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Case Report

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Quantitative thermal indices in infrared imaging as auxiliary tool in the diagnosis of peripheral artery disease and diabetic peripheral neuropathy among patients with type 2 diabetes

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Abstract

Biomedical thermography, when used to monitor changes in metabolic heat released from human legs, allows the disclosure of metabolic deficiencies associated with asymmetric alterations in the presence of long-term type 2 diabetes mellitus. In this case series a clinical evaluation was performed in 10 patients clinically diagnosed with a time evolution of type 2 diabetes mellitus for more than 5 years: 5 males (62 ± 10 years) and 5 females (56 ± 10 years). The clinical examination relied on infrared thermography as the only auxiliary imaging technique to diagnose diabetic peripheral neuropathy and peripheral arterial disease. The clinical evaluation indicates 100% agreement with the image analysis according to the quantitative thermal indices: asymmetry and thermal response index (ATR) and the thermal response index (TRI). These findings indicate that the proposed image analysis is a useful and adaptable tool for detecting subtle clinical signs and supporting timely diagnostic and therapeutic decisions.

Keywords endocrinology and metabolism, radiology, medical imaging, biomedical infrared imaging

Introduction

Diabetes mellitus is a major global health problem, reaching alarming levels according to the International Diabetes Federation (IDF) [1]. Type 2 diabetes mellitus (DM2) is the most common type of diabetes, accounting for more than 90% of all diabetes cases worldwide. A common DM2 complication is Diabetic Foot Syndrome (DFS); a group of anatomical and functional problems that affect the feet of people with diabetes characterized by diabetic peripheral neuropathy (DPN) and Peripheral Artery Disease (PAD).

DPN and PAD significantly increase the risk of foot ulcers, which can progress to minor or major amputations. The prevalence of this complication means that around 15% of diabetic patients would develop ulcerous foot-lesions during their lifetime [2]. It is estimated that between 40% and 50% of amputations in diabetics can be avoided through proper care and the appropriate treatment of early lesions [3]. Although various imaging techniques facilitate timely diagnosis by providing relevant information about the patient's vascular status [4], some are often costly, while others are limited by risks from contrast media and ionizing radiation, especially in view of the then exacerbated kidney damage and the ongoing oxidative stress and its potential involvement with deeper stages of diabetic neuropathy.

Therefore, validating imaging methods that do not increase existing damage and that support early diagnosis and monitoring of patients at high risk of developing DFS is a clinical necessity. Is in this instance that the Infrared IRIm can be used, since it is non-invasive, non-intrusive, is relatively low-cost, and capable of continuous image capture [5]. For this reason, it is proposed to evaluate this case series using IRIm in conjunction with quantitative thermal indices as an auxiliary tool in the early detection of peripheral damage, helping to prevent ulcers and reduce amputations.

Case series

This article presents information on 10 patients with a clinical diagnosis of DM2, with more than 5 years of disease progression. They participated as volunteers in a thermographic study of their lower

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Table 1 Clinical information of the participant group, which is divided according to the time of progression of DM2. HbA1c: glycated hemoglobin.

Time of progression [years]	Gender [Male (M)/Female (F)]	Age [years]	BMI [kg/m^2]	Glucose [mg/dL]	HbA1c [%]
5 to 9	F	62	28	115	6.4
	M	73	24.38	82	7.34
	M	61	25.31	138	7.35
	M	55	33.88	111	6.12
10 to 14	F	64	29.82	171	7.59
	F	51	18.83	292	13.8
	F	41	26.66	142	11.75
15 to 20	F	63	32	228	8.74
	M	49	28.08	348	12.05
	M	74	26.54	210	9.95

