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Use of infrared thermography to determine the foot sole thermal profile of plantar fasciopathy patients: a transversal study

Uso de la termografía infrarroja para determinar el perfil térmico de la planta del pie en pacientes con fasciopatía plantar: estudio transversal

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Keywords:

Plantar fasciitis, plantar fasciopathy, infrared thermography, thermal profile, skin temperature.

Abstract

Introduction: Infrared thermography is a safe, non-invasive and low-cost technique that allows for the fast recording of skin temperature. Plantar fasciopathy is the result of degenerative irritation of the plantar fascia and one of the most common musculoskeletal disorders. The aim of the study was to determine if plantar fasciopathy patients have a specific foot sole thermal profile that might be detect by infrared thermography.

Patients and methods: 32 feet of 16 subjects with unilateral plantar fasciitis were analyzed. The nonsymptomatic foot was taken as control. Foot sole temperatures were divided in 9 regions of interest and extracted by specific software to obtain thermal asymmetries between right and left foot sole regions. T-student test was used to determine significant statistical differences between feet and regions.

Results: Subjects with plantar fasciopathy showed significantly higher temperatures in the injured sole of the foot, mainly in the arch and heel regions (with asymmetries ranging from 0.28 °C to 0.55 °C [$p < 0.05$]).

Conclusions: Patients with plantar fasciopathy present a specific thermal profile with significant hyperthermia in the sole of the injured foot. Such asymmetry can be effectively detected by using infrared thermography to evaluate and diagnose this pathology.

Palabras clave:

Fascitis plantar, fasciopatía plantar, termografía infrarroja, perfil térmico, temperatura de la piel.

Resumen

Introducción: La termografía infrarroja es una técnica segura, no invasiva y de bajo coste que permite registrar rápidamente la temperatura de la piel. La fasciopatía plantar es el resultado de la irritación degenerativa de la fascia plantar y uno de los trastornos musculoesqueléticos más comunes. El objetivo de este estudio es determinar si los pacientes con fasciopatía plantar tienen un perfil térmico específico de la planta del pie que podría detectarse mediante termografía infrarroja.

Pacientes y métodos: Se analizaron 32 pies en 16 sujetos con fasciopatía plantar unilateral,tomando el miembro sano como control. Las temperaturas de la planta del pie se dividieron en 9 regiones de interés y se extrajeron mediante un software específico para obtener asimetrías térmicas entre las regiones del pie derecho e izquierdo. El test de *t* de Student fue utilizado para determinar diferencias estadísticas significativas entre ambos pies y regiones.

Resultados: Los sujetos con fasciopatía plantar mostraron temperaturas significativamente superiores en la planta del pie lesionada, principalmente en las regiones del arco y el talón (con asimetrías de entre 0.28 °C a 0.55 °C [$p < 0.05$]).

Conclusiones: Los pacientes con fasciopatía plantar presentan un perfil térmico específico con una hipertermia significativa en la planta del pie lesionado. Dicha asimetría puede detectarse de manera efectiva mediante el uso de termografía infrarroja para evaluar y diagnosticar esta patología.

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INTRODUCTION

Infrared thermography (IRT) is a safe, non-invasive and low-cost technique that allows for the rapid and non-invasive recording of radiating energy that is released from the body. IRT measures this radiation, directly related to skin temperature. IRT has been widely used since the early 1960s in different areas[1-3]. During the first decades after its development, research into the use of IRT in humans was mainly focused on its applications as a diagnostic tool. However, IRT was replaced by newer and more accurate technologies (such as X-rays and magnetic resonance imaging). Recent technical advances in infrared cameras have made new human applications of IRT (beyond diagnostic techniques) possible. Among others, the prevention and monitoring of injuries has been shown to be one of the most interesting and useful applications because of its ability to identify changes in body surface temperature, reporting on the metabolism of active muscles and monitoring training workload[4].

Ideally, our skin is maintaining a constant thermal pattern over time, with the constant aim of keeping the body in thermal balance or "homeothermy"[5,6]. However, a lot of factors can affect the thermal asymmetry of a person during their lifetime, and most of them are related to pathological reasons such as inflammation or nerve dysfunctions[1]. In this sense, IRT can help us to identify thermal asymmetries by comparing bilateral body areas (e.g., left and right knee, feet soles, etc.)[7,8]. Obviously, there are a lot of factors affecting skin temperature[1], which makes it in some cases impossible to prevent certain injuries. Nevertheless, the record of thermal images of a specific corporal region allows for standardized the area of interest and stablish either a pathological and non-pathological thermal pattern which will provide the capacity to recognize the injury once the thermal asymmetry appears[9,10]. Nowadays it can be found in the literature research where thermography was used for the diagnosis[11,12], follow-up of a injury and progression of treatment of diverse foot disorders[13,14].

