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Effect of winter swimming on morphological parameters of blood and a thermal evaluation of the body based on winter swimmers

Wpływ zimowych kąpieli na parametry morfologii krwi i ocenę termowizyjną ciała – badania „morsów”

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Key words
winter swimmers, morphology, thermal imaging, body surface temperature

Abstract
Objective: The aim of this study was to determine the effect of regular winter swimming on the morphological parameters of blood and the distribution of body surface temperature among winter swimmers.
Methods: The study involved 10 winter swimmers from the "Kaloryfer" Krakow Club of Winter Swimmers. During winter, from November through April, they regularly (once per week) immerse themselves in cold water. Venous blood samples were collected twice: at the beginning of the season and after the season. Thermal images were taken three minutes before immersion in cold water and immediately after it.
Results: Swimming in cold water induced a significant increase in red blood cells and haematocrit and a significant decrease in mean corpuscular haemoglobin and mean corpuscular haemoglobin concentration. No changes were found in white blood cells, platelets, haemoglobin or mean corpuscular volume. Body surface temperature decreased due to immersion in cold water.
Conclusions: Regular winter swimming results in considerable, non-pathological changes in haematological parameters and body surface temperature among winter swimmers.

Słowa kluczowe
pływacy zimowi, morfologia, termowizja, temperatura powierzchniowa ciała

Streszczenie
Cel pracy: Celem pracy było ukazanie wpływu zimowych kąpieli na parametry morfotyczne krwi oraz rozkład temperatury powierzchniowej ciała.
Materiał i metody: Badania zostały przeprowadzone na grupie członków Krakowskiego Klubu Morsów „Kaloryfer". Podczas sezonu trwającego od listopada do kwietnia zanurzali się oni regularnie (raz na tydzień) w wodzie o niskiej temperaturze. Od badanych osób pobrano dwukrotnie krew żylną, na początku sezonu oraz po jego zakończeniu. Wykonano zdjęcia termowizyjne przed zanurzeniem na 3 minuty w wodzie oraz po wyjściu z wody.
Wyniki: Zaobserwowano istotne statystycznie zwiększenie się liczby czerwonych krwinek oraz hematokrytu oraz istotne statystycznie obniżenie się średniej masy hemoglobiny w krwince czerwonej oraz średniego stężenia hemoglobiny w krwince czerwonej. Nie stwierdzono istotnych statystycznie zmian w liczbie białych krwinek, liczbie płytek krwi, stężeniu hemoglobiny oraz średniej objętości krwinki czerwonej. Pod wpływem zanurzania się w wodzie o niskiej temperaturze nastąpiło obniżenie się temperatury powierzchniowej ciała u włączonych do badania osób.
Wnioski: Regularne pływanie w zimnej wodzie wywołuje silne niepatologiczne zmiany we właściwościach hematologicznych krwi.

The individual division on this paper was as follows: A – research work project; B – data collection; C – statistical analysis; D – data interpretation; E – manuscript compilation; F – publication search

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INTRODUCTION

Exposure to cold water induces a number of physiological responses that aim to minimise body heat loss. The most important thermoregulation processes include the activation of the vascular and sympathetic systems, increased production of particular hormones and behavioural reactions. Moreover, immersion in cold water causes changes in morphological parameters of blood and body surface temperature.

Morphological parameters of blood

Considerable changes in blood morphology occur due to immersion in cold water, including an increase in haemoglobin by 10–20%, an increase in haematocrit, a decrease in leukocytes and an increase in platelets, blood viscosity and glucose concentration[1,2].

Also observed is an increase in mean corpuscular haemoglobin, mean corpuscular haemoglobin concentration and neutrophils, and a slight increase in platelets. The number of eosinophils and lymphocytes also decreases[1,2].

Effect of low temperature on body surface temperature

Thermography, a safe and non-invasive method, is used to analyse changes in body surface temperature. Thermography allows researchers to determine temperature distribution on the surface of the skin. The researched object emits infrared radiation, which is registered by a thermographic system, producing colour images. The system can measure temperature in several areas at the same time.

Thermal imaging allows the decrease in body temperature in exposed areas to be observed. The heat loss is related to metabolic changes in subcutaneous tissues, changes in tissue blood supply, heat conductivity of the skin and heat exchange through the skin[3].

