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COMPARATIVE AND ONTOGENIC PHYSIOLOGY

Dynamics of Parameters of Energy Metabolism at Adaptation to Diving in Human

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Abstract—Studies of the diving reflex in comparative evolutionary terms have shown that a complex of reactions providing the oxygen-saving effect during diving is inherent in human as well as in the secondary-aquatic mammals. This is confirmed by study of peculiarities of energy metabolism the simulated diving (it is the breath holding with face immersed into the cold water—what we call the cold-hypoxic-hypercapnic effect, CHE). Data of gas analysis have shown that the oxygen consumption rate during the diving imitation is statistically significantly lower than during the usual expiration delay (Genche's test). We have revealed that under effect of adaptation to CHE, on the background of a reduction of the total energy consumption by the organism there occurs a slight increase in contribution of aerobic processes to its energy supply. Adaptation to CHE has been shown to be accompanied by a decrease in reactivity of the parasympathetic chain of regulation of the heart chronotropic function and by an increase of duration of apnea. The apnea duration is directly correlated with level of insulin—the hormone stimulating activity of the anaerobic energy pathway provision. Under effect of adaptation to CHE there has been established an increase of the organism resistance to stress actions, which is confirmed by the lower levels of cortisol and thyroid hormones in representatives of the experimental group as compared with the control one.

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Key words: adaptation, anaerobic and aerobic metabolism, hormones of thyroid and adrenal cortex, oxygen-saving, diving reaction, technology of the cold-hypoxic-hypercapnic effect.

INTRODUCTION

The cognition of mechanisms of natural adaptations allows developing physiologically adequate methods of an increase of the human organism resistance to unfavorable environmental factors. An interest model in this aspect are secondary-aquatic mammals, as their adaptation to the water environment is related to decision of the chief—"fight for oxygen." Two aspects can be identified at evaluation of the evolutionary adaptation strategies of the diving mammals, which allow overcoming the oxygen deficit. The first aspect—the adaptive changes of the respiratory and cardiovascular systems responsible to supply and redistribution of oxygen in the organism. The physiological usefulness of these adaptations is connected with the more rational, economic, and complete use of oxygen under hypoxic conditions. The second strategic direction in evolution of the complex of interrelated functional mechanisms of adaptation to diving is an increase of oxygen stores. Realization of this direction in different species can have different solution: at the expense of an increase of the lung volume or at the expense of an increase of the oxygen reserves in blood and muscles [1, 2]. The organism provision with oxygen at the expense of the non-pulmonary reserves is considered to be more progressive form of adaptation to diving and is spread widely in diving mammals [3]. However, as calculations and experimental data demonstrate, even the highest level of the oxygen reserve that can be revealed in diving mammals is unable to provide long diving without involvement of additive adaptive mechanisms [1–5]. It has been established that many diving mammals can stay under water 4–5 times longer than the organism oxygen reserves allow them (under condition of maintenance of metabolism at the same level as on land in the state of rest of the conscious animal). At the same time, according to studies of some authors, in the majority of the secondary-aquatic amniotes, at diving, oxygen is used not completely [6]. This phenomenon can be explained, first, by the organism transition to the more economic metabolism level: for example, in pinnipedes it decreased 4–5 times, second, by the presence of the endogenous sources of oxygen. The second suggestion is based on the hypothesis put forward by the staff of our laboratory: according to it, in tissues of the secondary-aquatic mammals there is a peculiar "dynamic metabolic oxygen depot" that is formed due to intensive processes of lipid peroxidation and to an increase of the power of the enzymatic link of the antioxidant protection providing release of the endogenous molecular oxygen for maintenance of aerobic processes during apnea [7, 8].

Undeniably, the human life activity is connected to the lesser degree with hypoxic loadings. Man is not as skilful diver as aquatic and semiaquatic mammals; nevertheless, the human also has a complex of adaptive cardiovascular reactions analogous to those in diving animals [9–12]. The question arises: is it possible by means of training of the essential for the human "rudimentary diving reflex" to activate the chain of the biochemical readjustments analogous to those formed at diving in animals and to cause the organism transition to the more economic metabolism level? The latter is perspective for overcoming of the oxygen deficit accompanying many human diseases, such as ischemic disease of heart and brain, infarctions, insults, and others. In this connection, the goal of the present work consisted in study of the metabolic readjustment constructions appearing in human at activation of the diving reaction.

For this, it was necessary to solve the followed tasks: (1) to determine the oxygen consumption at imitation of diving in human by means of the model of the cold-hypoxic-hypercapnic action (CHE) and by the "dry hold-up of respiration" (Genche's test) with use of the method of gas analysis of the expired air; (2) to characterize the effect on the organism functional state of adaptation to CHE by parameters of the human bioenergetic metabolism and the biochemical and endocrine status; (3) to study dynamics of interconnections under the effect of adaptation to CHE between characteristics of the energy metabolism, parameters of the cardiovascular system, and peculiarities of realization of the diving reaction in the testees.

