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Skin temperature of the foot: Reliability of infrared image analysis based in the angiosome concept

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ABSTRACT

Objective: Studies reporting the reliability of image analysis when assessing skin temperature of the foot are scarce. The aim of this study was to assess the interrater and intrarater reliability of the analysis of foot skin temperature based on the angiosome concept and the association between skin temperature differences and the differences in size of the ROIs.

Methodology: Thermograms from 26 feet were analysed by two independent assessors and each assessor analysed the same images on different occasions. Mean temperature values of each of the six ROIs were extracted for analysis. Relative reliability was assessed by Intraclass Correlation Coefficient (ICC) measures and absolute reliability was assessed using Bland and Altman agreement measures and standard error of measurement (SEM). The Spearman correlation coefficient was used to assess the association between the skin temperature differences and the differences in size of the ROIs in the interrater and intrarater analysis.

Results: The ICC values evidenced excellent interrater and intrarater reliability with the 95% confidence intervals (CI) ranging between 0.962 and 1.000 and the SEM ranged between 0.00 °C and 0.36 °C. The mean absolute difference (bias) between the measurements ranged between 0.002 °C and 0.117 °C and small to moderate associations between the differences in skin temperature and the difference in the number of pixels were identified.

Conclusion: The excellent interrater and intrarater reliability measures suggest that the methodology of analysis was reliable and may be used in research and clinical settings. Although statistical significant associations between the skin temperature differences and the differences in size of the ROIs were found, the magnitude of the skin temperature differences between assessments and between assessors (0.02–0.17 °C) is not clinically relevant.

1. Introduction

The human body is a very efficient thermal system and the skin is the interface between the body and the environment. The skin, being a highly efficient radiator, radiates energy similarly to a black-body and is a key factor in thermoregulation [1,2]. Thermal imaging, unlike other imaging modalities, provides real-time physiological information on skin temperature distribution through the recording of thermograms [3].

Several factors can affect the accuracy, precision and responsiveness of thermal imaging measurements, such as the surface being imaged, the camera system, patient preparation, patient position, environment conditions, image processing, image analysis, image exchange and image presentation [4]. Temperature measurements from thermal images are based on the definition of regions of interest (ROIs) but the shape, size and placements of the ROIs are not defined similarly by researchers, even when analysing the same body region. This is perfectly acceptable as the definition of the ROIs is dependant of the goal of the study, but the reproducibility of the adopted methodology should be tested and reported. Diagnostic accuracy of thermal imaging is

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influenced by the shape and size of ROIs [e.g. 5]. Large variations in the size of ROIs leads to significant differences in temperature readings [6] and individual errors of temperature measurements, even in small ROIs over small finger joints, may be as high as 2.35 °C in newly trained thermographers [7].

Skin temperature is an important factor associated with foot complications. An increase in skin temperature, when compared with the contralateral limb, can predict neuropathic foot ulceration [8]. The International Working Group on the Diabetic Foot has suggested that monitoring skin temperature can reduce the incidence of recurrent plantar ulcers [9]. An increase in foot skin temperature has been observed in diabetic patients with neuropathy [10] and infection [11], and lower values of skin temperature have been documented in patients with diabetes and peripheral artery disease [12], suggesting that foot skin temperature assessment has a role in clinical practice, increasing the management quality of patients at risk to develop foot complications.

Research has been published on the topic of skin temperature analysis of the foot, both with automatic and manual analysis. An automated analysis [e.g. 13,14,15] is not available in most clinical setting realities and manual analysis is often performed [12,16–18]. As previously discussed, the placement of ROIs in thermograms contributes to uncertainty in measurements, however, the number of studies assessing the reliability of the analysis of foot temperature is very limited. Recently Silva, Castro, Carvalho, Chaves, Ruela and Iunes [18] have investigated inter and intrarater reliability of the analysis of thermograms but important information regarding the analysis is missing. The procedure for temperature extraction was not described and it is not clear if the measurements were based in a single pixel or in an area of pixels because this information was not reported.

An angiosome is a three-dimensional territory supplied by specific arteries and drained by specific veins [19]. The foot and ankle are supplied mainly by three arteries, the anterior tibial artery (ATA), the posterior tibial artery (PTA) and the peroneal artery (PA). The dorsum of the foot is supplied by the ATA, the lateral border of the ankle and heel are supplied by the PA and the remaining parts of the sole of the foot are supplied by three branches of the PTA. The medial calcaneal artery (MCA) supplies the medial aspect of the heel, the medial plantar artery (MPA) supplies the instep and the lateral plantar artery (LPA) supplies the lateral midfoot and forefoot [20–23]. The use of the angiosome concept to define the regions of interest is becoming increasingly popular but, to date, the reliability of the placement of ROIs based in this concept has not been assessed. Therefore, the aim of this study was to assess the interrater and intrarater reliability of the analysis of foot skin temperature based on the angiosome concept and the association between skin temperature differences and the differences in size of the ROIs.

