Original Articles

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Infrared images in the evaluation of the diabetic foot

Imagens infravermelhas na avaliação do pé diabético

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ABSTRACT

Introduction*:* Diabetes is a frequent pathology that has universal distribution. The incidence of the type 2 of this condition has been increasing with obesity. Early detection of dermatological, vascular, orthopedic and neurological origin pathologies helps the diagnosis and treatment of the diabetic foot.

Objective: To evaluate the feet of pre-diabetic and diabetic patients bearers of onychomycosis using thermography, aiming at identifying the vascular, neurological and orthopedic impairment, as well as following up the clinical development.

Methods: Capture of infrared images at baseline and after cold stimulus test, using an infrared sensor in a controlled environment.

Results: This examination allowed the suspicion of peripheral neuropathy of fine fibers to be raised, as well as to verify areas of footwear pressure and to evaluate the progression of Charcot foot.

Conclusions: Infrared imaging associated with dermatological examination can be a propaedeutic tool for the early identification of vasomotor alterations in the soles, even in asymptomatic patients.

Keywords: Diabetic foot; Diabetes Mellitus; Thermography

RESUMO

Introdução*: O diabetes é patologia frequente, de distribuição universal cuja incidência do tipo 2 vem aumentando com a obesidade. A identificação precoce das patologias de origem dermatológica, vascular, ortopédica e neurológica auxilia o diagnóstico e o tratamento do pé diabético.*

Objetivo: *Avaliar por termografia os pés de pacientes pré-diabéticos e diabéticos portadores de onicomicose, com o intuito de identificar o comprometimento vascular, neurológico e ortopédico, bem como acompanhar a evolução clínica.*

Métodos: *Captação de imagens infravermelhas basais e após teste de estímulo ao frio com sensor infravermelho em ambiente controlado.*

Resultados: *Esse exame possibilitou a suspeita de neuropatia periférica de fibras finas, áreas de pressão de calçados e avaliação da progressão do pé de Charcot.*

Conclusões: *O exame por meio de imagens infravermelhas associado ao exame dermatológico pode ser instrumento propedêutico para a identificação precoce de alterações vasomotoras nas plantas dos pés, também em pacientes assintomáticos*

Palavras-Chave*: Diabetes Mellitus; Pé diabético; Termografia*

INTRODUCTION

Diabetes mellitus (DM) is a chronic disease that affects 18.6% of the elderly population in Brazil. Due to its high incidence, this disease is used as a model for the study of foot diseases.[1] Dermatological changes affecting the feet are precocious and precede hyperglycemia, arising in the phase when there is an increase in the peripheral insulin resistance or in cases of obesity. Among them, the following stand out: dryness and desquamation, fissures in the heels, plantar intertrigo, callosities, onychomycosis and edema of the toes. These dermatological clinical

signs, common in the early forms of the diabetic foot, may also be part of other diseases, such as hypothyroidism and chronic intoxication by alcohol and drugs. The detailed clinical history assists in the diagnostic elucidation, as well as the dosage of glucose, insulin, glycated hemoglobin, TSH, free T4 and other complementary tests. Since dermatological alterations in the feet may develop into serious problems despite the fact that they start in an apparently benign way, the dermatologist has the opportunity to diagnose the disease early on through dermatological examination and the use of a non-invasive technique aimed at identifying the presence of vasomotor and vascular changes. The presence of several degrees of neurological and vascular diseases, ulcers, infection and necrosis can be observed in the more advanced stages of the disease. Diabetic foot is one of the most common of non-traumatic causes of amputation in the lower limbs, accounting for 80% of the amputees. Treatment requires the intervention of a multidisciplinary team in order to control infections, pain, metabolic disorders, nutritional deficits, as well as comorbidities and implementing surgical interventions. The assessment and classification of cases according to the intensity of the impairment are important strategies for the treatment and reduction of the risk of amputation.[1]