MATERIALS AND METHODS

To solve the posed tasks, we used the developed in the laboratory model of imitation of diving of structural-functional adaptations in the limits of technology of the cold-hypoxic-hypercapnic action (CHE) [13], which was performed by using the face immersion into water at hold-up of respiration. The water temperature was by 8–10°C lower than the environmental temperature (almost 12–14°C). Adaptation to CHE was achieved by the cold-hypoxic-hypercapnic training (CHHT) based on the every day use of the diving series.

The study consists of two observation series. The first series was dealing with study of oxygen consumption at CHE and Genche's test using data of gas analysis of the expired air. The tested subjects were 12 young athletes—the 13–14-year old swimmers. During the study they resided under similar conditions and at the same life activity regime. CHE was performed during the periodic group sport training and lasted for 4 weeks in combination with the general physical preparation.

In the second series, effect of adaptation to CHE on the organism functional status was evaluated from parameters of the human bioenergetic metabolism and biochemical and endocrine status. The study was performed on 20 practically healthy 20–22-year old men (students of the Military Medical Academy) who had similar level of the general physical preparation and resided under identical conditions.

In both series the study was performed twice. The background value of the cardiovascular system was determined initially, the status of regulation of the autonomic link was evaluated by the method of variation pulsometry. The electrocardiogram (ECG) in the second standard lead, the arterial pressure (AP), and the heart rate (HR) were recorded under the rest conditions, before immersion of the face into water, during the immersion, and at the recovery process by the apnea ending. The ECG recording was performed using the computerized cardiograph (Cardio-99, APRI). The parameters of the functional status of the cardiovascular system and of the organism adaptive capacities were evaluated from Rufier's index (RI) and adaptation index (AI) [14]. The activity of the sympathetic and parasympathetic parts of the autonomic nervous system was determined from parameters of the variation pulsometry. The following characteristics were analyzed: the mean duration of the cardiointervals, the cardiointerval variation dispersion (ΔX), myocardium stress index (MSI), the autonomic rhythm index (ARI). From the AP and HR parameters, the heart output value was calculated. From the character of the cardiogram changes, the parameters of the diving reaction were evaluated: the latent period of development of bradycardia (I, s), the expression of bradycardia, the rate of increase of bradycardia (V, arb.un.), the time of the appearance of the maximal cardiointerval at CHE (t, s), the time of the ECG recovery after CHE (L, s), and the time of apnea (T, s) [14].

In the first series of study of the additional procedure of evaluation of the cardiovascular system status was the method of differential sphygmogram. The pulsogram was recorded by using the program apparatus complex [16] that allowed record and analyzing synchronously in one study two main pulse characteristics—oscillations of the arterial wall (recorded from the digital artery) and the heart rhythm. The parameter of the vascular tonus of the digital artery was determined from the amplitude–time characteristics of the pulse wave. Apart from the above-described parameters, the oxygen consumption was determined by the gas analysis method. The oxygen pressure in portions of the reserve expiration was analyzed: after the usual quiet respiration, after the "dry hold-up" of expiration (Genche's test) and after CHE. The minimal pO_2 value was recorded in the expired air, the closest to that in the alveolar air. The absolute value of the pO_2 decrease in the above-described probes as well as the oxygen consumption rate (VpO_2) were determined:

$$VpO_2 = \Delta pO_2/T_{ap},$$

where $\Delta pO_2 = \Delta pO_2$ in the atmosphere air—pO_2 in the air portion of the reserve expiration after the corresponding probe; T—time of the hold-up of respiration at Genche's test or CHE. The gas analysis was performed by using a pO_2-MF01 microprocessor analyzer (the manufacturer—the "Scientific-production center of ecology and health").

In the second series of experiments the testees were divided into two representative subgroups. One from them, the experimental one, was submitted to the two-week CHE, the second group was not trained and served control to the first one. The repeated examination was performed after 2 weeks. Apart from evaluation of the cardiovascular system status and characteristics of realization of the diving reaction, the peculiarities of metabolism and hormonal status were studied: in the subject blood plasma, there were determined the background values of parameters reflecting character of the energy metabolism and of the pituitary hormones participating in its regulation and in the adaptogenesis processes. The blood for the study was taken from the elbow vain in the morning (10.00–11.00) on an empty stomach, at the period from 10 to 25 December. The blood plasma samples were frozen at –20°C in liquid nitrogen and stored not more than for 3 weeks. The analysis of the content of testosterone and insulin in the blood plasma was performed by using the radioimmunology method. To determine thyrotrophin, total thyroxin, and total triiodothyronine, the immunoenzyme analysis was performed with use of "Diaplus" and "Immunotech" test-systems. The content of the lactic [18] and pyruvic [17] acids in the blood plasma was determined by enzymatic methods. The limits of normal values were: for insulin—19.2–160 pmol/l; for cortisol—60–600, for testosterone 4.5–30.0; for thyrotrophin 0.1–5.0 mIU/l; for triiodothyronine—1.0–2.8, for thyroxin—60–160 nmol/l, for pyruvic acid—0.056–0.135, for lactic acid—0.88–1.33 μmol/ml.

