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Body surface temperature distribution in relation to body composition in obese women

Monika Chudecka [a,*], Anna Lubkowska [b,c], Agnieszka Kempińska-Podhorodecka [d]

[a] Department of Human Functional Anatomy and Biometry Institute of Physical Culture and Health Promotion of Szczecin University, al. Piastów 40b, 71-065 Szczecin, Poland
[b] Department of Functional Diagnostics and Physical Medicine, Faculty of Health Sciences, Pomeranian Medical University in Szczecin, ul. Grudziadzka 31, 70-103 Szczecin, Poland
[c] Department of Physiology, Faculty of Biology of Szczecin University, ul. Felczaka 3c, 70–453 Szczecin, Poland
[d] Independence Laboratory of Medical Biology, Department of Laboratory Diagnostics and Molecular Medicine Pomeranian Medical University in Szczecin al. Powstańców Wielkopolskich 72, 70-111 Szczecin, Poland

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ABSTRACT

Adipose tissue levels and human obesity are known to be associated with increased heat production. At the same time, subcutaneous adipose tissue provides an insulating layer that impedes heat loss. The energy implications of obesity and body thermoregulatory mechanisms remain relatively poorly understood. This study attempted to examine the potential relationship between body composition (subcutaneous and visceral fat) determined by bioimpedance as well as BMI (body mass index), and skin surface temperature distribution recorded at rest.

One specific aim of this study was to draw a thermal map of body areas in obese women and compare this with women of normal body mass, and thus to identify body regions within which heat transfer is particularly impeded. As high fat content is a good insulator, it could reduce the body‘s ability to respond effectively to changes in environmental temperature, which would be problematic for thermal homeostasis. Our results showed that core temperature did not differ between obese and normal body mass participants, while skin temperature of most body surfaces was lower in obese subjects.

The results of regression analysis showed that the mean body surface temperature (T_{mean}) decreased with increasing percentage of body fat (PBF) of the abdominal area. The opposite relationship was observed for the front area of the hand (simultaneous increase in T_{mean} and PBF). We also found a negative correlation between BMI and T_{mean} of the thigh areas, both the front and the back. From this it could be concluded that the mean body surface temperature is dependent on body fat.

1. Introduction

Maintenance of a constant body temperature, regardless of changes in ambient temperature, is controlled by various physiological functions of the human body, including vasomotor control, non-shivering and shivering thermogenesis, and heat exchange with the environment. Approximately two-thirds of the resting metabolic rate (RMR) is expended in meeting the requirement of homeothermy, i.e. maintenance of a constant internal body temperature of approximately 37 °C (Landsberg and Young, 1983; Prentice et al., 1986).

Heat flows from the internal parts of an organism towards the superficial body layers and the skin, as well as in the opposite direction, requiring activation of skin circulation with only a small portion of heat passively conducted via the tissues. Heat loss is proportional to the temperature gradient between the skin and the environment (temperature gradient for dry heat loss, or vapor pressure gradient for evaporative heat loss), together with the body surface area available, which is therefore important for heat exchange. Hence, for a given steady-state dry heat loss, a smaller person would require a higher skin temperature compared to a person with a larger surface area to achieve the same effect. As to mass, in variables thermal conditions, for an equal heat storage rate, a larger mass will warm up less than a smaller mass (Havenith, 2001).

Obesity is increasing worldwide at an alarming rate in both developed and developing countries, with an increasing incidence year-on-year observed among children and adolescents. Obesity

* Corresponding author.
E-mail addresses: monikachudecka@wp.pl (M. Chudecka), agnieszkakempinska@poczta.onet.pl (A. Kempińska-Podhorodecka).

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increases the risk of many serious and morbid conditions, such as diabetes mellitus, hypertension, dyslipidemia, and some cancers, as well as increasing the risk of death from coronary heart disease (Martorell et al., 2000). The negative health consequences of excess body mass and obesity have induced researchers to further explore the risk factors and the health effects.

