

ORIGINAL ARTICLE



Skin Temperature in Young Women with Low Values of Adipose Tissue

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ABSTRACT

Background. Skin temperature is an important indicator of the functional status of the body. Infrared thermal images of the body surface or its separate parts could be the indicator of body composition and, probably, the criterion of the functional activity of muscles. **Objectives.** This study aims to find a correlation between the average values of skin temperature in different parts of the body and the components of body composition in young women with low values of adipose tissue (FAT % = 20.73±5.50; BMI = 20.23±2.44). **Methods.** The study involved 69 healthy women aged 18-20 (BMI = 20.23±2.44). Participants were subjected to a 15-minute temperature adaptation in the room with a temperature of 22–24°C and humidity of 45-50%. We measured body composition using bioelectrical impedance analysis and taking eight photos of different body areas with the help of the thermal infrared camera. **Results.** Correlation analysis allowed us to reveal temperature correlations with BMI and FAT%. The most significant values were registered between FAT% and t_{mean} ($r=-0.36$), FAT% and t_{shinBL} ($r=-0.39$), FAT% and t_{shinBR} ($r=-0.38$). **Conclusion.** To forecast FAT% for this sample, the skin temperature of the shin is the most informative parameter (decrease by 1% results in the increase in FAT% by 1-1.5%). Moreover, we made a hypothesis that the differences between t_{mean} of shins and hips indicate the postural balance: $t_{\text{shinmean}} > t_{\text{hipmean}}$ is responsible for the shin strategy; $t_{\text{shinmean}} < t_{\text{hipmean}}$ indicates the hip strategy.

KEYWORDS: *Young Women, Body Composition, Skin Temperature, Temperature Distribution, Thermal Imaging*

INTRODUCTION

Skin temperature is an important indicator of the functional status of the body; its assessment is significant in different cases connected with adaptation to environmental factors and muscle activity. It also reveals the intensity of thermal output (1, 2). The formation mechanism of such differences can be connected with three main factors: the structure and functional activity of

skin capillary network, density and activity of sweat glands, and metabolic activity of tissues located directly under the skin (3, 4).

Hypothesis. Infrared thermal images of the body surface or separate parts of the body can be the indicator of body composition.

Aim. This research aims to study the correlation between body composition and the

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data on skin temperature for the whole body and its separate parts.

MATERIALS AND METHODS

The study was conducted in the Research center for Sports science at South Ural State University. The study involved 69 healthy women aged 18-20 years. The study was conducted in the daytime (5). The study was conducted in accordance with the Declaration of Helsinki. All participants expressed their informed consent for taking part in the study. The study was also approved by the ethical committee of South Ural State University.

Before the examination, the participants were subjected to a 15-minute temperature adaptation in a room with a temperature of 22–24°C and humidity of 45–50 %. All participants were in the condition of muscle rest, sitting or staying naked to the underwear. The choice for such a sample was determined by a relative complexity of data interpretation on body composition and, in particular, BMI (6-8). We suppose that if the hypothesis is confirmed for this sample, it will be proved for other categories of people.

We measured body composition by using Tanita BC-418 analyzer, calculated adipose tissue mass and percentage, and performed thermography with the help of Baltech-TR-01500 non-contact thermal camera. The thermal camera was located at a distance of 2 m from participants at the height of 150 cm from the floor. For each participant we made 8 photos (9-11): lower part of the body back view, upper part of the body back view, lower part of the body front view, upper part of the body front view, lower part of the body left view, upper part of the body left view, lower part of the body right view, upper part of the body right view (Fig. 1).

The thermogram data obtained were processed with the help of Baltech Expert specialized program, where for the quantitative analysis, on each image, we selected body areas (Table 1) manually to calculate the average temperature (12) automatically with the accuracy of up to 0.1°C or 2 % (Fig. 2). Apart from the temperature of the areas selected, we introduced the additional parameters obtained using the methods of mathematical processing: average body temperature (t_{mean}), average temperature of the upper part of the body (t_{meanT}), average temperature of the lower part of the body (t_{meanD}), difference between maximal and minimal temperatures ($t_{\text{max}}-t_{\text{min}}$), sum of body temperatures

($\sum t$), body temperature mode (t_{Mo}), average temperature of the right part of the body (t_{meanR}), average temperature of the left part of the body (t_{meanL}), average temperature of the front part of the body (t_{meanF}), average temperature of the back part of the body (t_{meanB}), temperature difference between the right and left parts of the body ($t_{\text{meanR}} - t_{\text{meanL}}$), temperature difference between the front and back parts of the body ($t_{\text{meanF}} - t_{\text{meanB}}$), average hip temperature (t_{hipmean}), average shin temperature (t_{shinmean}), temperature difference between hips and shins ($t_{\text{hipmean}} - t_{\text{shinmean}}$), temperature difference between the average and mode temperatures ($t_{\text{mean}} - t_{\text{Mo}}$).