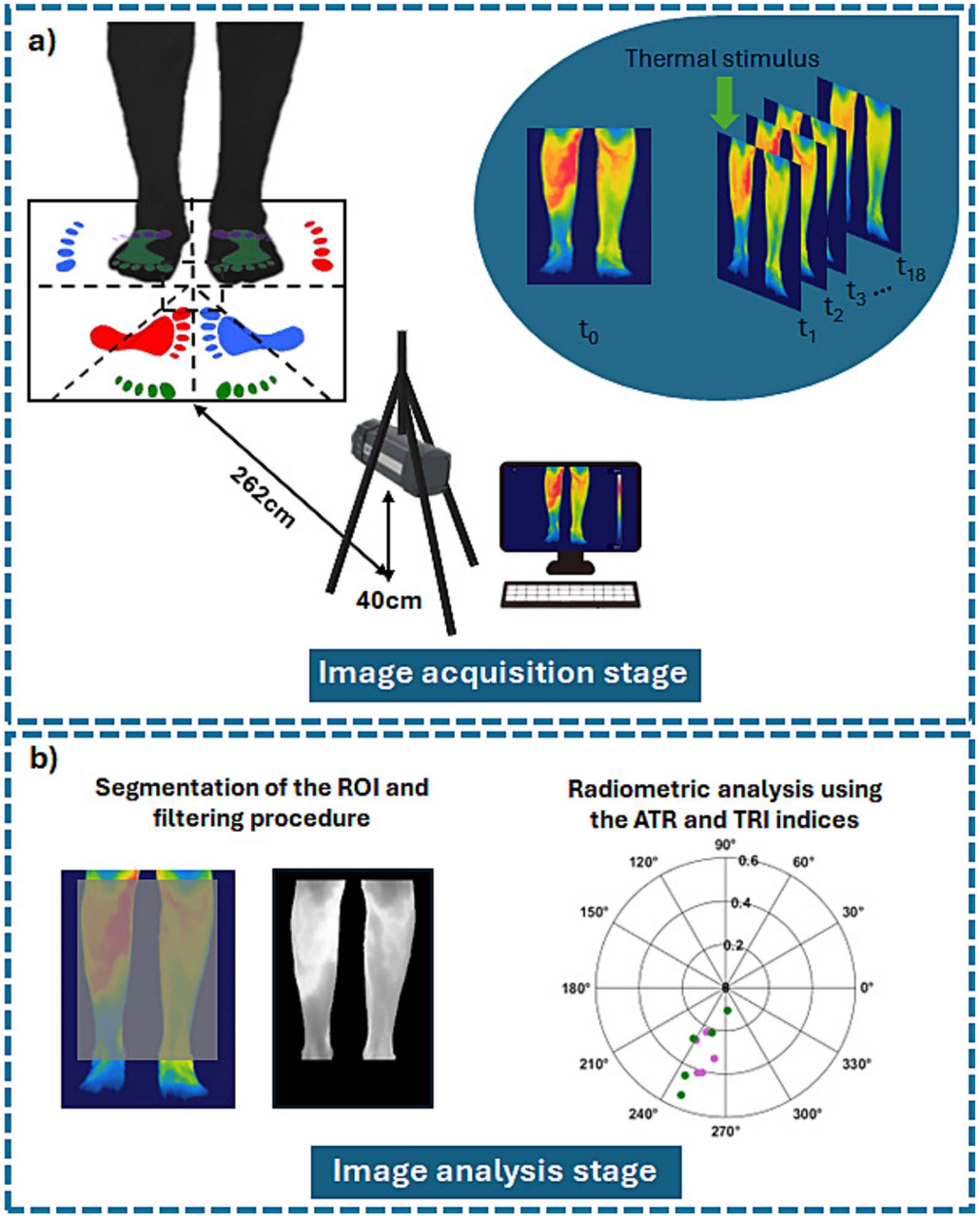

Figure 1 General diagram of the infrared image acquisition and analysis protocol. Two infrared image sequences are obtained from the lower extremities of each study subject: One for the frontal view and one for the posterior view, both in passive and active modes. Quantitative analysis is performed by combining the ATR and TRI index of each individual, using a polar representation.

