

Application of thermovision for estimation of the optimal and safe parameters of the whole body cryotherapy

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Abstract Exposure to the extreme low temperatures, ranging between -60 and -140 °C, has many beneficial effects on the human body what is exploited for example in sport medicine, for treatment of locomotory system diseases or even some psychiatric disorders. To insure the safe treatment in a cryochamber, careful planning of the procedure and proper qualification of patients, is required. Cardiovascular system, especially skin vasculature plays the major role of the body response to the extreme cold. The changes in skin blood flow are reflected in changes of the temperature distribution. Therefore, the thermal imaging, which allows to analyze the temperature distribution on the human body, may be successfully exploited to examine the influence of extremely low temperatures on the skin vascular system. The aim of this work was to examine the temperature, blood pressure, and heart rate changes after the whole body cryotherapy in healthy subjects to determine the safety conditions of the treatment. 480 healthy students of the Wrocław University School of Physical Education were divided into two groups (each 240 persons). All subjects were exposed for 1–3 min to the extremely low temperatures: -60 , -100 , -120 , and -140 °C. In one group, the thermograms were recorded before and 5 and 30 min after the cryotherapy by means of ThermoVision A20 M thermal camera. In the other one, heart rate and blood pressure were measured before and

5 min after the cryotherapy. It was demonstrated that 3-min exposure in the cryochamber and the temperature -120 °C are the optimal and safe cryotherapy parameters.

Keywords Whole body cryotherapy · Blood pressure · Heart rate · Thermovision

Introduction

The whole body cryotherapy is used in modern rehabilitation for treatment of various diseases. Systemic cryotherapy results in numerous clinical, hormonal, and biochemical effects [1–3]. The main goal of the cryotherapy is to cause the quick decrease of the body temperature to stimulate the cardiovascular system, followed by several positive reactions, among other anti-inflammatory and analgesic. The therapy, although stimulating, should not alter the hemodynamic parameters that must be kept in physiological range. The response to the extremely low temperatures is reflected by the vasoconstriction of the skin vessels, followed by the return to initial conditions after the therapy. However, after the therapy, first a decrease of the body temperature is observed, and then an increase. Vasodilatation of microcirculation and increased capillary blood flow quickly reinstate the temperature after the cryotherapy and even an increase is observed in some time after the treatment. Intensified perfusion of the skin may persist for longer time.

The cardiovascular changes have a stimulating effect, and therefore, the cryotherapy is used to combat pain, as anti-inflammation therapy, and also for relaxation and improving neurological, as well as psychological conditions [4–6]. Although, the range of indications treated by the whole body cryotherapy is quite wide, the optimal treatment conditions are still not established. Frequently,

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the 3-min exposure in $-110\text{ }^{\circ}\text{C}$ is recommended [7–12]; however, the treatment in $-175\text{ }^{\circ}\text{C}$ is used, as well [13, 14]. The applications of other temperatures are also reported, e.g., -100 , -120 , and $-130\text{ }^{\circ}\text{C}$ [2, 4, 6]. Exposure times also vary from 1 [15] to 3 min [8, 16, 17]. The time for adaptation in pre-chamber may be few seconds or 1 min [4, 7]. Moreover, the therapy parameters in case of healthy subjects are also not fully determined. It as an important issue since cryotherapy is also offered as wellness treatment. Therefore, it is important to insure that the exposure to the extreme cold is safe and do not alter physiology of human body.

The cryotherapy-induced microcirculation changes are reflected in the distribution of the skin temperature. The superficial temperature distribution of the human body can be monitored by means of thermal imaging [18, 19]. Thermal imaging is noncontact diagnosis method, and it is already applied to control the cryotherapy effects [16, 17, 20–22]. The main goal of our study is to determine the optimal exposure time and the temperature of whole body cryotherapy by exploiting the thermal imaging. Simultaneously, blood pressure and heart rate will be measured to check whether the body temperature changes cause any alteration of hemodynamic parameters.

Materials and methods

The study group consisted of 480 healthy volunteers—students of the Wrocław University School of Physical Education, aged 20–25 years. First, the students were examined by a physician and qualified to the whole body cryotherapy. All students were informed about the examination and agreed to take a part in the study. The study was performed under the permission from the Commission of Bioethics at the Wrocław University School of Physical Education.