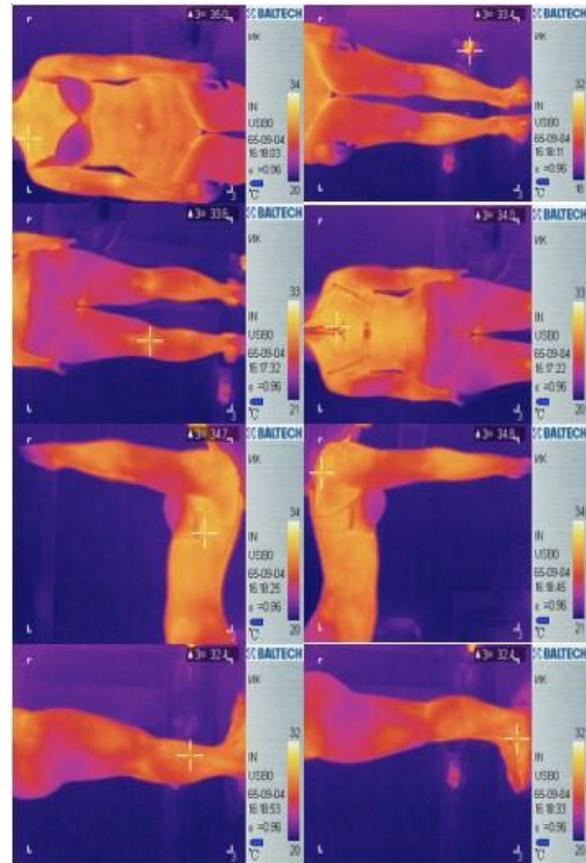


Figure 1. Example of thermal images

With the help of Tanita BC-418 body composition analyzer (input data: body type – standard, gender – female, age, body length) we registered the following parameters: body mass index (BMI), adipose tissue percentage (FAT%), adipose tissue mass, kg (FAT MASS), body mass without adipose tissue, kg (FFM), total body water, kg (TBW), adipose tissue percentage of the right leg (FAT%_{RL}), of the left leg (FAT%_{LL}), of the right arm (FAT%_{RA}), of the left arm (FAT%_{LA}), of the trunk (FAT%_{TRUNK}); adipose

tissue mass (kg) of the right leg (FAT MASS_{RL}), of the left leg (FAT MASS_{LL}), of the left arm (FAT MASS_{LA}), of the right arm (FAT MASS_{RA}), of the trunk (FAT MASS_{TRUNK}); mass (kg) of the right leg (FFM_{RL}), of the left leg (FFM_{LL}), of the right arm (FFM_{RA}), of the left arm (FFM_{LA}), of the trunk (FFM_{TRUNK}) without adipose tissue; muscle mass (kg) of the right leg (MUSCLE MASS_{RL}), of the left leg (MUSCLE MASS_{LL}), of the right arm (MUSCLE MASS_{RA}), of the left arm (MUSCLE MASS_{LA}), of the trunk (MUSCLE MASS_{TRUNK}). Moreover, we also calculated the following parameters: difference in the percentage of adipose tissue between the trunk and legs (average values of the right and left legs), %, (FAT%_{TRUNK} - FAT%_{LEG}); difference in the percentage of adipose tissue between the trunk and arms (average values of the right and left arms), %, (FAT%_{TRUNK} - FAT%_{ARM}); difference in the percentage of adipose tissue between legs and arms (FAT%_{LEG} - FAT%_{ARM}).

DISCUSSION

The study of body composition with the help of bioelectrical impedance analysis is one of the most accurate non-invasive methods with a measurement error for some parameters (in comparison with the hydrodensitometry and dual x-ray absorptiometry) of no more than 5 % (13-16).

Human skin is an almost perfect emitter of infrared radiation in the spectral region beyond 3 microns. This energy may be recorded as a thermogram to yield a quantitative temperature map of the skin. If the nude subject has remained quiet in a cool room for 10 to 15 minutes prior to thermography, the skin temperatures are determined largely by the vascularity of the skin itself and by the heat conducted from within the

body (17). Therefore, if we take into account that the greater the depth of the subcutaneous fat the more its mass and the less heat loss (18, 19), then we can assume correlations and certain dependencies (20-23), the establishment of which will allow the creation of a technique and device to estimate the content of adipose tissue with the help of skin temperature measurements.