Exposure to low temperatures results in severe hypothermia, primarily in surface tissues. The highest heat loss is observed in upper and lower limbs, i.e. in body parts with a relatively high ratio of surface area to volume[3].

Table 1

Values of RBC [10^6/mm^3], Hct [%], MCH [pg] and MCHC [g/dl] before the season

	RBC before the season [10^6/mm^3]	Hct before the season [%]	MCH before the season [pg]	MCHC before the season [g/dl]
Swimmer 1	5.01	44.5	29.7	33.5
Swimmer 2	4.64	42	30.5	33.7
Swimmer 3	4.91	43.7	30.8	34.6
Swimmer 4	4.37	40.8	31.9	34.2
Swimmer 5	4.71	42.1	30.1	33.7
Swimmer 6	4.35	41.6	32.9	34.4
Swimmer 7	4.47	42	31.8	33.8
Swimmer 8	4.97	44.5	30.7	34.3
Swimmer 9	5.21	46.9	30.5	33.8
Swimmer 10	4.59	42.6	31.3	33.6

RBC – red blood cells; Hct – haematocrit; MCH – mean corpuscular haemoglobin; MCHC – mean corpuscular haemoglobin concentration

Table 2

Values of RBC [10^6/mm^3], Hct [%], MCH [pg] and MCHC [g/dl] after the season

	RBC after the season [10^6/mm^3]	HCT after the season [%]	MCH after the season [pg]	MCHC after the season [g/dl]
Swimmer 1	4.67	45	31.5	32.7
Swimmer 2	5.33	45.2	27.2	32
Swimmer 3	5.21	45.9	28.9	32.9
Swimmer 4	4.69	43.2	30.3	33
Swimmer 5	4.63	41.2	29.4	33
Swimmer 6	4.82	46.1	30.8	32.3
Swimmer 7	4.58	42.9	30.8	32.9
Swimmer 8	5.39	48.9	28.9	31.9
Swimmer 9	5.33	48.1	29	32.1
Swimmer 10	5.08	47	30.1	32.5

RBC – red blood cells; Hct – haematocrit; MCH – mean corpuscular haemoglobin; MCHC – mean corpuscular haemoglobin concentration

Table 3

Mean values of RBC [10^6/mm^3] before and after the season and significance level between groups

	Before the season	After the season	
RBC [10^6/mm^3]	$\bar{x} \pm SD$	$\bar{x} \pm SD$	**Significance level**
	4.73 ± 0.3	4.98 ± 0.4	<0.05

RBC – red blood cells ; $\bar{x}$ – Arithmetical mean; *SD* – Standard deviation

Internal temperature of the body during physical effort depends, for example, on effort intensity, water temperature, water movement and clothing[4-6].

A water temperature of 18 °C constitutes a boundary value below which one should remain inactive to prevent excessive heat loss. For temperatures above 18 °C, one should keep moving in the water, as physical effort will increase metabolism and prevent heat loss. Moreover, while physical effort improves blood supply to active limbs, thus increasing the amount of supplied heat, the heat is dispersed into the water[4-6].

For water with a temperature of 5 °C, rectal temperature decreases by 1.2 °C within 20 minutes during

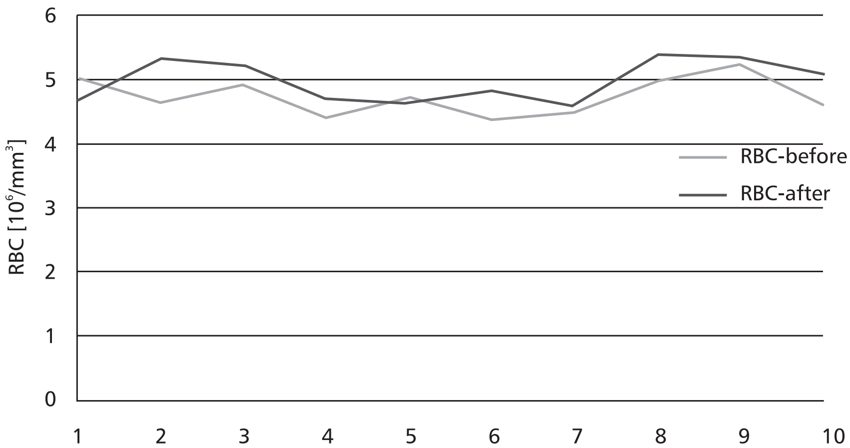

Figure 1

Mean values of RBC [106/mm3] before and after the season

Table 4

Mean values of Hct [%] before and after the season and the level of significance between groups

