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ORIGINAL RESEARCH

Lower extremity thermographic profile of individuals undergoing ulcerative wound treatment: a qualitative exploration of images

Perfil termográfico das extremidades inferiores de indivíduos em tratamento de feridas ulcerativas: uma exploração qualitativa das imagens

Perfil termográfico de los miembros inferiores en individuos en tratamiento por lesiones ulcerativas: una exploración cualitativa de imágenes

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ABSTRACT | Thermography proves to be a new concept in measuring the thermogenesis of biological systems, a valuable method for confirming clinical diagnosis discarding subjective analysis and personal criteria. The result of the thermographic evaluation is the subject of qualitative and quantitative analyses. This study aimed to identify the thermal profile of the lower extremities of individuals diagnosed with cardiovascular and endocrine and metabolic diseases in the treatment of ulcerative wounds. A thermographic evaluation was performed from 19 dorsal, plantar, lateral, and medial extremities. In the qualitative analysis, images with and without a wound were divided according to diagnosis. After the division, a checklist was elaborated for the qualitative evaluation of the images. A total of 100 individuals (49 women and 51 men) participated, 65 with cardiovascular disease and 35 with endocrine and metabolic disease. There was a difference in the thermal pattern between the extremities in both diagnoses. The groups presented similar thermographic characteristics with signs of more radiation in the wounds, predominantly with red and white stains. More regions of interest with lesions on the medial foot, lateral, and medial ankle border were observed in individuals with chronic cardiovascular disease. Those with endocrine and metabolic disease presented more regions with lesions in the plantar (forefoot), dorsal, and medial ankle regions. The profile showed a discrepancy in the thermal pattern in the regions of interest of wounded and without wound extremities according to the diagnoses. Signs of wounds emitting high levels of radiation were similar in both groups, but the physiology of the disease and treatment differed.

Keywords | Thermography; Wounds and Injuries; Diabetes Mellitus; Cardiovascular System.

RESUMO | A termografia revela-se como um novo conceito na mensuração da termogênese de sistemas biológicos e um método valioso para confirmação de diagnóstico clínico que dispensa análises subjetivas e critérios pessoais. O resultado da avaliação termográfica é alvo de duas análises: qualitativa e quantitativa. O objetivo deste estudo foi identificar o perfil térmico das extremidades inferiores de indivíduos diagnosticados

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com doenças de base endocrinometabólica e circulatória em tratamento de feridas ulcerativas. Para tanto, foi realizada avaliação termográfica de 19 regiões, distribuídas nas áreas dorsal, plantar, lateral e medial das extremidades. Na análise qualitativa, as imagens com e sem ferida foram divididas de acordo com o diagnóstico. Após a divisão, elaborou-se um checklist para a avaliação qualitativa das imagens. Participaram 100 indivíduos (49 mulheres e 51 homens), sendo 65 com doença circulatória e 35 com doença endocrinometabólica. Houve diferença no padrão de coloração entre as extremidades em ambos os diagnósticos. Os grupos apresentaram características termográficas semelhantes, com sinais de hiperradiação nas feridas, predominantemente de colorações vermelho e branco. Foi observado maior número de lesões na borda medial de pé e na lateral e medial de tornozelo nos indivíduos com doença de base circulatória. Já aqueles com doença de base endocrinometabólica apresentaram maior número de lesões nas regiões plantar (antepé), dorsal e medial de tornozelo. O perfil revelou discrepância na coloração das regiões de interesse da extremidade com e sem ferida, de acordo com os diagnósticos. Os sinais de hiperradiação das feridas foram semelhantes nos dois grupos, porém a fisiologia das doenças e os tratamentos diferiram.

Descritores | Termografia; Ferimentos e Lesões; Diabetes Mellitus; Sistema Cardiovascular.