Obesity is a condition associated with a high body heat content. The energy implications of obesity and body thermoregulatory mechanisms, in particular the maintenance of thermal homeostasis in the body, are relatively poorly understood (Landsberg et al., 2009). Resting metabolic heat production is significantly greater in obese individuals than in lean individuals due to the larger fat-free mass (FFM) of muscle that accompanies excessive adiposity. Yet obese individuals may lose a smaller fraction of their metabolic heat as the core temperature that triggers vasoconstriction is higher in obesity. De Jongh et al. (2004) reported that obesity is associated with impaired skin microvascular function both in the basal state and during physiological hyperinsulinemia, measured as postocclusive capillary recruitment and endothelium-dependent vasodilation.

Both external (climatic) and internal (metabolic) heat sources influence body temperature. Assuming that increased body fat in obese people, especially in the subcutaneous layer, acts as an insulator and may impair the mechanisms of heat elimination from the body, a question arises as to whether subcutaneous and visceral fat content, together with the nature of its distribution could affect resting surface body temperatures under conditions of thermal comfort.

1.1. Aim of the study

In this study, we sought to investigate how different levels of visceral and subcutaneous adipose tissue affect core body temperature, as well as to map the thermal profile of the skin surface in humans. This study also attempted to examine the relationship between body composition (subcutaneous and visceral fat) determined by bioimpedance as well as body mass index (BMI), and the resting skin surface temperature distribution recorded at rest.

One outcome specific aim of this study was to draw a thermal map of certain body areas in obese women compare the heat distribution with that of women of normal body mass.

2. Materials and methods

Each participant provided a written assent before participation in the study according to the Declaration of Helsinki. The study was approved by the local ethics committee (Pomeranian Medical University Ethics Committee, KB-0012/151/12).

2.1. Study group

The study involved 20 volunteers, women aged 20–25 years ($n=20$), with evidence of simple obesity, resulting when caloric intake exceeds energy expenditure (promoted by over-eating and physical inactivity) and with BMI values $>30\ \text{kg/m}^2$, and not using any form of hormonal contraceptives. Preliminary qualification excluded individuals with metabolic syndrome X, diagnosed on the basis of elevated blood pressure, increased insulin resistance, reduced HDL cholesterol of less than 50 mg/dL, and elevated triglycerides. A control reference group ($n=20$) comprised young women, students of physical education at the University of Szczecin aged 21–23 years with BMI values of 18.5–24.99 kg/m^2, i.e. in the normal range. The control group comprised only healthy women, with no injuries or observed inflammations.

2.2. Methods

The women were subjected to measurements of body height (using an anthropometer), and waist and hip circumferences (with an anthropometric tape), and the waist-to-hip circumference ratio (WHR) was calculated. The bioimpedance method and a Jawon Medical X Scan Plus II multifrequency segmental body composition analyzer were used to determine the composition of the body, including body mass [kg], percentage of body fat (PBM) [%], lean body mass (LBM) [kg], skeletal muscle mass (SMM) [kg], total body water (TBW) [%], visceral fat mass (VFM) [kg], and subcutaneous fat mass (SFM) [kg]. Body mass index (BMI) [kg/m^2] was also calculated. In order to determine the estimated internal temperature of the body, tympanic temperature measurements were performed using an infrared Microlife IR1DA1 tympanic thermometer. Infrared thermometry is a reliable alternative method for the measurement of tympanic temperature and may be a useful method of assessing core temperature in the human body (Flouris and Cheung, 2010). The tympanic membrane receives blood from the branches of the internal carotid artery that supply blood to the thermoregulatory center in the hypothalamus of the brain, while the ear canal is easily accessible for measuring temperature. However, some studies have demonstrated that this method of measurement is problematic and may result in questionable accuracy of this measurement, for example as a result of dirt, inaccurate placement or lack of skill of the measurer (Moran and Mendal, 2002).

The study was conducted during the spring semester. Body composition and tympanic temperature were measured at the same time of day (8–9 a.m.). As the same measurement instrument was used for all participants, it was assumed that any potential measurement error was the same for all subjects (Haugan et al., 2012; Sund-Levander et al., 2002).

To eliminate the effects of the phase of the menstrual cycle on the temperature ranges observed in the study, temperature measurements were performed during each participant‘s follicular phase. It is known that a number of physiological processes in a woman‘s body are related to the different phases of the ovulatory cycle. The most important of these include changes in the levels of gonadotropins, estrogens and progesterone in the blood, differences in the water balances and fluctuations in body temperature which is approximately 0.4 °C higher in the luteal phase than in the follicular phase of the cycle (Grucza et al., 1993; Hessemer and Bruck, 1985; Hirata et al., 1986; Stephenson et al., 1982).