	Before the season	After the season	
HCT [%]	$\bar{x}\pm SD$	$\bar{x}\pm SD$	**Significance level**
	43.07±1.9	45.35±2.4	<0.05

Hct – haematocrit; $\bar{x}$ – arithmetical mean; *SD* – Standard deviation

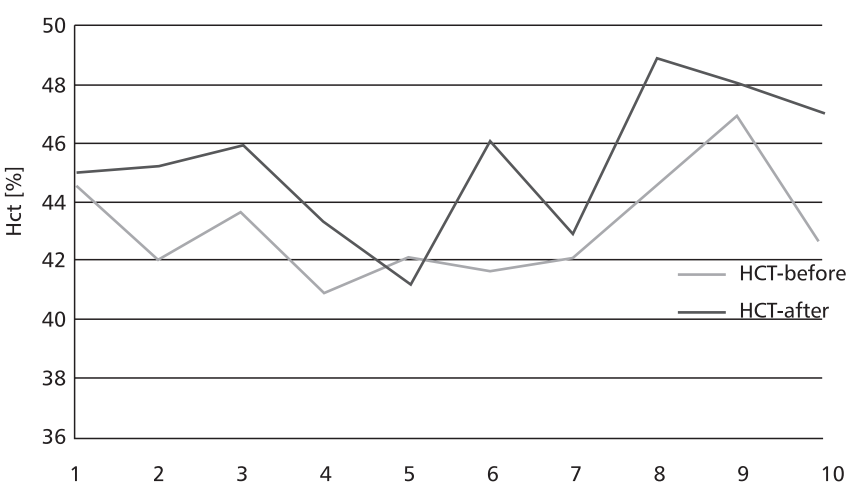

Figure 2

Mean values of Hct [%] before and after the season

inactivity and by 1.8 °C when swimming[4-6].

Swimming in cold water decreases tension strength in skeletal muscles, leading to reduced speed of muscle fibre contraction. This phenomenon usually does not concern large muscles located deep in the body, as they are protected by the surrounding outer tissues and increased thermogenesis[4-6].

Physical effort in cold water increases the production of hormones that stimulate the metabolism. The main energy substrates are carbohydrates and free fatty acids. Due to a lower diffusion of lactic acid into the blood, winter swimmers are better adapted exert physical effort. The maximal oxygen consumption at a lower heart rate increases, which shifts the anaerobic threshold towards higher physical strain. This leads to an intense activation of the sympathetic system and the contraction of skin vessels that prevent the transfer of heat from inside the body to the skin. Only the heat that penetrates the subcutaneous fat tissue is emitted into the environment. Another safeguard against excessive heat loss is a dense vasculature in areas most exposed to heat loss, i.e. the head, ear lobes, arms and legs[4-6].

Regular swimming in cold water increases resistance to infections of the respiratory system. Blood flow through the skin decreases, improving the heat-insulating qualities of the skin. A number of adaptive mechanisms become active, such as decreased cardiac output and heart rate and an increased contraction of vessels in the skin. Furthermore, parameters of aerobic capacity improve[4-8,12].

AIM OF THE STUDY

The aim of the study was to determine the effect of regular winter swimming with exposure to cryogenic temperatures on selected morphological parameters of peripheral blood and to determine changes in body surface temperature, including answering the following questions:

1. What is the effect of exposure to cryogenic temperatures during winter swimming on selected morphological parameters of peripheral blood?
2. What changes in body surface temperature occur in persons who regularly swim under exposure to cryogenic temperatures?

MATERIAL AND METHODS

Research subject and methodology

The research concerned a group of winter swimmers from the "Kaloryfer" Krakow Club of Winter Swimmers. Study participants comprised 10 men aged 30–35 years old, with a mean age of 33.6 years.