Plantar fasciopathy is the result of degenerative irritation of the plantar fascia caused by repetitive strain that seems to cause microtearing. It is one of the most common musculoskeletal disorders of the foot at the medial calcaneal tuberosity of the heel as well as the surrounding perifascial structures[15-17]. The plantar fascia is an aponeurosis that originates from the medial process of the posterior tuberosity of the calcaneus and extends distally to the phalanges. It plays an important role in the normal biomechanics of the foot[15,18]: It provides support for the arch, shock absorption during gait and during high intensity actions like running or jumping and it is an essential component for the windlass mechanism.

The regeneration process of an injury comprises three phases: the inflammatory response (phagocytosis 2-4 days), cells destruction release chemical substances which begin the inflammatory response; from the first 3 hours after the injury and until the next 3-4 weeks, the fibroblastic phase occurs, in this period we can find fibroblast proliferation, collagen synthesis and neovascularization of the injury area [19,20]; in the last step, starting 3 weeks after the injury there is the remodeling – maturation process which can be prolonged also during 12 months until tissue has been fully regenerated[21,22].

Since plantar fasciopathy is one of the most common musculoskeletal disorders and IRT is a fast, non-invasive and objective technology that is getting more popular to help IN diagnosing[13], the aim of this study is to describe the foot sole thermal profile of patients with plantar fasciopathy, to determine if IRT is able to detect significant differences between heathy feet and feet diagnoses with plantar fasciopathy.

PATIENTS AND METHODS

The study was conducted in a sample of 16 patients with plantar fasciopathy. Two groups were carried out, one with healthy feet and the other with pathological feet. The study was approved by the Aragón Clinical Research Ethics Committee (CEICA) with registration number C- P. - C- I- PI17/0254.

The main objective of this study was to determine the ability of infrared thermography to detect patterns of plantar fasciopathy in subjects diagnosed with this pathology. Secondary objectives were to determine the maximum and minimum temperature in the different segmented regions of the foot using automatic analysis software, to determine the region with the greatest change in temperature in subjects with plantar fasciopathy and to evaluate the qualitative colourimetric differences in each of the regions with the use of the different masks.

The inclusion criteria were patients with acute unilateral plantar fasciopathy (less than 1 month of evolution) for comparison with the contralateral foot. Exclusion criteria were obesity (> 30 BMI), bilateral plantar fasciopathy and unilateral plantar fasciopathy with more than one month of evolution and any inflammatory pathology affecting the foot.

After being informed regarding the aims, the procedures and the risks that were involved in the investigation, all of the subjects signed their consent to participate in the study and answered questions regarding injury history and other personal details. Anthropometric measurements of height (m) and weight (kg) were recorded.

The subjects were evaluated in a podiatry consultation in Spain (Podoactiva Headquarters, Walqa Technological Park, Huesca), where the patients came to office for their foot pain. Temperature and humidity were controlled so that the participants could undergo an acclimatization process of between 5 and 10 minutes with ambient temperatures between 21 °C and 28 °C and relative humidity values between 35 and 65 %. Plantar fasciopathy was diagnosed by a podiatrist specialized in biomechanics, and was confirmed with an ultrasound imaging test (E-cube 8® ALPINON Medical Systems, Korea). The Borg scale was performed on the subjects to quantify the level of pain.

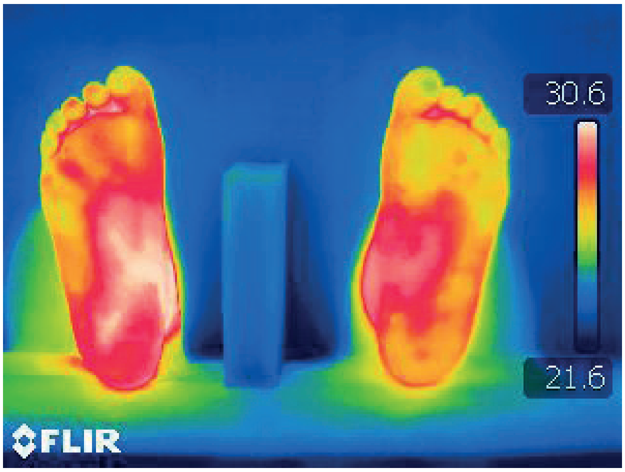

Figure 1. Example of image obtained with T335 FLIR infrared camera.