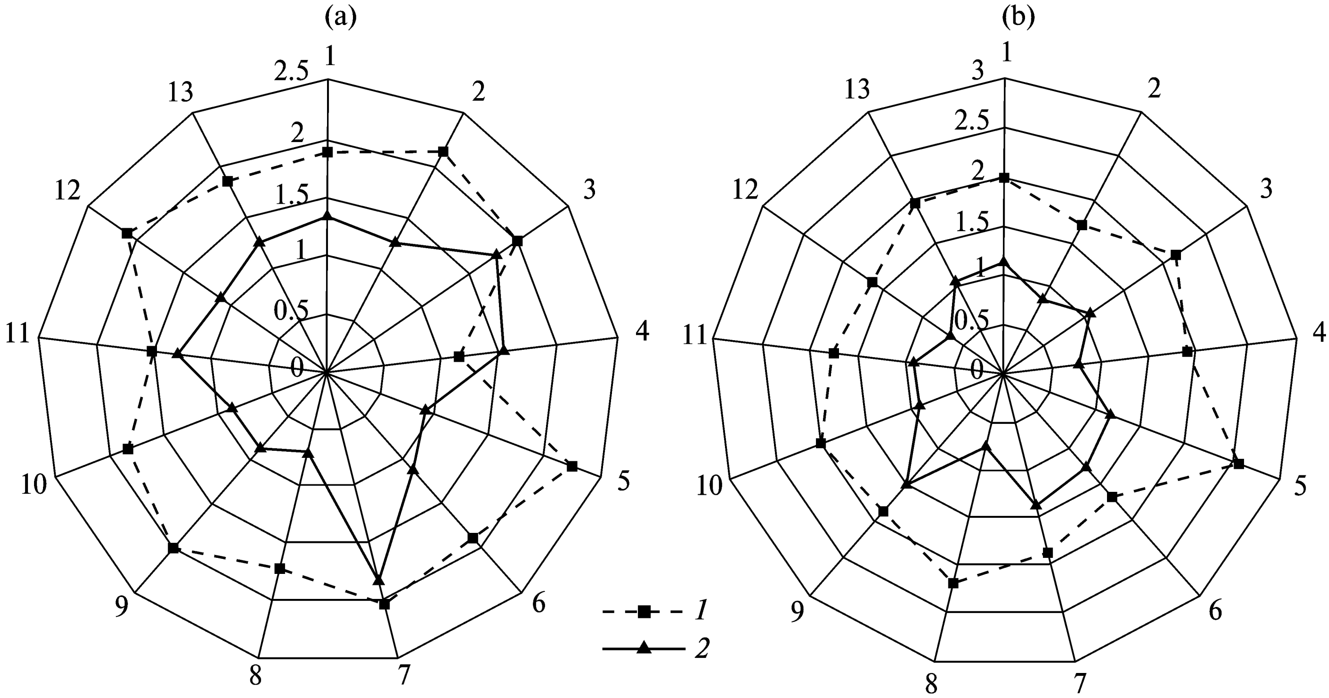


Fig. 1. Rate of oxygen consumption (arb.un.) at Genche's test (*1*) and at driving (*2*) before (a) and after (b) adaptation to the cold-hypoxic-hypercapnic action. Radial axes—individual values of oxygen consumption by testees (1—13—the testees).

The data of the studies were treated statistically (software Statistica 6.0, Stat-Soft/Inc). To study interconnection between parameters of metabolism and peculiarities of functioning of the cardiovascular system as well as between characteristics of the diving reaction, the correlation analysis was used.

RESULTS AND DISCUSSION

Study of oxygen consumption during the usual respiration (in the initial rest state), at Genche's test and CHE by the method of gas analysis has allowed revealing the followed facts.

The oxygen consumption rate (the rate of the pO_2 fall) at CHE on the whole in the group was statistically significantly lower than at the Genche's test (Fig. 1). Only in one out of 13 subjects in the first examination before CHHT, the oxygen consumption level at CHE was higher than at the Genche's test. Taken in account that the oxygen-saving effect during realization of the diving reaction is due mostly to the cardiovascular system reactions, we performed the correlation analysis between parameters of the bradycardia expression (the degree of deceleration of the heart rhythm during realization of the diving reaction), the value of the vascular tonus in the initial state and at realization of the diving reaction as well as between the absolute pO_2 values in the air of the reserve expiration after the usual respiration, after apnea at CHE, between the apnea time and the oxygen consumption rate—the pO_2 decrease for 1 s, by CHE. The analysis results are presented in Fig. 2. In the first examination (before CHHT) the negative correlation was revealed between the oxygen consumption rate and the apnea duration. Meanwhile, no correlation was found between the absolute values of oxygen consumption (ΔpO_2) and apnea duration at CHE. The obtained data can indicate that the apnea duration is limited not by the level of the oxygen decrease, but by some other factors, possibly, as we showed it earlier, by the low psychological tolerance to the physiological discomfort at CHE [19]. The reverse dependence is detected between the index of the