Peripheral neuropathy is a common complication in DM and affects more than 30% of patients. It is described as a set of alterations in the fine nerve fibers that affect both the vascular sympathetic reflex's and the sensory and neurovegetative peripheral nervous system's responses, with reduction of pain sensitivity and sweating. These changes precede the emergence of symptoms such as burning sensation in the feet, metatarsalgia and leg weakness, which may be aggravated by consumption of alcoholic beverages, vitamin B12 deficiency, hypothyroidism, difficulty in controlling blood glucose and peripheral resistance to insulin.[2]

Its clinical appearance is progressive, leading to the involvement of the thick fibers responsible for motor innervation, and resulting weakening of the lower limbs' musculature, with gait alterations and biomechanical problems. Patients experience frequent falls and osteoarticular changes that characterize the Charcot foot, with progressive flattening of the plantar arch and Morton's neuroma development.

On the other hand, the neurological and orthopedic alterations favor traumatisms in areas of greater pressure, leading to the formation of callosities and ulcerations. Examination of the skin reveals dried feet due to reduction of sweating, cracks in the calcaneus region, desquamation, onychocryptosis, chronic onychomycosis, plantar intertrigo, plantar hyperkeratosis, blisters and even ulcers. Identifying this process early on can prevent the clinical development of alterations in the foot, which have great impact in the patients' quality of life.

Noninvasive examination by capturing images of infrared rays emitted between 8 and 12 μm by feet can be used to quantify and map skin temperature changes and define certain diseases. Its use as a diagnostic method is based on the fact that various types of organic processes are manifested by changes in the production of heat and changes in blood flow patterns in organs and tissues. Neurovegetative nervous system controlled thermoregulation of the skin governs the capillary and arteriovenous flow through central and peripheral activity. In the case of DM, sympathetic neurovegetative neuropathies result in the opening of these shunts and increased blood flow to the skin.[3]

Plantar vasomotor alterations can be observed as they are influenced by the sympathetic neurovegetative system and the room temperature with assistance of thermography, performed with cameras or thermographic sensors, which record the patterns of the emitted heat through images termed thermograms. The goal is to thermally map the soles of the feet.

This mapping observes the concept of angiosomes, which are anatomical functional units grouped by regions that coincide with a particular vasculo nervous territory.[4-6] The six angiosomes of the feet and ankles are supplied by three main arteries: 1) the posterior tibial artery, which irrigates the plant of the foot (through the medial and lateral plantar branches) and part of the calcaneal region; 2) the anterior tibial artery, which irrigates the dorsum of the foot through the dorsal artery of the foot; and 3) the fibular artery, that irrigates the lateral border of the ankle. Only the dorsal plantar artery can be palpated in the clinical examination.

The objective of thermography is to capture infrared images emitted by the skin in order to record changes in the vasomotor control of the microcirculation and the arterial circulatory system, in this way mapping the area according to the distribution of angiosomes and plantar vasomotor reaction.[7-10] Plantar morphological patterns are described according to the vascular anatomy of the lower limbs.

Infrared images also assist in the evaluation of infectious and traumatic intercurrences, among others. Diabetic foot ulcer is one of the most severe complications and early detection of its risk is crucial to preserve the foot. Thermography is used both to measure hyper-radiant areas with an acute increase in the plantar temperature, as well as chronic increases due to intensified arteriovenous flow. [11-17] On the other hand, a chronic decrease in plantar temperature might indicate peripheral vascular disease, and instability in thermoregulation might lead to the suspicion of diabetic neuropathy.[18] This variation can be assessed using the provocative cold stress test, performed with the exposure of the feet at 15°C, where thermal reheating can be observed after 10 minutes, promoted by reactive hyperemia in the plantar region. Analysis of the images performed by a specialized digital imaging software makes it possible to measure the reheat reaction with a 0.2°C accuracy, yielding a comparative curve between the feet.[19]

METHODS

In this retrospective study, medical records and infrared images (thermograms) of 9 patients with onychomycosis and DM Wagner's Grade 0 were evaluated (the Wagner Grading System for Diabetic Foot Ulcers classifies diabetic foot ulcerations according to increasing degrees of severity from I to V).[20] Seven patients had DM type 2, and two had DM type 1. They were treated at a private practice between May 2016 and January