For each subject thermography was performed in a standing position. The study used a ThermaCAM SC500 thermal imaging camera (FLIR System), providing longwave (7.5 to 13 μm) imaging with thermal sensitivity of 0.1 °C. The study was conducted according to standards set by the European Thermographic Association (Fujimasa, 1995). A reliable visualization of temperature distribution over the body requires prior acclimatization, and therefore the participants were dressed in underwear (panties and bra) and earflaps, and remained for 20 min at a room temperature of 25 °C and 60% relative humidity before imaging. Thermal images were then obtained at a distance of 3 m.

The room (approximately 12 m^2 area) was closed, with a constant ambient temperature and humidity which were maintained at the same level during the measurement periods. There were no draughts or influences of air conditioning. There was a low intensity natural lighting. The room temperature during imaging experiments did not differ significantly between imaging of the normal body weight participants and the obese participants ($p=0.95$) and averaged 25.1 ± 0.3 °C for both groups. We therefore obtained thermal data at rest under thermoneutral conditions.

Measurement were always performed in the afternoon (after 4 p.m.). The similar times of tests and the same season was important to exclude the effect of circadian rhythms on body temperature fluctuations.

Measurement analysis used: Agema Report 5.4.1 and Agema Report Viewer 5.4.

Quantitative analysis of thermal images was performed for 12 areas of the body taken from the front and the back in a standing position (Fig. 1).

The mean surface temperature, T_{mean} was obtained for each chosen area, and was more representative of the complete area compared to minimum and maximum values.

2.3. Statistical analysis

Temperature data were found to be normally distributed (Shapiro–Wilk tests). The results are presented as arithmetic means (mean) with standard deviations (SD). Differences between the arithmetic means of morphological characteristics, body components, mean surface temperature (T_{mean}) and the tympanic temperatures of the obese women and women of normal body mass, were tested using two sample Student‘s test. We calculated Pearson‘s correlation and performed regression analyses between T_{mean} of the analyzed areas of the body, and BMI and body composition levels: PBF, VFM, SFM. Calculations were performed using Statistica 10 software (StatSoft).

3. Results

Analysis of study groups characteristics revealed no difference in age or body height between obese women and women of normal body mass. As expected however these groups did differ significantly in body mass, as well as in all body composition parameters (PBF, LBM, SMM, TBW, VFM, SFM), BMI and WHR ratio (Table 1).

The mean temperatures (T_{mean}) of the 12 areas of the body surface analyzed as well as core body temperature measured by infrared tympanic thermometer are presented in Table 2. Differences in T_{mean} of symmetrical body surfaces within studied groups were lower than 0.5 °C and were arbitrarily deemed to be negligible (Żuber and Jung, 1997).

The results presented in Table 2 show that the values of T_{mean} were similar in the two groups of women in the areas of the chest, upper back and hands. In the other analyzed areas of the body surface, values of T_{mean} in obese women were significantly lower than in women of normal body mass.

Next correlation analysis was performed, separately in the group of obese women and the group of normal body mass, between T_{mean} of the body surface areas and the levels of BMI, PBF, and SFM. In women of normal body mass there were no significant correlations, while among obese women there were significant correlations between T_{mean} of selected body areas and BMI, PBF, VFM and SFM. The results are shown in Table 3. The analysis showed a significant inverse dependence between T_{mean} of the abdomen, and BMI ($r=-0.84$, $p<0.0001$), PBF ($r=-0.88$, $p<0.0001$), VFM ($r=-0.7$, $p=0.001$), and SFM ($r=-0.62$, $p=0.006$). There was a significant inverse relationship between T_{mean} of the front thigh, and BMI ($r=-0.79$, $p<0.0001$), PBF ($r=-0.77$, $p=0.001$), VFM ($r=-0.61$, $p=0.01$), and SFM ($r=-0.54$, $p=0.026$), and also between T_{mean} of the back thigh, and BMI ($r=-0.75$, $p=0.001$), PBF ($r=-0.63$, $p=0.008$), VFM ($r=-0.57$, $p=0.010$), and SFM ($r=-0.53$,