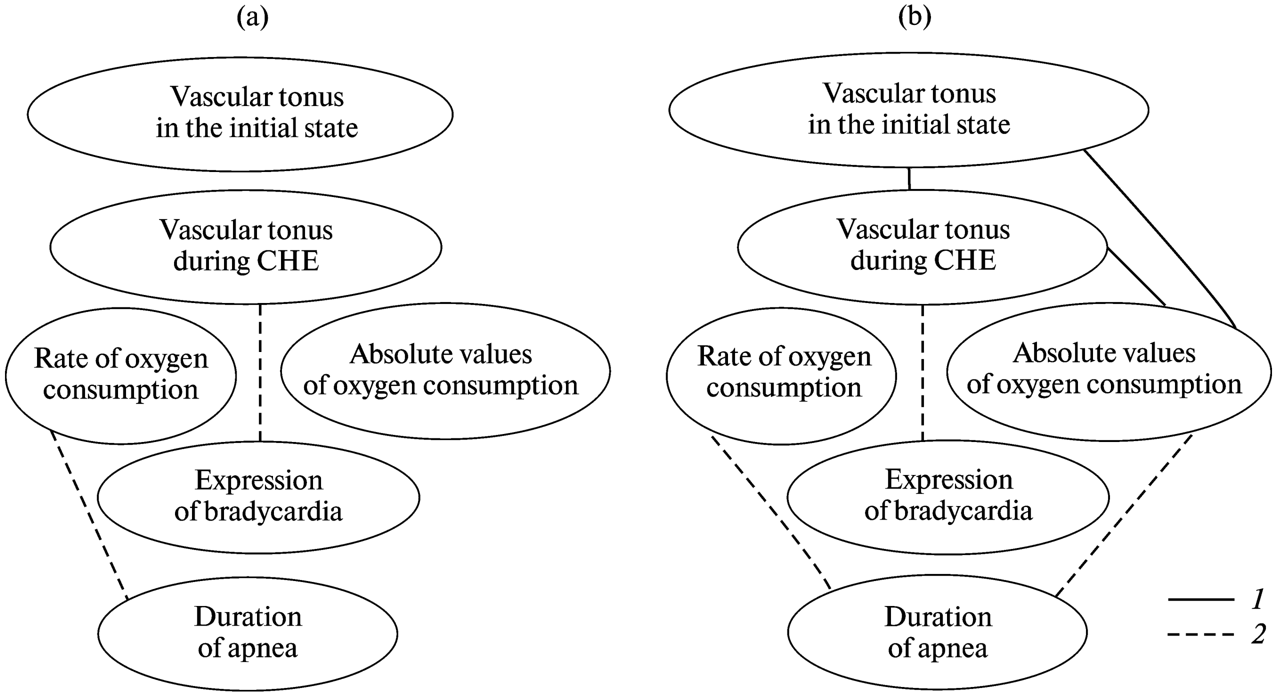


Fig. 2. Correlation connections between characteristics of diving reaction and parameters of oxygen consumption before (a) and after (b) CHE. (*1*) Reverse correlation ($p < 0.05$), (*2*) direct ($p < 0.05$).

bradycardia expression and the background value of the vascular tonus. The bradycardia at diving is known to be due to an enhancement of the effect of the vagus nerve system on the heart sinus node whose tonic effect increases under effect of stimulation of the face tactile and cold receptors at immersion into the water as well as of the vascular chemoreceptors that are activated in the apnea process under the effect of change of the blood gas composition. An increase of the vascular tonus at realization of the diving reaction, on the contrary, is due to an enhancement of sympathetic effects on their muscle walls. The bradycardia expression at diving is also affected by the blood acetylcholine level and the cholinesterase activity [20]. A high level of catecholamines in blood, on the contrary, interferes with development of bradycardia, but promotes vasoconstriction. Probably, the revealed here reverse correlation between the bradycardia expression at the process of the diving reaction realization and the value of the vascular tonus is due particularly to these unspecifically acting factors.

After adaptation, the statistically significant increase of the time of apnea at CHE was not accompanied by a statistically significant change of the absolute value (ΔpO_2) of the oxygen consumption (Table 1), but the oxygen consumption rate (V_{pO_2}) decreased statistically significantly. These facts can indicate indirectly the activation of the oxygen-saving mechanisms of the diving reaction under the CHE effect. The same is indicated by correlation analysis of the data obtained at CHE (Fig. 2). In the field of correlation interrelations, attention is attracted to the direct correlation between the absolute values of pO_2 and the vascular tonus value. The correlation between the absolute pO_2 values and the degree of deceleration of the heart rhythm (parameter of the bradycardia expression) during the diving reaction realization is absent. Taken into account that the bradycardia expression during diving does not change significantly under effect of CHE, whereas the vascular tonus increases statistically significantly, it can be concluded that the oxygen-saving effect of the diving reaction is due predominantly to vasoconstriction of peripheral vessels, rather than to the blood flow deceleration connected with development of bradycardia. At the same time, as noted by

