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Reduction of dynamic plantar pressures in an experimental sock. A preliminary report

Reducción de las presiones plantares dinámicas en un calcetín experimental. Un estudio preliminar

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Keywords:

Foot posture, skin care, foot, health, socks, comfort, plantar pressure, metatarsals, metatarsalgia, pain.

Abstract

Ojectives: Metatarsal overload is treated through selective off-loads, temporary or definitive. Thus, is proposed the implementation of a selective off-loading element (U-shaped) fitted in socks under the central forefoot. The aim of this study was to assess plantar pressures of the prototype in regard to a control sock made of the same fibers and pattern.

Patients and methods: Plantar pressures of 21 individuals (9 men and 12 women) were analyzed using the platform Footscan® (RSscan int). First, individuals wore their own socks, in the second analysis (randomly) they wore control socks and the socks having the off-loading pad implemented under the forefoot plantar area (experimental socks). Individuals answered a comfort survey, in which Likert scale (from 1 to 5) was used.

Results: A statistically significant reduction ($P = 0.037$) in the plantar pressure values was observed in the third metatarsal head: from 14.9 N/cm2 in barefooted patients and 14.7 N/cm2 in patients wearing the control sock to 12.3 N/cm2 in patients wearing the experimental sock. Regarding comfort, individuals gave a score of 3.13 ± 0.5 to the control sock, and 4.74 ± 0.5 to the experimental sock, showing a statistically significant difference among them ($p < 0.001$).

Conclusions: Experimental socks turned out to be more comfortable for the sample, and to reduce plantar pressure from the third metatarsal head. This could lead on to less discomfort for subjects having predisposition to pain in the area, and to avoid possible dermis injuries related to overpressure.

Palabras clave:

Postura del pie, cuidado de la piel, pie, salud, calcetines, confort, presión plantar, metatarsianos, metatarsalgia, dolor.

Resumen

Objetivos: Las sobrecargas metatarsales se tratan con descargas selectivas, provisionales o definitivas. Así, se propone implantar un elemento de descarga selectiva (forma de U) en el antepié central integrado en unos calcetines. El objetivo de este trabajo fue evaluar el patrón baropodométrico del modelo experimental respecto a un calcetín control fabricado en las mismas fibras y diseño.

Pacientes y métodos: En una muestra de 21 sujetos (9 hombres y 12 mujeres) se analizaron las presiones plantares con la plataforma Footscan® con sus propios calcetines, seguido (de forma aleatoria) con los calcetines control y posteriormente con otros iguales pero con el elemento de descarga en la zona plantar del antepié (calcetines experimentales). Los sujetos contestaron una encuesta de comodidad, mediante una pregunta tipo Likert de 1 a 5.

Resultados: En la tercera cabeza metatarsal se vio una reducción estadísticamente significativa ($p = 0.037$) de los valores de presión plantar, de los 14.9 N/cm^2 de los pacientes descalzos y 14.7 N/cm^2 del calcetín control a los 12.3 N/cm^2 en el calcetín experimental. En relación con el confort, los sujetos puntuaron con un 3.13 ± 0.5 al calcetín control y 4.74 ± 0.5 al calcetín experimental, con una diferencia estadísticamente significativa entre ambos ($p < 0.001$).

Conclusiones: Los calcetines experimentales resultaron más cómodos para los sujetos de la muestra, reduciendo la presión plantar en la tercera cabeza metatarsal. Esto podría conllevar una menor molestia para individuos con predisposición al dolor en dicha zona, así como evitar la aparición de posibles lesiones dérmicas asociadas a la hiperpresión.

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INTRODUCTION

The feet are the base of support of the body, made up of different bones, joints, ligaments, tendons and muscles that support the body weight and allow the development of different actions (jumping, walking and running)[1]. Due to their intimate interaction with the surface, they are subjected to continuous loads and repetitive impacts, which, added to the individual's own alterations, as well as gait alterations, structural problems or bone misalignments, generate damage to the elastic structures that trigger degenerative or overload ailments[2,3].

