Original Article

Adaptation of athletes to middle-altitude conditions via the intensive development of local-regional muscular endurance and strength motor capability, stretching, and relaxation

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Abstract:

The purpose of our research is to justify the impact of progressive technologies influencing the processes of short-term reactions and effective long-term adaptation during the basic and contest periods of training. Approach. The research involved 30 volunteers who had agreed to submit to a fasting blood test (cubital vein). 15 of the volunteers were highly-skilled skiers, and 15 were highly-skilled medium-distance runners. Performed laboratory testing included the examination of processes of free-radical oxidation and of antioxidant protection system, cortisol level assessment, protein synthesis evaluation, system analysis of multifunctional state of the body and of postural indicators. Results. The mechanisms of warming-up, stable state, transient processes, fatigue and recovery of different athletes at the plane and in the middle-altitude are revealed. Multifunctional data of short-term reactions and long-term adaptation with phase state analysis. Conclusions. The obtained data reflect integrative activity of athletes' body under extreme conditions (loads, hypoxia, temperature, and competition-related stress). The revealed indicators of state determine effective adaptation and sport performance.

Key words: hypoxia; acclimatization; skiers; lipid peroxidation; middle altitude; multifunctional data.

Introduction

Altitude training is an inherent component of the modern sport training process, especially for cyclic sports where athletes have to compete both on short and long distances. The increased hypoxic stress related to the altitude facilitates the main physiological reactions in the athlete's body which may lead to effective adaptation and better sport performance at the plain or in the lower middle-altitude. However, athletes are at a high risk of exposure to the negative effects related to hypoxia. Decrease in immunity, sleep disorder, and weight-loss associated with loads and dehydration may affect sport performance.

Influence of the mountain climate on the effectiveness of adaptation and sport performance is admitted by many scientists (Suslov, 2001; Kolchinskaya et al., 2003; Platonov, 2005; Potapov & Maleev, 2016). There are aggregate data concerning the problem under consideration and indicating the decrease of maximum oxygen consumption (MOC) with increase of altitude (Shevchenko et al., 2000; Kolchinskaya et al., 2003; Isaev & Erlikh, 2013; Erlikh, 2016). Meerson et al. (1992) based on the complex studies concludes that the adaptation of healthy untrained people to the periodic hypoxia in the hyperbaric chamber increases the tolerance to physical loads. This result is obtained with less functional exert of the heart as compared to the pre-adaptation period. The athlete's body is very responsive to the hypoxic changes related to the strenuous motor activity. Athletes' ability to maintain high adaptability for many years or even decades depends on the gene pool, biological reliability of the body, frequency of harmful exposure including hypoxia, optimal restoration periods, and compensatory rehabilitation of the body. Another important factor is well-timed application of advanced means of recovery and rehabilitation in sports. Topical issues include the problem of distribution of influence of environmental factors on sport performance and the scope of their effects. The leading factor is customized muscular and psychophysiological load that does not deplete the resources of the body and results in effective adaptation. The next factor is customized, balanced, functional nutrition that is adequate to energy expenditure and considers auxologic pattern of the body; such nutrition should be combined with appropriate natural factors of restoration processes as well as physiological support of the body. The supplementary factors include the one of middle-altitude which is a harmonious part of sport training system influencing sport performance. However without studying the cost of adaptation and related factors it is hardly possible to suggest that mountain adaptation makes Olympic champions out of athletes..

Material & methods

Our research was based on the hypothesis that application of new technologies of sport training under the conditions of effective mountain adaptation will eliminate the lagging in racing sports: ski racing (women), biathlon, and track and field.

The aim of the research was to justify the impact of progressive technologies influencing the short-term reactions and effective long-term adaptation during the basic and contest periods of training.

Participants

The research involved 30 volunteers, aged 19-23, who had agreed to submit to a fasting blood test (cubital vein). 15 of the volunteers were highly-skilled skiers, and 15 were highly-skilled medium-distance runners.

Procedure

The basic period engaged the focused development of local-regional muscular endurance (LRME; up to 50 %). It was followed by transfer of training means via interference of physical qualities to motor skills combined with special motor actions (MA), stretching, and relaxation. There was also a number of lab tests to study the processes of free-radical oxidation (FRO), antioxidant protection system, assessment of cortisol levels, protein synthesis, spectral analysis of blood flow, system analysis of multifunctional state of the body, and postural indicators. Lipid peroxidation was assessed using the methods by Aristova et al (2011) and Lvovskaya (1995, 2008). The processes of oxidative modification of proteins were evaluated (Arutyunan, 2000; Dubinina et al., 1995, 2008). Spectrophotometric detection of lipid peroxidation products of isopropyl alcohol and heptane blood serum extracts and the level of carbonylated proteins was performed using SF-56 spectrophotometer (Lomo-Spektr, Saint-Petersburg, Russia). Concentration of cortisol was assessed by fluorometric method (Balashov, 1990). Non-invasive system analyzer AMP (Kharkov, Ukraine) is a portable express-laboratory providing multifunctional information. Cardiohemodynamics was recorded by the means of bioimpedance rheopolygraphy based on Kentavr computer system (Mikroluks, Russia). Spectral analysis was performed automatically. Posturologic studies were conducted using the stabilometric system developed by MBN RF.

Statistical analysis

Statistical analysis was performed with the help of software Statistika 10.0; SPSS 17 based on the key methods. The significance of differences was assessed using the Mann-Whitney U test. At testing of null hypotheses the critical value of statistical significance level was set as 0.05. For all qualitative attributes in the groups under comparison the mean values, their errors, and standard deviations were assessed. The obtained data processed statistically are presented as $M \pm m$ in the paper. The correlation between qualitative attribute was evaluated using the methods of paired correlation analysis and logistic regression models.