2018. The study complied with the ethical criteria of the Helsinki Declaration. The capture of infrared images (thermograms) was performed in a controlled environment (room temperature at 23°C, and air circulation < 0.2 m/s) using a hypersensitive infrared sensor (18mm, 320x240 pixels resolution), Flir T420® (Flir Brasil, Sorocaba, São Paulo, Brazil). The baseline thermograms of the plant and dorsum of the feet were evaluated with a cold stress test, with immersion of the feet in water at 15°C for one minute and subsequent plantar registration after 10 minutes. The images were analyzed with assistance of the software Flir Tools® (Flir Brasil, Sorocaba, São Paulo, Brazil), with the measurement of the maximum, medium and minimum temperatures of the demarcated areas. Initially, the thermal pattern of the feet's dorsa and plants was observed, which should follow a thermal gradient pattern with hyper-radiation in the plantar arch and reduction of this radiation in the periphery, characterizing the butterfly pattern (Figure 1). Next, the forefoot, midfoot and hindfoot areas were measured according to the vascular territory of the anterior and posterior tibial arteries and their ramifications. Finally, the measurement of the toes was performed aimed at verifying the difference in temperature (ΔT), which is expected to be ≤ 0.4 °C, even after the cold stress test.

RESULTS

Four male and 5 female patients with DM and chronic onychomycosis, aged between 39 and 88 years, without history of foot ulcer (Wagner's ulcer Grade 0) were included in the present evaluation. Two patients (one with DM1 and one with DM2) underwent cold stress tests, aiming at enhancing the vasomotor reaction through cold stimulus. All evaluated patients were considered positive for abnormal sympathetic vasomotor instability in the feet, as they presented breakage of the transverse lines of the distal thermal gradient of the feet, as well as interdigital anisothermy ≥ 0,4°C – with or without the cold stimulus test (Figures 1 and 2). The patterns of plantar thermography varied according to the classification based on the anatomical units (angiosomes). A large increase in the area of plantar hyper-irradiation was observed in two T2 DM and Charcot foot bearer patients (aged 68 and 88 years), with one of the cases presenting recurrent paronychia, lymphedema and erysipelas, confirmed with ΔT above 3°C as compared to the contralateral limb (Figures 3a, 3b, 3c). The cases evaluated by thermography did not present poor vascular perfusion or ischemia – even in the hypothetic presence of those conditions, Nd:YAG laser would be contraindicated in the treatment of onychomycosis.

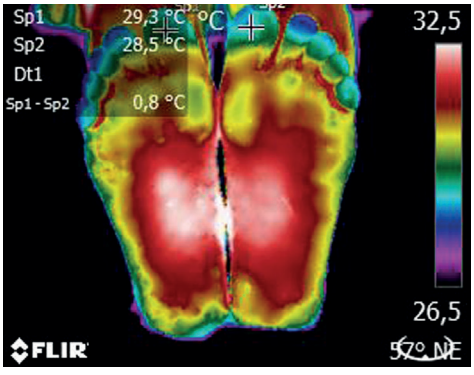

Figure 1: Seventy-five year-old male patient bearer of DM2, hyperglycemia, hyperinsulinemia, digital anisothermy with ΔT > 0.4°C, butterfly pattern with hyper-radiation to the calcaneus region

