively decrease plantar pressures. The foot and lower extremity disorders most often cited for this type of treatment include increased plantar pressures as a result of foot structure (pes cavus[1]); insensitivity of the plantar foot surface (diabetes,[2] leprosy[3]); metatarsalgia,[4] and hypersensitivity of the plantar foot surface (rheumatoid arthritis[5]). Although nonmolded insole materials, external metatarsal bars, or specially designed shoes can be an effective adjunct to the overall management of these conditions, several problems can prevent their use. The patient's particular shoe style may prevent the use of an insole material due to a lack of room in the toe box region. Many of the nonmolded insole materials are manufactured from polyethylene or compressed urethane foams. These materials are nonbreathable and do not absorb perspiration, which can lead to patient discomfort when using the insoles for long periods of time. If the use of an external metatarsal bar is required as part of the treatment program, the bar must be placed in all of the patient's footwear, which can limit the number of shoes that can be utilized. Finally, specially designed shoes, although fabricated to provide optimum relief of plantar pressures, are often cosmetically unacceptable to the patient.

Since most people wear some type of hosiery with their footwear, recent studies have considered the use of padded hosiery as another management approach for reducing plantar pressures. Researchers have reported that the use of padded hosiery effectively decreased forefoot plantar pres-

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sures in diabetic neuropathic patients,[3,4] reduced foot pain in rheumatoid arthritis patients,[7] and decreased blistering of the skin in healthy long-distance runners.[10]

Veves and co-workers were the first to report the successful use of padded hosiery as a method of decreasing plantar pressures. In their first study,[4] they used an optical pedobarograph to assess plantar pressures in 27 neuropathic diabetic patients during walking, under the following conditions: barefoot, wearing the patient's own hosiery, and wearing padded hosiery. The results from this study indicated that padded hosiery significantly reduced plantar pressures, especially in the forefoot region. Unfortunately, the durability of the hosiery was not evaluated. In a subsequent investigation, Veves and co-workers[3] used a similar protocol with 10 neuropathic diabetic subjects to investigate the effect of the padded hosiery in reducing plantar pressures over a test period of 6 months. They reported that a 31% reduction in plantar pressures was initially observed, but after testing at 3- and 6-month intervals, the plantar pressures were only reduced 15.5% and 17.6%, respectively. Veves et al. concluded that padded hosiery could be used for a considerable period of time for the purpose of reducing foot plantar pressures.

The findings of these investigations would seem to support the use of padded hosiery as part of a treatment program for foot disorders that require a reduction in forefoot plantar pressures. There is, however, an important issue regarding the methodology used in these previous studies, which tested the effectiveness of the padded hosiery in decreasing plantar pressure. The aforementioned investigations measured plantar pressures by having the subjects walk over an optical pedobarograph while wearing only the padded hosiery or control sock. The protocol used in these studies for testing ignores the effect of footwear as well as temperature increase and moisture build-up within the shoe, which could have a substantial effect on the ability of the padded sock to reduce plantar pressures.

A more appropriate method of testing the effectiveness of padded hosiery would be to measure plantar pressures within the shoe, after the subject has worn the sock and shoe for an extended period of time. Thus, the measurement of plantar pressures within standardized footwear appears to be the optimal method to test the effectiveness of padded hosiery.

The purpose of this investigation was to determine if the use of padded hosiery caused a significant reduction in plantar pressures measured at the sock-shoe interface compared to a control sock, at the time of initial fitting and after 8 weeks of continuous wear. The null hypothesis was that no significant change would occur in plantar pressures measured within the shoe as a result of wearing either padded hosiery or the control socks.

Methods

Subjects

Eight subjects, five men and three women, were selected from a group of volunteers. Volunteers were first screened for a history of congenital deformities of either lower extremity, severe orthopedic or neurologic injuries to the lower extremities, or traumatic injury to either lower extremity 6 months prior to data collection. The mean age of the subjects selected was 27 years, with an age range of 23 to 44 years. All male subjects selected had a shoe size of 9 to 9½, while the female subjects selected had a shoe size of 7½ to 8. The study protocol was approved by the Institutional Review Board of Northern Arizona University, and all subjects signed an informed consent prior to participating in the investigation.

Materials

A standard extra-depth shoe (P.W. Minor & Son, Inc., Batavia, NY) was issued to each subject and only used while the test socks were being worn. The women used model #11066, and the men used model #11068. Since the extra-depth shoes had a relatively soft sock liner, this was removed and replaced with a flat, nonmolded piece of XPE (55 durometer, Shore A). The XPE material (Alimed Inc., Dedham, MA) was 3/8 inch in thickness and cut to fit the shape of the original sock liner.

