Journal of Thermal Biology 66 (2017) 1–9

Contents lists available at ScienceDirect

Journal of Thermal Biology

journal homepage: www.elsevier.com/locate/jtherbio

The effect of body fat percentage and body fat distribution on skin surface temperature with infrared thermography

Ana Carla Chierighini Salamunes[a,*], Adriana Maria Wan Stadnik[a], Eduardo Borba Neves[a,b]

[a] Graduate Program in Biomedical Engineering, Federal Technological University of Paraná – UTFPR, Av. Silva Jardim, 807, Block V3, 80230-000 Curitiba, PR, Brazil

[b] Brazilian Army Research Institute of Physical Fitness, Av. João Luís Alves s/n, 22291-090 Rio de Janeiro, RJ, Brazil

ARTICLE INFO

Keywords:
Thermal imaging
Thermal distribution
Skin temperature
Body Composition
Adipose tissue

ABSTRACT

This study aimed to search for relations between body fat percentage and skin temperature and to describe possible effects on skin temperature as a result of fat percentage in each anatomical site. Women (26.11 ± 4.41 years old) (n =123) were tested for: body circumferences; skin temperatures (thermal camera); fat percentage and lean mass from trunk, upper and lower limbs; and body fat percentage (Dual-Energy X-Ray Absorptiometry). Values of minimum (T_{Mi}), maximum (T_{Ma}), and mean temperatures (T_{Me}) were acquired in 30 regions of interest. Pearson's correlation was estimated for body circumferences and skin temperature variables with body fat percentage. Participants were divided into groups of high and low fat percentage of each body segment, of which T_{Me} values were compared with Student's *t*-test. Linear regression models for predicting body fat percentage were tested. Body fat percentage was positively correlated with body circumferences and palm temperatures, while it was negatively correlated with most temperatures, such as T_{Ma} and T_{Me} of posterior thighs (r =−0.495 and −0.432), T_{Me} of posterior lower limbs (r =−0.488), T_{Ma} of anterior thighs (r =−0.406) and T_{Mi} and T_{Me} of posterior arms (r =−0.447 and −0.430). Higher fat percentages in the specific anatomical sites tended to decrease T_{Me}, especially in posterior thighs, shanks and arms. Skin temperatures and body circumferences predicted body fat percentage with 58.3% accuracy (R =0.764 and R^2 =0.583). This study clarifies that skin temperature distribution is influenced by the fat percentage of each body segment.

1. Introduction

Human body thermoregulation is influenced by several intrinsic and extrinsic factors. Body heat is mostly a co-product of metabolic activity, which is dissipated through skin, in order to maintain thermal balance. Core temperature differs from skin surface temperature, since the latter is highly influenced by ambient conditions, such as draughts and temperature (Plowman and Smith, 2009).

Skin temperature depends also on intrinsic factors, such as body fat percentage and subcutaneous fat (Chudecka et al., 2014; Neves et al., 2015c; Plowman and Smith, 2009). Adipose tissue depots in hypodermis act as an insulator, interfering in heat transfer between body and ambient (Henschel, 1967), consequently decreasing skin surface temperature (Gatidis et al., 2016; Neves et al., 2015c).

Infrared thermography (IRT) is a technology which assesses skin surface temperature by means of body radiation. The equipment is a non-invasive, non-contact, risk-free technology (Brioschi et al., 2012; Usamentiaga et al., 2014). It has been studied as a method of monitoring several diseases and dysfunctions, such as sports lesions (Bandeira et al., 2012) and premature diagnosis of breast cancer (Han et al., 2015; Collett et al., 2014). These and other physiological alterations result in thermal abnormalities which occur below the hypodermis, which is below the subcutaneous fat layer. Hence, thermal images might be misinterpreted if the examiner does not consider the insulating action of the adipose tissue.

IRT has already been used in studies relating body fat percentage – estimated with bioelectrical impedance – and skin surface mean temperature (T_{Me}) of different limbs in men and women (Chudecka and Lubkowska, 2016, 2015; Chudecka et al., 2014). Savastano et al. (2009) have studied the same pattern in normal weight and obese subjects, using a Dual-Energy X-Ray Absorptiometry (DXA) device, which can be considered as the gold-standard for body composition.

Abbreviations: BC, Body circumference; DXA, Dual-Energy X-Ray Absorptiometry; IRT, Infrared Thermography; T_{Me}, Skin surface mean temperature; T_{Mi}, Skin surface minimum temperature; T_{Ma}, Skin surface maximum temperature; ROI, Region of interest

* Correspondence to: Post-Graduate Program in Biomedical Engineering, Technological Federal University of Paraná – UTFPR, Av. Silva Jardim, 807, Block V3, 80230-000 Curitiba, PR, Brazil.

E-mail addresses: anacarlasalamunes@yahoo.com.br (A.C.C. Salamunes), stadnik@utfpr.edu.br (A.M.W. Stadnik), borbaneves@hotmail.com (E.B. Neves).

http://dx.doi.org/10.1016/j.jtherbio.2017.03.006
Received 13 November 2016; Received in revised form 15 March 2017; Accepted 15 March 2017
0306-4565/

However, results found by these authors were not specific for women, and none of the studies cited above have analyzed normal weight and overweight (non-obese) women with DXA. Also, the relation between skinfold thickness and skin surface temperature has already been described in some populations (Neves et al., 2015b, 2015c).

However, the effect of fat percentage in each anatomical site has not yet been explored. DXA devices allow to estimate lean mass, fat mass and percentage of fat from different limbs, enabling a precise analysis of these variables in skin surface temperature. The aim of this study was to search relations between body fat percentage and skin surface temperature and to describe possible effects on skin surface temperature as a result of the fat percentage of each anatomical site.