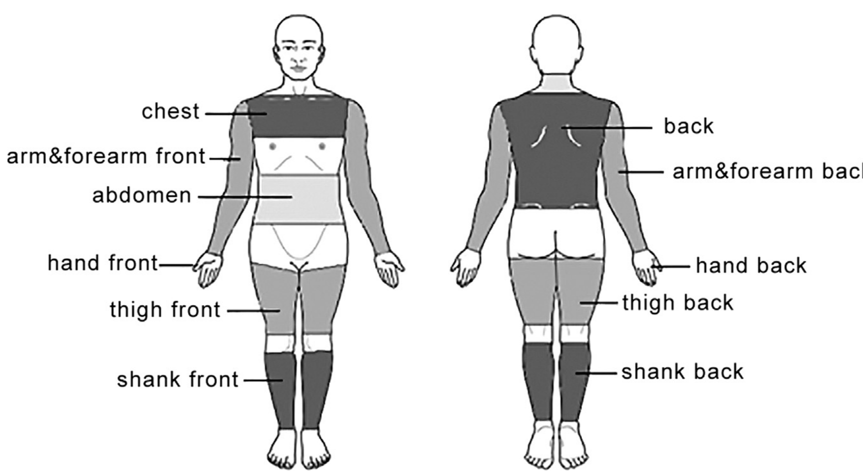

Fig. 1. The analyzed areas of the body.

Table 1
Characteristics of the studied groups and the results of the Student‘s test.

Parameters	Obese women $n=20$		Women of normal body mass $n=20$		Student‘s t-test
	Mean	SD	Mean	SD	
Chronological age	23.2	1.57	22.4	1.22	1.72
Body height [cm]	167.2	3.75	169	2.68	1.67
Body mass [kg]	90.7	5.12	60.4	2.56	**22.79**[a]
BMI (body mass index) [kg/m^2]	32.5	1.63	21.3	1.04	**24.82**[a]
PBF (percent of body fat) [%]	37.8	2.25	25.7	2.44	**15.41**[a]
LBM (lean body mass) [kg]	59.1	3.29	45.9	1.11	**16.45**[a]
SMM (skeletal muscle mass) [kg]	27	3.73	16.9	1.53	**10.82**[a]
TBW (total body water) [%]	42.1	4.1	33	0.64	**9.53**[a]
VFM (visceral fat mass) [kg]	4.3	0.63	1.6	0.21	**17.60**[a]
SFM (subcutaneous fat mass) [kg]	29.6	3.33	15.1	1.13	**17.85**[a]
WHR (waist hip ratio)	0.8	0.02	0.78	0.02	**3.00**[a]

[a] Statistically significant differences $t>2.03$, ($\alpha=0.05$).

Table 2
Mean surface temperature for the analyzed areas in obese women (mean and SD) and for women with normal body mass (mean and SD), and core temperature measured by an infrared tympanic thermometer.

T_{mean}	Obese women $n=20$		Women of normal body mass $n=20$		Student's t-test
Measured area	Mean	SD	Mean	SD	
Chest	33.6	0.24	33.9	0.6	1.93
Back upper	33.8	0.3	34	0.7	1.09
Arm, forearm front	32.3	0.19	32.9	0.9	**2.70**[a]
Arm, forearm back	32.1	0.2	32.7	0.8	**3.01**[a]
Hand front	31,7	0,3	31,9	0,8	0,97
Hand back	31.5	0.2	31.7	0.8	1.00
Abdomen	30.5	0.62	33.2	1	**9.61**[a]
Back lower	32.9	0.4	33.6	0.9	**2.96**[a]
Thigh front	30.9	0.32	32.7	0.6	**11.05**[a]
Thigh back	31	0.27	32.9	0.5	**13.97**[a]
Shank front	31.2	0.4	32.6	0.4	**10.49**[a]
Shank back	31.1	0.3	31.9	0.2	**9.50**[a]
Tympanic temp.	36.9	0.3	36.8	0.4	0.84

[a] Statistically significant differences $t>2.03$, ($\alpha=0.05$).

Table 3
Correlation between mean surface temperature (°C) and BMI (kg/m^2) and selected parameters of body composition: PBF (%), VFM, (kg), SF (kg) in obese women.