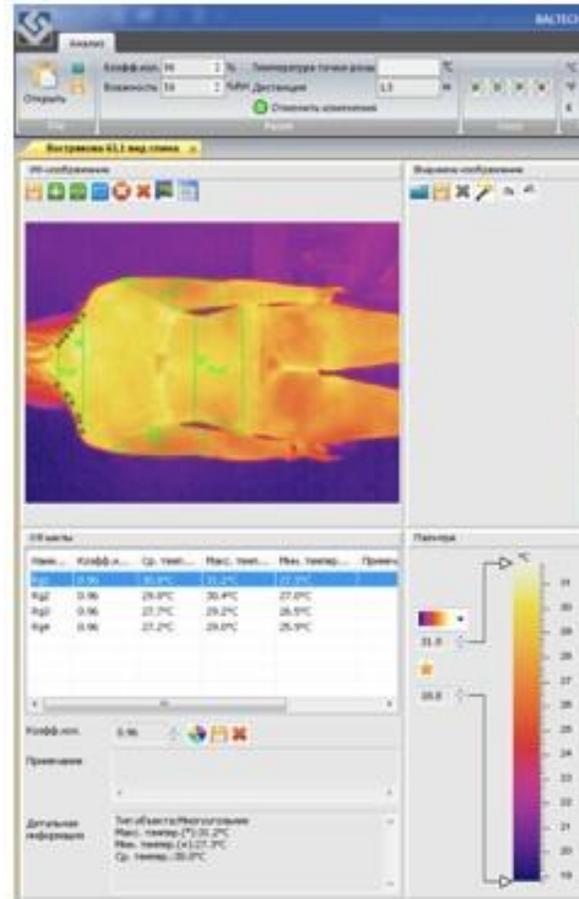


Figure 2. Example of thermogram processing in Baltech Expert program

Table 1. Body areas analyzed in Baltech Expert program

Back view		Front view		Left view		Right view	
Lower part of the body	Upper part of the body	Lower part of the body	Upper part of the body	Lower part of the body	Upper part of the body	Lower part of the body	Upper part of the body
t _{shin} BL	t _{collar}	t _{shin} FL	t _{celiac} plexus	t _{shin} L	t _{neck} L	t _{shin} R	t _{neck} R
t _{shin} BR	t _{waist} B	t _{shin} FR	t _{waist} F	t _{shin} L	t _{axilla} L	t _{shin} R	t _{axilla} R
t _{hip} BL	t _{arm} BL	t _{hip} FL	t _{arm} FL	t _{hip} L	t _{waist} L	t _{hip} R	t _{waist} R
t _{hip} BR	t _{arm} BR	t _{hip} FR	t _{arm} FR	t _{hip} L	t _{arm} L	t _{hip} R	t _{arm} R

t_{shin} BL: Left shin back view. t_{collar}: Collar area. t_{shin} FL: Left shin front view. t_{celiac} plexus: Celiac plexus. t_{neck} L: Neck left view. t_{neck} R: Neck right view. t_{shin} BR: Right shin back view. t_{waist} B: Waist back view. t_{shin} FR: Right shin front view. t_{waist} F: Waist front view. t_{shin} L: Shin left view. t_{axilla} L: Axilla left view. t_{shin} R: Shin right view. t_{axilla} R: Axilla right view. t_{hip} BL: Left hip back view. t_{arm} BL: Left arm back view (shoulder area). t_{hip} FL: Left hip front view. t_{arm} FL: Left arm front view. t_{waist} L: Waist left view. t_{waist} R: Waist right view. t_{hip} BR: Right hip back view. t_{arm} BR: Right arm back view (shoulder area). t_{hip} FR: Right hip front view. t_{arm} FR: Right arm front view. t_{hip} L: Hip left view. t_{arm} L: Arm left view (shoulder area). t_{hip} R: Hip right view. t_{arm} R: Arm right view (shoulder area).

The study of women with obesity (22) revealed that t_{mean} decreases with an increase in the percentage of fat deposits in the abdominal

area. It also revealed a negative correlation between BMI and t_{mean} of the hips both in the front and back parts. During the study (24), healthy

volunteers were divided into groups, according to a health risk classification based on BF%. The highest correlations in women were observed between posterior trunk and BF% ($\rho = -0,564$, $p < 0,001$) and, in men, between anterior trunk and BF% ($\rho = -0,760$, $p < 0,001$). The study of fat percentage and skin temperature in women aged 26.11 ± 4.41 revealed the accuracy of 58.3% in predicting fat percentage with the help of skin temperature and body circumference.

Table 2. Body composition parameters

Parameter	Mean	Minimum	Maximum	Std.Dev
Age	19,29	18,00	21,00	0,75
Body length	163,94	151,00	180,00	5,44
Body mass	54,45	36,90	79,80	7,77
BMI	20,23	14,40	26,80	2,44
FAT%	20,73	7,80	36,60	5,50
FAT MASS	11,62	2,90	25,60	4,54
FFM	42,84	33,80	56,60	4,12
TBW	31,36	24,70	41,40	3,02
FAT% _{RL}	27,19	19,30	38,20	4,10
FAT MASS _{RL}	2,81	1,40	4,90	0,71
FFM _{RL}	7,37	5,70	9,50	0,66
MUSCLE MASS _{RL}	6,95	5,40	9,00	0,62
FAT% _{LL}	27,20	17,60	37,90	4,18
FAT MASS _{LL}	2,72	0,60	4,80	0,75
FFM _{LL}	7,11	2,40	9,20	0,84
MUSCLE MASS _{LL}	6,70	2,20	8,60	0,80
FAT% _{RA}	21,00	4,40	39,70	6,63
FAT MASS _{RA}	0,55	0,10	1,30	0,24
FFM _{RA}	2,02	1,40	3,50	0,32
MUSCLE MASS _{RA}	1,89	1,30	3,30	0,30
FAT% _{LA}	21,68	4,80	38,20	6,20
FAT MASS _{LA}	0,58	0,10	1,40	0,26
FFM _{LA}	1,99	1,40	3,10	0,29
MUSCLE MASS _{LA}	1,85	1,30	2,80	0,26
FAT% _{TRUNK}	16,25	3,00	35,20	6,66
FAT MASS _{TRUNK}	4,99	0,60	14,10	2,70
FFM _{TRUNK}	24,30	18,60	32,90	2,35
MUSCLE MASS _{TRUNK}	23,21	17,80	31,50	2,26
FAT% _{TRUNK} - FAT% _{LEG}	-10,95	-22,30	-0,55	4,11
FAT% _{TRUNK} - FAT% _{ARM}	-5,09	-14,15	5,45	3,47
FAT% _{LEG} - FAT% _{ARM}	-5,86	-22,00	0,90	4,09