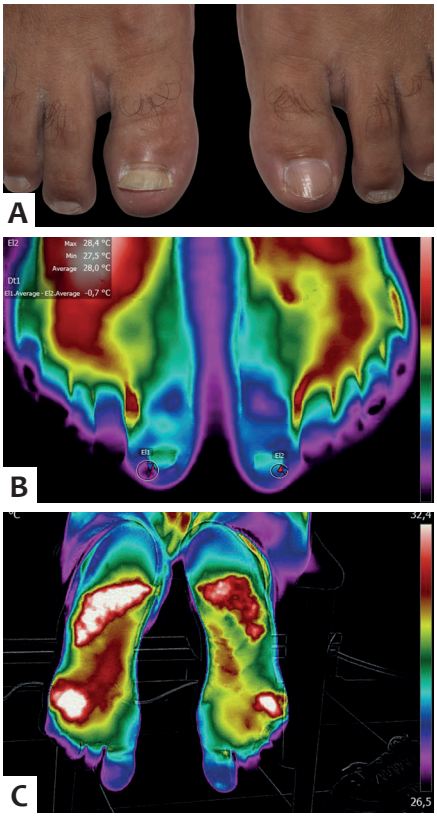

Figure 2: A - Fifty-nine year-old male patient, bearer of DM1, hypertension; onycholysis in the right hallux (coinciding with the jogging shoes' pressure area); dryness and fissures in the calcaneal region, which might have occurred due to peripheral neuropathy of fibers (reduction of sweating), **B -** Hyporadiant area in the right hallux (region of vascular suffering, coinciding to the jogging shoes' pressure area); breaking of the transverse lines of the thermal distal of the feet and digital anisothermy with hyper-radiation in the fifth metatarsus. **C –** Breakage of the transverse lines of the distal thermal gradient of the feet and digital anisothermy (ΔT > 0.3 °C, between the distal phalanges of the toes and hyper-radiation in the fifth left and right metatarsus); clinical history of L5-S1 lumbar hernia treatment, presents hypo-radiation bilaterally in the calcaneal region, characteristic pattern of neural root involvement at S1

DISCUSSION

Peripheral neuropathy is a common complication in diabetic patients, affecting more than 50% of that population.[1] This condition increases the risk of ulcerations that can lead to lower limb amputation. The patients examined did not had ulcers in the lower limbs, having therefore been considered grade 0 both by the Wagner's and the University of Texas' classification systems, used in the evaluation of the diabetic foot.[1,8] Infections or ischemia increase the risk of amputation, which suggests that diagnosis and regular follow-up decrease the morbidity and mor-

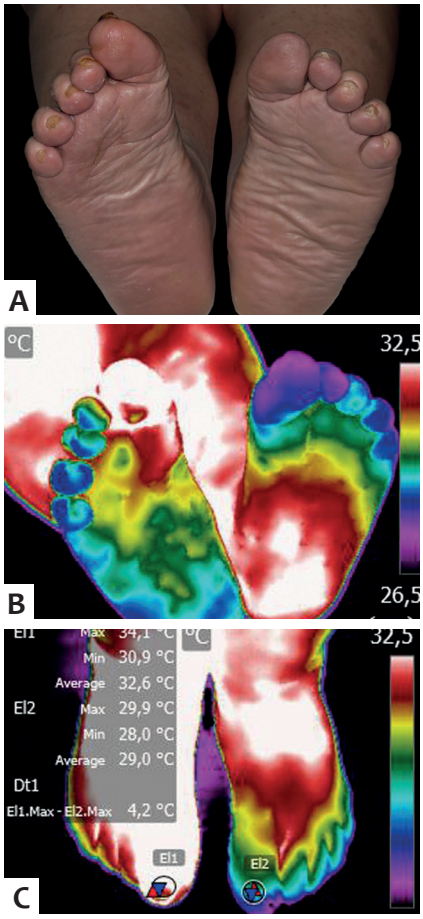

Figure 3: A – Sixty-eight year-old woman, bearer of DM2, hypothyroidism; clinical examination indicated a chronic lymphedema in the lower limbs and paronychia in the right hallux, drop in the plantar arch, loss of ankle dorsiflexion, ankle contracture, which are alterations commonly found in the Charcot's foot, confirmed by the radiological alterations found (subluxation of distal articulation of the right hallux, increase of soft parts, among others); thermography. **B –** Breakage of transverse lines of the distal thermal gradient of the feet with hyper-radiation throughout the soles, more pronounced in the left foot; pattern observed in cases of plantar circulatory and / or vasomotor alterations (peripheral neuropathy of fibers). **C –** Presence of hyper-radiation with ΔT > 4.2 °C when compared to the right and left halluces, with ascending pattern suggestive of lymphangitis; the infrared image accompanied by clinical examination confirmed the diagnosis of paronychia