Results

Time-related characteristics of acclimatization influence the dynamics of physical working capacity which becomes near-background (as before the training in the mountains) in two weeks.

During staying in the mountains the mechanisms of adaptation were under stress which decreased in the re-acclimatization period. The criteria of effective adaptation were the increased concentrations of hemoglobin, enzymes, creatine kinase (CK), urea, and cortisol. The reactivity of the body in middle-distance and steep-lechase racers was accompanied by shifts of interactive elements of system-supporting functions of homeostasis. After 38 days of acclimatization in the upper middle-altitude (1800-2000m) when the athletes returned to the plain 30.43% of 23 parameters exceeded the reference limits, 47.83% were below normal values, and 21.74% were instable. Lung ventilation increased by 17.50%, vital capacity – by 20.00%, maximum lung ventilation - by 16.42%, respiratory ration – by 21%, working level of oxygen consumption – by 15%, myocardial oxygen consumption – by 31%, oxygen saturation of the arterial blood – by 9.51%, and oxygen consumption per 1 kg of body weight – by 6.6%. Pulmonary gas exchange surface increased by 5.04%, oxygenation rate – by 15%, and red blood cell count per 1 ml – by 26.19% at the first stage of adaptation and by 34.40% at the second stage of short-term adaptation. Mean corpuscular volume increased by 8-10%, and symbate change of cellular hemoglobin content by 6.31-12.3% was observed. Cell-color ration increased by 7-9%, and hematocrit increased by 10.48-10.98%. Blood oxygen content also increased. All these changes were statistically significant ($p \leq 0.05 - 0.01$).

Renewal of the red blood in reticulocyte count drastically increased in 24 days of staying in the upper middle-altitude. Oxygen consumption at a height of 1000m was 3.52 L/min; 1500m – 3.50 L/min; 2000m – 3.47 L/min; lactate values were 0.76; 0.65; 0.64 mmol/L, respectively (the decrease was associated with adaptation to hypoxia). In the lower middle-altitude (1000m) there was a slight stress-tension, and stress markers were within the reference limits (lipid peroxidation and cortisol values). There was an insignificant increase of antioxidant activity of the blood plasma (AOA) restraining the stress-tension, and protein synthesis increased. In the middle and especially upper middle-altitude the indicators of lipid peroxidation (LPO) exceeded the control limits, and the parameters of cortisol were within the reference limits. Significant changes in protein synthesis were observed (Bakhareva et al., 2016). Stress-tension is manifested for up to 30 days of staying in the upper middle-altitude. According to our data (Isaev et al., 2014), that time the blood flow regulation changes in the following way: humoral-hormonal spectrum, vegetative and peripheral factors of regulation prevail. This indicated the physiological impact of training process and acquisition of the stable phase of adaptation by athletes. The participants performed motor actions (MA) typical of the plain conditions.

The mountain adaptation of ski racers and runners were conducted in the West Sayans (Mount Verkhnyaya Teya, 1000-1200m), the Urals (1200-1800m), Kislovodsk (1200m), and Cholpon-Ata (Kyrgyzstan,

1800-2000m), during the basic periods of training and final pre-contest stages of conditioning. For stepped adaptation in the middle-altitude the following heights were used: 1000m, 1500m, and 1800-2000m. It should be noted that at the plain and in the lower middle-altitude there were no significant differences in LPO parameters. Table 1 presents the data on molecular products of lipid peroxidation in the highly-skilled ski racers (15 athletes) during the contest period.

Table 1. Content of molecular products of lipid peroxidation in successful ski racers (n=15) at the plain, in 20 days, and in 30 days of acclimatization to the altitude.

Groups	Isopropyl-alcohol-soluble			Heptane-soluble		
	Primary (diene conjugates) E230/E220	Secondary (ketodienes and conjugated trienes) E278/E220	Final (Schiff bases) E430/E120	Primary (diene conjugates) E230/E220	Secondary (ketodienes and conjugated trienes) E278/E220	Final (Schiff bases) E400/E220
in 20 days	0.49±0.01	0.16±0.09	0.04±0.002	0.52±0.02	0.19±0.03	0.14±0.03
in 30 days	0.44±0.02	0.24±0.03	0.022±0.001	0.62±0.01	0.13±0.02	0.07±0.02
P ₁₋₂ < 0.01						
P ₁₋₃ < 0.05						

The state of LPO processes characterizes the level of special fitness and effectiveness of aerobic mechanisms of energy supply. The significance of differences was observed depending on the duration of staying in the upper middle-altitude in primary diene conjugates, secondary group in 20 days of acclimatization, and Schiff bases. These data suggest the maintenance of stress-tension in 20 days of staying in the altitude; and in 30 days the adaptive-compensatory redistributions of molecular isopropyl-alcohol-soluble products of LPO were observed. The mechanisms of these processes were previously described by Bakhareva et al. (2016). Heptane-soluble products of LPO had the symbate specifics of time-related shifts. Primary LPO products – diene conjugates – were an exception (in 30 days of acclimatization).

At mountain-related stress at the final stage of pre-contest conditioning the metabolic mobilization involves not only lipids, but also cell proteins the destruction of which damages the native structure of proteins; this characterizes overall physical state and adaptive-compensatory capacity of the body requiring the involvement of reserves (Fomina & Abalikhina, 2014).

Concentration of total protein and cortisol levels which is one of stress-tension markers depending on the duration of acclimatization is presented in Table 2.