RESUMEN | La termografía es un nuevo procedimiento para la medición de la termogénesis de los sistemas biológicos y un método valioso para confirmar el diagnóstico clínico que no requiere análisis subjetivos y criterios personales. El resultado de la evaluación termográfica está sujeto a dos análisis: cualitativo y cuantitativo. El objetivo de este estudio fue identificar el perfil térmico de los miembros inferiores en individuos con diagnóstico de enfermedades endocrinometabólicas y circulatorias en tratamiento por lesiones ulcerativas. Para ello, se realizó una evaluación termográfica de 19 regiones, distribuidas en las regiones dorsal, plantar, lateral y medial de los miembros. En el análisis cualitativo, las imágenes con y sin lesiones se dividieron por diagnóstico. Después de la división, se elaboró una lista de verificación para la evaluación cualitativa de las imágenes. Participaron 100 individuos (49 mujeres y 51 hombres), de los cuales 65 tenían enfermedad circulatoria y 35 enfermedad endocrinometabólica. Hubo una diferencia en el estándar de color entre los miembros en ambos diagnósticos. Los grupos mostraron características termográficas similares, con signos de hiperradiación en las lesiones, predominantemente de colores rojo y blanco. Se observó un mayor número de lesiones en el borde medial del pie y en el lateral y medial del tobillo en individuos con enfermedad circulatoria. Aquellos con enfermedad endocrinometabólica presentaron mayor número de lesiones en la región plantar (antepié), dorsal y medial del tobillo. El perfil reveló discrepancia en el color en las regiones de interés de los miembros con y sin lesiones según los diagnósticos. Aunque los signos de hiperradiación de las lesiones fueron similares en ambos grupos, la fisiología de las enfermedades y los tratamientos difirieron.

Palabras clave | Termografía; Heridas y Lesiones; Diabetes Mellitus; Sistema Cardiovascular.

INTRODUCTION

Created in the 1960s, infrared thermography is a painless, non-invasive, non-contrasting diagnostic method that allows for the issuance of highly suggestive reports to be used in health care. However, at the time of its creation, the resolutions of the images were low and presented little sensitivity[1].

Currently, infrared thermography emerges as a new concept in measuring thermogenesis in biological systems, proving to be valuable for confirming a clinical diagnosis, since it does not require subjective analysis and personal criteria[2], as in cases of breast tumors[3], melanomas[4], rheumatologic diseases[5], and endocrine and metabolic diseases such as diabetic neuropathies and diabetic foot[6].

Among these diseases, cardiovascular and endocrine and metabolic systems lead to increased health care costs, which are expected to grow even more by 2030—30%–34%—worldwide[7]. The increase in the incidence can be attributed to the population's aging and the growing urbanization, leading to the spread of obesity and a harmful lifestyle[8]. These consequences have been demonstrated using infrared images, as in the evaluation of the cutaneous microcirculation of individuals with diabetic foot by visualizing the extent of inflammatory processes and necrosis, favoring early intervention and improving the prognosis of foot ulcers and the neuropathic progression of the disease[6].

Thermal images obtained from thermography are, mostly, subject of qualitative and quantitative analyses. Generally, a qualitative analysis is used to observe

thermal profiles. On the other hand, to define and to quantify the level of severity of an anomaly, quantitative thermography is used[9].

Thus, this study aimed to describe, employing qualitative evaluation, the pattern of thermal images of the lower extremities of individuals diagnosed with chronic endocrine and metabolic and cardiovascular diseases in the treatment of ulcerative wounds.

METHODOLOGY

This is a cross-sectional descriptive study, with a sample of 100 individuals, 49 women and 51 men.

The study used the following inclusion criteria: individuals aged over 18 years, diagnosed with chronic endocrine, metabolic, or cardiovascular diseases—diabetes mellitus, obesity, hypertension, and coronary artery diseases (angina pectoris and myocardial infarction; stroke; hypertensive heart disease; rheumatic fever; cardiomyopathy; cardiac arrhythmia; congenital heart disease; valvular heart disease; cardiac arrhythmia; aortic aneurysm; peripheral arterial disease; and venous thrombosis)[10,11]—, and who have ulcerative wounds on the lower extremities under treatment. As exclusion criteria, the following were considered: subjects with self-reported cognitive dysfunction, with ulcerative wounds on the upper limbs, or those who underwent a procedure for the amputation of the lower limbs.

Data were collected from March 2018 to April 2019, at the facilities of the general outpatient clinic of the Hospital Regional de São José, as well as the vascular and endovascular surgery sector of the Instituto de Cardiologia de Santa Catarina, both institutions located in the municipality of São José, in the metropolitan area of Florianópolis, state of Santa Catarina (SC), Brazil. The outpatient clinic receives several patients from all over SC who seek evaluation and treatment for ulcerative wounds on the lower limbs, since it is a reference hospital for performing these procedures.