During the winter season (from November to April), the group of swimmers immersed themselves regularly in water with a temperature of 2.0 °C to 7.2 °C in Zakrzówek Lake (an artificial lake created by flooding a quarry). Venous blood samples were collected from the study participants twice: at the beginning of the season in

Table 5

Mean values of MCH [pg] before and after the season and the level of significance between groups

	Before the season	After the season	
MCH [pg]	**x̄±*SD***	**x̄±*SD***	**Significance level**
	31.02±0.9	29.69±1.3	<0.05

MCH – mean corpuscular haemoglobin; x̄ – arithmetical mean; *SD* – standard deviation

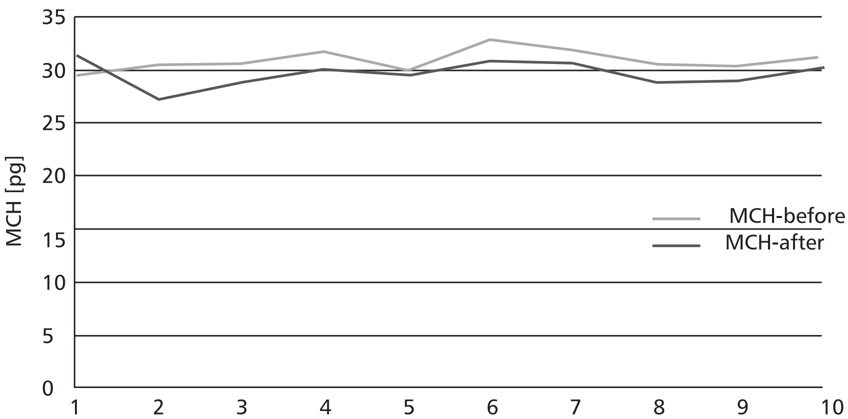

Figure 3

Mean values of MCH [pg] before and after the season

Table 6

Mean values of MCHC [g/dl] before and after the season and the level of significance between groups

	Before the season	After the season	
MCHC [g/dl]	**x̄±*SD***	**x̄±*SD***	**Significance level**
	33.96±0.4	32.53±0.4	<0.05

MCHC – mean corpuscular haemoglobin concentration; x̄ – arithmetical mean; *SD* – standard deviation

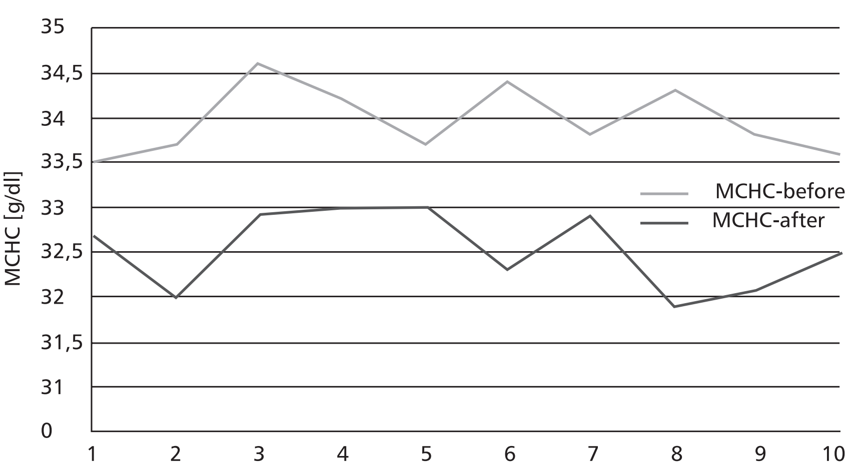

Figure 4

Mean values of MCHC [g/dl] before and after the season

November and at the end of the season in April in order to analyse blood morphology parameters. One-millilitre samples were collected from the ulnar vein into Vacuette tubes with EDTA directly before the first swim, approximately two minutes before immersion in the water, on an empty stomach. The procedure was repeated after the last swim, directly after each participant left the water. The collected blood was transported to a laboratory at the Motor System Pathology Centre of the University of Physical Education in Krakow.

Permission no. 63/KBL/OIL/2010 for conducting the study was obtained from the Bioethics Commission at the Regional Medical Chamber in Krakow.