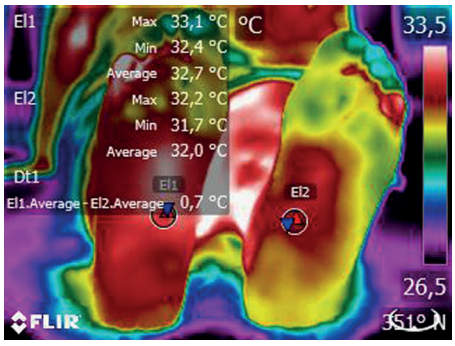

Figure 4: Eighty-eight year-old female patient, bearer of DM2, bilateral plantar callus more prominent on the right side, steppage gait, right plantar arch drop, with hyper-radiation of right fifth toe; breakage of the transverse lines of the distal thermal gradient of the feet and interdigital anisothermy with ΔT > 0.4°C

tality of diabetic patients with and without ulcers. In addition, diabetic patients with mild neuropathies are more prone to trauma and infection due to the fact they have reduced protective sensitivity, this being a factor to be considered.[2] Diabetic patients are more likely to have proximal and distal occlusive arterial vascular diseases, and may course with other intercurrences of superficial and deep venous origin, lymphatic occlusive diseases, in addition to posttraumatic vascular disorders or due to exposure to cold, meaning that clinical examination combined with thermography based propaedeutic examination may help in the differential diagnosis.[3,6,14,17]

The cold stimulus test followed by infrared imaging is used due to the fact it significantly increases the sensitivity of the method, and is indicated in tandem with ambulatorial exams performed when there is complaint of burning feet, signs of increased peripheral insulin resistance or of increased glucose tests in asymptomatic patients, or still when there are cutaneous signs of neurovegetative neuropathy.[19] The reactive hyperemia response can be measured and depicted on a graph used to monitor treatment. However, it is important to note that loss of fine nerve fibers can occur in other diseases, such as fibromyalgia syndrome, motor neuron disease, Ehlers-Danlos syndrome and Parkinson's disease, among others,[19] isolated or associated with diabetes. The clinical examination of the feet in the studied group showed areas of plantar dryness and desquamation, hyperkeratosis and plantar arch drop (Charcot's foot in two cases), in addition to steppage gait, associated with the results of basal thermography, evidencing areas of plantar hyper-radiation in the regions where there was frequent contact with footwear and inadequate tread (Figure 4). In diabetic patients, fine fibers neuropathy may gradually combine with that of large fibers in type 2 diabetes patients, and generally affect the distal extremities in the upward direction.[19] Patients may experience burning sensation, stinging, pruritus in the lower limbs in addition to cramps and restless legs during the night.[2] It may be accompanied by other neurovegetative symptoms, such as changes in sweating, diarrhea, constipation, dry eyes, palpitation, hot flashes, sensitive skin, burning feet and heat intolerance. Other tests may be necessary to confirm the diagnosis of diabetic peripheral neuropathy, by applying neurological protocols and performing skin biopsy with 3mm punch followed by histological examination with special stains, aiming at assessing adnexa and quantifying nerve fibers in the dermis.[2]

CONCLUSION

Infrared imaging of the feet may be a useful propaedeutic tool alongside ambulatorial clinical examination, as it provides assistance in the mapping of the lower limbs – in special the plantar region – in the preliminary and early diagnosis of fiber neuropathy and in the identification of areas of infection and poor blood perfusion, aiding in the preparation of differential diagnoses and aggravating risk factors already in the first ambulatorial clinic visit or at the dermatologist's practice. ●

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Oversight of the manuscript and image reviews according to the method validated in her doctoral thesis on the use of infrared images in the evaluation of peripheral neuropathy of thin fibers of the diabetic foot

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Review of the manuscript and infrared images, rectification of diverging points