The evaluation of ulcerative wounds is conducted by physicians and nurses, who perform local therapy, consisting of cleaning the wound. If debridement procedures are necessary, an occlusive dressing is made with hydrogel or hydrocolloid. The chemical method is performed by applying collagenase and papain, and the mechanical method by a surgical instrument for the debridement of wounds when necessary. There is also compressive therapy, which consists of applying rigid bandages and inelastic bandages of Unna's paste.

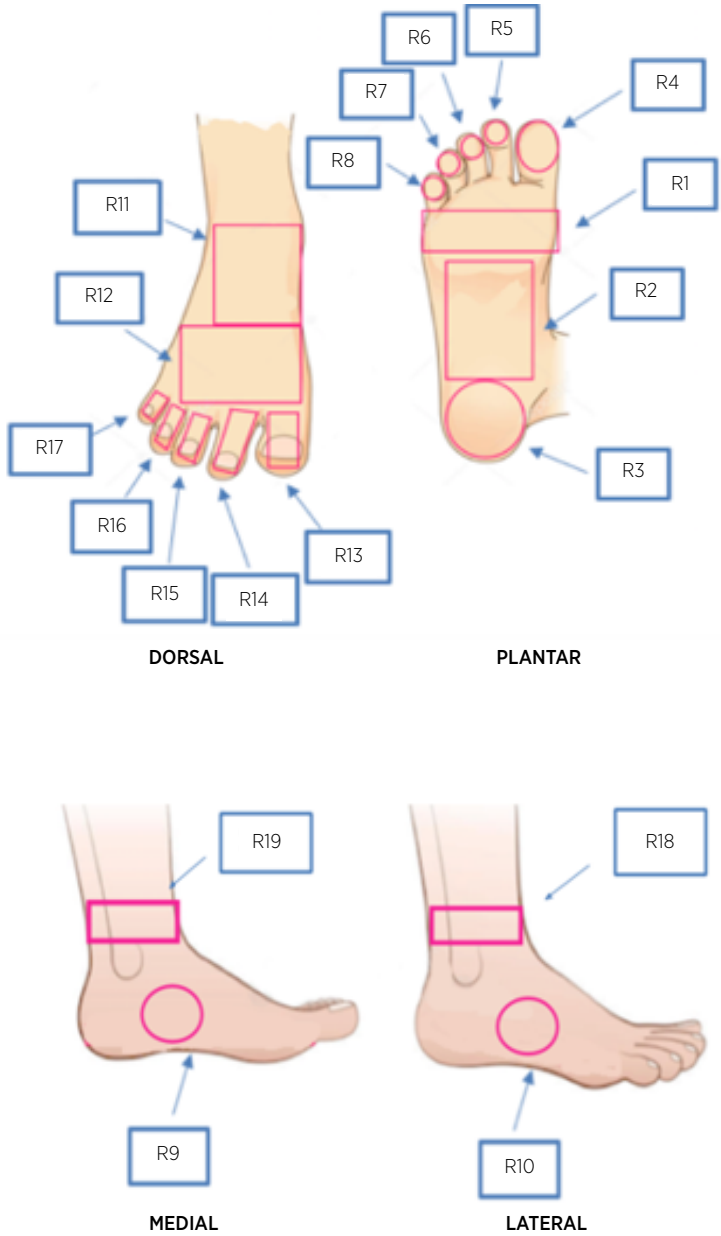
Individuals were invited to participate in the research and then signed an informed consent form. After this procedure, data collection began via a questionnaire based on the individual record form regarding: age, gender, medical diagnosis, education level, practice of physical activity, use of assistive devices, and evaluation of the time spent sitting or lying down on a weekday.

To capture the thermographic images, participants were individually referred to the room of the outpatient clinic where the thermographic camera was installed to collect the images. The ambient temperature and humidity were controlled and the room was isolated form airflow that could result in heating or thermal variations. For image collection, the FLIR T420 thermographic camera was used, suitable for the application of functional diagnosis, with a 320×240 image resolution, thermal sensitivity of up to 30°C, and spectral range of 7–13 micrometers[12].

The photographs were taken at a distance of approximately 80cm from the participant, who remained in the supine position on a stretcher, with lower limbs extended and without shoes, socks, and dressings, for 10 minutes for acclimatization. Then, a sequence of images was taken according to the guidelines of the *Associação Brasileira de Termologia* (Brazilian Association of Thermology – Abraterm) and under conditions recommended by the American Academy of Thermology (AAT)[13,14].