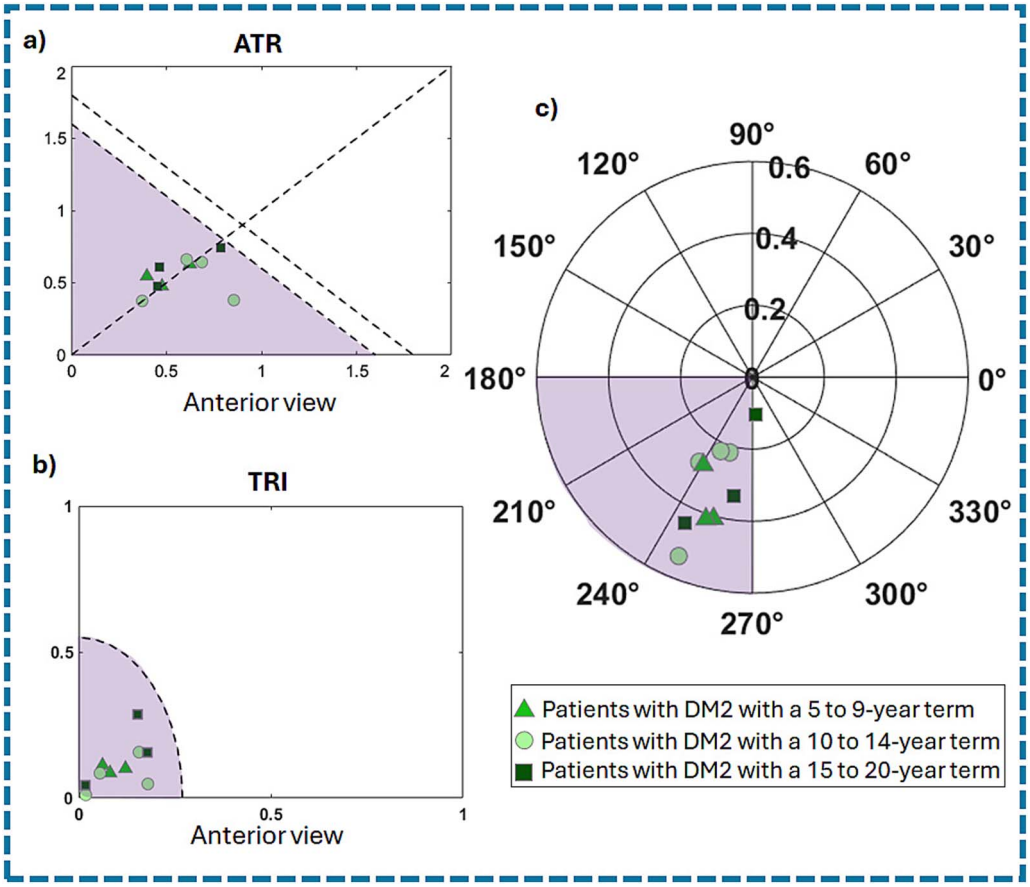

Figure 2 Results of the radiometric data analysis using the indices: (a) ATR, (b) TRI, and (c) polar representation. The population is divided into three groups of patients diagnosed with DM2 according to the years term. The triangular marker corresponds to patients diagnosed with DM2 with 5 to 9 years term; the circular marker corresponds to patients diagnosed with DM2 with 10 to 14 years term; and the square marker corresponds to patients diagnosed with DM2 with 15 to 20 years term. The range of values within which the metabolic performance of a person with DM2 can be considered deficient due to the presence of DPN or PAD is highlighted in purple.

extremities, according to the clinical protocol DI/10/301/4/115 of the General Hospital of Mexico.

Participants were fully informed about the protocol, and their questions were answered before signing consent. Subsequently, all participants underwent a physical examination and blood tests for clinical evaluation by an expert angiologist on the diagnosis and treatment of patients with DFS. Additional participant details can be found in Table 1.

Therefore, the methodology had two stages, as shown in Fig. 1. In the first, IRIs was obtained using an acquisition protocol with a mat marking the position of the feet for anterior and posterior views. The camera was set 262 cm away and 40 cm high to standardize the images. IRIs of the lower extremities was recorded at rest and every 15 s for 4.5 min after applying an external thermal stimulus.

In the second stage, the radiometric information embedded in the IRIs was expertly extracted to identify their actual physical nature and some of its dynamical properties owed to the DM2 disease, this, using the radiometric indices previously proposed by this research group. This analysis combines the information obtained with the asymmetric and thermal response index (ATR) [6] and the thermal response index (TRI) [7], using the methodology described in ref. [8]; where is also described the robustness and improved diagnostic performance that one can achieve when it is applied. This methodology is used for the first time in this work as a diagnostic tool.

All patients were clinically diagnosed with PAD and DPN to varying degrees. When the two etiologies are intertwined, we refer to this as mixed peripheral damage (MPD), so all patients in this study have MPD.

These clinical findings can be confirmed with ATR and TRI indices, particularly considering their joint visualization to highlight physiological alterations. The results and behavior of each index can be observed in Fig. 2.

For clarity, patients were divided into three subgroups based on progression of DM2. Figure 2 shows no significant differences among them, indicating that DM2 deterioration depends on factors beyond disease duration; furthermore, as disclosed in the figures, although many patients are diagnosed years after onset, the clustering tendency is noticeable, as highlighted with the shadowing in the graphs.

Discussion

DPN reduces the body's response to external thermal stimuli [9] while PAD alters vascular networks and metabolic heat [10]. To detect these particularities, the IRIm protocol used in this study compared heat conservation and dissipation between the right and left legs using ATR and TRI indices in specific regions of interest.

Each index provides an assessment that highlights specific aspects of DPN and PAD. Specifically, in the presence of DPN, the response

to thermoregulation processes becomes deficient, and it is reflected as a decrease in the values of the ATR index [6] (see Fig. 2a). Instead, the TRI represents the temporal response of thermal asymmetry and measures the statistical dependence between left-to-right projections, making it more sensitive to assessing temperature differences in metabolic heat maps of the lower extremities, which are altered in the presence of PAD. So, as the severity of PAD increases, the correlation in the heatmap decreases, reducing the TRI values [7] (see Fig. 2b).

In the joint polar representation, see Fig. 2c), the information from the analyzed population is grouped in the quadrant determined by the angles 180° and 270°, supporting the hypothesis that patients with DPN and PAD should be in this quadrant [8], and setting this methodology as a tool with sensitivity 100% to detect MPD.

The finding suggests that the proposed protocol to evaluate the metabolic performance of the lower extremities of diabetic subjects whose disease progression is greater than 5 years and who present damage due to DPN and PAD, may be a useful tool supporting rapid decisions on appropriate studies and treatments. These results allow us to consider evaluating this methodology in a broader diabetic population to detect conditions at very early stages, for which it is necessary to have a larger and more diverse clinical database.

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Conflict of interest

The authors declare that they have no conflict of interest.

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Ethical approval

The acquisition and analysis protocol presented in this work was evaluated and approved by the Ethics Committee of the General Hospital of Mexico (DI/10/301/4/115). Furthermore, because thermography is completely noninvasive, acquisition protocols ensure the well-being of participants.

Consent

All the volunteers whose data was used in this work signed the consent statement prior to enrollment and data collection, according to the journal's patient consent policy.

Guarantor

Crescencio García-Segundo.

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