Once the physical exploration was done, thermal images were taken using a T335 FLIR infrared camera (FLIR Systems, Sweden) with the patient lying on the stretcher, both feet were at the extreme of the stretcher and thermal images were taken so the feet sole were clearly differentiated from the rest of the body (Figure 1).

In order to analyse the thermal images and extract the quantitative data from them we use ThermoHuman online software (PEMA THERMO GROUP, Spain), which uses machine learning and automatized computer vision to divide the feet sole into 18 regions of Interest as shown in Figure 2.

Kolmogorov–Smirnov tests were used to verify the normality of the dependent variables. The results indicated a normal frequency distribution in all of the samples; therefore, parametric statistics were applied. Student´s t-Test for related samples were performed to compare paired data between the group of feet with fasciopathy (n = 16) and healthy feet (n = 16). The significance level was set at 0.05.

RESULTS

Table I shows the anthropometric characteristics of the sample.

Table II shows the mean temperatures by region for the healthy foot and the foot with fasciopathy, and the p-value by region. It can be seen that the regions showing statistically significant differences are: 2nd to 5th toe, 1st metatarsal bone, external arch, internal arch, internal heel and external heel.

Figure 3 shows the correlation between weight and temperature asymmetry at the 1st metatarsal, showing an increase in temperature asymmetry at the 1st metatarsal as weight increases in the injured foot.

Figure 4 shows the relationship between weight and temperature asymmetry at the external heel, showing less temperature asymmetry in the injured foot as weight increases.

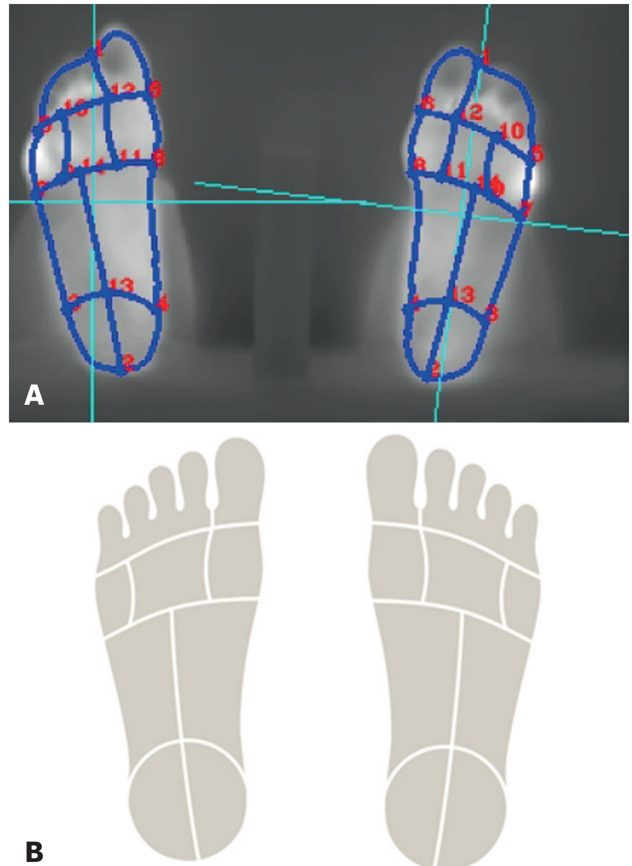

Figure 2 A and B. Automatized division of the feet in regions of interest.

Table I. Anthropometric characteristics of the sample (mean + standard deviation) (n = 16).

Characteristics of the sample	
Age (years)	43.92 ± 9.85
Weight (kg)	75.63 ± 10.83
Height (m)	1.68 ± 0.09
BMI (kg/m^2)	26.66 ± 2.35
Foot size (UE)	40.19 ± 2.23

BMI: body mass index.

Figure 5 shows the relationship between pain in the injured foot and temperature in the 5th metatarsal. The graph shows that the greater the pain, the lower the temperature in the 5th metatarsal.

DISCUSSION

The main objective of this study was to find out whether patients with plantar fasciopathy have an increase in temperature in the injured foot compared to the healthy foot, and thus

Table II. Mean temperatures by region for the healthy foot and the foot with fasciopathy.

