UDC: 613.67.092.19: 615.832

PROMISING NON-PHARMACOLOGICAL APPROACHES TO EMERGENCY ENHANCEMENT OF HUMAN RESISTANCE TO OVERCOOLING

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Developing of the Arctic territories of Russia makes it expedient to devise safety means for emergency enhancement of professionals' resistance to overcooling in order to reduce health risks associated with long-term dwelling under Arctic conditions.

To develop and test promising means of non-pharmacological interventions suitable for enhancing the hypothermic resistance of subjects at work under cool environmental conditions, we recruited 37 able-bodied male volunteers, which were assigned to two experimental groups. In Group 1 (25 subjects), 10 sessions of cryothermic training (CTT) consisted of placing each subject in a cryochamber at –150±2 °C for 2 to 5 minutes. In Group 2 (12 subjects), CTT was supplemented with 10 sessions of normobaric hypoxic preconditioning: 40 minutes of inhaling of a gas mixture containing 15% oxygen. Hypothermic resistance was assessed during the first and the tenth training procedure **in regards to functional indices of responsiveness**. The procedures were found to enhance gradually the hypothermic resistance, the outcome being more pronounced in the Group 2. **Amelioration of** the subjective tolerance to cold was roughly the same in both groups. The mean time of tolerance to hypothermia increased during the tenth vs. the first session by 40% in Group 1 vs. 49% in Group 2. Rectal temperature decrease decelerated by 19% vs. 25%, respectively. Systemic circulation responsiveness to hypothermia decreased by 23–40% vs. 28–50%, respectively. Thus, the combined hypothermic and hypoxic preconditioning is found to be an effective and safe means of non-pharmacological emergency enhancement of tolerance to hypothermia.

***Keywords**: marine medicine, Arctic, hypothermic tolerance, cryothermic training, hypoxic preconditioning*

Introduction

Currently, in connection with developing of the Arctic territories of Russia, the number of specialists of various profiles performing professional activities in the special conditions of the North is significantly increasing, where low ambient temperatures with high air velocities are the primary unfavorable climatic factors [*1, p. 102; 2, p. 9*]. In light of this, the stability of the body to overcooling (hypothermic resistance) is of particular importance for the successful performance of labor activity, preservation of health, and subject's performance [2, p. 19; 3, p. 69]. The human body has a fairly wide range of physiological thermoregulatory mechanisms that prevent acute hypothermia (physical and chemical thermogenesis, centralization of the circulation, reduction of alveolar ventilation, etc.). At the same time, long-term adaptation (acclimatization) to low ambient air temperatures is one of the most complex and physiologically "costly" types of adaptation,

directly determined by health status, the level of hypothermic resistance, the volume of reserve and protective capabilities of the body, the lack of which can lead to the development of an unacceptable functional status (misadaptation) [4, p. 666; 5, p. 82].

In this connection, in order to ensure reliable functioning and fulfill the professional tasks of specialists in a cold climate, along with the use of appropriate exposure suits, special regulation of work regimes and other organizational arrangements [1, p. 103; 6, p. 51], an important aspect is the development of safe technologies for emergency enhancement of hypothermic resistance and for expansion of the body's functional reserves ("physiological preparation") [3, p. 70; 7, p. 27].

Numerous experimental and clinical-physiological studies devoted to the problem of artificial increase of human resistance to exogenous hypothermia with the use of non-drug aids (cold water treatment, sinter swimming, cold water dousing or wraps, etc.) have shown numerous difficulties in this process [8, c . 104; 9, p. 205]. These difficulties are primarily due to the pronounced discomfort of routine cold procedures, their damaging effects on the body, the difficulty of individually selecting the optimal intensity of lifestyle cold factors, the need for long training courses, the risk of disruption of adaptation in the event of even a slight excess of the individual "compensation threshold" of similar cooling effects. In this regard, it is important to develop alternative options for increasing hypoxic resistance using non-drug methods that have less pronounced damaging effect. In particular, in a number of studies (including those performed by us), high efficiency and relative safety of the cryothermic training method (CTT), which is a short-term (up to several minutes) cyclic effects of extremely low temperatures of the surrounding gas environment on the human body is shown [10, p. 24; 11, p. 127; 12, p. 808; 13, p. 51; 14, p. 100].