Table 2. Total protein concentration and cortisol levels in skiers depending on the duration of staying in the upper middle-altitude (n=15).

	Total protein, g/L	Cortisol, kmol/L
at the plain	81.61±5.47	367.30±34.14
in 20 days	89.32±3.84	780.92±54.32
in 30 days	80.64±6.96	392.64±27.42
P1-2	< 0.05	< 0.01
P1-3	> 0.05	> 0.05

It has been established (Isaev et al., 2016) that normalization of cortical-subcortical processes occurs after 30 days of staying in the upper middle-altitude.

Blood flow regulation in athletes is being redistributed. According to the examination data, athletes were at regulating and forming phases of long-term adaptation. In comparison with orthostasis, the applied standard physical load resulted in significant shifts of “very low frequency / total spectrum power” ratio, so the parameters increased and ranked as follows: blood pressure (BP), heart rate (HR), stroke volume (SV), ejection fraction (EF), diastolic filling wave (DFW), large vessel pulsation amplitude (LVPA), finger pulsation amplitude (FPA), and cardiac minute output (CMO). These data indicate the influence of factors related to the central hemodynamics and amplitude of rheowaves in the early restitution of blood circulation elements. The second level of regulation involved the values for “the lowest frequency / total spectrum power” ranked as follows: FPA, DFW, BP, HR, LVPA, SV, EF, CMO. For “low frequency / total spectrum power” the parameters ranked in the following way: CMO, LVPA, EF, SV, DFW, HR, BP, FPA; and for “high frequency / total spectrum power” the pattern was the following: CMO, SV, EF, LVPA, DFW.

Cortisol is a hormone increasing the intensity of breakdown of proteins and release of amino acids, which leads to glucose synthesis. Decreased metabolism in successful skiers at the plain and in the lower middle-altitude indicates the decreased tension, the economization of the body functioning at a relative rest. The body adapted to hypoxia experiences the transformation of sympathicoadrenal system (SAS) characterized by hypertrophy of sympathetic neurons, increase and synthesis of catecholamines and catecholamine store in the adrenal glands, and also the increased adrenoreactivity of the heart (Meerson, 1992; Novikov et al., 2000).

Adaptation to hypoxia mobilizes stress-limiting systems, which protects the body from various disturbing factors (Isaev & Erlikh, 2013; Glazachyov et al., 2010). Adaptive-compensatory changes occur in athletes; these changes involve the increased myoglobin concentration in muscles and the improved ability to

utilize oxygen thanks to increased number of mitochondria, their respiratory function, and enzyme and antioxidant activity (Solkin et al., 2012; Glazachyov et al., 2010). Systemic circulation is essential in the regulation of athletes' multifunctional activity under the conditions of active orthostasis and standard loads (Tables 3, 4, 5, and 6). Change of body position leads to insignificant changes of the circulatory system relative to the total spectrum power of frequency of oscillations (the lowest frequency, very low frequency, low frequency, high frequency), the succession of their regulation according to 4 criteria of oscillations (Tables 3,4).

Table 3. Spectral characteristics of circulation elements in ski racers after the physical load in conditional units (n=15).

After 20 squats (3-minute recovery)		Total spectrum power, TSP	Fm, middle of spectrum	The lowest frequency spectrum, TLF(S)	Very low frequency, VLF	Low frequency, LF	High frequency, HF
Heart rate	Mean	9.367	0.053	2.277	6.813	0.274	0.000
	Deviation	5.950	0.058	1.570	4.588	0.293	0.000
Blood pressure	Mean	58.321	0.032	13.781	42.019	2.521	0.000
	Deviation	29.718	0.008	10.858	23.813	1.995	0.000
Stroke volume	Mean	17.479	0.050	2.752	10.491	3.835	0.404
	Deviation	9.105	0.020	2.878	6.848	6.685	0.555
Cardiac minute output	Mean	0.115	0.068	0.010	0.052	0.040	0.011
	Deviation	0.075	0.033	0.008	0.035	0.050	0.015
Ejection fraction	Mean	2.087	0.051	0.435	1.177	0.466	0.008
	Deviation	1.133	0.023	0.423	0.740	0.345	0.015
Diastolic filling wave	Mean	1.138	0.023	0.420	0.631	0.085	0.001
	Deviation	0.543	0.005	0.203	0.440	0.085	0.003
Large vessel pulsation amplitude	Mean	0.768	0.058	0.300	0.468	0.105	0.003
	Deviation	0.665	0.071	0.146	0.341	0.174	0.002
Finger pulsation amplitude	Mean	520.082	0.021	255.530	264.343	0.206	0.000
	Deviation	403.575	0.003	200.540	204.208	0.225	0.000

Table 4. Ratio of frequency characteristics of the blood flow to the total spectrum power after the physical load in conditional units.

After 20 squats (3-minute recovery)	The lowest frequency spectrum / Total spectrum power	Very low frequency / Total spectrum power	Low frequency / Total spectrum power	High frequency / Total spectrum power
Blood pressure	24.309	72.734	2.925	0.000
Heart rate	23.629	72.048	4.322	0.000
Stroke volume	15.743	60.020	21.943	2.309
Cardiac minute output	8.730	45.238	34.921	9.524
Ejection fraction	20.819	56.402	22.343	0.392
Diastolic filling wave	36.901	55.431	7.428	0.080
Large vessel pulsation amplitude	22.025	51.300	26.129	0.274
Finger amplitude pulsation	49.133	50.827	0.040	0.000

Table 5. Spectral characteristics of circulation elements in ski racers in the active orthostasis in conditional units.