The images of the lower extremities with and without an ulcerative wound were captured separately. To establish the temperature of the lower extremities, regions of interest (ROIs) were defined based on the areas of risk for ulceration in diabetic patients (Figure 1)[8]. The protocol delimited the anatomical regions of the feet and ankles in: plantar, from R1 to R8; dorsal, from R11 to R18; lateral, R10 and R18; and medial, R9 and R19. Thus, to capture the images respecting the ROIs, photographs were taken starting with the transverse scheme (plantar and dorsal regions of the foot), followed by the lateral scheme (lateral ankle) and, finally, to the medial scheme (medial ankle).

For the analysis of the thermographic images, FLIR and QuickReport programs were used and for each ROI, the average, maximum, and minimum temperatures were collected.



Plantar and dorsal region

Forefoot region (R1)
Midfoot region (R2)
Hindfoot region (R3)
Posterior hallux region (R4)
Posterior region of the 2nd metatarsal (R5)
Posterior region of the 3rd metatarsal (R6)
Posterior region of the 4th metatarsal (R7)
Posterior region of the 5th metatarsal (R8)
Superior anterior (dorsal) region (R11)
Inferior anterior (dorsal) region (R12)
Anterior hallux region (R13)
Anterior region of the 2nd metatarsal (R14)
Anterior region of the 3rd metatarsal (R15)
Anterior region of the 4th metatarsal (R16)
Anterior region of the 5th metatarsal (R17)

Lateral and medial region

Medial region of the foot (R9)
Border region of the foot (R10)
Lateral region of the ankle (R18)
Medial region of the ankle (R19)

Figure 1. Regions of interest of the anterior, posterior, lateral, and medial extremities of the lower extremities

For the qualitative analysis, thermographic images of the lower extremities with and without an ulcerative wound were divided into: images of subjects diagnosed with chronic cardiovascular diseases and diagnosed with chronic endocrine and metabolic diseases. After division, a checklist of items to be evaluated in the images was elaborated[15]. The checklist consisted of the following items: symmetry and discrepancy in the pattern of bilateral staining, evaluated by observing the similarities and differences in coloration between ROIs and comparing the limbs with and without a wound. ROIs of wounds with signs of less radiation present black to green coloration and wounds with signs of more radiation, yellow to white. For each image to be included in the checklist items, a minimum number of three IRs per lower extremity area was established.

RESULTS

The mean age of the study participants was 63.5±9.3 years. Of the 100 participants, 65 were diagnosed with cardiovascular diseases and 35 with chronic endocrine and metabolic diseases. Based on the data shown in Table 1, the number of subjects with an ulcerative wound on the lower extremity—divided by medical

diagnosis according to the IRs of the thermographic images—was observed. Among those diagnosed with cardiovascular diseases, a higher number of lesions was observed in R10, R18, and R19, corresponding to the medial border of the foot and lateral and medial ankle; and among the individuals diagnosed with chronic endocrine and metabolic diseases, there was a higher number of lesions in R1, R11, R13, and R19, corresponding to the forefoot, dorsal, and medial ankle.

Regarding the checklist for the evaluation of thermographic images (Table 2), we verified an overall discrepancy in the ROI thermal pattern between the lower extremity with a wound and those without it (Figure 2). Individuals diagnosed with cardiovascular disease and with chronic endocrine and metabolic disease presented the same thermographic characteristics of ROI with signs of more radiation in the wounds (red and white) (Figure 3). This may characterize an increase in vascularization and local metabolism in the ulcerative wounds of individuals.

Table 1. Number of regions of interest with lesions according to medical diagnosis

Image characteristic	Cardiovascular disease	Chronic endocrine and metabolic disease
Thermal symmetry	11	7
Discrepancy in thermal pattern	64	37
Less radiation	29	11
More radiation	40	28

Table 2. Number of alterations found in the lower extremities with and without ulcerative wound after qualitative analysis of thermographic images

Region of interest (ROI)	Cardiovascular disease	Chronic endocrine and metabolic disease
Forefoot region (R1)	5	15
Midfoot region (R2)	2	2
Hindfoot region (R3)	-	3
Posterior hallux region (R4)	3	3
Posterior region of the 2nd metatarsal (R5)	3	-
Posterior region of the 3rd metatarsal (R6)	3	1
Posterior region of the 4th metatarsal (R7)	6	1
Posterior region of the 5th metatarsal (R8)	5	1
Medial region of the foot (R9)	7	2
Border region of the foot (R10)	17	2
Superior anterior (dorsal) region (R11)	8	8
Inferior anterior (dorsal) region (R12)	7	2
Anterior hallux region (R13)	5	5
Anterior region of the 2nd metatarsal (R14)	7	-
Anterior region of the 3rd metatarsal (R15)	4	1
Anterior region of the 4th metatarsal (R16)	5	1
Anterior region of the 5th metatarsal (R17)	6	1
Lateral ankle (R18)	34	2
Medial ankle (R19)	28	6