Another variant of non-drug aids is the use of artificial gas mixtures with reduced oxygen content or hypoxic preconditioning (HP) as an adaptive factor. In a number of studies it has been shown that, in carrying out HP along with the increase in resistance to hypoxia by the mechanism of "cross-adaptation", structural and functional changes are formed in animals and humans that increase the overall and hypothermic resistance [8, p. 66; 15, p. 234]. Given that various adaptive effects of CTT and HP are based on different physiological mechanisms, **we hypothesized** that they might be synergistic in terms of improving human resistance to hypothermia in the combined use of these aids.

Thus, **the purpose of this study** was to assess the efficacy and safety of the combined use of CTT and HP for the emergency enhancement of cold resistance in persons working in conditions of low ambient temperatures**.**

Materials and methods. This study was conducted with the participation of 37 male volunteers aged 20-35 years (mean age 27.2±1.9 years) divided into 2 groups that did not differ in age, baseline hypothermic resistance, and functional parameters (see below).

The criteria for including volunteers in the study were male gender, corresponding age, absence of a history of craniocerebral trauma, chronic physical and mental pathology, acute colds absence at the time of the examination, satisfactory results of primary medical examination, and high motivation to participate in research. The selection of volunteer testers began with an individual interview of each candidate for participation in the study by a medical specialist. During the conversation, passport data were examined,

purpose, tasks, and stages of the assessment, as well as diagnostic methods used and health risks during the procedures were explained. If a candidate met the listed requirements and conditions, he signed a mandatory voluntary informed consent to participate in the study. Further, the medical specialist looked through the extract from the outpatient card of the candidate for the last 5 years issued by the polyclinic at the place of his residence, conducted a survey of health complaints, the presence of bad health habits, performed a primary medical examination and a functional examination.

Candidates with the following contraindications were not allowed to participate in the study: presence in the history, or in the extract from the outpatient card of chronic, often relapsing, somatic diseases of internal organs, mental illnesses, alcoholism, drug addiction; presence in the anamnesis of allergic conditions, skin and venereal diseases; family history – presence of close relatives of chromosomal abnormalities, malformations, mental illnesses, or endocrine diseases.

The study was organized and conducted in accordance with the provisions and principles of existing Russian and international legislative acts, in particular, with the Constitution of the Russian Federation (Articles 41 and 21), Federal Law No. 323-FZ of 21.11.2011 “On the Fundamentals of Public Health Protection in the Russian Federation”, the Helsinki Declaration of 1964 and its revisions of 1983 and 2013. Before beginning the study, each subject was insured in case of health disorders related to the effects. The legitimacy of research was confirmed by the conclusion of an independent ethical committee.

In Group 1 (25 subjects), cryothermic sessions were used to increase cold resistance, implemented using certified cryocamera “KAEKT-01-KRION" (domestic production). The chosen mode of CTT was based on the recommendations of well-known specialists in the field of cryothermie [10, 11, 18] as well as on our own studies [13, 14], and it and consisted in the following. Before the beginning of exposure, the height of the “working room” of the camera was adapted to the growth of the subject so that his head in standing position was completely outside the chamber and his body inside. Then, for 2-5 minutes, the body of the subject in the underwear and light shoes (slippers) was exposed to liquid nitrogen vapors fed into the chamber. The heated gas was removed by extracting, maintaining the temperature inside the chamber within -150±2°C. Duration of the effects was directly determined by the individual sensitivity to cryothermie: duration of the exposure was increased in parallel with the increase in the tolerance of supercooling of the trainees. As a rule, gradual lengthening of the exposure began after the 4^{th}-5^{th} procedure. Cryothermic exposures in the chosen regime were carried out daily (or every other day if, for personal reasons, it was impossible for the examinee to arrive on a routine basis); the total number of procedures in one cycle was 10.