It has been estimated that between 50 % and 70 % of the walking population will suffer some type of foot problem and a 90 % of relevant forefoot disorders[2,4]. The overload suffered by the structures of the foot can end up generating pathologies, pain in the metatarsal area or metatarsalgia and the appearance of calluses or helomas on the sole of the foot are common[5]. This symptomatology is usually associated with an increase in plantar pressures in the central area of the forefoot[6-8]. Currently, patient education together with the use of discharge elements is the most widely used treatment alternative to alleviate these pathologies.

These discharge elements can be made with soft materials such as felt or foams of different composition. The design would cover the metatarsal area except for the overloaded and / or painful sector, adopting the shape of a U or horseshoe. In this way, it would be possible to reduce the high plantar pressures and release the pressure in the desired area, eliminating the external forces derived from the soil, in order to eliminate the associated symptoms[9].

Selective off-loading to the forefoot can be achieved by different methods[10]. With the help of adhesive felts, temporary selective discharges can be achieved, but these must be replaced in a short period of time[9]. The off-loading can be integrated, with a longer duration, in plantar orthosis, raising the plane of contact of the metatarsals that support less load and thus relieve pressure in the desired area[2,11,12]. Both methods are an external element to the user's usual clothing and that is also subject to intense wear and tear. For this reason, it would be desirable to have off-loading elements for the metatarsal area, easy for a user to use and that do not involve major alterations in their usual clothing.

Socks, a common element in daily life, have been used as a device for integrating different elements beneficial to health[13-15]. However, none of these have specifically used the plantar area of the sock. Thus, a model of socks has been proposed with a discharge element integrated into the body of the sock to provide it with the possible beneficial effects that a temporary or definitive discharge element could have[16]. This is made up of a padded area (made with different threads woven on the base of the sock) with a discontinuity or horseshoe-shaped opening (U) with an anterior opening in the area of the second and third metatarsal heads, with a thickness of approximately +3 mm compared to the thickness of the rest of the sock. This could have the effect of increasing comfort and relief in the area, reducing pain or discomfort associated with overpressure. These possible beneficial effects could be very useful in socks intended for long walks, or during different stages.

However, this sock proposal has not been tested to evaluate its effectiveness, so the objective of this work was to evaluate the plantar pressures at an initial moment and compare them with the use of the normal control commercial sock (*Lurbel Tierra,* MLS Textiles 1992 SL, Ontinyent, Spain) and the use of the sock with selective metatarsal off-loading in the second and third metatarsophalangeal joints (experimental, modified Lurbel Tierra).

PATIENTS AND METHODS

A prospective, experimental, cross-sectional and analytical pilot study is proposed. The subjects were informed verbally and in writing about the objectives and the procedure to be followed, signing the informed consent. The study was approved by the Bioethics and Biosafety Commission of the University of Extremadura (Id: 180 // 2020) and registered in clinicaltrials.gov with the number NCT04697914. The convenience sample consisted of 21 sports-active subjects (9 men and 12 women), with a mean age of 27.2 years (range, 19-52 years). The anthropometric characteristics are shown in Table I.

Inclusion and exclusion criteria

The inclusion criteria for the study were: a) subjects between 18 and 65 years old, b) with a structurally normal foot, without obvious deformities, c) not having significant

Table I. Anthropometric characteristics of the sample.

	N	Minimum	Maximum	Mean	Standard deviation
Age	21	19	52	27.29	10.189
Weight (Kg)	21	53.0	103.0	67.752	11.4441
Heigh (m)	21	1.5	1.8	1.672	.0810
BMI (kg/m^2)	21	19.0	32.9	24.152	3.0844