Standing		Total spectrum power	Fm, middle of spectrum	The lowest frequency spectrum	Very low frequency	Low frequency	High frequency
Blood pressure	Mean	21.601	0.026	7.708	13.767	0.124	0.000
	Deviation	20.413	0.003	7.883	12.530	0.125	0.000
Heart rate	Mean	49.113	0.047	12.244	22.368	14.493	0.005
	Deviation	22.625	0.023	10.360	11.910	14.763	0.015
Stroke volume	Mean	23.504	0.045	5.223	13.252	4.535	0.492
	Deviation	15.755	0.020	6.733	10.555	2.790	1.240
Cardiac minute output	Mean	0.148	0.063	0.027	0.065	0.050	0.008
	Deviation	0.070	0.030	0.030	0.050	0.030	0.018
Ejection fraction	Mean	2.865	0.037	0.648	1.630	0.588	0.000
	Deviation	1.383	0.010	0.558	1.093	0.460	0.000
Diastolic filling wave	Mean	0.753	0.039	0.226	0.384	0.142	0.004
	Deviation	0.403	0.018	0.170	0.245	0.075	0.005
Large vessel pulsation amplitude	Mean	0.365	0.082	0.033	0.118	0.186	0.028
	Deviation	0.250	0.055	0.043	0.105	0.148	0.050
Finger pulsation amplitude	Mean	229.668	0.003	130.713	98.983	1.418	0.000
	Deviation	185.627	0.021	97.059	87.656	0.914	0.000

Table 6. Ratio of frequency characteristics of the blood flow to the total spectrum power in the active orthostasis in ski racers.

Standing

	The lowest frequency spectrum / Total spectrum power	Very low frequency / Total spectrum power	Low frequency / Total spectrum power	High frequency / Total spectrum power
Blood pressure	35.685	63.735	0.572	0.000
Heart rate	24.930	45.545	29.509	0.011
Stroke volume	22.221	56.382	19.293	2.093
Cardiac minute output	18.405	43.558	33.742	5.521
Ejection fraction	22.621	56.885	20.527	0.000
Diastolic filling wave	30.072	50.966	18.841	0.483
Large vessel pulsation amplitude	8.978	32.419	51.122	7.731
Finger pulsation amplitude	52.287	47.222	0.492	0.000

According to overall estimates of circulation elements, the indicators ranked as follows: CMO, HR, FPA. The rest values do not differ from each other. Considering VLF/TSP ratio, the distribution was the following: BP, EF, SV, DFW, FPA, HR, CMO, LVPA. The second significant place was taken by the TLF/TSP ratio: FPA, BP, DFW, HR, EF, SV, CMO, LVPA. LF/TSP ratio ranked as follows: LVPA, CMO, HR, EF, SV, DFW, BP, FPA. The insignificant contribution to regulation was made by HF/TSP ratio ranked in the following way: LVPA, CMO, SV, DFW, HR.

Tables 7 and 8 present the indicators of metabolic state and blood circulation in middle-distance runners.

Table 7. Concentration of electrolytes, water, enzymes, bilirubin, protein, creatinine, dopamine β -hydrolase, urea, lactic acid, glucose, glycogen, and lipids in athletes under the conditions of the upper middle-altitude (n=15).

Indicator	M	m	Control
Aspartate aminotransferase, mmol/L	0.29	0.03	0.10-0.45
Alanine aminotransferase, mmol/L	0.61	0.06	0.10-0.68
Aspartate aminotransferase, U/L	33.64	3.03	8.0-40.00
Alanine aminotransferase, U/L	24.04	1.28	5.0-30.00
Aspartate aminotransferase / Alanine aminotransferase, AST/ALT ratio	1.40	0.36	0.80-1.20
Total bilirubin, μ /L	12.17	2.90	8.60-20.50
Direct bilirubin, μ /L	2.69	0.69	2.20-6.10
Indirect bilirubin, μ /L	9.48	2.41	1.70-10.20
Glucose, mmol/L	4.99	0.99	3.90-6.20
Creatinine, mmol/L	80.44	8.81	55-123
Glycogen, mg%	14.79	2.15	11.70-28.60
Urea nitrogen, mg	13.86	2.31	6.00-23.00
Amylase, g/L*h	16.03	2.29	12-32
Acetylcholine, μ g/mL	82.02	2.49	81.10-92.10
Erythrocyte acetyl cholinesterase, μ mol/L	261.41	4.59	220-278
Glutamic acid, mmol/L	0.004	0.0001	0.0045-0.0055
Plasma protein, g/L	73.47	3.67	60-85
Creatinine kinase of muscles, μ mol/min/kg	474.86	4.41	473-483
Creatinine kinase of the heart, μ mol/min/kg	36.59	1.65	35.10-38.10
Lactic acid, mmol/L	1.41	0.19	0.29-1.38
Dopamine- β -hydrolase, nm/mL/min	30.23	3.38	28.00-31.50
Urea, mmol/L	4.87	1.16	2.10-8.20
Calcium, mmol/L	2.59	0.41	2.25 – 3.00
Magnesium, mmol/L	0.86	0.01	0.70 – 0.95
Potassium, mmol/L	4.35	0.33	3.48 – 5.30
Sodium, mmol/L	141.71	2.11	130.5 – 156.6
Intracellular water, %	41.25	0.38	39 – 42
Total water, %	67.77	3.45	53 – 60
Extracellular water, %	22.27	0.17	21 – 23
Intracellular water, %	41.10	0.32	39-42
Total water, %	69.25	2.51	53-60
Total cholesterol, mmol/L	6.25	0.96	3.11-6.48
β -lipoproteins, mmol/L	47.72	5.79	17-55
β -lipoproteins, g/L	4.26	0.98	3-6
Low density lipoproteins, mmol/L	2.49	0.28	2.35-2.43
Very low-density lipoproteins, mmol/L	0.32	0.02	0.20-0.52
High density lipoproteins, mmol/L	1.29	0.27	0.78-1.74
Triglycerides, mmol/L	1.54	0.81	0.55-1.85
Glucose, mmol/L	5.28	0.86	3.9-6.2
Glycogen, mg%	14.58	0.18	11.7-20.6

Table 8. Organ blood flow values in highly-skilled racers under the conditions of the upper middle-altitude (n=15).