The subjects were randomly divided into two groups (each composed of 240 persons), named T and H. All subjects were exposed to the extremely low temperatures in a

cryochamber. The group T was composed of 154 female students aged 19.32–25.92 years (mean age 21.58 ± 1.55) and 86 male students, aged 19.38–25.34 years (mean age 22.22 ± 1.64). The group H were 137 women in the age from 21.79 to 25.67 years (mean age 22.86 ± 0.94) and 103 men in the age years 21.78–25.59 (mean age 22.74 ± 0.99).

Further, both groups were randomly divided into eight subgroups each composed of 30 persons (1T–8T and 1H–8H). In the groups T, the temperature distribution was monitored before— T_1 , 5 min— T_2 , and 30 min— T_3 after the cryotherapy by means of ThermoVision A20M thermal camera. The thermal images were captured from the distance 2 m. Humidity and temperature in the laboratory room were kept constant and were always the same for the duration of the study (temperature $22\text{ }^{\circ}\text{C}$, relative humidity 60 %). In the groups H, heart rate and systolic and diastolic pressure were measured before and 5 min after the cryotherapy.

The influence of the following cryotherapy parameters, temperatures -60 , -100 , -120 , and $-140\text{ }^{\circ}\text{C}$ and exposure times 1–3 min, was examined. The applied cryotherapy parameters are depicted in Table 1.

Recorded thermograms of frontal and back side of the body were analyzed by means of the ThermoCAM Researcher Professional 2.9 software. Mean temperatures of dorsal and ventral sides were determined in selected regions of interests (ROI)—trunk, upper and lower extremities. The exemplary thermograms are presented in Fig. 1.

The relative temperature changes, between first and second recording T_{12} and between first and third one T_{13} , were determined by the following expressions:

$$T_{12} = \frac{T_1 - T_2}{T_1} \times 100\% \quad (1)$$

$$T_{13} = \frac{T_1 - T_3}{T_1} \times 100\%. \quad (2)$$

The blood pressure BP_{sys} and BP_{dias} were measured on the left hand by means of sphygmomanometer working with the accuracy $\pm 3\text{ mmHg}$. The heart rate HR was measured for 1 min at the wrist on the radial artery.

Table 1 Examined cryotherapy parameters in subgroups 1T–8T and 1H–8H

Group T	Group H	Pre-chamber		Cryochamber	
		Temperature/ $^{\circ}\text{C}$	Exposure time/min	Temperature/ $^{\circ}\text{C}$	Exposure time/min
1T	1H	-60	1		
2T	2H	-60	3		
3T	3H	-60	1	-100	1
4T	4H	-60	1	-100	3
5T	5H	-60	1	-120	1
6T	6H	-60	1	-120	3
7T	7H	-60	1	-140	1
8T	8H	-60	1	-140	3

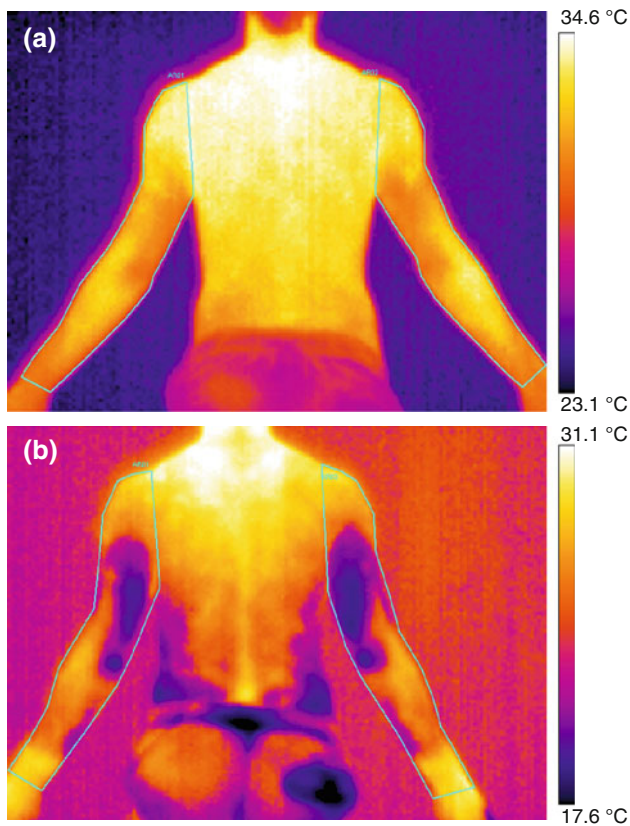


Fig. 1 Exemplary thermograms of the dorsal side of the upper body recorded before entering the cryochamber (a) and 5 min after 3 min cryotherapy at $-120\text{ }^{\circ}\text{C}$ (b)

For the evaluation of the temperature differences between various body parts as well as differences between examined groups, the analysis of variance (ANOVA) was applied. The least significant differences (LSD) multiple comparison test was exploited for the post-hoc analysis. In the analysis, the statistically significant p value was set as $p < 0.05$. The analysis was performed by means of Statistica PL program.