BMI: Body mass index

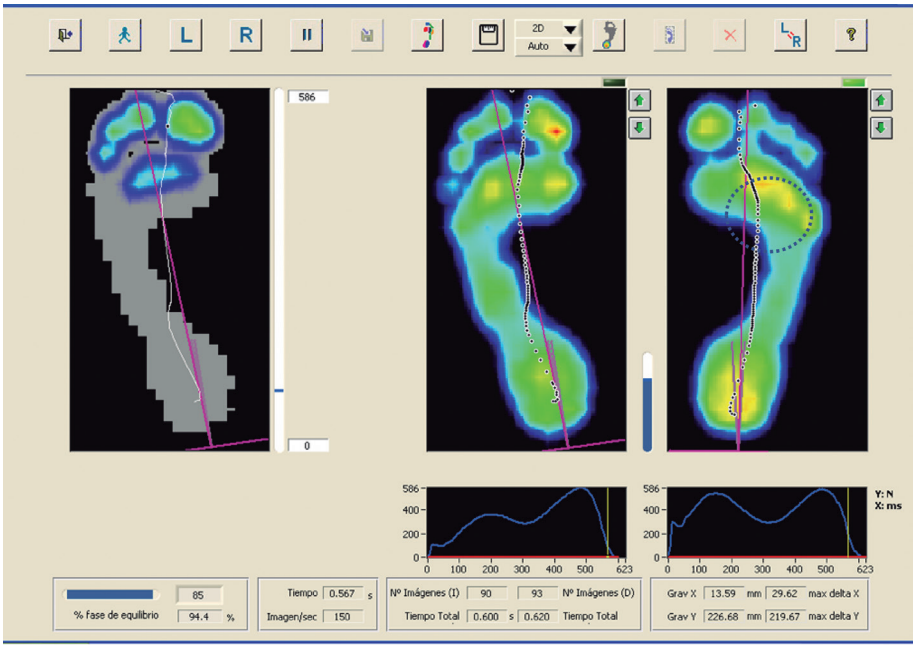

Figure 1. Pressure map with the subject barefoot. Mild hyperpressure zone (yellow and orange color) in the second and third metatarsal heads, right foot.

pain in the plantar area of the foot. People who presented minor discomfort in the anterior central area and plantar of the foot when walking, running or playing sports were allowed. These discomforts were characterized by appearing occasionally, by presenting mild and non-painful hyperkeratosis. In no case did these discomforts prevent them from carrying out their normal physical activity.

The exclusion criteria for the study were: a) subjects with the presence of infectious diseases of the plantar skin, for example, plantar warts, b) subjects with bandages, casts or splints at the level of the lower limb or abnormal gait patterns, c) subjects who have suffered fractures in the lower limbs or that they had been operated in the last 12 months.

Measurement of plantar pressures

The equipment used for baropodography evaluation was the FootScan® pressure platform (RS Scan Int, Beringuer, Belgium), which has shown good reliability[17]. To acquire the measurements, the protocol of the second step was followed, which has been shown to be reliable and with good repeatability[18]. Each subject was instructed on how to step on the platform and no measurements were taken until they were familiar with the system. The subject went through the platform with his own sock, taking the previous reference. Subsequently, one of the researchers gave him the control sock (*Lurbel Tierra)* or the experimental sock (*Lurbel Tierra* with discharge plate at forefoot) at random, so as not to interfere with the results. The participants were blinded to the study, but the researchers were not. Thus, the sample subjects did not know which of the two tested models turned out to be the experimental ones. After this delivery, and adjustment of the sock, a new measurement of the plantar pressures were taken, in the same way as previously. Posteriorly, the other pair of socks were provided, and the third baropodometric measurement was taken. A total of three valid measurements were taken with each foot and sock pattern. Using the associated software, the forefoot was divided into 7 zones (1st toe, minor toes and 1st to 5th metatarsal head) (Figure 1). The variable analyzed was the maximum pressure in the area. For the statistical analysis, the mean of the three measurements was used, so that the measurement did not depend on the variability of the steps.

Socks

The control sock was the *Lurbel Tierra* walking model, (composition 50 % Regenactiv®, 25 % Cool-Tech®, 17 % ionized polyamide and 8 % lycra, Figure 2 Left). The experimental sock, with the off-loading, was designed on the same previous model, but with the off-loading element (Figure 2, Right) in the forefoot based on the utility model ES1247681[16]. The discharge was woven onto the sock itself, with thread of the same composition (in red, with Regenactiv®, Cool-Tech® fibers and ionized polyamide), in such a way that the difference in thickness was constituted with respect to the control sock.