Table 1. Oxygen consumption from results of gas analysis of expired air and of index of the arterial wall tonus (n = 12)

Parameters	Absolute values of pO_2 (Hg mm)			Rate of change of pO_2 at Genche's test (Hg mm/s)	Absolute pO_2 values after CHE (Hg mm)	Rate of pO_2 change at CHE (Hg mm)	Time of apnea at CHE (s)	Index of the arterial wall tonus (arb.un.)	
	in atmospheric air	after usual expiration	after Genche's test					in the initial state	at CHE
Before CHE	155 ± 3	122 ± 5	94.2 ± 5.8	1.88 ± 0.12	106 ± 6*	1.22 ± 0.07**	40 ± 9	23.7 ± 4.3	47 ± 7#
After CHE	160.9 ± 3	124 ± 5	96 ± 6	1.93 ± 0.09	105 ± 7	1.04 ± 0.05**,##	60 ± 8#	19.5 ± 3.8	64 ± 6##

Note: Asterisks indicate the statistically significant difference of the Genche's test—CHE within the limits of one examination *—$p < 0.05$, **—$p < 0.01$, the sign #—the statistically significant differences before CHE—after CHE (by Mann–Whitney criterion (*—$p < 0.05$, **—$p < 0.01$).

Anderson and coauthors [21], the vasoconstriction at diving also develop in pulmonary vessels; in this connection the oxygen utilization in lungs can decrease. In this case the gas analysis of the expired air after apnea cannot indicate completely the oxygen consumption by the organism during diving. Therefore, there was performed a series of studies dealing with dynamics of biochemical parameters caused by the diving reaction and CHE.

In the second series of studies the testees were divided into two groups—control (n = 8) and the group adapted to CHE (n = 12). The necessity of the control group was due to high sensitivity of the studied parameters to change of the testees' functional status. The parameters of the functional status of testees of the control group at the primary and secondary examination and levels of the same parameters in subjects of the experimental group are presented in Table 2. Analysis of the initial parameter did not reveal statistically significant differences between the groups. In both groups the parameters were within the limits of normal values. Thus, the initially control and the experimental groups can be considered the representative ones. The results of the repeated study can be affected by the following moments. First, the study coincided with beginning of the session and, hence, with intensive mental load and the examination stress. Second, as shown by our earlier performed studies [12, 22], duration of adaptation to CHE for 2 weeks is not sufficient for formation of the steady adaptation. It is this that probably can account for the increase of the triiodothyronine and cortisol content in blood to the level exceeding the upper limit of the norm in both groups. An increase of the cortisol level in the control group is statistically significant, whereas in the experimental group it is not. The triiodothyronine level rose statistically significantly in both groups, but it is statistically significantly higher in the control group as compared with the experimental one (2.56 ± 0.22 versus 2.20 ± 0.07 nmol/l, respectively, at $p < 0.043$). In the experimental group the total thyroxin level did not change, while in the control one it rose and became statistically significantly higher than in the experimental group (9 ± 3 in the experimental group, 104 ± 4 in control, $p < 0.003$).

The pyruvic acid content in blood of subjects of the control group increased by 48%, whereas the lactic acid content decreased by 14%. In the experimental group these both parameters decreased: the pyruvic acid content by 9%, the lactic acid level by 51% ($p < 0.01$). The ratio lactic acid/pyruvic acid decreased statistically significantly (by 37% in the control and by 28% in the experimental group).

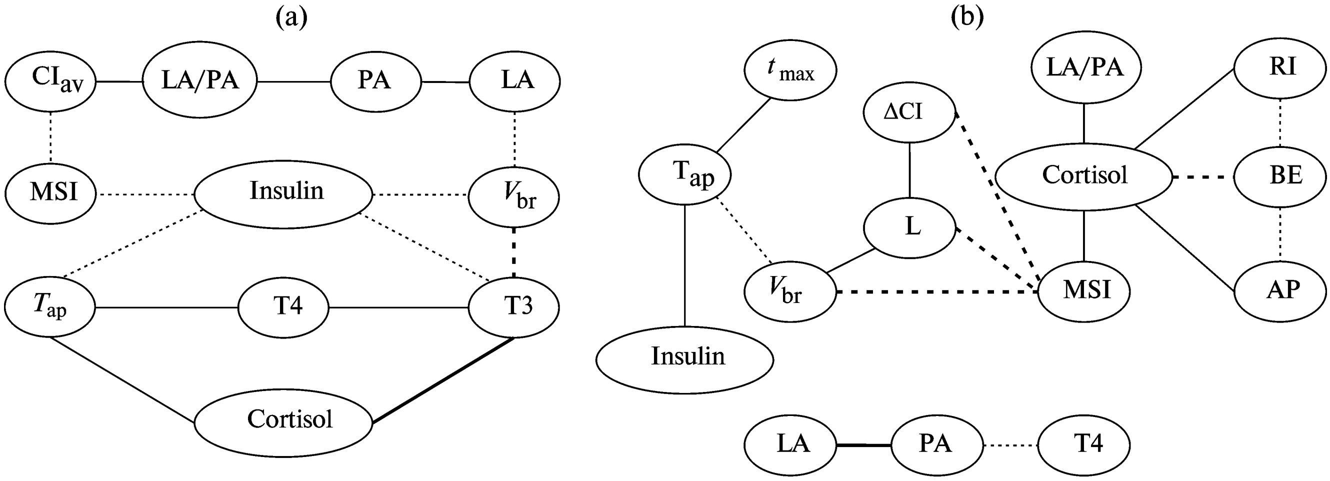
In both groups the tendency for an increase of the amount of erythrocytes and of hemoglobin in blood is observed (Table 2).