Haematological parameter measurements

Measurements were conducted using an ABX Micros 60 haematological analyser.

The following parameters were measured:

1. Red blood cells (RBC, $10^6/mm^3$);
2. Haemoglobin (Hgb, g/dl);
3. Haematocrit (Hct, %);
4. Mean corpuscular haemoglobin (MCH, pg);
5. Mean corpuscular volume (MCV, μm^3);
6. Mean corpuscular haemoglobin concentration (MCHC, g/dl);
7. White blood cells (WBC, $10^3/mm^3$);
8. Platelets (PLT, $10^3/mm^3$).

Measurements of body surface temperature

In order to assess the body temperature of the winter swimmers, thermal images were taken using the following thermographic camera:

- **Thermal imaging camera:** NEC TVS 200EX, serial no. 9090846, calibration certificate no. TVS – 09071, produced by NEC AVIO Infrared *Technologies* Co., Ltd., measurement range from – 20° C to 500° C, 60 Hz, resolution 320x240.
- **Anemometer:** Testo 410 – 2, series no. 38511706/805, calibrated according to EC Directive 89/336/EEC.
- **Software:** Report v. 2.1
- Thermal images of each participant were taken at the beginning of the season in November three minutes before immersion and one minute after it.

The images provided data on the minimal and maximal temperature of four parts of the body: the chest, abdomen, arm and thigh.

Table 7

Minimal temperature [°C] before and after immersion in cold water measured in four parts of the body in winter swimmers

Minimal temperature [°C]	Chest		Abdomen		Arm		Thigh	
	Before	After	Before	After	Before	After	Before	After
Swimmer 1	26.1	17.0	28.1	15.1	26.2	17.1	14.0	11.2
Swimmer 2	27.1	16.1	26.2	14.3	25.9	16.0	22.0	14.2
Swimmer 3	29.2	12.0	26.0	11.5	26.5	12.0	19.5	10.1
Swimmer 4	25.2	13.0	24.0	12.5	26.7	13.8	15.0	10.2
Swimmer 5	22.5	13.1	22.1	12.5	26.5	15.0	22.0	11.9
Swimmer 6	22.2	12.1	25.3	10.2	27.0	12.0	23.1	11.1
Swimmer 7	28.1	15.1	27.0	12.1	29.0	15.0	24.0	12.0
Swimmer 8	28.0	14.5	29.0	12.0	28.2	16.8	22.1	11.0

Table 8

Maximal temperature [°C] before and after immersion in cold water measured in four parts of the body in winter swimmers

Maximal temperature [°C]	Chest		Abdomen		Arm		Thigh	
	Before	After	Before	After	Before	After	Before	After
Swimmer 1	28.0	19.0	28.1	19.1	26.4	18.2	16.0	14.3
Swimmer 2	29.2	19.2	27.0	17.9	26.5	18.0	23.7	16.0
Swimmer 3	28.0	14.2	27.1	12.1	27.0	13.1	23.2	11.0
Swimmer 4	27.8	13.8	25.0	13.0	28.0	14.2	19.5	12.5
Swimmer 5	28.1	16.0	26.4	15.2	28.0	16.0	24.1	14.2
Swimmer 6	27.0	15.5	26.1	14.0	26.0	13.8	24.2	14.0
Swimmer 7	30.0	16.0	28.0	14.0	30.0	16.0	25.5	15.0
Swimmer 8	29.0	15.5	30.1	13.2	29.0	17.1	24.5	14.5

Statistical methods

Research results were analysed using the Statistica 10.0 MR1 2012 PL software package. Student's *t*-test was used to analyse changes in the morphological parameters of blood and body surface temperature. Results were considered statistically significant at a significance level of $p<0.05$.

RESULTS

Morphological parameters

A comparison of absolute values of the morphological parameters of blood indicated that Swimmer 1 showed the highest increase in RBC, and Swimmer 2 had the highest decrease in RBC. Swimmer 6 showed the highest increase in Hct, and Swimmer 10 showed the highest decrease in Hct. Swimmer 6 showed the highest increase in MCM, and Swimmer 1 showed the highest decrease in MCM. Swimmer 9 showed the highest increase in MCHC. No study participant showed a decrease in MCHC (Tables 1 and 2).