(continues)

Table 2. Continuation

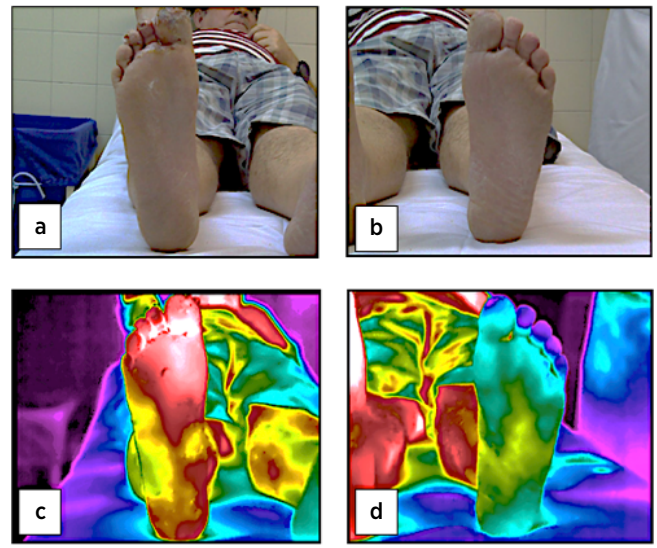


Figure 2. Photograph of the right plantar region with wound (a) and left without wound (b); and thermographic image of the right plantar region with wound (c) and left without wound (d), showing signs of discrepancy in the thermal pattern

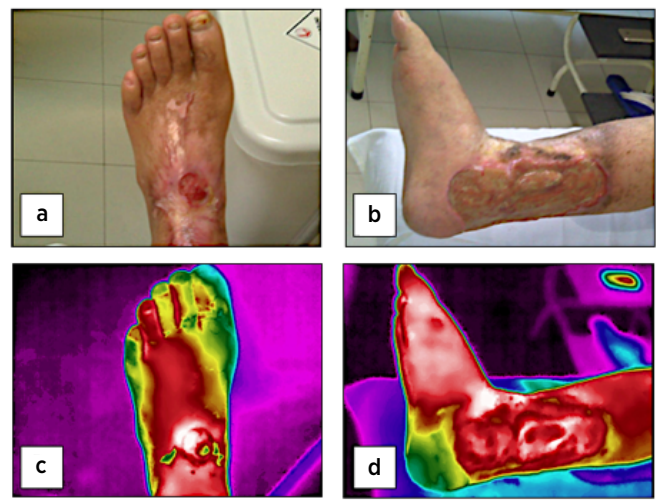


Figure 3. Photograph of the left dorsal region (a) and right medial region (b) with wound; and thermographic image of the left dorsal region (c) and right medial region (d) with wound, showing signs of more radiation

DISCUSSION

This study established the thermographic profile of the lower extremities of individuals diagnosed with chronic endocrine and metabolic and cardiovascular diseases in ulcerative wound care, via a qualitative evaluation of thermographic images. The discrepancy in thermal pattern between the lower extremities with and without wound provided a great number of images with the characteristic more radiation in both groups. These particularities can often be related to issues such as the continued treatment of wounds in the outpatient clinic, which in some cases included debridement, leading to processes that stimulate healing, causing vasodilation, and, consequently, increased metabolism.

According to Rocha Júnior et al.[16], tissue repairing is divided into: hemostasis; inflammatory phase; granulation tissue formation with extracellular matrix deposition (collagen, elastin, and reticular fibers); and remodeling. Hemostasis is the process in which platelet activity and the coagulation cascade occur; the inflammatory phase is characterized by the presence of inflammatory cells in the scar tissue; during the formation of granulation tissue with extracellular matrix deposit, repairing connective tissue and epithelium. In connective tissue repair, granulation tissue formation occurs, with endothelial and fibroblast proliferation. Remodeling is the last phase of healing, which happens in collagen and matrix and lasts for months, being responsible for the increase in tensile strength and the decrease in the size of the scar and erythema.