Indicator	M	m	Reference limits
Myocardial blood flow, %	4.58	0.18	4.32-5.02
Skeletal muscle blood flow, %	16.62	0.23	14.56-16.93
Cerebral blood flow, %	14.44	0.34	12.82-14.9
Hepatoportal blood flow, %	24.10	0.40	20.28-29.86
Renal blood flow, %	24.14	0.41	21.58-25.09
Skin blood flow, %	6.78	0.13	7.9-9.19
Blood flow of other organs, %	7.76	0.12	5.76-6.7
Myocardial blood flow, mL/min	265.46	10.74	250-290
Skeletal muscle blood flow, mL/min	1091.81	14.91	930-1100
Cerebral blood flow, mL/min	844.88	20.07	750-800
Hepatoportal blood flow, mL	2008.97	33.70	1690-2488
Renal blood flow, mL/min	1600.08	27.34	1430-1662
Skin blood flow, mL/min	429.62	1.79	500-535
Blood flow of other organs, mL/min	505.73	7.86	375-390
Pulmonary circulation resistance, dyne/cm	136.78	1.82	140-150
Central venous pressure, mmH ₂ O	70.31	10.82	70-150
Systemic circulation time, s	19.27	0.67	16-23
Pulmonary circulation time, s	4.52	0.42	4.0-5.5
Cerebral blood flow per 100g of tissue, mL/100g	52.94	0.26	50-55
Blood flow per 1g of the thyroid, mL	3.91	0.05	3.7-4.3
Blood flow per 1g of brain tissue, mL	3.10	0.12	2.9-3.2
Cerebrospinal fluid pressure, mL	109.20	7.97	90-145
Life sustenance energy expenditure, kcal/kg/min	4.96	1.93	1.23-4.30
Width of the 3 rd ventricle of the brain, mm	5.68	0.37	4-6

Table 9. Key values of the blood system and the metabolic state indicators (enzymes, urea, creatine kinase, bioelements and hormones – cortisol and testosterone) in highly-skilled middle-distance runners (merited Masters of Sport (MMS), Masters of Sport – International Class (MSIC), Masters of Sport (MS), n=9) after 38 days of acclimatization at a height of 1800m.

Table 9 presents the metabolic state indicators in highly-skilled racers.

Statistics	M±m	Max	Min	Control
Hemoglobin, g/L	150.20±1.10	164	148	120-160
Hematocrit, vol%	48.50±0.69	51	46	38-49
Alanine aminotransferase (ALT), U/L	32.00±3.86	46	18	5-30
Aspartate aminotransferase (AST), U/L	50.50±7.86	79	22	8-40
Creatine kinase (CK), U/L	526.50±80.72	819	234	230-550
Urea, mmol/L	5.75±0.48	7.5	4	2.5-6.8
Calcium (Ca), mmol/L	2.58±0.41	3.48	2.67	2.3-3.0
Magnesium (Mg), mmol/L	0.94±0.02	1	0.87	0.70-0.99
Phosphor (P), mmol/L	1.53±0.03	1.6	1.45	0.81-1.55
Iron (Fe), mmol/L	13.10±1.27	17.7	8.5	9.50-29.90
Testosterone, nmol/L	23.00±2.79	30.1	15.9	9.30-17.34
Cortisol, nmol/L	472.00±26.22	567	377	150-770
AST/ALT ratio	1.47±0.39	3	1	1.33±0.43

As seen from Table 9, the values exceeding the reference limits were observed for ALT, AST, testosterone, and AST/ALT ratio. It may be suggested to be the consequences of prolonged acclimatization.

Correlations between the metabolic state indicators are shown in Tables 10 and 11.

Table 10. Correlations between biochemical indicators in elite middle-distance runners under the conditions of mountain climate.

Hemoglobin	Hematocrit	0.71
Hemoglobin	Alanine aminotransferase (ALT)	-0.68
Hemoglobin	Aspartate aminotransferase (AST)	-0.75
Hemoglobin	Creatin phosphokinase	-0.43
Hemoglobin	Testosterone	0.72
Creatin phosphokinase	Alanine aminotransferase	0.65
Creatin phosphokinase	Aspartate aminotransferase	0.66
Alanine aminotransferase	Aspartate aminotransferase	0.87
Cortisol	Testosterone	0.34
Transferrin	Iron	0.45
Hematocrit	Iron	0.36
Urea	Magnesium	0.51

There are physiologically significant correlations which are of particular interest; these are correlations between red blood indicators and enzyme activity, CK and enzymes, urea and magnesium, hematocrit and iron. The role of hematocrit, enzymes and CK in metabolic processes is proved to be essential. Cortisol and testosterone are stress-realizing indicators. Cells and tissues are saturated with iron with the help of transferrin which is able to transfer ferric ions. According to Skalny (2004), ligand complexes of iron stabilize the genome and if ionized may be LPO inductors, cause stress-tension and DNA damage, and lead to cell death.