The padded hosiery used in the study was a commercially available ThorLo Running Sock (model #XJ, Thorneburg Hosiery Co, Statesville, NC). A 100% cotton nonpadded athletic stocking was used as the control sock. Prior to testing, each subject was fitted with a pair of extra-depth shoes and three pairs of socks: a pair of non-padded 100% cotton socks (control), a pair of padded hosiery (wash-only socks), and a pair of padded hosiery to be used for testing (test socks). Each pair of socks were indelibly marked to ensure each subject used the same three pairs of socks throughout the 8 weeks of the study.

Instrumentation

The EMED Mikro pressure measurement system (NOVEL Gmbh, Munich, Germany) was used to collect plantar pressure data within the shoe. The EMED Mikro system is a nontethered unit that samples and records pressure data from an attached insole at a rate of 100 Hz. The EMED insole sensor, which was attached to the Mikro system, consisted of a matrix of 85 capacitance transducers and was approximately 2 mm thick. The women's size 7½–8 and the men's size 9–9½ insoles were calibrated prior to the start and at the conclusion of data collection, using a rubber bladder that was pressurized with compressed air. Temperatures within the shoe were recorded using a thermistor (YSI Inc., Yellow Springs, OH, Tele-Thermometer, model #44TD) and a tubular temperature probe (YSI Inc., model #403).

Procedures

Initial Testing. On the first day of testing, each subject's weight and height were measured and recorded. Each subject was then instructed to don the control socks and extra-depth shoes with the EMED insole positioned in the right shoe. The EMED Mikro system was then connected to the insole and secured around the subject's waist using a special carrying case. The subject then practiced walking over a 25-m concrete floor for approximately 5 minutes. At the end of the 5-minute practice session, the subject was again asked to walk over the concrete floor while pressure data were collected for six consecutive steps of the right foot. The same procedure was then repeated to test both the wash-only socks and the test socks. Upon completion of data collection of the test socks, the EMED insole was removed from the extra-depth shoe and the skin temperature between the first and second metatarsal heads was measured with the shoes on. The temperature was recorded after a 2-minute stabilizing period. The subject then wore the test socks and extra-depth shoes for the next 4 hours. During the 4-hour wear period, the subject's activities included walking to and from class, sitting in class, and walking 1 mile either on a treadmill or outdoors. At the end of the 4-hour wear period, the subject returned and the temperature measurement was repeated without removing the shoe. After the temperature was recorded, the shoe was quickly removed, the EMED insole positioned on top of the XPE, and the foot placed back into the shoe immediately to minimize the loss of humidity and heat within the shoe and sock. The procedure (previously described for obtaining plantar pressures) was then repeated a second time on the test socks to determine the effect of the 4 hours of activity.

Between Test Days. Each subject then wore the test socks and extra-depth shoes 5 days per week, 4 hours per day for the next 8 weeks. Each day, throughout the entire 8 weeks, the subjects would don their test socks and shoes at 8:00 each morning under the supervision of one of the investigators. Each subject would then perform the same activity as described previously, including a 1-mile walk, during the next 4 hours. The wash-only socks and test socks were machine washed and dried every 2 days, by the same investigator (V.H.) using identical cleaning procedures.

Final Testing. At the end of the 8-week activity period, the same pressure and temperature data collection procedures described for initial testing were repeated, while the subject wore the extra-depth shoes and the control, wash-only, and test socks. Data for the test socks were again collected immediately upon donning, and again after 4 hours of activity. Pressure data were again collected for six consecutive steps of the right foot.

Data Analysis

The EMED Multimask software (NOVEL Gmbh) was used to divide each step into the following plantar regions: hallux, medial forefoot, central forefoot, and lateral forefoot. Peak pressure was then calculated for each plantar region, and the mean was determined for the six steps analyzed for each of the conditions tested.

Since the intent of this investigation was to determine if the padded hosiery could effectively decrease plantar pressures in comparison to a nonpadded stocking and because of the fact that data from two different-sized insoles had to be combined for statistical analyses, the investigators normalized the plantar pressure data from each region to the control sock pressure values. Thus, the average peak plantar pressure value obtained for each "test condition" for each plantar region measured was divided by the control sock average peak plantar pressure value to determine the percent change in peak plantar pressure for each region.

Statistical Procedures

For this study, the independent variables tested were wear time and conditions. The two levels for the variable wear time were initial and final testing. The three levels for the variable conditions were wash-only sock, prior to wearing the test sock (pretest sock), and after wearing the test sock

for 4 hours (post-test sock). The dependent variable was the percent change in peak plantar pressure for each of the four plantar regions, compared to the control sock condition.

To determine the reliability of each subject's stance phase durations for the six steps collected on initial and final testing, a type three (3,1) intraclass correlation coefficient[11] was used. In addition to means and standard deviations, a two-way repeated measures analysis of variance (ANOVA) was used to determine if differences existed between the variables wear time and conditions for each of the plantar regions analyzed. If the results of the ANOVA were significant, Tukey's post hoc comparisons were used to determine if differences existed among the various levels of the variables' wear time and conditions. An alpha level of .05 was used for all decisions of statistical significance.