In Group 2 (12 subjects) cryotermic training was realized in combination with hypoxic preconditioning, successively in a single cycle, first cryothermic effect, then (after warming the subject for about 30-40 min) hypoxic effect. This course of CTT was similar to that of Group 1 subjects. Normobaric hypoxic effect was modeled using certified hypoxicators of the membrane type “Hypoximed” (domestic). The HP mode, which had been used earlier to solve similar problems, was used again [8, p. 336; 15, p. 148]: 40-minute continuous breathing with a hypoxic mixture of oxygen content of 12%. The total number of daily combined cycles of CTT and HP was also 10.

To assess the dynamics of hypothermic resistance in subjects of both Groups during the 1st and 10th procedures of CTT, the thermal status, subjective and functional indices were assessed. For the assessment of the thermal status, computer thermometers Elab (Japan) were used, with the help of which the rectal temperature (T_p, °C) and the rate of its decrease (°C/min) were recorded. The influence of CTT procedures on the subjective and psychoemotional state of volunteers was assessed using the standardized questionnaire "Health, Activity, Mood" – HAM (quoted from [16, p. 76]), filled before and after cryothermic effect. As an integral indicator of the HAM test (Int. Ind. HAM, points), the average values for 3 of its registered parameters were calculated. The changes (Δ) of Int. Ind. HAM were determined in cryoothermia in comparison with the corresponding thermo-comfort conditions.

Before the beginning of the control cryoexposures, as well as in the process of their conducting using the automated cardiological complex TM-2425/2025 (A & D Company, Japan), the systemic circulation parameters were assesseed: exercise heart rate (EHR, stresses/min), systolic, diastolic and mid-dynamic arterial pressure (SAP, DAP, and MAP, respectively, mm Hg). The changes (Δ) of the listed indicators were analyzed in comparison with the thermo-comfort conditions.

Statistical processing of the obtained data was carried out with the use of proprietary software package pp. "Statistica" v.12.0, according to existing requirements [17, p. 56]. The associated data were compared with the use of the Wilcoxon T-test, the data divorced from each other were compared with the use of the Mann-Whitney U-test; group results were presented in the form of median (Me), lower and upper quartiles (Q25, Q75). Differences at significance level $p < 0.05$ were taken as statistically significant, and differences at significance level <0.01 were taken as statistically highly significant.

Results of the study and discussion

The results of primary (prior to training) assessments conducted in thermo-comfort conditions showed (Table 1) that in all volunteers the parameters of the functional status registered corresponded to ranges of reference values, which, as is indicated above, was the decisive criterion for inclusion in the study. At the same time, there has not been marked any significant intergroup differences in all indicators in comparison groups, which confirms the correctness of group formation.

Table 1

The initial indicators of the functional status of the subjects of the compared groups, Me (Q25; Q75)

Indicator, unit.	Group	
	Group 1 (**Ошибка! Ошибка связи.**)	Group 2 (n_2=12)
Int. Ind. HAM, points	5.51 (5.09÷ 6.01)	5.54 (4.96÷5.95)
EHR, str./min	69 (65÷ 73)	71 (66÷ 75)
SAP, mm Hg	122 (112÷ 126)	124 (117÷127)
DAP, mm Hg.	77 (72÷82)	79 (75÷ 84)
MDP, mm Hg	92.0 (85.3÷ 96.7)	94.0 (91.0÷99.3)

Note: Validity of differences of indicators over the 1st examination.

The analysis of the results obtained in the process of CCT and HP being carried out showed that none of the subjects in both groups had any unacceptable deviations in hir health status, functional and subjective parameters that would not allow him the possibility of full exercise of his training regime. The four cases of refusal to participate in the studies were related only to individual social and domestic causes (business trips, illness of relatives, other personal circumstances). According to the design of the study, the results of these individuals were excluded from the analysis.

Observation of the test subjects during the training cycles showed that the initial period of training, for the majority of those assessed, was accompanied by negative subjective manifestations, primarily due to the cryotermic stimulus. However, according to experts in the field of cryomedicine [11, p. 128; 18, p. 8], such phenomena should not be the reason for refusing to conduct CTT, since they reflect the tension of adaptive homeostatic mechanisms in the body, which is an obligatory component of the adaptation process.