Std.Dev.: standard deviation. BMI: body mass index. FFM: body mass without adipose tissue (Fat Free mass). TBW: total body water. FAT%_{RL}: adipose tissue percentage of the right leg. FAT MASS_{RL}: adipose tissue mass (kg) of the right leg. FFM_{RL}: mass (kg) of the right leg. MUSCLE MASS_{RL}: muscle mass (kg) of the right leg. FAT%_{LL}: adipose tissue percentage of the left leg. FAT MASS_{LL}: adipose tissue mass (kg) of the left leg. FFM_{LL}: mass (kg) of the left leg. MUSCLE MASS_{LL}: muscle mass (kg) of the left leg. FAT%_{RA}: adipose tissue percentage of the right arm. FAT MASS_{RA}: adipose tissue mass (kg) of the right arm. FFM_{RA}: mass (kg) of the right arm. MUSCLE MASS_{RA}: muscle mass (kg) of the right arm. FAT%_{LA}: adipose tissue percentage of the left arm. FAT MASS_{LA}: adipose tissue mass (kg) of the left arm. FFM_{LA}: mass (kg) of the left arm. MUSCLE MASS_{LA}: muscle mass (kg) of the left arm.

Table 3. Parameters of skin temperature in different parts of the body

	Mean	Minimum	Maximum	Std.Dev
t _{neckL}	34,67	29,90	37,70	1,45
t _{neckR}	34,55	30,00	37,00	1,36
t _{axillaL}	34,72	31,30	38,00	1,36
t _{axillaR}	34,52	31,50	37,40	1,10
t _{celiac plexus}	33,58	28,80	36,10	1,47
t _{collar}	34,79	30,10	37,40	1,25
t _{waist F}	33,24	28,70	35,70	1,38
t _{waist B}	33,11	29,00	36,20	1,45
t _{waist R}	33,04	30,10	35,70	1,24
t _{waist L}	33,02	28,70	36,10	1,45
t _{arm BL}	31,52	27,40	34,50	1,49
t _{arm BR}	31,61	27,60	35,40	1,35
t _{arm FL}	33,21	30,40	35,60	1,24
t _{arm FR}	32,99	29,00	35,50	1,41
t _{arm R}	31,99	28,90	35,20	1,30
t _{arm L}	31,81	28,60	34,90	1,36
t _{shin BL}	31,04	28,20	34,10	1,34
t _{shin BR}	31,18	28,60	34,30	1,27
t _{shin FL}	31,58	27,50	33,80	1,39
t _{shin FR}	31,56	27,60	33,80	1,34
t _{shin R}	31,43	28,90	34,10	1,20
t _{shin L}	31,54	28,70	34,10	1,25
t _{hip BL}	30,88	27,50	34,60	1,61
t _{hip BR}	31,12	27,60	34,60	1,58
t _{hip FL}	31,19	26,70	33,70	1,52
t _{hip FR}	31,08	26,60	33,60	1,56
t _{hip R}	30,61	27,30	33,70	1,42
t _{hip L}	30,50	27,00	33,00	1,52
t _{mean}	32,31	29,58	34,89	1,08
t _{meanT}	33,27	30,52	36,06	1,06
t _{meanD}	31,03	27,54	33,62	1,32
t _{max-t_{min}}	5,77	3,90	9,30	1,23
Σt	904,7		828,10	976,90
	3			30,37
t _{Mo}	32,59	28,80	36,10	1,61
t _{meanL}	32,10	29,19	34,67	1,14
t _{meanR}	32,06	28,86	34,63	1,15
t _{meanF}	32,76	28,94	35,15	1,24
t _{meanB}	31,85	27,79	34,54	1,32
t _{meanR} - t _{meanL}	-0,05	-2,18	0,73	0,35
t _{meanF} - t _{meanB}	0,92	-1,34	4,21	1,01
t _{hipmean}	30,75	26,22	33,65	1,57
t _{shinmean}	31,31	25,73	33,95	1,31
t _{hipmean} - t _{shinmean}	0,56	-3,62	5,35	1,19
t _{mean} - t _{Mo}	-0,28	-4,14	2,28	1,45

Std.Dev.: standard deviation. t_{neckL}: Neck left view. t_{neckR}: Neck right view. t_{axillaL}: Axilla left view. t_{axillaR}: Axilla right view. t_{celiac plexus}: Celiac plexus. t_{collar}: Collar area. t_{waist F}: Waist front view. t_{waist B}: Waist back view. t_{waist R}: Waist right view. t_{waist L}: Waist left view. t_{arm BL}: Left arm back view (shoulder area). t_{arm BR}: Right arm back view (shoulder area). t_{arm FL}: Left arm front view. t_{arm FR}: Right arm front view. t_{arm R}: Arm right view (shoulder area). t_{arm L}: Arm left view (shoulder area). t_{shin BL}: Left shin back view. t_{shin BR}: Right shin back view. t_{shin FL}: Left shin front view. t_{shin FR}: Right shin front view. t_{shin R}: Shin right view. t_{shin L}: Shin left view. t_{hip BL}: Left hip back view. t_{hip BR}: Right hip back view. t_{hip FL}: Left hip front view. t_{hip FR}: Right hip front view. t_{hip R}: Hip right view. t_{hip L}: Hip left view. t_{mean}: average body temperature. t_{meanT}: average temperature of the upper part of the body. t_{meanD}: average temperature of the lower part of the body. t_{max-t_{min}}: difference between maximal and minimal temperatures. Σt : sum of body temperatures. t_{Mo}: body temperature mode. t_{meanL}: average temperature of the left part of the body. t_{meanR}: average temperature of the right part of the body. t_{meanF}: average temperature of the front part of the body. t_{meanB}: average temperature of the back part of the body. t_{meanR} - t_{meanL}: temperature difference between the right and left parts of the body. t_{meanF} - t_{meanB}: temperature difference between the front and back parts of the body. t_{hipmean}: average hip temperature. t_{shinmean}: average shin temperature. t_{hipmean} - t_{shinmean}: temperature difference between hips and shins. t_{mean} - t_{Mo}: temperature difference between the average and mode temperatures.