Results and discussion

First, the changes of hemodynamic parameters after cryotherapy (subgroups 1H–8H), were analyzed to check the safety of the chosen treatment parameters. In all examined H subgroups, the systolic pressure BP_{sys} before cryotherapy ranged from 116 to 125 mmHg, whereas after the treatment, these values ranged from 122 to 135 mmHg. Diastolic pressure BP_{dias} before cryotherapy was between 74 and 77 mmHg, and 79–84 mmHg after the therapy. The heart rates ranged from 75 to 80 bpm before, and from 83 to 91 bpm after cryotherapy.

The changes of hemodynamic parameters after cryotherapy were visible in all examined subgroups 1H–8H

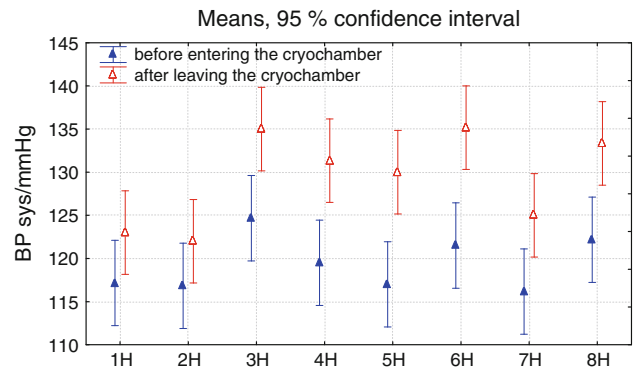


Fig. 2 Mean values of systolic pressure BP_{sys} before and after cryotherapy

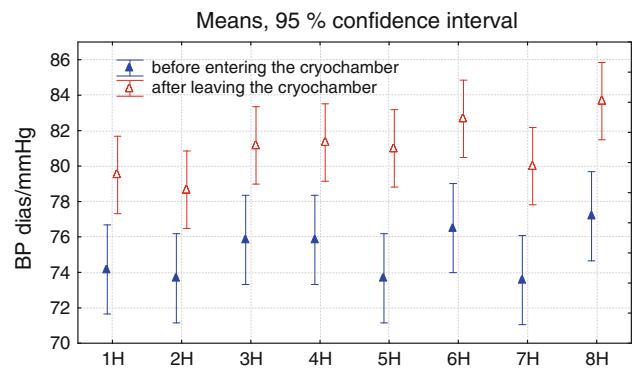


Fig. 3 Mean values of diastolic pressure BP_{dias} before and after cryotherapy

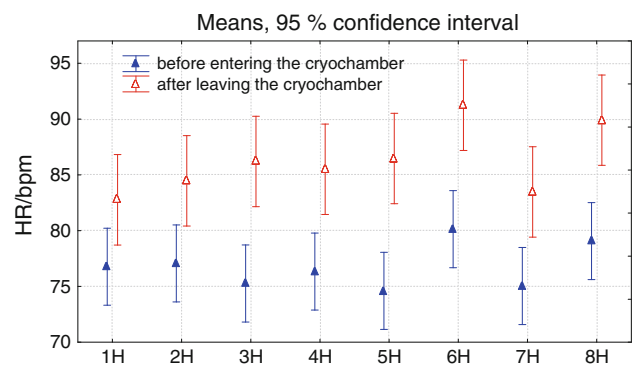


Fig. 4 Mean values of heart rates (HR) before and after cryotherapy

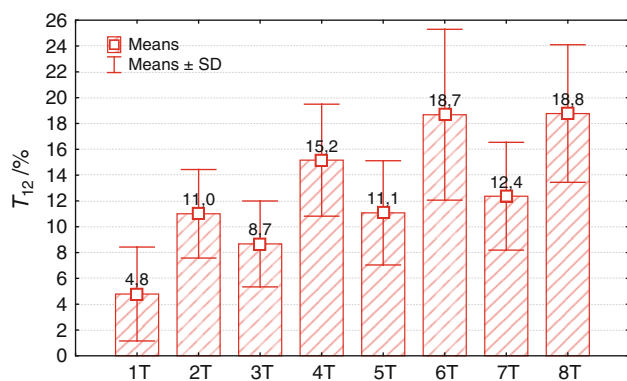
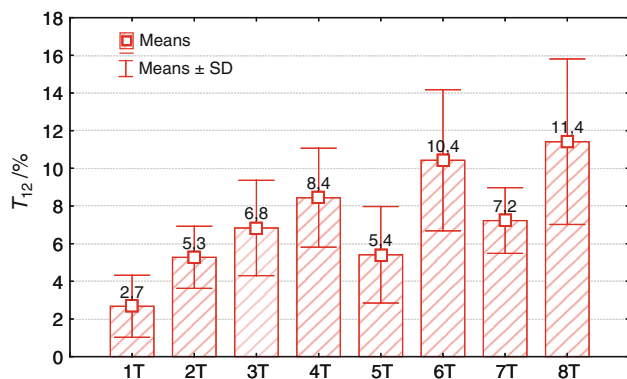
(see Figs. 2, 3, 4). They were statistically significant, showing the dependence from the cryotherapy parameters. However, all measured values remained in physiological range. The systolic pressure BP_{sys} did not exceed 135 mmHg, and the highest measured BP_{dias} reached 84 mmHg. The highest heart rate after the cryotherapy was 91 bpm. This indicates that applied cryotherapy parameters did not cause any harm to the treated persons.

Table 2 Post-hoc comparison of hemodynamic parameters

Parameter	Subgroup (1H–8H)		Before and after cryotherapy differences		Subgroup and before and after cryotherapy differences	
	<i>F</i>	<i>p</i> value	<i>F</i>	<i>p</i> value	<i>F</i>	<i>p</i> value
BP _{sys}	2.91	0.0062	433.39	0.0000	5.39	0.0000
