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Skin temperature evaluation by infrared thermography: Comparison of image analysis methods

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HIGHLIGHTS

- Analysis of calf temperature distribution by infrared thermography.
- Comparison among a well established method of image analysis and two new methods.
- Temperature mean value obtained with different method give comparable results.
- Method based on maxima values shows less operator dependencies.
- New Tmax method seems to be able to detect asymmetry on human body.

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ABSTRACT

Body temperature in medicine is a parameter indicating abnormal activity of human tissues; it is used to diagnose specific pathologies or as an indicator of the muscle activity during physical exercise.

Temperature measurements through infrared thermography have the advantages to be non-invasive and to record temperature data simultaneously from different points on a wide area of the body.

The difference between the values of temperature traditionally measured with contact probes or standard technique and the ones measured by thermal imaging lies in the fact that the first produces a scalar value, while the second gives a distribution over a surface. The analysis of thermographic images, with the goal of obtaining a temperature value representative of a specific area, is usually performed by different methods of averaging temperature values inside a selected Region of Interest (Troi and Tot). In this paper the authors present a critical comparison between the methods mainly used in literature in the specific case of a muscular group of calves on a population of 33 healthy subjects. Here, the authors describe an alternative method (Tmax) to obtain a temperature value of a specific area based on maximal temperature detection instead of considering the average temperature on the selected area. No meaningful difference in mean temperature between Troi and Ttot was found ($p = 0.9$), while temperature values calculated using Tmax were higher than the above methods ($p < 0.001$). The high correlation among the compared methods prove that they can equally represent temperature trends in cutaneous thermographic analyses.

1. Introduction

The first use of infrared thermography (IRT) in the biomedical sciences was reported only in 1960 [1], although the diagnostic applicability of temperature measurement by infrared technique were already proposed by Hardy in 1934 [2]. IRT has been used in the last 50 years to study diseases in which skin temperature is an indicator of inflammation or blood flow changes due to a clinical abnormality [3,4]. In living body measurements, mechanisms of skin heating/cooling are complex due to the combined effects of radiation and local blood flow.

Considerable progress has been achieved over the last 20 years in the knowledge of the physiological mechanism of skin temperature distribution and in the methodology of usability of IRT for the standardization of measurement protocols and the statistical data analysis [1,3,4].

The use of IRT in the measurement of temperature of human skin has the advantage to be completely non-invasive. The advantage of using this technique, compared to alternative methods requiring a contact between the object and the sensor, lies in the fact that with the use of IRT the skin temperature is not influenced by the presence of any probes that could modify the temperature

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variation of the surface through conduction or through irradiation. Thermal imaging permits also to have an instantaneous temperature map of several parts of the subject analysed.

In order to perform correct and reliable thermographic measurements on humans, several conditioning factors should be controlled: Ring and Ammer suggest the requirements for the environmental conditions, the experimental set up and the preparation of the subject [3,5].

To the authors' knowledge, despite the increasing popularity of the IRT in biomedical field, no papers are currently available investigating the characteristics of the method to calculate the representative temperature value of the anatomical region under inspection.