2. Materials and methods

2.1. Ethics

This research was approved by the Research Ethics Committee of the Technological Federal University of Paraná (Certificate of Presentation for Ethical Consideration – CAAE n°53602116.3.0000.5547). Prior to participation, the subjects signed a written informed consent.

2.2. Subjects

The subjects were: women from the city of Curitiba, Brazil; 18–35 years old; they were classified as having normal weight or being overweight, but not obese (body mass index from 18.5 to 29.99 kg/m^2); and they were not pregnant. A total of 185 women were enrolled in the study. Women with suspected pregnancy were excluded, as well as those who had already been pregnant and the ones who had had fever since 15 days prior to participation (Brioschi et al., 2012). Subjects who went through bariatric surgery, liposuction, abdominoplasty or any procedure interfering on body fat mass were also excluded. After analyzing the criteria above, 130 women were recruited and evaluated. Among these, seven subjects were excluded because of high variation of skin surface temperature between left and right limbs. Finally, data from 123 women was analyzed (n =104 normal weight and 19 overweight).

2.3. Study design

This study aimed to analyze how adipose tissue interferes in the skin surface temperature of several body segments, in young women, based on the hypothesis that individuals with lower body fat percentage would have higher skin surface temperature than those with higher body fat percentage. Since adipose tissue distribution may not be homogenous, it was also hypothesized that anatomical sites with exceeding fat percentage would have lower skin surface temperature. Hence, the sample was divided into groups of low and high fat percentage per anatomical site and their results were compared statistically (Fig. 1).

Skin temperature may be increased by muscle mass (Neves et al., 2015a). Thus, in order to assure that changes in skin surface temperatures were due to adipose tissue only, lean mass was assessed and its results were also compared between the selected groups. A secondary aim was to verify the possibility of developing a mathematical model to estimate body fat percentage based on body circumferences and infrared thermography. A DXA device was considered gold-standard for body composition (body fat percentage and lean mass) and skin surface temperature was assessed with a thermal camera.

Subjects were tested in two different laboratories. In the first one, anthropometric evaluation was performed, followed by the acquisition of thermal images. In the second ambient, body composition was assessed with DXA.

2.4. Orientations for participants

In order not to interfere in thermal results, prior to participation, subjects were oriented: not to practice any physical activity and not to shave any body parts as of three days before participation; and not to ingest any alcoholic drinks, as of two days before participation. On the day scheduled for evaluation, participants should: not wear any accessories such as watches, bracelets and rings; not ingest caffeine; not use any skin products, such as lotions and deodorants; ingest only small portions of food as of four hours before examination; and not smoke as of two hours prior to participation (Brioschi et al., 2012; Fernández-Cuevas et al., 2015).

Testing was scheduled for dates when participants would not be having their menstrual period, but phases of menstrual cycle were not controlled. Even though the core temperature is higher in the luteal phase compared to follicular phase (Grucza et al., 1993), skin temperature is equivalent in both phases (Garcia et al., 2006; Nagashima, 2015). Since intake of oral contraceptives might alter body temperature (Grucza et al., 1993), all values of skin surface temperature were compared between women who were (n =72) or were not (n =51) taking contraceptive pills. Testing was performed in the afternoon, in order to avoid changes in the circadian cycle (Fernández-Cuevas et al., 2015).

2.5. Thermal images

Body temperatures were acquired with a Fluke Ti400 thermal camera, set for 0.98 emissivity (Fernández-Cuevas et al., 2015; Ring and Ammer, 2012). Before image acquisition, participants went through 15 min of acclimatization in standing position, wearing swimsuits, in a controlled room with temperature set at 21 °C (Fernández-Cuevas et al., 2015). The participants did not stand in front of the air-conditioning system, and doors and windows were kept closed during evaluation, hence there were no draughts influencing the examination. The thermal camera was placed 2.5 m away from the participant. Four thermal images were taken of each participant in orthostatic position: both superior and inferior limbs in anterior and posterior views. By using Smartview 3.1.4 software, 30 regions of interest (ROI) were selected. ROI selected in anterior and posterior views, on both right and left sides, were: arms, forearms, upper limbs (arms and forearms), thighs, shanks and lower limbs (thighs and shanks). Palms, abdomen and flanks temperatures were also acquired on both sides. Chosen ROI are shown unilaterally in Fig. 2. Mean, minimum and maximum temperatures (T_{Me}, T_{Mi} and T_{Ma}, respectively) were registered from each ROI.

2.6. Anthropometrics and DXA

Body mass was measured with a Wiso digital scale (W721), with 180 kg capacity and 100 g precision. A stadiometer (WCS Wood Portable Compact) of millimeter precision was used to register stature, in meters. Body mass index (mass/stature^2) was calculated in order to classify participants as normal weight or overweight.

Body circumferences (BC) were measured with an inelastic metal tape on the right limbs. Measurements of BC were performed on the arm, forearm, waist, abdomen, hip, thigh and leg, as follows. The arm was measured at the midpoint between the acromion and the olecranon; the forearm, abdomen, hip and leg circumferences were measured in the largest portion of each of these regions; waist was measured in the smallest portion between the 12th rib and the iliac crest; and thigh circumference was measured at the midpoint between the inguinal line and the upper edge of the patella. Measurements were performed twice, in circuit.

A DXA device (Hologic DXA System) was used to estimate total body fat percentage. Also, data of lean mass and fat percentage from the following body segments were acquired: left upper limb; right