BP _{dias}	1.84	0.0804	322.80	0.0000	0.71	0.6634
HR	1.68	0.1146	348.00	0.0000	2.07	0.0473

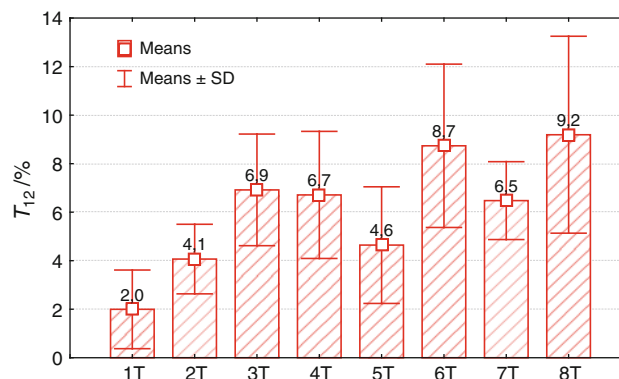
Statistically significant values in bold

F Fisher LSD test value

**Fig. 5** The relative temperature changes in the lower extremities between first and second recording T_{12} **Fig. 6** The relative temperature changes in the upper extremities between first and second recording T_{12}

It is known that the body cooling may result in the increase of blood pressure and heart rate, what can be dangerous especially for persons with some defects in the cardiovascular system.

Yamauchi and coworkers [13, 14] stated that cryotherapy does not alter the hemodynamic parameters (ECG signals, heart rates, and blood pressure). Our study confirmed these results. The observed changes, although statistically significant did not exceed the safety range. In young adults after effort (e.g., sport excursions), the

**Fig. 7** The relative temperature changes in the trunk between first and second recording T_{12}

systolic blood pressure should not exceed 200 mmHg and diastolic 110 mmHg. In all examined cases of cryostimulation, these values did not exceed the safe range.

In order to check how these changes are influenced by cryotherapy parameters, the ANOVA and LSD multiple comparison Fisher test for the post-hoc analysis, were applied (see Table 2).

It was stated that BP_{sys} differences between groups after the cryotherapy were statistically significant. Comparing hemodynamic parameters before and after the cryotherapy, all measured changes, appeared to be significant. Taking into account the therapy parameters (different in each subgroup), the statistically significant changes of BP_{sys} and HR values, were stated by LSD test. However, cryotherapy did not cause any fear for hemodynamic parameters.

