Influence of Muscle Cross-sectional Area in Skin Temperature

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Abstract: The present study aimed to determine the correlations among the arm subcutaneous fat percentage (SFP), arm muscle cross-sectional area (MCSA), arm total cross-sectional area (TCSA), and the difference between core temperature and skin temperature in biceps and triceps areas, measured using thermography. This research focused on a cross-sectional study using a quantitative approach with participants consisting of young, untrained volunteers from the city of Curitiba, Brazil. The total sample size was 20 volunteers including 13 males and 7 females. A statistical correlation between MSCA and core and skin Δ temperature for the right and left biceps ($r = -0.487$, $p = 0.030$ / $r = -0.518$, $p = 0.019$), and also between TCSA core and skin Δ temperature for the right and left biceps ($r = -0.513$, $p = 0.021$ / $r = -0.554$, $p = 0.011$) was identified. These results confirmed that arm muscle cross-sectional area influenced skin temperature at the biceps region. This result can also be generalized to other areas of the skin, which show similar characteristics to the studied area.

1 INTRODUCTION

Thermography use in the biomedical field has increased significantly in the last decade (Bandeira et al., 2012, Sanches et al., 2013, Bandeira et al., 2014). Health professionals have used thermal variations or absolute temperatures of the regions of interest (ROI) to determine or assist in diagnosis(Bandeira et al., 2014).

Since thermography measures the infrared radiation emitted by the surface of the skin, and heat-producing regions (heart and muscle) are located in the innermost part of the body, there are some factors that may influence the conduction of internal heat to the skin's surface. Bandeira et al. (2012) suggested that one of these factors is the layer of subcutaneous fat. Colman and Beraldo (2010), Roschel et al. (2011), and Czuba et al. (2013) suggest that the level of physical training induces morphological changes in muscle tissue by modifying the cross-sectional area of the muscle (muscle hypertrophy), the type of muscle fiber, and the amount of mitochondria and muscle vasculature. Muscle hypertrophy is accompanied by increased capillary density. This vascular change could also alter the temperature of the skin over the considered muscle. Although the layer of subcutaneous fat and muscle hypertrophy have the potential to influence the skin temperature (Tsk) at the considered ROI, the relationship between these factors and skin surface temperature was unable to be identified in the literature.

Elucidation of these relationships can contribute to a better understanding of human thermal physiology. This knowledge can be applied immediately in the development of products such as sporting clothing (Bogerd et al., 2010) and work accessories (Psikuta et al., 2013). Thus, the present study aimed to determine the correlations among the arm subcutaneous fat percentage (SFP), arm muscle cross-sectional area (MCSA), arm total cross-sectional area (TCSA) and the difference between core and skin temperature in the biceps and triceps measured using thermography.

2 METHODS

This research can be characterized by a cross-sectional study with a quantitative approach, conducted with young and untrained volunteers from the city of Curitiba, Brazil.

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2.1 Volunteer

This study was approved by Human Research Ethics Committee of Campos de Andrade University Center under CAAE number 28901414.3.0000.5218. This study involved 26 volunteers selected among graduate students in physical education. Six of them were eliminated from the sample because they had tympanic temperature below 35.6°C (Lu et al., 2009), which would be incompatible with a healthy condition. This usually occurs when the volunteer has any anatomical changes in the ear canal. The total size of sample was 20 volunteers (13 males and 7 females).

2.2 Instrumentation and Data Acquisition

The infrared thermograms were taken in an acclimatized room with temperature of 24ºC. The volunteers remained in the room for 15 minutes reaching thermal balance before the images acquisition.

Thermal images were acquired from both arms (i.e. biceps brachii and triceps brachii regions) biceps. The core temperature (Tc) was measured by tympanic access because the eardrum shares the same arterial blood supply as the hypothalamus. Measurements of tympanic temperature were performed using a Braun Thermoscan infrared ear tympanic thermometer.

Fluke-Ti10 thermal imager; a computer with specific software to thermograms acquisition and processing (Fluke Smartview 3.5); and a digital thermo-hygrometer (Minipa® model MT241) for room temperature and humidity monitoring were also used.

The thermal imager has 160 X 120 focal plane array, uncooled microbolometer, which has sensors that allow measuring the temperatures ranging from -20ºC to +250ºC. This camera presents sensitivity to detect differences in temperature lower than 0.13ºC and it has accuracy of ± 2ºC of absolute temperature.

The following equipment was used for the anthropometric assessment: 0.5cm wide flexible measure tape, graded until millimeters; calibrated scientific adipometer (Cescorf); stadiometer (WCS Woody Compact) and one digital scale (Wiso W801), with capacity of 0-180kg and grading of 100g.

Skinfold thickness was measured using the triceps and bicepss. A single trained professional collected this data three times which was used for the calculation of the arithmetic average (Neves et al., 2013).