The correlation between magnesium and urea concentration is of interest as it is one of indicators of fatigue. Magnesium stimulates protein production, decreases neuromuscular tension in cells, takes part in mitochondrial processes, reduces neuronal excitability, and suppresses aggregation of platelets; this element is also involved in such essential functions as synthesis of proteins and nucleic acids, and metabolic functions including energy transfer, storage, and utilization. The correlation between values of hematocrit and iron indicates the O₂ transfer and oxidation processes determined by enzyme reactions.

Table 11. Lipid metabolism indicators in middle-distance runners.

Indicator	M	m	Reference limits
Total cholesterol, mmol/L	6.02	0.55	3.11 - 6.48
β-lipoproteins, mmol/L	45.91	4.22	17 - 55
β-lipoproteins, g/L	4.44	0.55	4.11-4.30
Low density lipoproteins, mmol/L	2.31	0.01	2.35 - 2.43
Very low-density lipoproteins, mmol/L	0.31	0.001	0.2 - 0.52
High density lipoproteins, mmol/L	1.12	0.002	1.25 - 4.25
Triglycerides, mmol/L	0.98	0.08	0.55 - 1.85
Glucose, mmol/L	5.27	0.26	3.9 - 6.2
Glycogen, mg%	14.92	0.24	11.7 - 20.6

In spite of a high level of adaptability (fitness) of athletes, the final stage-related (preparation for four socially important competitions) features of free radical LPO reactions were observed. Lipid peroxidation has a certain physiological sense and is apparently associated with regulatory mechanisms at a cellular level. High intensity of glucose uptake by red blood cells and high levels of lactic acid in muscles may be assumed to suppress the mobilization of lipids. This phenomenon is observed at strenuous loads when oxygen deficiency causes glycolysis and lactate accumulation in blood. And vice versa, the increased lipolysis inhibits the mobilization of glycogen and glucose uptake. The reduced levels of glycogen concentration in the liver and low levels of blood glucose lead to mobilization of lipids again. Eventually, after the energy supply with glucose the liver starts transform lipids into fat acids – easily utilized energy sources – and transport them to blood.

The following blood system indicators were beyond the control limits: mean cell hemoglobin concentration (MCHC), mean corpuscular volume (MCV), cell-color ration, and clotting time. These data suggest the tension of red blood and blood clotting ability. The analysis of electrolyte and water exchange, enzyme and hormone activity, and lipid metabolism shown that a few indicators exceeded the reference limits: total water, low density lipoproteins (LDL).

Under the conditions of the upper middle-altitude the following indicators were beyond the control limits: oxygenation rate, Tiffeneau index (FEV₁/FVC ratio), working level of oxygen consumption, blood pH, circulatory volume, CMO, venous blood CO₂. Against the background of the stated indicators, gastric juice pH was 1.40 ± 0.09 (the control values ranged from 1.2 to 1.7), basal sphincter of Oddi pressure was 40.64 ± 0.63 mmHg (the control values ranged from 39 to 41 mmHg), and lactic acid concentration was 0.92 ± 0.16 mmol/L (the control values ranged from 0.99 to 1.38 mmol/L). Just one runner had the initial level of lactic acid equal to 1.58 mmol/L, which exceeded the control limits. Further the indicators of the blood system and metabolic state in a day and in 20 days of re-acclimatization at the plain are given.

Along with group data, there are individual values in athlete B.E. (female, MSIC): hematocrit 46 %, hemoglobin 161 g/L, ALT – 30, AST – 45, urea – 7.50, CK – 819.00, Ca – 2.66, Mg – 1.00, P – 1.49, Fe – 11.50, cortisol – 465.00, testosterone – 23.50. Individual values in B.Y. (MMS) were respectively: 50; 155; 29; 37; 7; 425; 2.67; 0.91; 1.60; 12.20; 381; 24.10. Individual values in M.K. (MS) were: 51; 164; 25; 22; 4.70; 311; 2.54; 0.87; 1.56; 15.00; 439; 28.90. Individual values in MSIC were: 45; 146; 36; 51; 4.50; 394; 2.52; 0.94; 1.59; 8.50; 460; 15.90. Several indicators had a significant variability: CK, cortisol, iron, testosterone, hematocrit, hemoglobin, AST, ALT, urea. The increased level of calcium was observed from group and individual data. Along with that, AST/ALT ratio according to individual data was the following, respectively: 1.50; 1.28; 0.88; 1.42 (the reference limits were 1.33 ± 0.33).

Elite athletes' (MS, MSIC, MMS) indicators are given. 75% of the examined athletes had high values of hemoglobin, hematocrit, ALT, and AST. The levels of CK, urea, and bioelements were also higher than the mean values in 65% of athletes. Testosterone level exceeded the model values in 45% of cases, and other parameters had the values within the reference limits. AST/ALT ratio in 75% of cases exceeded the mean values and control values (85%) (Hargreaves, 1998).

Discussion

Many authors discuss the influence of hypoxia on the sport performance progress during the re-acclimatization period and further competitions. According to another point of view, the mountain climate does not have any positive impact on success in sport. There are contradictory opinions on the mountain adaptation time, living altitude, and training (Suslov, 2001; Kolchinskaya et al., 2003; Platonov, 2005; Erlikh, 2016).

Eller's research (1977) involving long-distance runners did not reveal any protein deficiency associated with inhibited protein synthesis in conjunctive tissues or insignificant use of proteins at high training loads (HTL). Ambiguity of interpretations of protein synthesis is discussed in several sources (Tsygan et al., 2005; Isaev et al., 2014; Fomina & Abelinikhina, 2014; Bakhareva et al., 2016). The ambiguity is associated with

acceleration of either catabolism or anabolism under the conditions of motor activity. Some authors deny the increase of protein metabolism and do not think that proteins play a special energetic role at muscular work (Tsygan et al., 2005). There is also an opinion that motor activity leads to increase of protein catabolism and anabolism.