Next, the thermovision analysis was performed in the subgroups 1T–8T. Thermovision recordings revealed that directly after the cryotherapy the mean temperature of the body surface decreased, however the decrease was dependent on the body region (see Figs. 5, 6, 7). The lowest cooling temperatures (–120 and –140 °C) and longer exposure time (3 min) caused the stronger response of the human organism (subgroups 6T and 8T).

Thermal imaging showed that the highest temperature decrease directly after the cryotherapy was observed in the lower extremities; along with the slowest return to the initial conditions. In the lower extremities, the cooling effect was stronger (the mean temperature decrease was up to 6.13 °C), whereas in the trunk, it was weaker (0.63–2.09 °C).

In the subgroup 6T, the highest drop of the temperature in the lower extremities was noted: $T_{12} = 18.68\%$, as well as in the subgroup 8T, $T_{12} = 18.77\%$. The same trend was observed in upper extremities: $T_{12} = 10.43\%$ in the subgroup 6T and $T_{12} = 11.41\%$ in the subgroup 8T.

In order to determine whether the temperature differences depend upon the cryotherapy parameters, the ANOVA and the LSD multiple comparison tests were

Table 3 ANOVA; the LSD test for multiple post-hoc comparison of inter-group differences T_{12} before entering the cryochamber and directly after cryotherapy

Subgroup	1T–2T	3T–4T	5T–6T	7T–8T	2T–4T	4T–6T	6T–8T
Temperature	60 °C	100 °C	120 °C	140 °C	60–100 °C	100–120 °C	120–140 °C
Time	1–3 min	1–3 min	1–3 min	1–3 min	3 min	3 min	3 min
Entire body	0.0000	0.0001	0.0000	0.0000	0.0001	0.0025	0.5449
Trunk	0.0169	0.8106	0.0000	0.0018	0.0024	0.0195	0.5970
Upper extremities	0.0028	0.0432	0.0000	0.0000	0.0003	0.0217	0.2560
Lower extremities	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.9154

Statistically significant values in bold

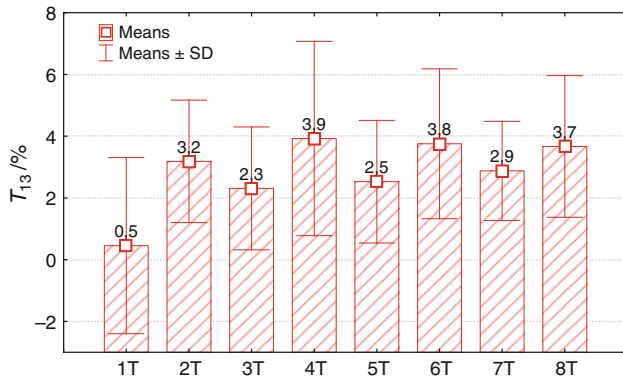


Fig. 8 The relative temperature changes in the lower extremities between first and third recording T_{13}

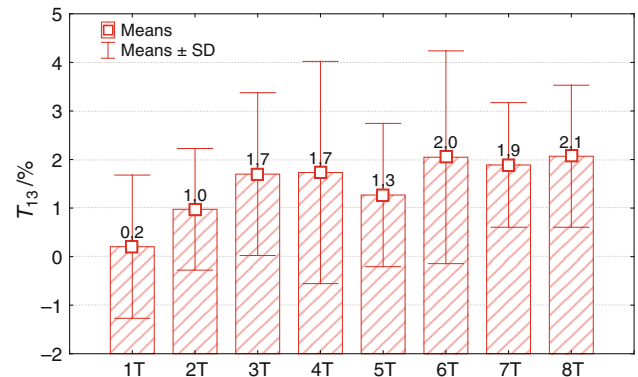


Fig. 10 The relative temperature changes in the trunk between first and third recording T_{13}

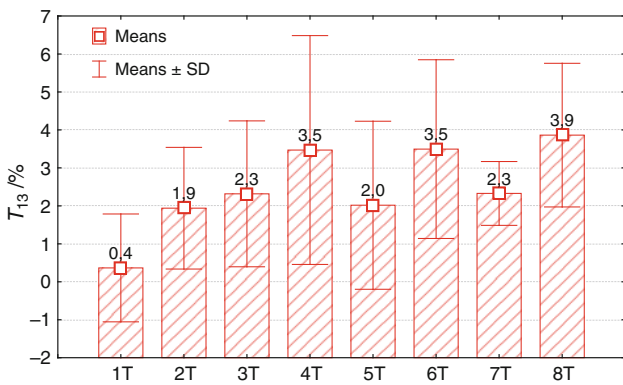


Fig. 9 The relative temperature changes in the upper extremities between first and third recording T_{13}