By analyzing the obtained results, it is to be noted that the repeated examination of the subjects was performed on the background of intensive mental load with elements of stress (session). In subjects of the experimental group they occurred on the background of adaptation to CHE. The intensive mental function, especially with stress, is known to occur on the background of increased energy consumption [23]. The thyroid-produced

Table 2. Parameters of the functional state in the initial state and after two weeks at the repeated examination

Parameters	Initial state $x \pm S_x$	After adaptation to CHE $x \pm S_x$
Control group ($n = 8$)		
Expression of bradycardia (arb.un)	1.40 ± 0.12	1.54 ± 0.25
Duration of apnea (s)	28.5 ± 4.0	33.9 ± 4.4
Latent period of bradycardia (s)	12.9 ± 2.9	15.3 ± 2.9
Time:		
of recovery of ECG (s)	7.8 ± 2.7	14.9 ± 4.6
of appearance of CI_{max} at CHE (s)	19.9 ± 3.4	27.5 ± 4.5
Content:		
of insulin (nmol/mol)	44 ± 8	56 ± 9
of cortisol (nmol/mol)	529 ± 23	644 ± 19*
thyrotrophin (mIU/l)	2.2 ± 0.4	2.2 ± 0.4
of total T3 (nmol/mol)	1.9 ± 0.2	3.6 ± 0.2*
of total thyroxin (nmol/mol) 87.9 ± 5.6	103.6 ± 3.7*	
of PA (μmol/ml)	0.141 ± 0.024	0.208 ± 0.119
of lactic acid (μmol/ml)	1.36 ± 0.25	1.19 ± 0.62
Ratio lactic acid/PA (μmol/ml)	10 ± 3	6.3 ± 1.5**
The number of erythrocytes (1012 cells/l)	4.45 ± 0.44	4.80 ± 0.26
The content of hemoglobin (g/l)	134 ± 1.1	14.8 ± 9*
Experimental group ($n = 12$)		
Expression of bradycardia (arb.un)	1.36 ± 0.06	1.46 ± 0.09
Duration of apnea (s)	43.3 ± 6.3	71.7 ± 8.3*
Latent period of bradycardia (s)	14.2 ± 3.5	23.8 ± 4.8*
Time:		
of ECG recovery (s)	14.4 ± 5.2	27.5 ± 18.5
of appearance of CI_{max} at CHE (s)	23.4 ± 4.3	49.2 ± 8.0**
Content:		
of insulin (nmol/mol)	46 ± 6	47± 4
of cortisol (nmol/mol)	597 ± 18	608 ± 15
of thyrotrophin (mIU/l)	1.4 ± 0.2	1.9 ± 0.1*
of total T3 (nmol/mol)	1.9 ± 0.1	2.2 ± 0.1**
of total thyroxin (nmol/mol)	88.7 ± 3.0	88.7 ± 2.7
of PA (μmol/ml)	0.140 ± 0.032	0.129 ± 0.029
of lactic acid (μmol/ml)	1.51 ± 0.43	0.99 ± 0.23
Ratio lactic acid/PA (μmol/ml)	11 ± 2	7.8 ± 1.5*
The number of erythrocytes (1012 cells/l)	4.24 ± 0.22	4.52 ± 0.26*
The content of hemoglobin (g/l)	131 ± 12	143 ± 6*

Note: Asterisks indicate the statistically significant differences by Mann–Whitney criterion: (*—$p < 0.05$, **—$p < 0.01$).