When the participants had walked all three times on the pressure platform, they answered a question related to comfort, which they scored from 1 to 5 (1 very uncomfortable, 2 uncomfortable, 3 neutral, 4 comfortable and 5 very comfort-

Figure 2. Left; control sock (gray threads) and experimental (red threads). Right, detail of the central discharge integrated in the experimental sock.

able). The subjects did not know which was the experimental or control model, since they scored the sock with red or gray threads (Figure 2). In the comfort test, an open response was also allowed by the participants.

Statistic analysis

For the data analysis, the plantar pressures of the right foot, chosen at random, were taken into account[19]. The pressure data were adjusted to normality (Kolgomorov-Smirnov test, $p > 0.05$), for which an ANOVA test was applied for repeated measures. For the comparison of comfort, a student's t test was performed for paired samples. Statistical analysis of the results was performed using the SPSS version 22.0 program (UEX campus license). A hypothesis contrast test was performed in which a significance level of 5% ($p < 0.05$) was established.

RESULTS

At the initial moment, the highest plantar pressures were located in the third metatarsal head with 14.9 ± 4.3 N/cm2, followed by the second head with 12.9 ± 3.8 N/cm^2 (Table II). The lowest plantar pressure value was obtained in the smaller toes, with 3.7 ± 2.7 N/cm^2. Comparing the previous values with the control and experimental socks, it was found that the plantar pressures in the areas of the first toe, the lesser toes, the 1st metatarsal head and the 4th and 5th metatarsal head remained unchanged in the two conditions in which the subjects walked. In the 3rd metatarsal head (central area of the forefoot) a statistically significant reduction ($p = 0.037$) in plantar pressure values was observed, of 14.9 N/cm^2 in barefoot patients and 14.7 N/cm^2 in the control sock at 12.3 N/cm^2 in the experimental sock (Table II). In the area of the 2nd metatarsal head, there seems to be a trend toward lower plantar pressure in the experimental sock, although it was not statistically *significant* ($p = 0.065$).

Regarding comfort, the subjects scored 3.13 ± 0.5 for the control sock and 4.74 ± 0.5 for the experimental sock, with a statistically significant difference between both ($p < 0.001$). Among the open responses it was found the following comments (by response frequency): 1) experimental more comfortable and padded; 2) control: Comfortable and comfortable, experimental: more fluffy, and 3) experimental: fluffy and warm, Control: Warm and less fluffy. These scores were given by comparison between both socks.

DISCUSSION

The new sock proposal, which incorporates a selective release element at the central forefoot level, has managed to offload the compromised area by moving away its contact with the ground, which has been reflected in a lower plantar pressure in the area. This same effect has been observed in similar elements, such as discharges with felt or EVA's of different densities[11,12,20]. The current proposed design, with off-loading in the center of the forefoot, was proposed because the greatest plantar pressures in the anterior region of the foot are found in its central part, although there is still controversy as to whether it is the second or third metatarsal

Table II. Comparison of plantar pressure values in the three situations.

	Descriptive statistics			
	Previous	Control	Experimental	*p* Value
	N/cm^2			
1st toe	9.3 ± 4.7	9.7 ± 5.6	9.2 ± 4.7	0.545
Lower toes	3.7 ± 2.7	3.4 ± 3.2	2.9 ± 2.2	0.641
1st MTH	6.8 ± 2.9	6.9 ± 3.8	6.2 ± 2.9	0.443
2nd MTH	12.9 ± 3.8	11.8 ± 5.1	11.0 ± 4.7	0.065
3rd MTH	14.9 ± 4.3	14.7 ± 9.7	12.3 ± 4.6	**0.037**
4th MTH	10.8 ± 4.9	10.1 ± 6.3	10.2 ± 5.0	0.633
5th MTH	5.4 ± 4.0	4.0 ± 2.3	4.5 ± 3.8	0.128

MTH: metatarsal head.

head that supports the greatest pressure. Domingo et al.[21], as in this study, shows that the greatest pressure peaks are found in the third metatarsal head, however others give this greater pressure to the second metatarsal head[22,23]. Ultimately the predominance of the central forefoot is evident.