Being conducted in parallel in Group 2, hypoxic preconditioning did not have such a significant effect on the health status, although the majority of the subjects noted that the initial HP procedures were also the most difficult period of the training cycle.

Nevertheless, as indicated above, the subjects of both groups were able to complete the training in full, and from about the middle of the training cycle, most of them noted improvement in the tolerability of cryotermic actions, which allowed us to gradually increase the duration of their exposure, observing the principles of individuality and safety.

The results of studies of the functional status of volunteers during the first and the final cryothermic procedures are presented in Table. 2.

Comparison of the data presented in the table with the results obtained by other authors [3, p. 70; 7, p. 29] showed that the initial level of cold resistance in our subjects was moderate or moderately depressed. By the end of the course, the average duration of cryothermic procedures in both groups was increased by more than 1 min compared with the 1st procedure ($p < 0.001$), which we regarded as the leading sign of increased cold resistance due to the training. About the same was evidenced by a significant decrease in the rate of fall in rectal temperature during supercooling recorded in both groups, a reduction in the severity of subjective discomfort and compensatory reactivity of the systemic circulation indices for intensive cold exposure.

Table 2

The parameters of the functional state of the subjects (n=25) during the procedures of CTT, Me (Q25; Q75)

Indicator, unit.	*Stage of assessment* *Group*			
	1st procedure		*10th procedure*	
	Group 1	Group 2	Group 1	Group 2
Duration of hypothermia, min	2.74 (2.52÷ 2.88)	2.65 (2.40÷ 2.79)	3.82 (3.51÷ 3.98) $p<0.001$	3.95 (3.66÷ 4.09) $p<0.001$; $p_{1-2}=0.048$
Speed of rectal t° decrease, °C/min	0.26 (0.22÷ 0.27)	0.27 (0.22÷0.29)	0.21 (0.19÷0.23) $p=0.002$	0.19 (0.18÷0.21) $p<0.001$÷ $p_{1-2}=0.044$
ΔInt. Ind. HAM,	-2.03	-2.11 (-1.96÷-	-1.74 (-1.69÷ -	-1.75 (-1.59÷ -

points	(-1.90÷ -2.21)	2.30)	2.00) p=0.021	2.20) p=0.025
Δ HER, str./min	17 (12÷23)	17 (13÷24)	13 (9÷ 17) p=0.003	14 (8÷ 18) p=0.005
Δ SAP, mm Hg	11 (9÷ 14)	12 (10÷ 15)	7 (6÷ 10) p<0.001	6 (5÷10) p<0.001
Δ DAP, mm Hg	7 (5÷ 10)	8 (4÷ 11)	4 (3÷ 5) p=0.005	4 (2÷ 5) p=0.004
Δ MDP, mmHg	8.33 (5.12 ÷ 10.98)	8.98 (6.02÷ 11.21)	5.02 (3.66÷ 6.03) p< 0.001	4.98 (3.47÷ 5.95) p<0.001

Note: Validity of differences: of indicators over the 1st procedure; p_{1-2} – between the groups.

A comparative analysis of the effectiveness of approved training options for increasing the hypothermic resistance of subjects showed that the positive dynamics of the heat status in extreme supercooling in the Group 2, in which the combined trainings had been conducted, was more pronounced, (Figure 1).

Thus, the maximum duration of hypothermia during the 10th procedure in the Group 1 increased by an average of 40% (compared with the 1st procedure), while in the Group 2 – by 49% (p_{1-2}= 0.048); the slowdown in the rate of incidence of rectal temperature in the Group 1 was 19% on average, while the Group 2 – almost 25% (p_{1-2}= 0.044). A somewhat greater degree of positive shifts in persons who underwent combined effects was noted in other parameters of the functional status: a decrease in the reactivity of the indices of systemic circulation during supercooling in the Group 1 was 23-40%, in the Group 2 – 28-50%. The absence of intergroup differences in these indicators, as well as the approximately similar improvement in the subjective tolerance of effects in the comparison groups, is, in our opinion, due to the longer duration of exposure to cryotherapy in the Group 2 in the conduct of the final CTT procedure.