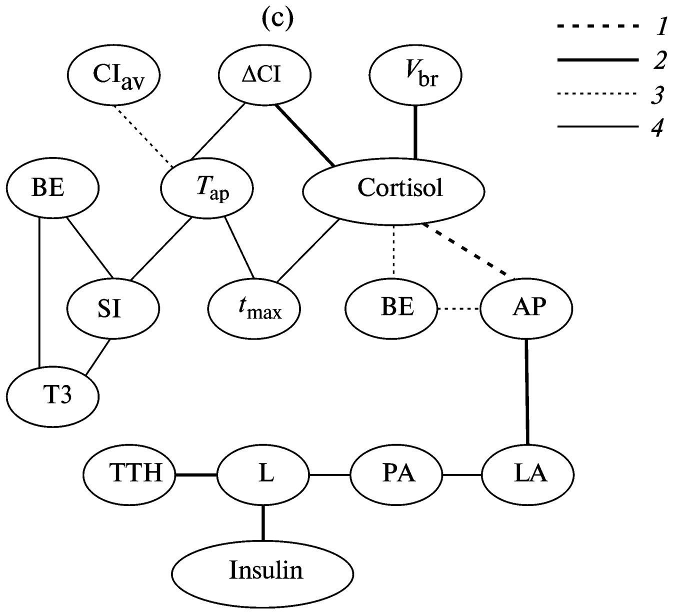


Fig. 3. Correlations of functional parameters of Military Medical Academy students ($n = 20$) in the state of rest (a), after the two-week long cold-hypoxic-hypercapnic training in the experimental group (b), and at repeated examination in the control group (c). (*1*), (*3*) direct correlation ($p < 0.01$, $p < 0.05$, respectively), (*2*), (*4*) reverse correlation ($p < 0.01$, $p < 0.05$, respectively). CI_{av}—the averaged value of cardiointervals, MSI—myocardium stress index, V_{br}—rate of the bradycardia increase during realization of diving reaction, T_{ap}—time of apnea at immersion of face into water, T_4—thyroxin, T_3 —triiodothyronine, LA—lactic acid, PA—pyruvic acid, LA/PA—ratio of concentrations of lactate to pyruvic acid, RI—Rufie index, AP—adaptation potential, I_{max}—time of the maximal CI appearance during apnea at realization of diving reaction, ΔCI—difference between the maximal CI during realization of diving reaction and on the background, BE—expression of bradycardia during realization of diving reaction, SI—stress index, TTH—thyrotrophic hormone.

hormones—thyroxin and triiodothyronine—enhance oxidative processes in mitochondria, which leads to enhancement of energy metabolism. The quicker activation of the energy formation occurs under the effect of triiodothyronine (after 6–12 h). A statistically significant increase of this hormone in both groups can be connected with preparing and passing examinations. The enhancement of energy consumption processes is indicated by an increase of intensity of the aerobic link of energy formation. This is confirmed by a statistically significant decrease of the ratio lactic acid/pyruvic acids well as by an increase of the hemoglobin level and the erythrocyte number in both groups (a statistically significant increase in the experimental group and that at the tendency level—in the control group). In the testees of the control group this occurs on the background of the more intensive basal metabolism, which is confirmed by a statistically significant increase of the total thyroxin level as well as by the higher level of pyruvic acid in the experimental group. The thyroxin level is practically not increased relative to the background values in the experimental group, while the ratio lactic acid/pyruvic acid decreases at the expense of a statistically significant decrease on the background of the tendency for a pyruvic acid decrease, which can indicate transition to the more effective, economic energy consumption process. Taken in account the fact that the MMA students at the period of observation were in the same regime of life activity (living, alimentary ration, physical and mental loads), it can be suggested that this is connected with results of the cold-hypoxic-hypercapnic training.

A cortisol elevation can be due to an increase of the mental load and stress elements accompanying the examination session. According to studies of Mityushov [23] and Sokolova [25], excitation of the central nervous system under the effect of small doses of glucocorticoids, and the learning process is accelerated. According to Nozdrachev's data [26], cortisol at a concentration of 10–7–10–6 g/ml increases the rate of synaptic transmission and lability in autonomic ganglia, i.e. improve processes of the autonomic regulation. The less expressed cortisol increase in subjects of the experimental group seems to be reflection of their higher resistance to stress actions, which also might be result of CHE. There is detected no statistically significant rise of the insulin content in blood increasing intensity of aerobic respiration after two-week CHE.

It is established that CHE changes essentially the structure of correlation interconnections between the parameters characterizing metabolism, autonomic regulation, activity of the cardiovascular system, and parameters of the diving reaction.

In the initial state (Fig. 3a) there is revealed the direct correlation between the parameter of the apnea duration and thyroxin—the hormone regulating level of the energy exchange. The thyroid hormones, in turn, are in the direct correlation dependence on the cortisol level (an element of the stress-realizing system) and in the reverse correlation dependence on the insulin level (an element of the stress-limiting system), which agrees well with the current conception of regulation of the organism energy metabolism. The reverse correlation is detected between the parameter of the vagus reactivity, i.e., of the rate of the bradycardia rise—V_{br} (the response reaction of the vagus system by strength and time) during realization of the diving reaction and levels of triiodothyronine, insulin, and lactic acid in blood. Based on this it can be suggested that the subjects with the most pronounced vagus reactivity at realization of the diving reaction are characterized by the lower blood level of triiodothyronine—the hormone regulating energy metabolism of the aerobic character as well as by the lower levels of insulin and lactic acid—parameters of the organism anaerobic metabolism. Thus, it can be suggested that the people with the highly-reactive type are characterized by the lower power of the energy supply systems. These data agree in part with the earlier obtained results, according to which the testees of the highly reactive type of realization of the diving reaction have the lower possibilities of aerobic metabolism [27].