Measured area	BMI (kg/m^2) r		PBF (%) r		VFM (kg) r		SFM (kg) r	
Chest	0.08	$p=0.967$	0.22	$p=0.721$	0.33	$p=0.600$	0.26	$p=0.769$
Back Upper	−0.39	$p=0.121$	−0.33	$p=0.171$	−0.36	$p=0.113$	−0.35	$p=0.136$
Arm, Foream front	−0.18	$p=0.324$	0.05	$p=0.869$	−0.12	$p=0.408$	−0.2	$p=0.286$
Arm, Forearm back	−0.04	$p=0.571$	0.07	$p=0.797$	−0.04	$p=0.440$	−0.09	$p=0.381$
Hand front	**0.51**	**$p=0.039$**	**0.52**	**$p=0.025$**	0.24	$p=0.243$	0.22	$p=0.294$
Hand back	0.25	$p=0.325$	0.38	$p=0.109$	0.13	$p=0.536$	0.1	$p=0.644$
Abdomen	**−0.84**	**$p=0.000$**	**−0.88**	**$p=0.000$**	**−0.7**	**$p=0.001$**	**−0.62**	**$p=0.006$**
Back lower	−0.41	$p=0.179$	−0.35	$p=0.266$	−0.35	$p=0.161$	−0.32	$p=0.173$
Thigh front	**−0.79**	**$p=0.000$**	**−0.77**	**$p=0.001$**	**−0.61**	**$p=0.010$**	**−0.54**	**$p=0.026$**
Thigh back	**−0.75**	**$p=0.001$**	**−0.63**	**$p=0.008$**	**−0.57**	**$p=0.010$**	**−0.53**	**$p=0.018$**
Shank front	−0.06	$p=0.916$	−0.13	$p=0.883$	0.19	$p=0.297$	0.18	$p=0.371$
Shank back	0.04	$p=0.585$	0.06	$p=0.513$	0.21	$p=0.361$	0.24	$p=0.353$

Significant correlations are shown in bold ($p \le 0.05$)
r-correlation coefficient (high correlation – bold characters)

$p=0.018$). Additionally there was a significant correlation between increases in hand T_{mean} and increased BMI ($r=0.51$, $p=0.039$) and PBF ($r=0.52$, $p=0.025$).

Since our results showed that BMI and PBF, VFM, and SFM were all highly correlated with each other, so we used a one-dimensional linear regression model which took into account the variable having the greatest impact.

Correlation analysis helped determine the dominant dependent variables that were most correlated with independent variables, i.e. the mean temperatures of selected areas. These were identified as BMI and PBF; these dominant variables were then used for the regression analysis.

The results of linear regression analysis showed that the mean body surface temperature (T_{mean}) decreased with increasing percentage of body fat (PBF) of the abdominal area ($R^2=0.779$, $p<0.0001$). However a simultaneous increase in T_{mean} and PBF was observed for the front area of the hand ($R^2=0.366$, $p=0.0285$). We also found a negative relationship between BMI and T_{mean} of the thigh areas, both the front ($R^2=0.629$, $p<0.0001$) and the back ($R^2=0.568$, $p<0.0004$) (Table 4).

Table 4
Results of regression analysis T_{mean} of chosen body area against (PBF and BMI), $p<0.05$.

T_{mean} of hand front area against PBF (percent of body fat), $R^2=0.366$	$p=0.0285$
T_{mean} of abdomen area and PBF (percent of body fat), $R^2=0.779$	$p<0.0001$
T_{mean} of the thigh front area and BMI (body mass index), $R^2=0.629$	$p<0.0001$
T_{mean} of thigh back area and BMI (body mass index), $R^2=0.568$	$p<0.0004$

R^2 – the coefficient of determination.

4. Discussion

The aim of this study was to achieve a better understanding of body heat management in obese women by evaluating the relationships between the percentage composition of body fat, lean body mass, skeletal muscle mass, visceral fat as well as subcutaneous fat mass and temperature profiles of the chosen body surface areas under thermoneutral conditions.

We detected no differences in core temperatures between the normal body mass women and the obese women. These results confirm previous published data showing that the internal temperature of the body does not depend on body composition, including the content and location of fat, and consequently obesity is not accompanied by disorders of resting thermoregulatory mechanisms under conditions of thermal comfort (Heikens et al., 2011; Hoffmann et al., 2012).