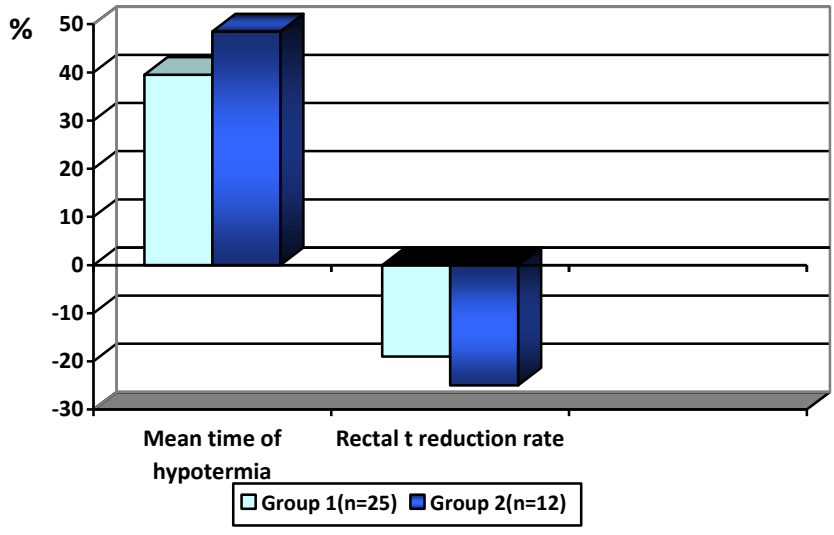

Fig. 1. Relative shifts in the mean thermal indexes recorded during the final cryothermia (in comparison with the first procedure), in the comparison groups

The obtained data, on the whole, allow us to conclude that the non-drug aids used by us are an effective and safe way of urgently raising hypothermic resistance of a person.

Realizing that the main contribution to the detected phenomena belongs to CTT, nevertheless, the results of our study showed that the parallel use of another (nonspecific) version of training effects significantly

increases the effectiveness of a specific training. As indicated above, this fact is a consequence of "cross-adaptation", which stimulates the development of additional structural and functional changes in the body and, as a result, an increase in overall resistance, resistance to any external influences, expansion of reserve capabilities of physiological and regulatory systems [8, p. 134; 15, p. 218; 19, p. 174]. Nevertheless, the approved version of the combined use of cryotermic training and hypoxic preconditioning is very "stressful"" for a human body and can be used only if the trainee does not have any deviations in his state of health. In addition, carrying out CTT requires high motivation of the patient, mobilization of strong-willed efforts, which also significantly limits the wide application of the method in preventive and clinical medicine [3, p. 69; 7, p. 27; 10, p. 30].

In connection with the foregoing, it is necessary to develop further such procedures, in which drug therapy combined with and physical trainings seems promising, combining several non-drug effects (for example, CTT and oxygen-helium mixture, argon-containing gas-air environment), which should lead to synergetic sanogenic and ergogenic the effects of the methods used, to shorten the training period while increasing the success of training.

Conclusion. The study carried out has shown that the crypthermic training in the mode developed by us is the effective and rather safe way of an emergency increase in hypothermic resistance of the human body. The effectiveness of such training can be significantly enhanced by the parallel carrying out of CTT and HP, the mode of which was also developed in this study.

REFERENCES

1 *Azarov I.I., Butakov S.S., Zholus B.I., Zetkin A.Yu., Remmer V.N*. The experience of preserving the health of servicemen in the Arctic in everyday activities and in emergency situations //*Morskaya meditsyna* [Marine medicine]. 3 (3). 2017: 102-111.

2 *Mosyagin I.G.* Strategy of development of marine medicine in the Arctic main regional direction of the national marine policy of Russia //*Morskaya meditsyna* [Marine medicine] 2017, 3 (3): 7-22.

3 *Mosyagin I.G., Lobozova O.V., Ivanov A.O., Anistratenko L.G., Bepkishkiy E.N.* Optimization of psycho-physiological adaptation of students and cadets in the initial period of training using cryothermic training //*Voenno-meditsynsky zhurnal* [Military Medical Journal] 2015, 8 (8): 68-70.