Table 4 ANOVA; the LSD test for multiple post-hoc comparison of inter-group differences T_{13} before cryotherapy and 30 min after leaving the cryochamber

Subgroup	1T–2T	3T–4T	5T–6T	7T–8T	2T–4T	4T–6T	6T–8T
Temperature	60 °C	100 °C	120 °C	140 °C	60–100 °C	100–120 °C	120–140 °C
Time	1–3 min	1–3 min	1–3 min	1–3 min	3 min	3 min	3 min
Entire body	0.0002	0.0245	0.0144	0.0450	0.0365	0.9899	0.8145
Trunk	0.1323	0.9466	0.1282	0.7256	0.1379	0.5391	0.9688
Upper extremities	0.0022	0.0243	0.0040	0.0025	0.0029	0.9616	0.4711
Lower extremities	0.0000	0.0017	0.0165	0.0045	0.1478	0.7378	0.8649

Statistically significant F values in bold

exploited for the post-hoc analysis (see Table 3). Analyzing inter-group differences between before and after therapy T_{12} measurements, it was proved that the higher body temperature decrease is observed for longer exposures. The LSD test confirmed statistically significant differences T_{12} between subgroups, dependent on exposure times (1T–2T, 3T–4T, 5T–6T, and 7T–8T). Only in trunk region, after exposure in -100 °C, these differences between subgroups 3T i 4T were not statistically significant. Nonsignificant differences were stated between groups exposed for 3 min, one to -120 °C (6T) and the other one to -140 °C (8T).

As it was already mentioned, cooling the body in extreme low temperatures is a strong stimulus to the

vascular system. Therefore, just after the cryotherapy, lowering the body surface is observed. However, later on, a transient increase of the temperature may take place. Figures 8, 9, and 10 present relative temperature changes T_{13} between first and third recording in lower and upper extremities, and in the trunk region.

After 30 min from the cryotherapy, the statistically significant inter-group differences of T_{13} were stated in the groups treated with the same temperature, however, with the different exposure times. From the other site, 3-min exposure and various temperatures did not cause statistically significant differences (Table 4).

In the subgroups 2T, 4T, 6T, 8T treated for 3 min, temperature differences T_{13} between the subgroups in the region of lower extremities ranged 3–4 % and in upper extremities, did not exceed 4 % in the subgroups 4T, 6T, 8T. However, the temperature differences 30 min after the cryotherapy were dependent more on the exposure time than on the temperature itself.

For example, similar reactions were observed after the treatment in the temperature $-120\text{ }^{\circ}\text{C}$ (subgroup 6T) and in $-140\text{ }^{\circ}\text{C}$ (subgroup 8T). Longer exposure time causes also longer return to the initial temperatures.

Conclusions

The temperature of the human body is strongly connected with its physiological state. The human organism is homoeothermic, meaning that it preserves constant temperature that is, to some extent, independent from the temperature of the environment. The reaction to the external changes in the environment temperatures is regulated by the skin vasculature. The superficial body temperature distribution is not even; the highest one is on the trunk, the lower in the extremities [23]. It may be influenced by pathological changes [4, 17], as well as by external stimuli [24, 25]. Due to these poikilothermic and behavioral features, the human body may be exposed safely to extremely low temperatures [2, 4, 26–29].

Often, the treatment in a cryochamber is applied not only for rehabilitation, but also for wellness. The main goal of the exposure in a cryochamber is lowering the body temperature, thus causing positive biostimulation effects. In our study, we proved that the exposure time plays a deciding role in the stimulation. Longer exposure resulted in lower skin temperature and longer return time to initial values. The stronger cooling effect is observed in lower extremities, the smaller temperature decrease was stated in the trunk. The optimal safe treatment parameters are 3-min exposure and the treatment temperature equal $-120\text{ }^{\circ}\text{C}$, since in this case the cooling effect, thus stimulations, was most intensive. One has to notice that the similar effects

were observed after 3-min exposure to $-120\text{ }^{\circ}\text{C}$, as well as to $-140\text{ }^{\circ}\text{C}$, therefore the temperature $-120\text{ }^{\circ}\text{C}$ is more recommended as it is more economically rational.

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