Table 4. Results of the correlation analysis between body composition parameters and skin temperature in different parts of the body ($p \leq 0.05$)

	BMI	FAT%	FAT MASS	FFM	TBW
BMI		0,80	0,86	0,66	0,66
FAT%	0,80		0,96	0,38	0,38
FAT MASS	0,86	0,96		0,59	0,59
FFM	0,66	0,38	0,59		
TBW	0,66	0,38	0,59		
t_{neck}L	-0,31	-0,34	-0,31		
t_{neck}R	-0,27	-0,31	-0,27		
t_{axilla}L		-0,28			
t_{axilla}R					
t_{celiac} plexus					
t_{collar}	-0,37	-0,34	-0,33		
t_{waist} F	-0,27	-0,26			
t_{waist} B	-0,36	-0,35	-0,35	-0,25	-0,24
t_{waist} R	-0,27	-0,27	-0,27		
t_{waist} L	-0,28	-0,27	-0,27		
t_{arm} BL		-0,28	-0,27		
t_{arm} BR	-0,26	-0,31	-0,29		
t_{arm} FL	-0,26	-0,29			
t_{arm} FR		-0,26			
t_{arm} R		-0,29			
t_{arm} L	-0,33	-0,40	-0,35		
t_{shin} BL	-0,29	-0,39	-0,37		
t_{shin} BR	-0,29	-0,38	-0,33		
t_{shin} FL	-0,30	-0,25	-0,25		
t_{shin} FR	-0,30	-0,30	-0,27		
t_{shin} R		-0,27			
t_{shin} L	-0,26	-0,28			
t_{hip} BL	-0,31	-0,36	-0,35		
t_{hip} BR	-0,31	-0,33	-0,33	-0,26	-0,26
t_{hip} FL	-0,26				
t_{hip} FR					
t_{hip} R					
t_{hip} L					
t_{mean}	-0,33	-0,36	-0,33		
t_{mean}T	-0,32	-0,36	-0,32		
t_{mean}D	-0,31	-0,35	-0,30		
t_{max}-t_{min}					
∑t	-0,33	-0,36	-0,33		
t_{Mo}		-0,31	-0,29		
t_{mean}L	-0,34	-0,37	-0,34		
t_{mean}R	-0,29	-0,33	-0,30		
t_{mean}F	-0,29	-0,28	-0,26		
t_{mean}B	-0,35	-0,40	-0,38		
t_{mean}R - t_{mean}L	0,33	0,27	0,27		
t_{mean}F - t_{mean}B					

BMI: body mass index. FAT MASS: adipose tissue mass, kg. FFM: body mass without adipose tissue, kg. TBW: total body water, kg. t_{neck}L: Neck left view. t_{neck}R: Neck right view. t_{axilla}L: Axilla left view. t_{axilla}R: Axilla right view. t_{celiac} plexus: Celiac plexus. t_{collar}: Collar area. t_{waist} F: Waist front view. t_{waist} B: Waist back view. t_{waist} R: Waist right view. t_{waist} L: Waist left view. t_{arm} BL: Left arm back view (shoulder area). t_{arm} BR: Right arm back view (shoulder area). t_{arm} FL: Left arm front view. t_{arm} FR: Right arm front view. t_{arm} R: Arm right view (shoulder area). t_{arm} L: Arm left view (shoulder area). t_{shin} BL: Left shin back view. t_{shin} BR: Right shin back view. t_{shin} FL: Left shin front view. t_{shin} FR: Right shin front view. t_{shin} R: Shin right view. t_{shin} L: Shin left view. t_{hip} BL: Left hip back view. t_{hip} BR: Right hip back view. t_{hip} FL: Left hip front view. t_{hip} FR: Right hip front view. t_{hip} R: Hip right view. t_{hip} L: Hip left view. t_{mean}: average body temperature. t_{mean}T: average temperature of the upper part of the body. t_{mean}D: average temperature of the lower part of the body. t_{max}-t_{min}: difference between maximal and minimal temperatures. ∑t: sum of body temperatures. t_{Mo}: body temperature mode. t_{mean}L: average temperature of the left part of the body. t_{mean}R: average temperature of the right part of the body. t_{mean}F: average temperature of the front part of the body. t_{mean}B: average temperature of the back part of the body. t_{mean}R - t_{mean}L: temperature difference between the right and left parts of the body. t_{mean}F - t_{mean}B: temperature difference between the front and back parts of the body.