2. Methodology

This study was conducted with data from a larger prospective cohort study (ClinicalTrials.gov Identifier: NCT03254095), approved by the ethical committee of Centro Hospitalar do Porto.

2.1. Sample size requirements

Minimum sample size was calculated with the formula by Bonett [24]. Considering two raters, a confidence interval width of 0.2, a desired intraclass correlation coefficient of 0.9 and a significance level of 0.05 the minimum sample size was 20 feet.

2.2. Skin temperature assessment

Skin temperature measurements were performed in the morning, away from airflow and infrared radiation sources, after a 10-minute acclimation period in a room with controlled ambient temperature (23.3 ± 0.6 °C) and relative humidity (54.4 ± 5.5%). An infrared camera (FLIR Systems, E60, Wilsonville, OR, USA), which has a sensor array size of 320x240, noise equivalent temperature difference (NETD) of 50 mK at 30 °C and ± 2% of repeatability of the overall reading with emissivity set to 0.98 was used to acquire images of the plantar and dorsal aspects of the feet. The camera was always turned on at least 40 min before the first assessment of the day to allow sensor stabilization. The camera was positioned perpendicular to the feet at 1 m distance for image acquisition. The patients were seated, with knees extended and legs supported by a chair while acquiring plantar thermograms, and when acquiring dorsal thermograms patients were seated with knees flexed. All thermograms were acquired by the same researcher.

2.3. Reliability assessment

Thermograms from 13 diabetic foot patients (26 feet) were analysed with FLIR ResearchIR Max software (FLIR Systems, version 4.30.0.69) by two blind assessors. Both assessors had less than one year of experience analysing thermal images but were previously instructed about the angiosome concept and respective ROIs corresponding to the ATA, PA, MCA, LPA, MPA. The assessors were asked to evaluate all the

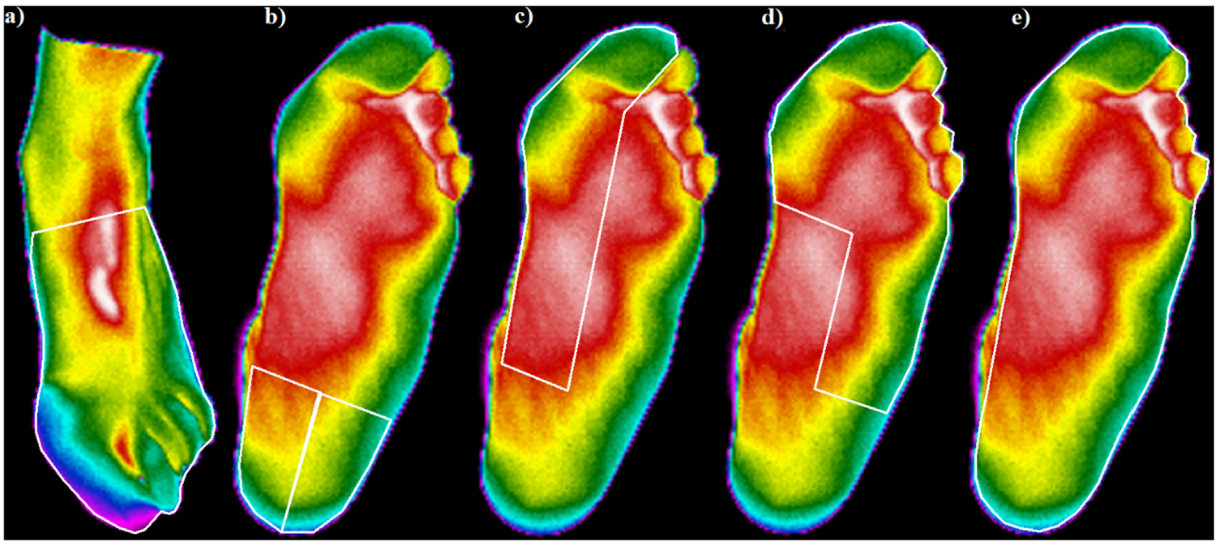

Fig. 1. Regions of interest corresponding – from left to right – to (a) the ATA, (b) the MCA and PA, (c) the MPA, (d) the LPA and (e) the entire plantar surface.