Two groups of the correlation dependences are of the greatest interest in the adapted to CHE subjects at their repeated examination. The apnea time is in the direct dependence on the insulin level in blood and in the indirect dependence on the rate of the rise of bradycardia. Taken this in account, it can be suggested hypothetically that the testees with the longest hold-up of respiration were characterized by a low rate of the bradycardia rise, i.e., were of the reactive type. Insulin is known to stimulate the anaerobic mechanism of the energy supply. Hence, it can be suggested that the processes of the energy supply are readjusted in subjects of the reactive type under the effect of adaptation to CHE—the anaerobic mechanisms of the energy supply are activated. These considerations are confirmed by the data obtained earlier [27]. The second group of the correlation connections is revealed between the cortisol level and parameters of the cardiovascular system (CVS) (direct dependence on the myocardium stress index (MSI), adaptation potential (AP), Rufier index (RI)). This can be related to that the individuals characterized by low parameters of glucocorticoids in blood (cortisol) have the highest adaptation possibilities as a result of adaptation (the low parameters of MSI, RI, and AP), i.e., the CVS stress is reduced and the role of the stress-realizing system is decreased regularly with formation of adaptation. The direct correlation is found between the recovery period of the heart rhythm after the CHE and the rate of the bradycardia increase, i.e., the recovery time is shorter in the less reactive people. There is detected the reverse correlation between levels of thyroxin and pyruvic acid in blood and the direct correlation between levels of pyruvic and lactic acids. Taken in account that according to data of the repeated examination the thyroxin level did not change and the levels of pyruvic and lactic acids decreased, it can be concluded that some increase of contribution of the aerobic process to the energy supply occurs under the effect of adaptation to the CHE on the background of a decrease of the total energy supply.

The activity of the stress-realizing system increased in the control group (Fig. 3c) at the second stage of the study, on the background of the intermediate stress produced by the examination session, which is reflected not only in an increase of the cortisol and triiodothyronine levels , but also in the characters of correlation connections relations. Duration of apnea is in the direct correlation with the cortisol level as well as with parameters of the cardiovascular system reflecting activity of the sympathetic regulatory effects (RVI, MSI ,CI_{av}), which, in turn, are in the direct correlation dependence on the T_3 level. The adaptation parameter (the value reverse to the adaptation potential) of the subjects non adapted to CHE is in the indirect correlation dependence on the cortisol level. Thus, it can be suggested that the adaptation potential in the non-adapted subjects will be determined by the power of the stress-realizing systems. The direct correlation between the apnea time at CHE, the cortisol level, and the parameters characterizing peculiarities of the realization of the reflex bradycardia (a CI increase relatively to the initial background—ΔCI, the time of the appearance of maximal CI—t_{max}, the rate of the bradycardia rise—V_{br}) allow suggesting that the apnea duration in the non-adapted testees on the background of the stress-realizing systems increased activity is determined by the degree of involvement of the oxygen-saving link of the diving reaction—the reflex bradycardia. The time of recovery after the CHE (*L*) is in the direct correlation dependence on the blood level of insulin, pyruvic and lactic acids, as well as of TTH, i.e., of the parameters characterizing the anaerobic component of the organism energy supply.

On the whole, the studies showed that the complex of reactions providing the oxygen-saving effect at diving imitation is intrinsic to human, the same as to the diving animals. The adaptation to CHE is accompanied by an increase of this effect.

Taken into account that under effect of adaptation the expression of bradycardia changes insignificantly, the vascular tonus increases, and the rate of a decrease of pO_2 at CHE is in the direct correlation dependence on its value, it can be suggested that the oxygen-saving effect at realization of the diving reaction is due mostly to vasoconstriction of peripheral vessels (a decrease of blood supply of the organs the least needing oxygen) than to a deceleration of the blood circulation produced by the reflex bradycardia.

In the organism not adapted to CHE the reactivity of the vagus system (the rate of development of bradycardia during diving) is in the reverse correlation dependence on the triiodothyronine level—the parameter characterizing regulation of aerobic metabolism. This agrees with our previous data, according to which the testees of the highly reactive type at performance of physical load of the aerobic character were characterized by the higher parameters of a the lactate rise [27], and this allows suggesting that the subjects with the expressed, intensively developing bradycardia at CHE are distinguished by the lower aerobic possibilities. The testees not adapted to CHE differed from the adapted ones by the statistically significantly higher parameters of cortisol and thyroxin, and duration of their apnea at CHE was in the direct correlation dependence on these parameters. This allows suggesting that the apnea duration in the non-adapted testees depends on power of the stress-realizing systems and hormones regulating aerobic element of the energy supply. The apnea duration in the testees adapted to diving, on the contrary, is in the direct correlation dependence on the level of insulin—the hormone stimulating activity of the anaerobic pathway of the energy supply. Adaptation to CHE on the background of the examination stress is accompanied by an increase of the organism resistance to the stress actions, which is confirmed by the lower values of cortisol and thyroid hormones in representatives of experimental group as compared with the control one.

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