The development of pain and hyperkeratosis due to overuse is perhaps the most common cause of foot pain[5,6,8,24]. People with pain in the forefoot generally show higher plantar pressure values compared to people without the presence of pain[25,26]. This increase in plantar load may be related to the deterioration of the shock absorbing systems of the foot, for example or the decrease in the thickness of the plantar pad[27]. Thus, to mitigate this overload, different materials with cushioning capacity can be used, with the aim of replacing the foot pad[9,28]. Various studies has shown that these relief materials significantly reduce the pressure in the metatarsal area[29-33], and can be used temporarily, with removable felts, or be incorporated into personalized plantar orthoses[11,12,20].

The use of fenestrated discharges, with selective cut-outs that accommodate the overloaded area, have shown better results compared to others that include shock-absorbing materials that covered all the metatarsal heads[28]. In this way, the design chosen in the experimental sock, with the padding that adopts the shape of a horseshoe or U with the proximal opening, avoids the possibility of encapsulating any tissue and the possible formation of window edema. In addition, this design has shown a greater ability to reduce localized pressures than O-shaped or donut-shaped discharges that can increase the pressure in the area[31].

By using the experimental sock, it has been observed that the greatest reduction in load occurs just in the area with the highest pressure value, which was in the third metatarsal head. With the experimental sock, it has been possible to reduce the pressure in this area by 17.45 %. Nordisen et al.[31] described a pressure decrease of 6.51 % using 3 mm felts, a thickness very similar to the element implemented in our sock. However, using thicker discharges, with 5 mm felts, reductions between 25.5 % and 31.07 % can be achieved[9,34]. Thus, with the discharge sock we have achieved a reduction similar to the achieved with thicker felts. In addition, this pressure reduction will be sustained over time, contrary to what has been demonstrated with the use of adhesive felts, since after several days the pressure increases again[34]. In Figures 1, 3 and 4, a typical case is presented that would summarize our results, with the plantar pressure focus in the area of the second and third metatarsal heads (blue circle).

Thus, the experimental sock model is an alternative treatment to reduce plantar hyperpressions and the pain they trigger. Since they have been rated as more comfortable than controls, they could be used as an element of daily life by those individuals who present discomfort in the central metatarsal area or mild hyperkeratosis in the center of the forefoot. In addition, these socks would be an ideal way to relieve pain that manifests itself during sports practice due to overstressing of the metatarsal area in long-term activities such as hiking, trekking, trail or running, among others and could reduce the prevalence of hyperkeratosis[33]. On the other hand, socks would not replace an orthotic treatment aimed at

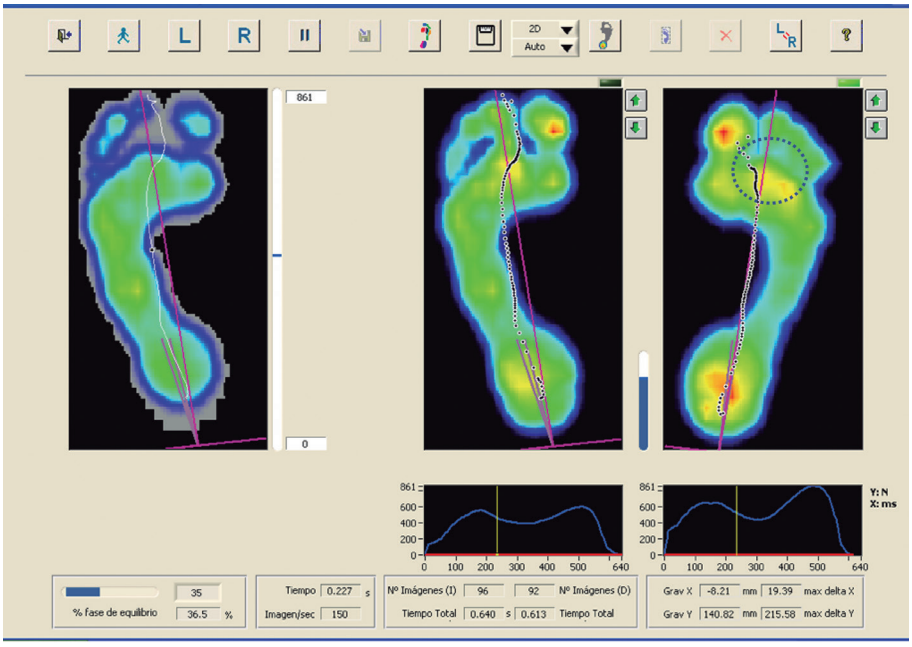

Figure 3. Pressure map with control socks *(Lurbel Tierra)*. With the control sock, the zone of mild hyperpressure continue existing (yellow and orange color), although reduced, right foot.