The values for TCSA and MCSA were calculated from the equations proposed by Frisancho (1981). These calculations were also used in studies of Pompeu et al. (2004) and Ripka et al. (2012) which are described in the Equations 1 and 2.

$$TCSA = MAC^2 \div (4 \times \pi) \quad (1)$$

$$MCSA = [MAC^2 - (TT \times \pi)]^2 \div (4 \times \pi) \quad (2)$$

Where: TCSA = arm total cross-sectional area (cm^2), MCSA = arm muscle cross-sectional area (cm^2), MAC = mid-arm circumference (cm) and TT = triceps skinfold thickness (cm)

The Equations 3 and 4 were used to calculate the SFP.

$$FA = TCSA - MCSA \quad (3)$$

$$SFP = (FA \div TCSA) \times 100 \quad (4)$$

Where: FA = arm fat area (cm^2) and SFP = arm subcutaneous fat percentage (%).

2.3 Data Processing and Analysis

Each image was analyzed by Fluke Smartview 3.5 software. This program was set to treat each image in the color palette red/blue, with emissivity of 0.98 and 24°C of background temperature (Neves and Reis, 2014). The circle tool was used and the average temperature of ROI over biceps and triceps muscles was considered, as illustrated in Figure 1.

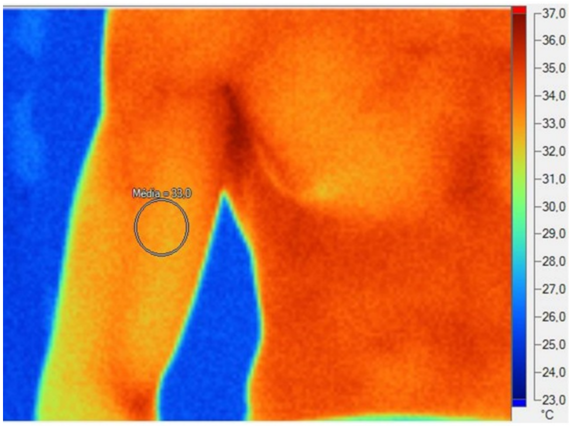

Figure 1: Illustration of right biceps thermogram analysis.

The Statistical analyses were performed with Statistical Package for Social Sciences (SPSS, version 21.0). Descriptive statistics (means and SD) were used to summarize the characteristics of the study sample, Shapiro-Wilk test was performed to test the variable distributions, Pearson correlation and t test for paired sample was used for the main analysis. The statistical significance level was defined as $p < 0.05$.

3 RESULTS

Core results for the study are located below in Table 1. The results of Shapiro-Wilk test showed a *p* value ranging from 0.203 to 0.945 for the studies variables.

Table 1: Average (Avg) and standard deviation (SD) of studied variables, Curitiba-PR, Brazil, 2014.

Variables	N	Avg	SD
Age (years)	20	26.40	9.10
tympanic temperature (°C)	20	36.14	0.35
Weight (Kg)	20	71.35	9.68
height (cm)	20	172.50	6.30
R triceps skinfold thickness (cm)	20	11.19	6.19
L triceps skinfold thickness (cm)	20	11.65	6.54
R biceps skinfold thickness (cm)	20	7.93	5.09
L biceps skinfold thickness (cm)	20	7.66	4.62
R MCSA (cm^2)	20	69.14	27.93
L MCSA (cm^2)	20	65.96	27.97
R triceps temperature (°C)	20	31.31	0.55
L triceps temperature (°C)	20	31.35	0.57
R biceps temperature (°C)	20	33.26	0.63
L biceps temperature (°C)	20	33.04	0.61
Δ R triceps temperature (°C)	20	4.82	0.61
Δ L triceps temperature (°C)	20	4.79	0.59
Δ R biceps temperature (°C)	20	2.88	0.70
Δ L biceps temperature (°C)	20	3.10	0.70

Legend: Avg = average, SD = standard deviation, R = right, L = left, Δ = difference between core temperature and skin temperature in considered area.

The t test for paired sample showed statistical differences between biceps and triceps skinfold thickness for both arms ($p < 0.001$). Figures 2 and 3 show the relationship between MCSA (cm^2) and Δ Temperature [core - skin] (°C) for the right and left biceps, respectively.

Table 2 shows the results of Pearson correlations among the studied variables. Although SFP does not correlate with MCSA in this study, it was also carried out the calculation of the partial correlation

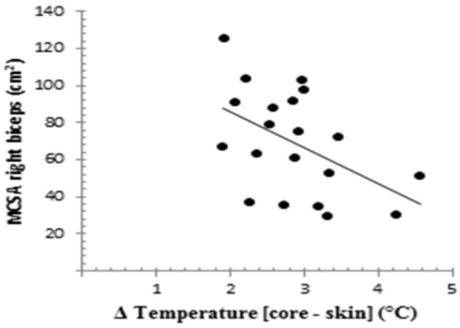

Figure 2: Scatter plot of relationship between right biceps MCSA (cm^2) and Δ Temperature [core - skin] (°C).

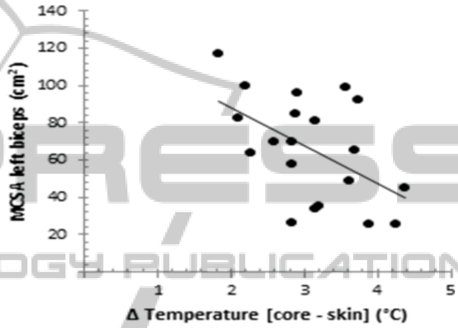

Figure 3: Scatter plot of relationship between left biceps MCSA (cm^2) and Δ Temperature [core - skin] (°C).