Region	Fasciopathy (temperature)	Healthy (temperature)	Diference	p-value
2nd to 5th toe	27.45 ± 2.27	27.23 ± 2.34	0.22 ± 0.39	0.039
1st toe	27.48 ± 2.43	27.26 ± 2.55	0.22 ± 0.57	0.138
5th META	27.79 ± 2.22	27.73 ± 2.21	0.06 ± 0.49	0.617
2nd to 4th META	28.38 ± 1.99	28.14 ± 2.07	0.24 ± 0.50	0.072
1er META	28.25 ± 2.12	27.97 ± 2.13	0.28 ± 0.43	0.021
External arch	28.15 ± 1.57	27.88 ± 1.58	0.28 ± 0.42	0.018
Internal arch	29.70 ± 1.30	29.38 ± 1.37	0.32 ± 0.34	0.002
External heel	28.19 ± 1.62	27.72 ± 1.66	0.48 ± 0.69	0.014
Internal heel	28.62 ± 1.69	28.07 ± 1.55	0.55 ± 0.54	0.001

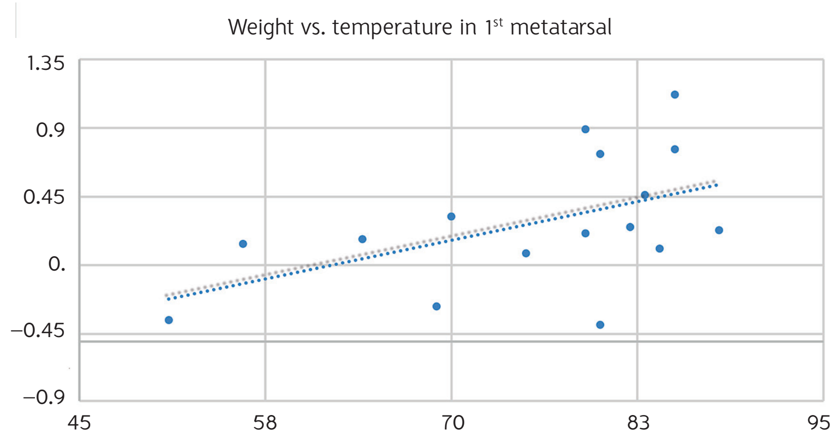

Figure 3. Correlation between weight and temperature asymmetry in the 1st metatarsal of the foot with fasciopathy.

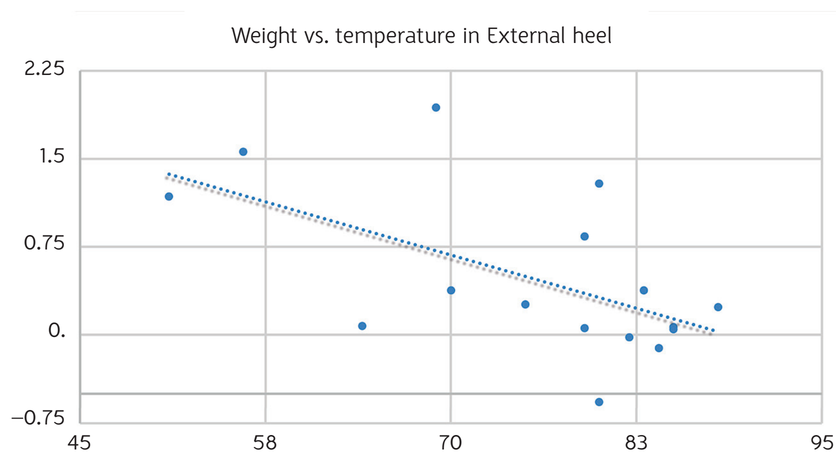

Figure 4. Correlation between weight and asymmetry in the injured external heel.

be able to define a thermographic profile of the patient with plantar fasciopathy using infrared thermography, an inexpensive, non-invasive and safe technology.