The problem of stepped re-acclimatization and participation in competitions under the conditions of plain and lower middle-altitude is underinvestigated. According to most authors, the effective adaptation to competition-related loads is formed depending on the individual peculiarities, and the stable phase of adaptation under new conditions is achieved in 20-25 days after returning from the middle-altitude. However, there are data on lesser time of re-acclimatization for the participation in socially important contests (14-19 days). There is still a topical issue of being at a mid-stage during the period between returning from the upper middle-altitude and getting to the site of competition. In our opinion, this mid-stage period of re-acclimatization is 7 days long. Contradictory data are obtained from the analysis of hormonal spectrum of reaction, enzyme activity, spectral analysis of blood flow regulation, vector of some gas-exchange processes, and electrolyte exchange – in particular, concerning the use of reserve iron of ferritin, neurotransmitter acetylcholine, cortisol, features of water-lipid exchange, and protein synthesis. The stated above requires further research and new interpretations of the data obtained for various altitude-related conditions of re-acclimatization.

According to the work by Grushin and Nageikina (2016), acclimatization contributed to the outstanding performance of the Soviet female ski racers at the world's championships and Olympic Games. The model developed by Ivanov and Grushin helped the USSR champions succeed due to the huge volume of cyclic exercises with the total distance of up to 9-10 thousand km skied by female athletes within the full-year cycle. Original methodic recommendations on the middle-altitude suggested by Grushin and Nageikina (2016) are not substantiated enough as they do not consider the state of athlete's body. It is known that it is better to live in the upper middle-altitude, but to train in the lower middle-altitude (Radchenkov et al., 2012; Erlikh, 2016). The author's opinion on introduction of the mountain conditioning into the basic training cycle seems reasonable, but the effectiveness of 7-21-day wide-range microcycles is debatable. Second, during the 7-day period acclimatization is performed, and the body "gets accustomed" to the mountain conditioning under the conditions of hypoxia. During the 21-25-day cycle the cardiovascular and respiratory systems become adjusted to the upper middle-altitude environment (Suslov, 2001; Kolchinskaya et al., 2003; Platonov, 2005; Erlikh, 2016).

The advanced research works have shown that acclimatization of the higher nervous activity occurs in 30 days and later depending on the individual features (Shevchenko et al., 2000; Isaev & Erlikh, 2013; Isaev et al., 2016).

The total duration of staying in the mountains is associated with individual capacity for mountain adaptation and may be up to 120 days. We studied the specifics of 30-, 60-, 90-, and 120-day periods of mountain adaptation. The duration of acclimatization determines the period of stable phase of adaptation under the conditions of forthcoming competitions.

The last question is why it is difficult now to train the skiing champions. Is the middle-altitude factor essential in successful sport performance?

Russian female ski racers think themselves to be lucky if they can get into the list of the thirty best athletes of the world. Athletes from the Nordic countries, Italy, Switzerland, Canada, and the USA adopted the updated pose mode of running to some extent resembling the track and field running technique. This resulted in higher speeds of ski running. The control of the running state and technique shows that during the contest period athletes are able to stay at the phases of forming and stable adaptation. The phases of skiing motions (time, force, tempo of motor actions of upper and lower limbs) changed significantly; the sliding phase of movement reduced. The volume of the 1st and 2nd intensity zone loads decreased, while the 3rd and 4th zone loads increased; the sport training process became more intensive. The stated above suggests that it is necessary to develop a new integral model of female ski racers' training in the Russian Federation (RF).

For the above discussed reasons, talented male athletes leave the RF national team coaches and start cooperating with foreign coaches, which results in better sport performance. The control of the state determining the response to the current applied load is not described in works by Grushin, which means that the "price" of adaptation is not analyzed. Planning the conditions of competition requires modeling of the altitude and environment of the competition site (temperature, humidity, levels of electromagnetic and ultraviolet radiation, height above mean sea level, wind rose, snow composition, piste elevation etc.).

The study reveals the correlation between the sport mastery levels and concentration of primary and secondary LPO products. Generation of oxygen radicals of phagocytic cells is one of the mechanisms triggering free-radical LPO reactions which are the basis of cell destruction of any genesis. Lipid oxidation capacity indicators in judokas decreased as the intensity of physical loads was growing. This phenomenon can be explained by the ability of stress-inducing stimuli to increase lipid peroxidation with the growth of physical loads.

The production of oxidized lipids facilitates their release from membranes and contributes to the faster renewal of membrane structures (Burlakova & Khrapova, 1985). The dynamics of LPO activation depended on the level of athletes' adaptedness to the applied loads. It is proved by the data on the metabolic state in martial art practitioners during the period of the highest physical and psychoemotional tension and related hypoxia

(Isaev, 1993; Isaev et al., 2004; Isaev & Erlikh, 2010). According to some modern sources, LPO and antioxidant activity (AOA) of blood plasma are correlated (Meerson et al., 1992). However, the results of research did not reveal any group correlations between AOA and LPO parameters or hemodynamics. It may be assumed that the impact of strenuous training and competitive loads and related hypoxia leads to temporary disruption of intersystem connections and to autonomous coordination (synchronization) of regulatory and biocontrolled processes. It is accompanied with correlations linked to intersystem parameters of some systems of the body. AOA dynamics is of particular interest due to changes in hypoxic effects of physical loads in sport.