Table 2: Results of Pearson correlations among the variables: arm muscle cross-sectional area, arm total cross-sectional area, arm subcutaneous fat percentage and Δ = difference between core temperature and skin temperature in considered area, Curitiba-PR, Brazil, 2014.

Right side		MCSA	TCSA	SFP
Δ triceps temp	Pearson	-0.252	-0.217	0.234
	p value	0.284	0.357	0.320
	N	20	20	20
Δ biceps temp	Pearson	-0.487*	-0.513*	0.264
	p value	0.030	0.021	0.261
	N	20	20	20
Left side		**MCSA**	**TCSA**	**SFP**
Δ triceps temp	Pearson	-0.374	-0.371	0.317
	p value	0.104	0.107	0.173
	N	20	20	20
Δ biceps temp	Pearson	-0.518*	-0.554*	0.341
	p value	0.019	0.011	0.141
	N	20	20	20

* Correlation is significant at the 0.05 level (2 ends).
Legend: MCSA = arm muscle cross-sectional area (cm^2), TCSA = arm total cross-sectional area (cm^2), SFP = arm subcutaneous fat percentage (%), Δ = difference between core temperature and skin temperature in considered area (°C).

between MSCA and Δ temperature (core - skin), controlled by SFP, for the right biceps r_p = -0.463 (p = 0.046) and left biceps r_p = -0.452 (p = 0.050). And also between TCSA and Δ temperature (core - skin) for the right biceps r_p = -0.460 (p = 0.048) and left biceps r_p = -0.470 (p = 0.042).

4 DISCUSSION

Literature shows that the formation of new blood vessels plays an important role in several physiological processes including physical exercise recovery (Hitoshi et al., 1994)., a process known as angiogenesis (Schulz and Yutzey, 2004). The results of this study suggest that individuals with greater arm muscle cross-sectional area tend to have Tsk closer to Tc, possibly because they have a higher blood flow in the identified muscle. This hypothesis is supported;, under normal circumstances (no pathology), few physiological occasions induce angiogenesis, one of them being physical exercise (Prior et al., 2004). Thereby, increasing the number of capillaries would support the need to increase blood flow to the muscle (Fleck and Kraemer, 2006, Prior et al., 2004).

Authors McCall et al. (1996) found an increased number of capillaries in proportion to the increase of the muscle fiber, thus maintaining a unchanged capillary density per unit area of the fiber and muscle area. However, others have found no proportional increase in the microcirculation with increased muscle size (Weber et al., 2010). These differences, in the magnitude of alterations in response to increased muscle mass, can be explained due to different training protocols applied (Komi, 2006). The training protocol studied by McCall et al. (1996) used isotonic contractions for 12 weeks. Moreover, Weber et al. (2010) studied the physiological response to isokinetic training for 8 weeks.

Although the SFP has not shown significant correlations, some authors (Bandeira et al., 2012, Neves and Reis, 2014) claim that the layer of subcutaneous fat can increase the difference between the core and skin temperatures. The results of the partial correlations (right biceps r_p = -0.463, p = 0.046, and left biceps r_p = -0.452, p = 0.050), controlled by SFP, enhance the reliability of the correlations presented in Table 2 and the idea that increased muscle mass leads to a temperature closer to the center skin temperature.

The study identified significant correlations between muscle areas and the Δ temperature for biceps but the same was not observed in the triceps; this difference could be explained by the arm vascularization and the fat layer over of each muscle. Although the contribution of the biceps (less than 42% of MCSA) is fewer than that of the triceps (approximately 57% of MCSA) (Miyatani et al., 2004), it was observed that the biceps skinfold is also less than the triceps, allowing for thermogenic effects within the biceps. However, for the triceps, the heat dissipation is more limited by the presence of a major fat layer. Another important anatomical difference between the two muscles is the location of the brachial artery biceps, this difference may have influenced the results.

One possible immediate clinical implication concerns the recovery time from a muscle damage. Several muscle recovery strategies are based on the increase in local blood flow to carrying of reconstructive substances and removal of metabolites(Kovacs and Baker, 2014). Assuming that subjects with greater muscle area have increased local vascularity than those with smaller muscle area, the first may have faster muscle recovery that the last, because the blood flow is critical factor to the recovery muscle process(Imtiyaz et al., 2014).

5 CONCLUSIONS

It was concluded that the arm muscle cross-sectional area influences skin temperature measured at the biceps region. This result can be generalized to other areas of the skin, which show similar characteristics to the studied area, i.e., large muscle volume, superficial vascularization and small subcutaneous fat layer. The knowledge about the relationship among skin temperature, core temperature and the arm muscle cross-sectional area can be used during all thermogram analyses and in the design of sporting clothes and work clothes. This study suggests that one strong person (large MCSA) can dissipate heat more readily than those with small muscle mass (small MCSA).

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