Results

The intraclass correlation coefficient for stance phase duration reliability between initial and final testing was found to be .87. Means for the percent change in peak plantar pressure by region are listed in Table 1. The mean change in foot temperature after 4 hours of activity was 6.6°C for initial testing and 7.1°C for final testing.

The results of the ANOVA were significant ($P < .005$) only for the variable conditions for the hallux and central forefoot regions. Significant differences were not found for the variable wear time among any of the four plantar regions studied. The results of Tukey's comparisons indicated that the post-test sock condition was significantly different ($P < .05$), compared to either the pretest or wash-only sock conditions in the hallux and central forefoot regions.

Discussion

The authors' first question in interpreting the results of this study was whether the subjects' stance phase durations were consistent between initial testing and final testing. The consistency of stance phase durations was an important issue, since a poor level of reliability between the 2 days of testing, which were separated by 8 weeks, could indicate that the subject's speed of walking was different on both testing days. Substantial variations in walking speed have been shown to influence the magnitude of plantar pressure data.[12] The reported intraclass correlation coefficient indicates that the subjects' stance phase durations were extremely consistent between the two test days and that further analysis of the results could continue.

The intent of this investigation was to determine if the use of padded hosiery caused a significant reduction in plantar pressures measured at the sock-shoe interface, in comparison to a control sock, when initially fitted and after 8 weeks of continuous wear. Based on the findings of the statistical analyses, the use of padded hosiery did significantly decrease plantar pressures at the sock-shoe interface, in comparison to nonpadded control stockings and the wash-only padded hosiery. The significant decreases in plantar pressures, however, were only observed in two of the four plantar regions investigated, at both initial testing and final testing. The two regions with significant decreases in plantar pressures were the hallux and the central forefoot. These results suggest that, although the padded hosiery tested in this investigation decreased foot plantar pressures, it did not cause a uniform pressure reduction over the entire plantar surface of the forefoot. Finally, the type of padded hosiery tested did not appear to be affected by washing over the 8-week period, since there were no differences noted between the wash-only test sock and the two test sock conditions.

The findings of this study are in partial agreement with the previously published findings of Veves and co-workers,[7] except that they reported a more uniform decrease in pressures over the plan-

Table 1. Percent Change in Peak Plantar Pressure Compared to the Control Sock Condition by Region for both Initial and Final Testing

	Wash-only Sock		Pre-test Sock		Post-test Sock	
Region	Initial	Final	Initial	Final	Initial	Final
Hallux	−0.96	−0.49	−3.09	−0.76	−16.40	−13.71
Medial forefoot	7.02	−0.05	10.41	0.75	−9.12	7.16
Central forefoot	0.72	−2.65	4.97	1.58	−10.23	−3.75
Lateral forefoot	−2.43	−0.57	0.72	−2.89	4.20	−3.17

(−) denotes a decrease of the percent change in peak plantar pressure.

tar surface of the forefoot. It should be noted again, however, that Veves and co-workers did not test the effectiveness of the padded hosiery in reducing plantar pressures within the shoe. Although Veves et al.[7] did use hosiery manufactured by the same company (Thorneburg Hosiery Co.) as the padded hosiery used in the present study, they did not provide the specific model numbers of the socks that they tested. Also, it was unclear from the description of their methods when the testing was performed. Was the testing performed after the subject had worn the padded hosiery for several hours on the day of testing, or was it conducted immediately after donning the padded hosiery? How did the researchers control for the effect of moisture build-up and temperature change on the ability of the padded socks to reduce plantar pressures, since the sock was removed from the shoe for testing? The fact that the present study found a mean change of 6.6°C and 7.1°C after 4 hours of activity on initial and final testing, respectively, would indicate that temperature and, possibly moisture, could change the effectiveness of the padded hosiery. Considering these findings, the authors believe that the most appropriate method for determining the effectiveness of padded hosiery in reducing plantar pressures should be with measurements conducted within the shoe.

The primary limitation of this study was the number of subjects who participated. It was the authors' intent to have a total of 10 subjects, but 2 who were originally selected to participate dropped out of the project after 2 weeks of participation. The authors, however, still believe that the findings of this investigation are of value because it presents the first attempt to evaluate the effectiveness of padded hosiery in reducing plantar pressures using measurements that were obtained within the shoe.

Summary

The results of this investigation indicate that commercially available padded hosiery can significantly decrease forefoot plantar pressures when initially donned, after wearing for 4 hours of activity, and over a period of 8 weeks of wear. The pressure reductions that were identified were not uniform across the entire forefoot but were limited to the hallux and central forefoot. Although the results of this study indicate that padded hosiery is of use in patients requiring a reduction in plantar pressures, the clinician cannot assume that decreases in plantar pressures will occur in all plantar regions of the patient's forefoot. Therefore, additional therapeutic modalities should be considered to augment the beneficial effects of padded hosiery.

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