In our study, the average values of BMI corresponded to normal values and were within the range of 10-15% and, in terms of body mass and body length, within the range of 5% (reference age 20 years) (25). Results of the analysis of the average fat percentage revealed underfat values (26). At the same time, the percentage of adipose tissue in limbs was significantly higher than its values in the trunk;

this is particularly obvious due to the analysis of FAT%_{TRUNK} - FAT%_{LEG} - 10.95 % (Table 2). We can assume that such a dispersion is the result of the initial symptoms of a venous outflow disturbance due to the hypertonia of shin muscles (literally the mechanical compression of deep veins). As a result, adipose tissue as a source of energy is spent primarily in the areas with better blood circulation, for example, in the trunk,

resulting in such pronounced differences. Probably, when studying young women, it is necessary to pay attention not only to BMI and FAT%, but to conduct a comparative assessment of FAT% in the limbs and trunk.

Average values of t_{mean} were 32.31 ± 1.08 C° (Table 3) with a variability of approximately 3 C° being almost identical to the parameters of t_{Mo} (Fig. 3). The maximal temperature was registered in the area of the celiac plexus ($t_{\text{celiac plexus}} = 34.79 \pm 1.25$ C°), while the minimum temperature was registered in the outer part of the left hip ($t_{\text{hipL}} = 30.50 \pm 1.52$ C°). The average temperature dispersion ($t_{\text{max}} - t_{\text{min}}$) of the body was 5.77 ± 1.23 C°, the minimal individual dispersion was equal – 3.9 C° (girl with a body length of 158 cm, body weight 53.9 kg, BMI 21.6 kg/m², FAT% 22.9),

and the individual maximal dispersion was equal to 9.3 C° (girl with a body length of 170 cm, body weight 48.8 kg, BMI 15.9 kg/m², FAT% 14.7). We can assume that the girl with an obvious mass deficiency demonstrates the disturbances of thermoregulation. For example, a maximal temperature of 36.9 C° was registered in a collar area, while a minimum temperature of 28.7 C° was fixed in the outer part of the left hip. It correlates negatively with FAT% in the trunk (10.3) and legs (21.2) ($\text{FAT\%}_{\text{TRUNK}} - \text{FAT\%}_{\text{LEG}} = 10.9$ %). Therefore, the study of differences between maximal and minimal skin temperatures together with a comparative assessment of FAT% of the trunk and limbs can be regarded as a diagnostic criterion for Anorexia Nervosa or other nervous diseases.

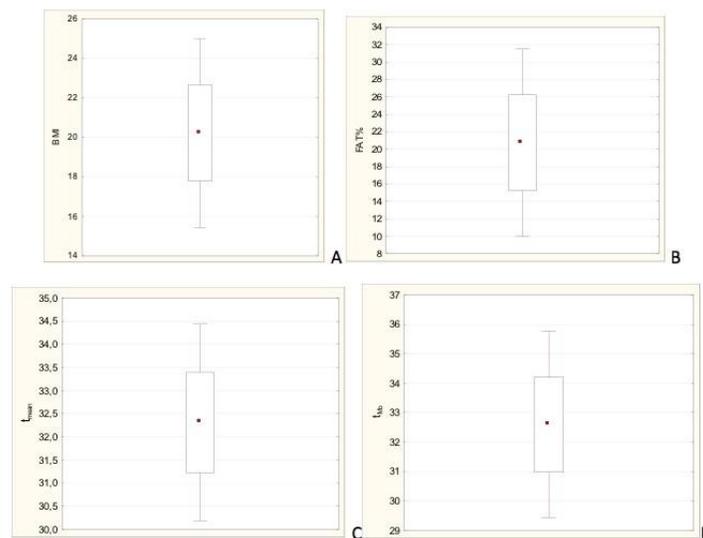


Figure 3. BMI (A), FAT% (B), t_{mean} (A), and t_{Mo} (B) data distribution in the sample studied

In our opinion, the information on temperature differences between shins and hips ($t_{\text{hip,mean}} - t_{\text{shin,mean}}$) indirectly proves the study (27) revealing differences in the microcirculation of the different parts of the legs. For instance, the skin temperature of hips is higher than a shin temperature by 0.56 ± 1.19 C°; the maximal individual difference is 5.35 C°. In some cases, the skin temperature of shins was higher than the temperature of hips by 3.62 C°. Probably, these values are the result of the beginning of ischemic foot disturbances (28) detected by differences in the strategy of postural balance, walking, and/or flat feet (if any). The study (29) contains the data on the correlation between the balance and decrease in the function of mechanoreceptors and

proprioceptors, dehydration, and hyperthermia. The study of Montgomery et al. revealed that the cooling of the large parts of lower limbs gradually affects dynamic balance (30). Cieślińska-Świder et al. found a correlation between abdominal obesity in women and postural instability (31). Studying the athletes' balance, we established that high values of a statokinesiogram area in vertical posture (more than 140 mm) show discoordination in the functioning of shin and foot muscles (antagonist-synergist), which compensatory stimulates significant muscles efforts in order to align the axis of the foot, shin, knee, and hip. During the study with the participation of elite football players with Gastrocnemius-soleus equinus (GSE),

Rodríguez-Sanz et al. revealed that the increase in skin temperature in the area of the anterior tibialis muscle is a direct result of muscle activity (32). Consequently, the study of leg temperature can provide the information on peculiarities of the postural balance strategy.