The discussed above changes in lipid metabolism and lipid peroxidation at a partial hypoxia did not lead to myocardial damage in most athletes. Adaptation-related changes associated with muscular loads and hypoxia caused the significant activation of enzymes (creatine kinase, peroxidase, and phospholipase) in athletes during the high tension period. This assumption is proved by the observed dynamics of middle molecules of the blood plasma relative to changes of the intensity of loads. The dynamics of mid-molecule peptide (MMP) concentration absolutely correlates with the intensity of muscular activity phase. High concentration of peptides in blood at intensive physical loads and moderate hypoxia is related to adaptation as it leads to decrease of glycolysis and prevents lactacidosis. It should be added that MMP serve as the indicator of autointoxication and may be regarded as an objective criterion of exhaustion and decreased physical capacity of the athlete during the given period of training and competitive impacts.

During the acclimatization process the studies revealed physiological, transient, and premorbid states, dynamic desynchronization, and adequate mobilization in the athletes. The stability of hypoxia at rest and under the special loads has its individual limits. In the mountains the venous return curve shifts upward, pressure in the right atrium falls below the resting level, and the HTL results in active stimulation of the myocardium by sympathetic nerves and in changes in metabolism influencing the coronary blood flow regulation. At hypoxia the energy supply of the heart involves free fatty acids (FFA) and anaerobic glycolysis (Raff, 2001). The increase in cerebral blood flow rate leads to the “shift tension” of endothelial cell membrane and, consequently, to the production of vasodilating nitrogen oxide (NO) (Guyton & Hall, 2008). Eventually, protein synthesis increases; hormones, collagen, and growth factors are secreted; and cell division is enhanced (Isaev & Erlikh, 2013). The local blood flow becomes more intensive in response to increased activity of metabolic processes in the cerebral tissue (Romanov, 2014). Transient processes are manifested not only in dynamic situations, but also at the phases of long-term stepped acclimatization and after returning to the plain or the site of competition in the lower middle-altitude.

The control over motions in the anteroposterior (sagittal) plane is the most sensitive to hypobaric hypoxia at a height. Adaptive-compensatory mechanisms causing the cerebral perfusion and oxygen transport to the brain stem and cerebellum are triggered. The postural control is protected better in comparison with oxygen transport to cortical areas.

Athletes can train at a fast elevation to the altitude, but the volume training should be gradually increased during the first 3-5 days. Athletes' balance and reaction rate are improved in 3-6 days of acclimatization. 20% of athletes may have the symptoms of acute mountain sickness during the first 3 days of exposure to the altitude effects (at a height of up to 3800m). Hypoxia stimulates the process of acclimatization, which leads to hematologic, respiratory, and muscular (buffers and metabolic effectiveness) adaptation; the latter, in its turn, influences the working capacity at a sea level. Coaches should be very careful while planning the training process, as Hydren et al. (2013) states. Most authors admit the great importance of individualized approach and acclimatization as well as of prevention of injuries and diseases in athletes (Koehle et al., 2014; Khodaei et al., 2016).

The research did not reveal any significant differences of the postural control for heights of 1630m and 2590m. It may be associated with the action of compensatory mechanisms including the cerebral perfusion or other unknown mechanisms.

The studies performed by Stadelman et al (2015) did not reveal any cognitive defects when the participants took cognitive tests at a height. It may be related to the sufficient sensitivity of cognitive tests. There is a fact which is still to be explained: the significant changes of cognitive processes were not observed in healthy men at altitudes under consideration. This finding raises a question whether the phenomenon is related to the enhancement of adaptive-compensatory mechanisms, or to the decreased sensitivity of the applied tests.

The role of talocrural (ankle joint) strategy and adaptation in the middle-altitude is associated with the sagittal and vertical changes determining the adoption of pose mode of running by ski racers and runners. This is also accompanied by certain frontal shifts, which is seen from the computer stabilometric data and calculations of conditional changes of skiing techniques and locomotions of running (high-speed filming). Our previous studies (Ryabina & Isaev, 2014) show the vector of biomechanical changes (angular and dynamic factors influencing the cycle of skiing motions – particularly, the diagonal stride at various terrain reliefs). The studies also show the contribution of MA technique changes to ski racers' velocity and speed-strength indicators. It should be noted that the system concept of statokinetic stability (SKS) reflects the complexity and variety of parameters regulating the efficient performance including the physical working capacity, psychophysiological safety, sensitivity and reactivity of elements providing the SKS and differentiating the contribution of analyzer systems. Designing the stepped models of regulation of pose characteristics of cyclic motions with synchronous

acquisition of information on the dynamic characteristics makes it possible to develop an aggregate model of effective technique and adaptation. The integral assessment and correction of state and fitness result in improved sport performance.

Conclusions

1. For the blood flow regulation influenced by acclimatization the following succession of manifesting factors was observed: large vessels including the cardiac filling, and central hemodynamics factor. The acclimatization of the cardiopulmonary system in the athletes took 25-30 days, and of psychophysiological state – 30-35 days.

2. The short-term acclimatization in the upper middle-altitude due to sympathetic activation during the first week was accompanied by the mobilization of external respiration function, gas exchange, systolic and minute blood volume, dilatation of the vessels in the brain, myocardium, and skeletal muscles, and constriction of skin capillaries.

3. Due to increased viscoelastic properties of antagonistic muscles in the ankle and hip joints leading to the joint fluid growth the statokinetic stability was enhanced. This decreased shock-absorbing loads on the spinal column, which was indicated by the increase of C2-C7 and TH11-TH12 arch chords and by diverse changes of normal bowing in the thoracic (C7-TH12) and lumbar (L1-L5) segments.

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