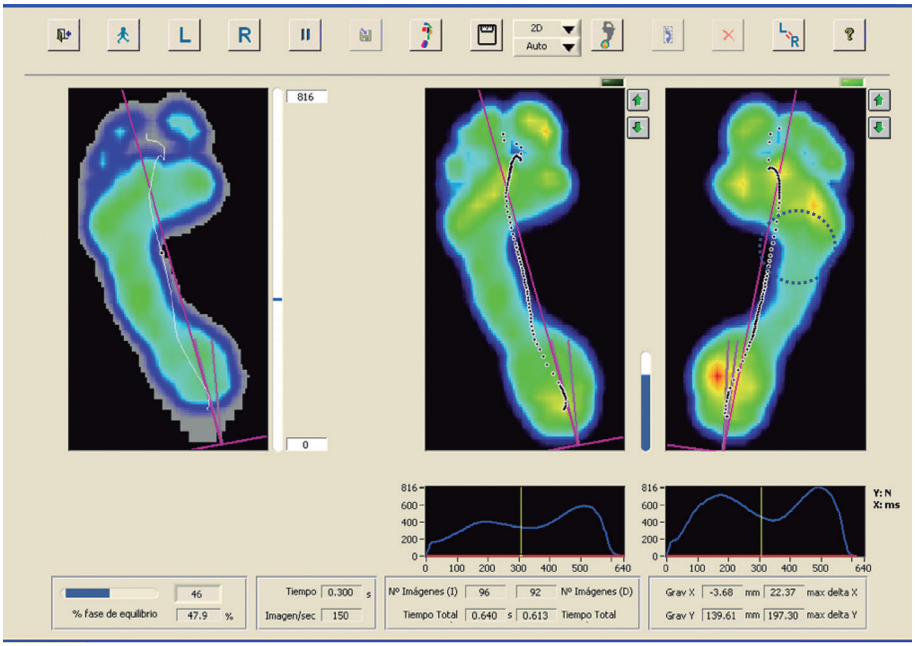

Figure 4. Pressure map with the experimental socks. The disappearance of the area of mild hyperpressure, right foot, is verified.

compensating for foot alterations, although they could also be used as an adjunvant. In the same way, the use of the padding included in the sock has the advantage of being able to use a discharge element in a comfortable way, this is adapted to the contour of the foot and takes up little space, therefore, it would be advisable for different moments of daily life in which the use of footwear does not allow the use and adaptation of plantar orthoses inside.

The present study has some limitations. One of them may be the short period of time in which socks prove their effectiveness, althought the long-term, the long-term effectiveness of socks has yet to be tested. Another possible limitation is the effectiveness time of the sock, since depending on its use, sports, walking or hiking, it could have a lower durability. Work is being done to assess these aspects, such as their long-term effectiveness and also to check whether their use and washing can limit the reduction of dynamic plantar pressures.

In conclusion, the present study has shown that the experimental socks have achieved an effective reduction of the plantar pressure in the third metatarsal head and have been more comfortable than the control socks. This reduction in load could lead to less discomfort for the subjects in this area, as well as avoid the appearance of possible dermal lesions associated with hyperpressure (such as corns or blisters).

CONFLICT OF INTERESTS

The authors declare that the 1992 MLS textiles company, manufacturer of Lurbel socks, has selflessly manufactured and assigned the experimental socks to the authors. The company has licensed the exploitation rights of the aforementioned utility model to the University (owner of its rights). There is no direct economic link between the company and any of the study authors.

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The study did not have external funding, since the company MLS textiles 1992 only donated the socks for the study.

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