We performed non-parametric correlation analysis with the data obtained using impedancemetry and skin thermography, the main results of which are presented in Table 4. The values obtained were lower than in the study of Neves E.B. et al. (24), which is possibly due to the specificity of the sample studied. We would like to pay attention to the insignificant values and number of correlations between skin temperature, FFM, and TBW, which require additional studies and making changes in the design of further works.

Nevertheless, all correlation values were at the level of statistical significance and allowed us to perform polynomial 2D scatterplots (Multiple and Regular) by choosing values of $r \geq 0.35$ between the data of the thermography and FAT%.

Figure 3 demonstrates the distribution of BMI, FAT%, t_{mean} , and t_{Mo} data in the sample studied. Figure 3 demonstrates that a decrease in t_{mean} is connected with an increase in FAT%, and the range of t_{mean} temperatures from 32.3 to 33.0 C° can be considered as optimal in accordance with normal FAT% values for this sample. While studying the correlation between BMI and average skin temperature, we decided to divide t_{mean} by the average temperature of the upper part of the body (trunk, neck, arms - t_{meanT}) and the average temperature of the lower part of the body (legs - t_{meanD}). As a result of significant differences (almost parallel, BMI increases as well as FAT% with the increase in skin temperature), t_{meanT} and t_{meanD} were not revealed (Fig. 4). At the same time, to forecast FAT% using t_{meanD} , it is necessary to take into account the difference of temperatures as in the lower part the temperature is approximately 2.5 C° lower. In general, normal values of BMI are characterized by the range of temperatures from 32.5 C° to 33.5 C° for t_{meanT} and from 31.1 C° to 29.5 C° for t_{meanD} .

The correlation between temperatures and FAT% in local skin areas can be considered as one of the possible means to forecast body composition and to search for the patterns of the effect of postural balance and walking on the

content of adipose tissue in the limbs. The study of posterior shin surface temperature and FAT% demonstrated a significant correlation (Fig. 5). For example, in girls with an obvious deficiency of FAT%, we registered a high shin temperature, which is almost 3 C° higher than in girls with the FAT of more than 30%, which is probably connected with the postural balance and ankle strategy, when the main load falls on shin muscles. Consequently, the increase in body mass can result in adaptive changes, which can be measured with a certain accuracy by changing the strategies and using skin thermography.

A value within the range of 30.5-31.0 C° when FAT% is at the level of 22-29% can be regarded as a median value of t_{shin} normal temperature. A similar correlation was revealed comparing FAT% and skin temperature of the left arm (shoulder area) (Fig. 6): the higher the temperature, the lower the FAT%. However, using a graphical construction, we can estimate only FAT% from 15 to 25%, which is not sufficiently informative.

Fig. 6-10 demonstrate the correlation between local skin temperature and FAT%. It should be noticed that a graphical construction of the skin temperature and FAT% of arms, as well as FAT_{TRUNK}% and waist temperature (back view), show the increase in the adipose tissue percentage with a decrease in skin temperature. However, despite the statistically significant correlations, in young women with low and normal body mass, this correlation can be regarded as a tendency, which does not reveal all anatomical and physiological reasons.

The analysis of shin temperature and FAT% of the legs revealed an almost linear dependency: the decrease in temperature by 1 C° results in the increase in FAT% by 1-1.5%. Consequently, shin temperature can be the indicator of both FAT% and FAT% in legs.

CONCLUSION

In young women with underfat values of adipose tissue (less than 21%), we revealed that these values were exceeded by 10.95% in legs compared to the trunk, which is almost identical to the range of maximal and minimal temperatures (about 6 C°). It is possible that such a tendency should be taken into account during the study of nervous diseases and the assessment of treatment efficiency for diseases like Anorexia Nervosa.

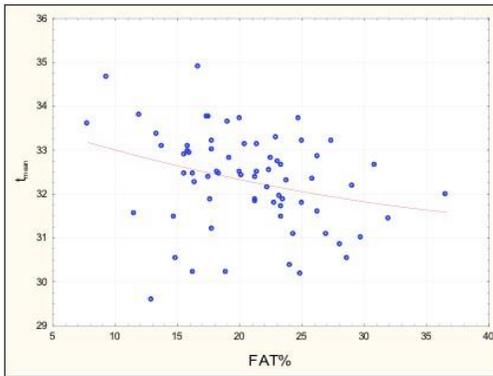


Figure 4. Correlation between FAT% and the average skin temperature of the body

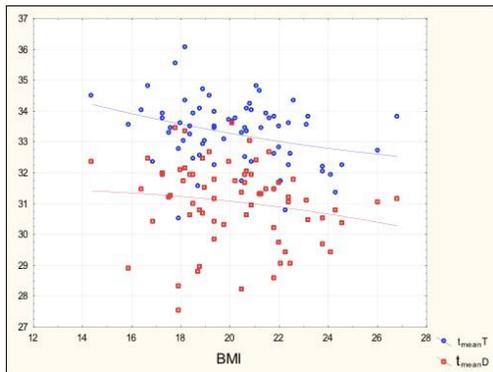


Figure 5. Correlation between BMI and the average skin temperature of the upper and lower parts of the body