Our results show a statistically significant difference between different areas or regions between the injured foot and the healthy foot. These areas being the 2nd to 5th toe, 1st metatarsal, external arch, internal arch, external heel and internal heel; the explanation for these increases in temperature with respect to the healthy foot can be found in the increase in vascularization that occurs in the injured areas

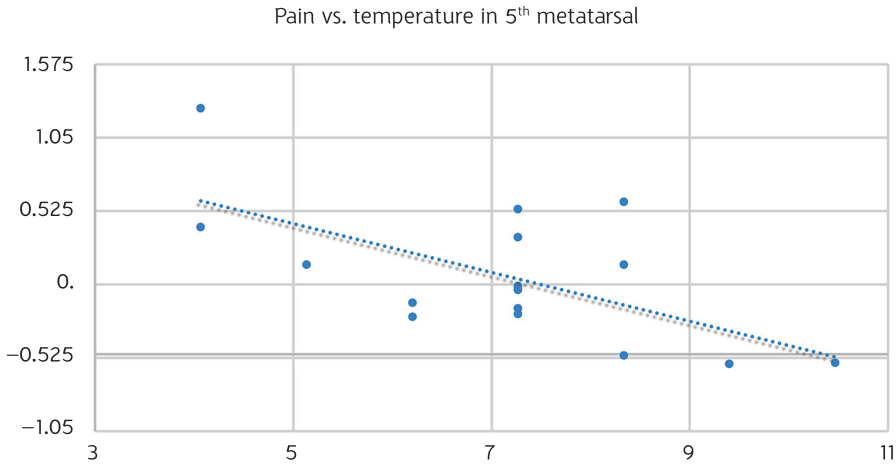

Figure 5. Correlation between pain and temperature in the 5th metatarsal of the injured foot.

in acute conditions, which is necessary for the repair of the tissue[23-26].

The heel and arch areas, both internal and external, are the most common areas of pain in patients suffering from plantar fasciopathy and the most commonly injured areas in the tissue itself, being these areas the ones that will require the greatest blood supply to generate tissue repair[27]. The areas from the 2nd to the 5th toe and the 1st meta, also show a significant increase in temperature between the foot with fasciopathy and the healthy foot, with a possible explanation in the antialgic gait that the patient will carry out to avoid pain[25,27].

On carrying out different correlations between the data studied, we observed that the greater the weight of the patient, the greater the temperature asymmetry in the injured first metatarsal, the explanation being found in the above mentioned, where due to the antalgic gait we are going to generate a greater support time in the first metatarsal, also taking into account that the plantar pressure is directly proportional to the vertical force, therefore, this vertical force will be greater if the weight is greater, thus increasing friction and therefore the temperature[28-30]. We also observed that the greater the weight, the less asymmetry in the injured external heel, suggesting that the greater the weight, the greater the surface area in contact with the ground, and therefore the greater the friction and temperature, thus reducing asymmetry, despite having one injured foot and the other not injured[30].

Finally, we found that the greater the pain, the lower the temperature in the 5th metatarsal of the foot with fasciopathy, which could be explained by the premature toe-off of the foot and the decrease in the 2nd rocker or gait rocker, to avoid tensile stress on the plantar fascia, being in this gait rocker, the moment of maximum load on the 5th metatarsal, so if we decrease the pressure and contact time in this rocker because of the increase in pain of the patient, we will decrease the pressure under the 5th metatarsal[25,31].

No previous studies have been found that relate the use of thermography in patients with plantar fasciopathy, but in diabetic patients, such as the work of Astasio-Picado et al., 2018[32], where the authors point out thermography as a tool to be taken into account in order to determine temperature variations by regions in the foot in patients with diabetes, something that is along the same lines as our study in patients with plantar fasciopathy and the variation in temperature in the different regions of the foot.

As lines of future research, we propose the use of IRT to measure the evolution of the recovery process of plantar fasciopathy, that is, to observe whether the temperature values normalize between one foot and the other at the same time as the patient recovers from pain, as well as the application of the same for the comparison of different types of treatments and therapeutic approaches to plantar fasciopathy. Furthermore, in the process of proximal approximation, IRT could be used for the study, evaluation and approach of pathologies related to upper structures of the Achilles-calcaneal-plantar system.

In conclusion, with this cross-sectional study we have shown that thermography can be a useful technology to determine the thermographic profile of patients with plantar fasciopathy in the acute phase. In turn, we can say that patients with plantar fasciopathy present statistically significant differences in temperature in certain regions compared to the healthy foot. The maximum temperature was located in the medial heel area, the areas with the greatest thermal asymmetry were the medial and lateral heel. Despite the influencing factors, the use of thermography with a specific protocol and software ensured reliable and objective results in the diagnosis of plantar fasciitis. Studies with a larger number of subjects in the control group analyzing the evolutionary thermal pattern of plantar fasciitis are necessary to reinforce these conclusions.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interests in this study.

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