In the last years IRT has progressively turned into an important technique to record variations of cutaneous temperature linked to physical activity. Gold et al. [6] measured temperature of the dorsal hand of office workers using a rectangular analysis tool of a thermal camera software, positioned following anatomical features. Merla et al. [7] studied thermoregulation during and after the exercise in runners, Zontak et al. [8] and Torii et al. [9] for bicycle ergometer, Ludwig et al. [10] for breathing exercise, Formenti et al. [11] and Ferreira et al. [12] for resistance exercise in different categories of subjects (trained/untrained and old/young respectively). In such exercise-associated skin temperature changes studies, researchers began to specify the methods to calculate the representative temperature value of the area under investigation. The analysis of thermographic images is usually performed by a dedicated software selecting a Region of Interest (ROI) on a specific body area. In the study concerning breathing exercise, Ludwig et al. [10] considered ten ROI on the subject's trunk. Thermal data of seven ROI was calculated averaging the temperature value of all the pixels included in each ROI. For the others three ROI (left and right pectoral muscles, and navel) thermal data were extrapolated using an alternative method: a larger ROI was selected including all the investigated area (anatomical ROI), then a dedicated software automatically found the warmest pixel in the ROI and averaging the temperature over the 24 neighbouring pixels. This procedure was set up as a consequence of the irregular thermal distribution inside the ROI where subcutaneous circulation was more evident with their irregular shapes. It also permitted to avoid any possible operator dependence, although Ferreira et al. in their experiment found no significant intra-individual variability [12]. A similar method was used by Formenti et al. [11] to evaluate skin temperature in trained and untrained subjects. They investigated how the training level improves the ability to rapidly elevate skin temperature in response to a localized exercise. To obtain a reliable mean temperature of calves surface, avoiding the operator dependence of the ROI selection process, a new procedure was set-up. A region was selected by the operator for each calf including all the muscles involved in exercise. Inside this region, the software selected the five hottest pixels with five pixels of minimum distance from each other. This criterion allowed the authors to obtain a more reliable sampling of the warmest areas of the calves. Finally Jones and Plassmann [13] presented in their paper different ways to use IRT for diagnostics on human, starting from single static image to very high frequency capture, using the ROI method to calculate the temperature as well.

All the aforesaid papers show a non-homogeneity in the analytical methods to calculate a representative temperature value of a body area. The reason being that, although with similarities, each of the authors uses a specific method to analyse an area of interest.

Skin temperature also depends on anatomical factors, such as the presence of irregularities on the surface and the presence of different kind of subcutaneous tissue (fat tissue and muscular tissue) [7]. These factors can influence distribution of the skin temperature of a specific body area, thus it is frequent to find a non-Gaussian thermal distribution inside a selected ROI. In fact analysing cutaneous temperature the authors found abnormal thermal distribution of calves. For example in Fig. 1(*left*) it is possible to notice that, especially the left calf of the subject, presents a non-regular thermal distribution, while on the right of the same figure there is a subject having a normal thermal distribution of their calves. Accordingly, as demonstrates the irregular thermal distribution characterizing the subject's calves in Fig. 1, it may not always be correct the choice to average over the temperature value of all the pixels included in a selected ROI. From this consideration it is clear that the ROI method can not be used for all skin areas and for all situations. It would be correct to calculate the temperature values using other methods.

The aim of this study was to compare three different methods of thermal imaging analysis presented in literature. To perform this comparison the authors evaluated the results obtained through the analysis of thermal images recorded on a well defined muscular area (calves) using different methods (Troi, Tmax, Tot) completely described in the 'Materials and Methods' section.

First, authors hypothesized that the two methods based on wide area calculation, Troi and Ttot, should be equivalent methods, while Tmax, based on threshold criterion, should be slightly different.

Second, the authors sought the best method to check difference in skin temperature between left and right calf of the same subject.

The comparison proposed in this work among the temperature values of the same body area (calves muscular group) obtained by three different methods could be helpful to better understand the advantages and the disadvantages of each method and can contributes to a detailed definition of criticisms and specific skills of these tools for thermal imaging analysis in the field of biomedical applications.

2. Materials and methods

2.1. Subjects

The subjects taking part in this study were selected from a various heterogeneous population of the Università degli Studi di Milano and from a high level synchronized swimming team. Authors considered subjects from 15 to 45 years old in order to extend as more as possible the sample variety. Thus authors collected 12 female athletes, 9 male athletes, 10 female sedentaries, 2 male sedentaries. The 33 healthy subjects had a wide range of anthropometric characteristics and level of physical activity (from sedentary to athletes). The choice of different categories of subjects was made in order to test how robust are the methods when there is an high interindividual variability.

They had not assumed drugs or medications with a potential effect on cardiovascular and thermoregulatory functions during the two months prior the tests.

The Ethical Committee of the Università degli Studi di Milano approved this study. After a thorough explanation of the protocol that was going to be used, the subjects, or the parents of the underage ones, accepted informed written consent to participate in this study.

2.2. Experimental protocol

Subjects observed the following standard preliminary protocol for infrared thermal imaging measurements, indicated by [7,12] in previous studies: they abstained from assuming alcoholic or caffeine-containing products for a 4-h period prior to the start of the experiment; they removed body hair on legs that were clean and