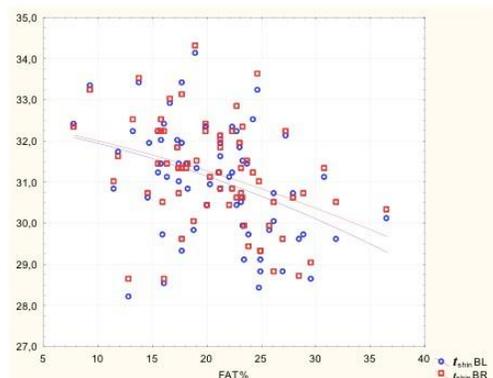


Figure 6. Correlation between FAT% and the average skin temperature of the right and left shins

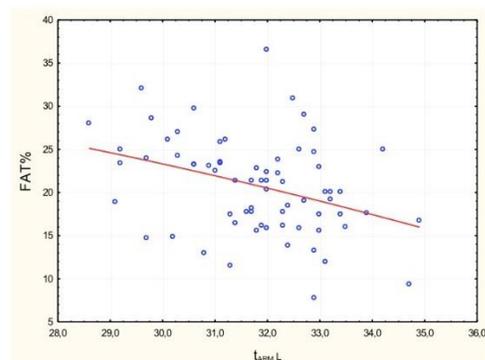


Figure 7. Correlation between FAT% and the average skin temperature of the left arm (shoulder area)

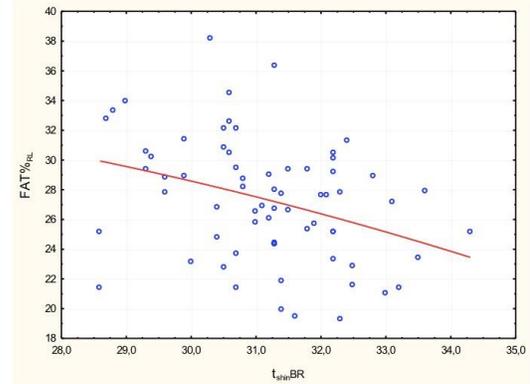


Figure 8. Correlation between FAT%RL and the average skin temperature of the right shin (back view)

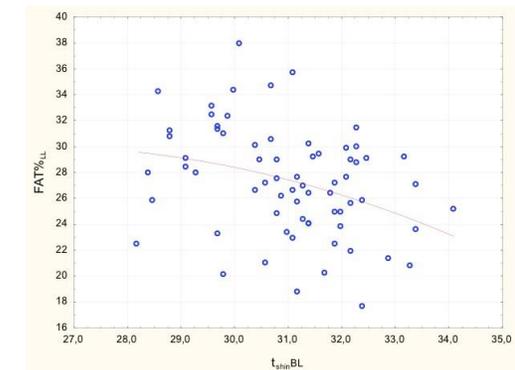


Figure 9. Correlation between FAT%LL and the average skin temperature of the left shin (back view)

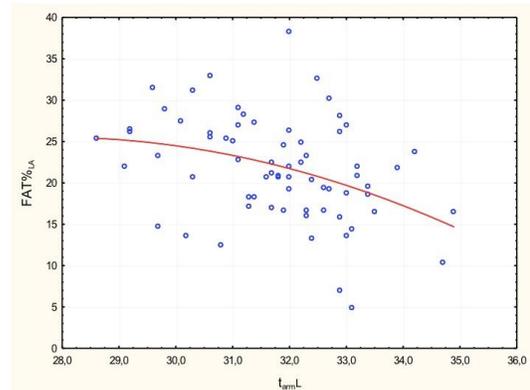


Figure 10. Correlation between FAT%LA and the average skin temperature of the left arm (back view)

The results of the correlation analysis of FAT% data and skin thermography in young women demonstrate statistically significant correlations, which do not exceed -0.40 . Values of t_{mean} and FAT% are connected ($r = -0.36$), but for this sample, shin temperature data ($r = -0.39$) are more informative showing an almost linear correlation (decrease in temperature by $1\text{ }^{\circ}\text{C}$ results in the increase in FAT% by 1-1.5%).

In young women with an obvious deficiency of FAT%, we revealed a high temperature of shin skin, which is almost $3\text{ }^{\circ}\text{C}$ higher than in women

with FAT% of more than 30%. Consequently, the information on temperature differences between shins and hips or shins and FAT% could be the indicator for the strategy of postural balance. As a hypothesis for further studies, we can assume that women with higher values of shin temperature use the ankle strategy of postural balance, while women with higher values of hip temperature use the hip strategy.

Limitations and Further Research

The experiments were conducted on healthy volunteers in accordance with the approval granted by the Ethical Committee of the University, prior to the study, the participants' informed consent was obtained.

APPLICABLE REMARKS

- The authors suggest that the correlations established between FAT and skin temperature, combined with the results of further studies, will allow developing a brand-new algorithm and state-of-the-art equipment for monitoring human health with IR thermography.

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- In particular, the peculiarities revealed in the range of hip and shin temperatures can be used as criteria for diagnosing, for example, flat feet or varicose veins.
- A wide range of temperatures can also be a sign of neurologic, CNS-related, endocrine, and metabolic disorders.
- Early diagnostics of skin temperature with IR thermography can be used as an additional diagnostic tool in orthopedics, nutrition science, and endocrinology.

Conflict of Interests

The authors claim that there is no known conflict of interests.

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