One of the factors which could affect body surface temperature distribution is microvascular function in humans with different body compositions. We hypothesized that compared with normal body mass subjects, obese subjects would exhibit increased heat dissipation through the extremities (in particular, the hands) and decreased heat dissipation from the abdomen. Indeed, we observed some significant differences with respect to the resting body surface temperature of the observed areas. Our results confirm that in obese women, the high fat content creates an insulating barrier for conduction and exchange of heat, and thus reduces the body's ability to respond effectively to changes in environmental temperature at sites where the excess adipose tissue impedes heat transfer. Another factor which also affects the heat emission processes in obese women is impaired skin microcirculation in these areas (Antonios et al., 1999; Levy et al., 2001).

In obese individuals body mass increases without a proportional increase in height, resulting in a lower ratio of surface area to body mass (Verbraecken et al., 2006), and as cutaneous heat loss is relatively proportional to skin surface area (Sessler et al., 1991), obese individuals may lose their metabolic heat more slowly than those with normal body mass (Kurz et al., 1995). Thus, obesity itself reduces the ratio of heat loss to heat production and should lead to the retention of body heat.

Because the core temperature in the obese women studied was homeostatically regulated, thermoregulatory reflexes had to compensate and must therefore be biased toward heat dissipation in those with excessive adiposity. Peripheral sites, such as the hands, would be expected to remain effective for heat dissipation in obese individuals (due to relatively little adipose accumulation compared to more central locations such as the abdomen or hips) (Aita and Yoshizumi, 1994). Similar to Savastano et al. (2009) we hypothesized that under thermoneutral conditions heat dissipation from distal extremities (in particular the hands) would be augmented in obese subjects, whereas heat dissipation from central sites (such as the abdomen) would be reduced.

In the present study, the lowest mean temperatures in obese women were observed in the areas of the abdomen and thighs, corresponding to the areas with the greatest accumulation of body fat, and therefore suggesting that its insulating function hindered heat conduction. The mean temperatures were significantly lower than in the control group of normal body mass women. These results agree with other reports that local skin temperatures are influenced by subcutaneous adiposity (Livingston et al., 1987; Aita and Yoshizumi, 1994.; Claessens-van Ooijen et al., 2006).

It should be noted that we found no evidence of significantly increased mean surface temperatures of the distal parts of the upper limb (hand front, hand back) in obese women compared to normal body mass individuals, which seems to contradict with a previous report by Landsberg et al. (2009). However, it was suspected that peripheral sites such as the hands would be expected to remain effective for heat dissipation in obese individuals (relatively lower adipose accumulation than more central locations), but this study did not confirm that.

While considering the relationship among body surface temperature, BMI and selected parts of body composition, we found that such a relationship was significantly validated by correlation and regression analyses, and occurred only in the case of obese women. We therefore concluded that in women with normal BMI and body composition, in spite of differences between individuals, these parameters had no significant impact on T_{mean} in the selected areas of the body, they were significant only in obese subjects. The abdomen and thighs are the areas with the greatest accumulation of body fat, which has a significant impact on the surface temperature (which was much lower in obese subjects than in the control group). It is noteworthy that the temperature of these areas is not only inversely proportional to the subcutaneous fat content, but also, and even more so, proportional to the share of visceral fat. Although there was no difference in temperatures in the front and back of the hands between the groups, it should be noted that a positive correlation did exist between PBF, BMI and T_{mean} in the front hand area of obese women.

Cheng et al. suggested that skin and core temperatures contributed linearly to the control of vasoconstriction and shivering in men and that the cutaneous contributions averaged 20% in both men and women (Cheng et al., 1995). Individuals differing in body size, shape and composition appear to respond quantitatively differently to variations in both ambient and core temperatures, but the interrelations between morphological components and temperature regulation are complex.

Some limitations of our study must be noted: the absence of some body composition measures (e.g. DXA, MRI) and the relatively small sample size. Additionally, we did not measure skin–surface temperature of the finger, and forearm-minus-finger temperature gradients are accurate indices of thermoregulatory peripheral vasoconstriction (Rubinstein and Sessler, 1990). The research was a pilot study, and in the future we are considering an extension of research to male subject, as well as studies of changes in body surface temperature in obese people taking part in the influence of physical activity.

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