4 *Bryuk K.* Heat balance and regulation of body temperature. In.: Fiziologiya cheloveka. *Ed. R. Shmidt, G. Tevs*. Moscow: Mir; 2010: 665-87.

5 *Fricke R.* Mechanisms of human cold adaptation // *Circumpolar health: Proc. of 8th symp*. Toronto, 2009: 65-86.

6 *Blaginin A.A., Vislov A.V., Lizogub I.N.* Actual issues of medical support of aviation specialists in the Arctic region //*Voenno-meditsynsky zhurnal* [Military Medical Journal]. 2015; (1): 50-54.

7 *Mosyagin I.G., Lobozova O.V., Ivanov A.O., Bezkishkiy E.N*. The impact of cryothermal training on the level of functional abilities of students in the initial learning period. Ekologiya cheloveka. 2014; (10): 25-29. (In Russ).

8 *Novikov VS., Shustov EB., Goranchuk VV*. Correction of functional states in extreme impacts. St. Petersburg: *Nauka*; 1998: 544 p. (In Russ).

9 *Taghawinejad M., Fricke R., Duhme L.* Temperature regulation in man - a practical study. - N.Y .: The Mosby Comp., 2003: 366.

10 *Portnov VV*. Cryotherapy: theoretical basis and application in practice. In: *Obschaya i lokalnaya vozdushnaya krioterapiya*. Moscow; 2007: 33-32. (In Russ).

11 *Kiryanova VV*. Clinical aspects of application of General cryotherapy. In: *Materialyi II mezhdunarodnoy nauchnoprakt. konf. «Krioterapiya v Rossii»*. SPb.; 2009: 127-131. (In Russ).

12 *Klimenko T, Ahvenainen S, Karvonen SL*. Whole-body cryotherapy in atopic dermatitis. *Arch. Dermatol*. 2008;144(6):806- 808.

13 *Eroshenko A.Yu., Ivanov A.O., Stepanov V.A., Linchenko S.N., Bugayan S.E., Kochubeynik N. V., Sklyarov V.N., Groshilin S.M*. Aerocryothermal training as a method of emergency increase of human resistance to exposure to low ambient temperatures. *Medical Herald of the South of Russia*. 2017; 8 (4): 47-52. (In Russ.) DOI 10.21886 / 2219-8075-2017-8-4-47-52.

14 *Linchenko S.N., Ivanov A.O., Stepanov V.A., Barachevskiy Yu.E., Abushkevich V.G., Bugayan S.E., Kochubeynik N.V., Groshilin S.M.* Restoration and expansion of the functional potential of human body by means of aerocryothermal training. // Kubanskij Nauchnyj Medicinskij Vestnik. 2017; 24 (6): 95-101. (In Russ., English abstract). DOI: 10.25207 / 1608-6228-2017-24-6-95-101

15 *Goranchuk V.V., Sapova N.I., Ivanov A.O.* Hypoxic therapy. - SPb .: OLBI, 2003: 564 p.

16 *Rostomashvili L.N., Ivanov A.O.*. Integrated diagnostic of development of persons with complex impairments. St. Petersburg; 2012: 159 (In Russ).

17 *Grzhibovskii A.M*. Data types, validation and distribution of descriptive statistics. *Ekologiya cheloveka*. 2008;(1):52-58. (In Russ).

18 *Baranov A.Yu.* Cryotherapy as a means of accelerating the rehabilitation of patients after surgery // *Proceedings of the 2nd International Scientific and Practical Conference "Cryosurgery. Modern methods and innovative technologies"* M., 2012: 6-9.

19 *Alekperov I.M., Plakhov N.N.* The role of nonspecific physical training in increasing the functional reserves of the body of seamen when adapting them in conditions of navigation to low latitudes. Actual questions of physical and special training of power structures. 2015 (3): 170-174.

The study did not have any sponsorship.

The authors declared no conflict of interest.

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Date of receipt of the article: *April 16, 2018.*