Mean RBC was significantly higher by 5.03% after the season than before it among the study participants ($p<0.05$) (Table 3, Figure 1). Mean Hct was significantly higher by 5.03% after the season than before it among the study participants ($p<0.05$) (Table 4, Figure 2). Mean MCH was significantly higher by 4.28% after the season than before it among the study participants ($p<0.05$) (Table 4, Figure 2). Mean MCHC was significantly lower by 4.21% after the season than before it among the study participants ($p<0.05$) (Table 6, Figure 4).

Body surface temperature

Table 7 shows the distribution of minimal body surface temperature before and after immersion. No statistically significant differences in minimal body temperature occurred due to immersion in cold water.

Table 8 shows the distribution of maximal body surface temperature before and after immersion. No statistically significant differences in maximal body temperature occurred due to immersion in cold water.

DISCUSSION

The conducted research provides a better understanding of the changes that occur in morphological parameters of blood and the distribution of body surface temperature among winter swimmers thanks to the observed statistically significant increase in RBC and Hct and the statistically significant decrease in MHC and MCHC.

On the other hand, no statistically significant differences were found for the following morphological parameters: Hgb, MCV, WBC or PLT.

Lombardi et al.[9] investigated the effect of winter swimming on morphological parameters of blood. Their study was conducted with 15 persons who took part in a 150 m swimming competition in water with a temperature of 6 °C. It was observed that the mean intensity of physical effort in water with a temperature of 6 °C caused an increase in the number of erythrocytes, leukocytes and thrombocytes. Also observed was an increase in Hgb and Hct, but no significant changes in MCH, MCV or MCHC.

Pendergast et al.[10] also observed an increase in Hgb and Hct, which they explained by the fact that some of the blood plasma moved from the intravascular space to the extravascular space due to the increased activity of the sympathetic nervous system.

Teległów et al.[11] conducted a study on the effect of winter swimming and whole body cryotherapy on morphological and rheological parameters of blood. They found a decrease in the concentration of fibrinogen in blood plasma following winter swimming compared to the initial level; this was in contrast to whole body cryotherapy, which caused an increase in fibrinogen and platelets and a decrease in glucose concentration.

A wide-ranging analysis of the effect of cold water swimming on selected biochemical and morphological indicators of blood in healthy persons by Kępińska and Szyguła[12] indicated

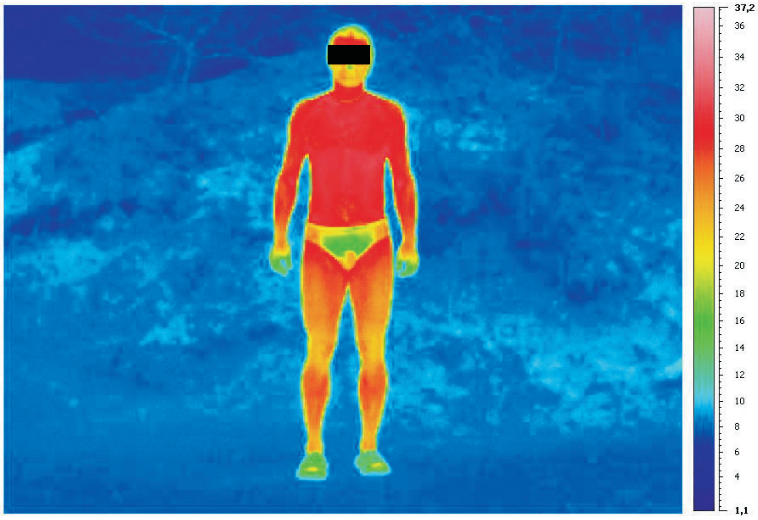

Figure 5

Distribution of body surface temperature before immersion in cold water – thermal images