In individuals with cardiovascular diseases, atherosclerosis stands out as one of the most common diagnoses. It is characterized by a process of peripheral vascular disease in which excessive blood coagulation and increased vascular resistance occur, leading to obstruction of the arteries and distal arterioles, hindering blood flow[17].

Initially, the small tibial and peroneal arteries at the knee and ankle are obstructed[17]. It is a major risk factor for ulceration and amputation due to impaired blood perfusion in the lower limbs since depriving the tissues of adequate oxygen, nutrients, and antibiotics supply impairs ulcer healing, which can lead to gangrene[18].

The signs and symptoms that individuals present are the clearest aspect of the pathophysiology of peripheral vascular disease (PVD), with hypertension secondary to reflux and/or obstruction in the venous system being the most discussed symptom. These signs and symptoms cause pain, discomfort, and decreased temperature in the affected limb and can eventually evolve into varicose stasis ulcers[19]. However, ulcer formation might be associated with fluid accumulation and fibrin deposition in the interstitium, leading to venous occlusion. Nutrient and oxygen deficiency related to this process can cause ulcerations and necrosis. Another mechanism is the reaction between leukocytes and adhesion molecules of the endothelium, which can trigger inflammation and damage the venous valves, increasing susceptibility to ulcer formation[20].

Vestjens et al.[21] developed a checklist of clinical signs and symptoms to evaluate the pattern of chronic wounds regarding signs and symptoms of infection. This tool included a combination of classic and secondary signs and symptoms of chronic wound infection. The authors concluded that erythema, increased temperature, pain, edema, and purulent secretion are considered classic signs and symptoms of infection and quantified the relationship between increased skin temperature and wound infection.

The regions with the highest number of lesions found in individuals with vascular disease are located in the lateral and medial regions of the ankle and the foot, and these thermographic findings of the lower extremities corroborate the literature. Varicose ulcers are generally found in the "gaiter area," the region between the ankle and mid-calf, and in the medial portion of the leg, above the medial malleolus[22]. In cases of arterial ulcers, their occurrence is in the region of the toes, feet, or heel, which is in agreement with the thermographic finding of individuals with vascular disease[23].

The evaluation checklist showed that, in individuals with endocrine and metabolic diseases, the lesions were usually located in the forefoot, and in the dorsal and medial ankle. According to Bakker et al.[24], these regions are the most affected by injuries, starting at the toes, due to the high external pressures caused by muscle atrophy. The lesions then extend into the interdigital grooves by cracks and small cuts, favoring the colonization of fungus on the skin. The distal region of the foot is also a focus of injury, because the metatarsal prominences, when ulcerated, can cause infections that can penetrate

the phalangeal joints, leading to local compromises and/or osteomyelitis. The medial region of the foot is usually the site of the development of calluses and lesions as it is a region of support[24].

A study by Guimarães et al.[25], which aimed to capture basal infrared images, showed, after a cold stimulation test, with an infrared sensor in a controlled environment, in individuals diagnosed with onychomycosis and diabetes mellitus, that the patterns of plantar thermography varied according to the classification based on anatomical units (angiosomes). The authors observed an increase in radiation in two patients' forefoot, aged 68 and 88 years, with type 2 diabetes mellitus and Charcot's joint, which corroborates the findings of the checklist of thermographic images of diabetic individuals in this study.

CONCLUSION

Based on the thermographic evaluation of the lower extremities with and without a wound of individuals diagnosed with chronic endocrine and metabolic and cardiovascular diseases, individuals diagnosed with cardiovascular disease had more injury in R10, R18, and R19, which correspond to the medial border regions of the foot and lateral and medial ankle. Those diagnosed with an endocrine and metabolic disease presented a higher number of lesions in R1, R11, R13, and R19, corresponding to the plantar, dorsal, and medial ankle regions.

The pattern of thermal imaging showed a discrepancy in the thermal pattern in ROIs between the lower extremity with and without an ulcerative wound, both in individuals with cardiovascular disease and in those with endocrine and metabolic disease. Both groups presented the same thermographic characteristics, with a sign of more radiation in the ROIs of the wounds, of red and white coloration. Finally, the thermographic pattern of the lower extremities showed signs of more radiation in the ulcerative wounds, which was similar in both groups. This conclusion can be explained by the inflammatory process in ulcerative wounds that occurs in most individuals in the treatment process, as well as by the methods and procedures used in the treatment of these wounds, which increase metabolism and local blood circulation.

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