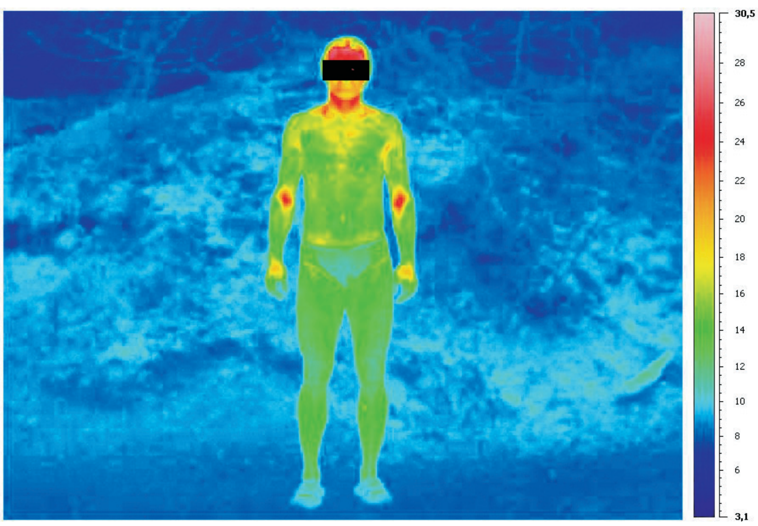

Figure 6

Distribution of body surface temperature after immersion in cold water – thermal images

an increase in erythrocytes, thrombocytes and leukocytes. As far as leukocytes are concerned, the study found a decrease in eosinophils and an increase in neutrophils, lymphocytes and monocytes. No changes in MCH, MCV or MCHC were observed.

Gregson et al.[13] assessed skin temperature following immersion in cold water and whole body cryotherapy. A significant decrease in skin temperature was found. Specifically, the temperature decreased by approximately 10 °C following a five-minute immersion in cold water and by approximately 8 °C following cryotherapy. This discrepancy may have been caused by the fact that immersion in cold water was one minute longer than the cryotherapy session and that cold water affected the whole surface of the body (except the head), while cold air adheres to the skin to a lesser extent.

Enwemeka et al.[14] conducted similar research in which they observed a decrease in temperature in surface muscles (up to 1 cm below the skin). The highest decrease in temperature was observed approximately 20 minutes after immersion in cold water. The skin showed a similar decrease in temperature compared to the surface muscles.

Sieroń et al.[15] conducted a study on the effect of whole body cryotherapy on the human body, which found that the greatest decrease in temperature occurred in upper and lower limbs. On the other hand, no change in trunk temperature was noted. This was caused by the fact that thermoregulation mechanisms differ between the trunk and the limbs, and these body parts have a different structure.

A study by Rajewski et al.[16] on the dynamics and distribution of temperature changes in selected areas of the body following whole body cryostimulation found that body parts with a high ratio of surface to volume, i.e. the limbs, lose the highest amount of heat.

Cholewka et al.[17] researched changes in skin temperature that occur as a result of whole body cryotherapy. They found that the highest decrease in body surface temperature occurred in the lower limbs. They also observed significant differences in the temperature of the same body parts between study participants, which they attributed to different BMI values between the participants.

Castello et al.[18] reached similar conclusions. They compared changes in muscle and skin temperature following whole body cryotherapy (at – 110 °C) and immersion in cold water (8 °C). The study was conducted with 20 healthy, active men who spent four minutes in a cryochamber. Seven days later, they were immersed in cold water. The minimal and maximal temperature of the vastus medialis muscle and the thigh and rectal temperature were measured prior to exposure to cold and 60 minutes after the exposure. The study found that the skin, vastus medialis, and rectal temperature decreased with whole body cryotherapy, causing a greater decrease in temperature than immersion in cold water.

Bleakley and Hopkins[19] observed a decrease in skin temperature of 5–15 °C following cryotherapy and immersion in cold water. They pointed out that a skin temperature of 12.5–13.5 °C is required for a 10% drop in neural conductivity to be observed.

This study indicated that RBC and Hct increase with an increase in the contraction of peripheral blood vessels. However, further research is required to provide a better understanding of the phenomenon, especially in terms of other haematological indicators. The main cause of the observed changes in peripheral blood was a shift in blood plasma from the intravascular space, especially the capillary system of the skin, to the between-tissue space, leading to the increase in RBC and, consequently, Hct.

CONCLUSIONS

Exposure to cryogenic temperatures during winter swimming leads to an increase in RBC and Hct and a decrease in MCH and MCHC. Persons who regularly expose themselves to water with a cryogenic temperature show no significant changes in body surface temperature.

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