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Cardiovascular and Respiratory Systems of Students Living under Mountain Hypoxia

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***Abstract* – The article studies the effect of high-altitude hypoxia on indicators of students' cardiovascular and respiratory systems. The results show that mountain conditions increase the level of blood oxyhemoglobin, duration of excitement to the ventricles, lung ventilation, blood pressure, a heart rate, atrial systole, and contribute to the spread of excitement to the ventricles. The level of oxyhemoglobin in experimental group I and experimental group II exceeded that in the control group by 1.2 and 1.3 %, respectively. The heart rate of female students was less by 2.0 beats per minute in the low mountains, and by 4.3 – in the middle mountains (in male students – by 1.5 and 3.7, respectively). The systolic pressure level was lower by 4.9 mm in girls and by 3.6 – in boys. The lung ventilation value was higher by 0.90 liters in female students and by 0.45 liters in male students. The LC value increased by 0.33 liters in female and by 0.47 liters in male residents of Sharoy district.**

Key words – hypoxia, low mountains, middle mountains, blood pressure, heart rhythm, lung capacity.

I. INTRODUCTION

Hypoxia accompanies a person throughout his life.

Places located at an altitude of 500 meters or more above sea level are mountains.

The terrestrial land is 875 m above the sea level. Up to 30–35 % of the land are located above this mark. It is believed that up to 40 % of the whole land are occupied by mountains. Plains and river valleys are more populated than mountains. 600 million people live in mountainous areas.

The average life expectancy in mountain people is 15–20 years higher than that of people living in plains. For example, a resident of the Azerbaijani mountain village (2200 m) Pirassura M. Eyvazov lived 152 years.

Being in the country of long-livers in 1994, Belvefer, reported that residents of the Hunza valley did not know about diseases, their life expectancy was about 120 years.

According to N. Agadzhanyan and A. Katkov, acclimatization to mountain conditions can prevent early aging (“Reserves of our body”).

By the number of the population, the low mountains rank first, the middle mountains (200–3000 above sea level) rank second. People live even at an altitude of up to 4,500 meters (highlands).

The population of mountainous regions of the Soviet Union made up more than 20 % of the total number. A distinctive feature of mountain areas is diversity of natural conditions. They are distinguished by various resources: water; land; forest; grazing and other. This is due to the presence of special climatic and meteorological conditions in the highlands. Mountain air has one feature that is important to human health. It was noticed by Louis Pasteur in the second half of the 19th century. Mountain air contains less bacteria. Sterility of air samples increases. Therefore, good health and high performance are features of mountain people. They are also distinguished by a large chest, high lung capacity and increased long bones. Oxygen deficiency is due to low pressure in the surrounding atmosphere.

John Bancroft believed that oxygen is the most important substance that the body needs. Due to the fact that the inhabitants of plains and cities were attracted by beauty of mountains, mountain hypoxia has been studied for a long time. As a result, there are new sports and hobbies: mountain climbing; mountain tourism, skiing and cycling; rock climbing, etc. This was facilitated by human desire to reach the heights, develop aeronautics, aviation and cosmonautics. This contributed to studies of the cardiovascular and respiratory systems. When climbing to a height, a proportional decrease in atmospheric pressure occurs, but the percentage composition of air does not change [13].

A gradual decrease in partial pressure of oxygen causes adaptive reactions of the body. The factors that determine peculiarity of human adaptation to high-altitude hypoxia are as follows: experience of oxygen deficiency; levels of physical activity; duration and depth of oxygen starvation; physical and mental conditions; gender; age. In adapting to the mountain conditions, individual tolerance of oxygen deficiency is important. The function of the regulatory systems changes.

At the beginning of the adaptation process, heartbeat increases which causes an increase in systolic ejection of blood, and an increase in the minute volume of blood. Blood pressure increases. Increasing activity of the cardiovascular system increases the oxygen capacity of blood and oxyhemoglobin which helps satisfy the need for oxygen.

Prolonged exposure to hypoxia can reduce these indicators.

While adapting to the lack of oxygen, there is an increase in lung ventilation; however, this increase does not correspond to the natural needs of the body.

Although due to this, in the alveoli gas exchange is significantly improved and partial pressure of oxygen increases. The ventilation of all the alveoli of the lungs, high efficiency of their perfusion and a good diffusion ability decrease the level of lung ventilation.

The respiratory rate does not change. The altitude of 3000 meters above the sea level causes disruption of the respiratory rhythm, poor lung ventilation, reduction of the blood oxygen which is an indicator of insufficient adaptation.

Since antiquity, the effect of mountain hypoxia has been considered one of the most effective methods to increase functional reserves of the body. Although in-depth research on health effects of hypoxia were conducted only in the twentieth century [11, 12].

It was established that the hypoxia therapy normalizes the activity of all body systems, metabolism of nutrients, blood circulation and enhances energy processes in cells.

In the last few decades, the effects of the mountain climate have been widely used in medicine to increase functional reserves of the body [12].

In training athletes, normobaric hypoxia is widely used to stimulate non-specific resistance of the organism [16, 18]. Many diseases are treated using the same method [19].

It is known that in training highly skilled athletes, artificial hypoxia stimulates the systems providing oxygen [14, 4, 17].

As a result of adaptation to the middle mountains conditions, there is an increase in the protective functions of the body [9].

Climbing rapidly to an altitude of 4500 meters above the sea level, 75 % of non-adapted people can develop acute mountain sickness when carbon dioxide does not have time to accumulate in the body [2, 5].

We found that when exposed to hypoxia, there is a slight increase in the level of total protein and globulins in the blood serum and an insignificant drop in the content of albumin, sugar and pulse rate [3].

According to the researchers, in the conditions of deficient oxygen, there are fluctuations in the central nervous system. At the beginning, excitability prevails, and inhibition deepens. This means that at the beginning of adaptation to hypoxia, excitability of the sympathetic nervous system prevails. While being in these conditions for a long time, excitability of the parasympathetic nervous system prevails.

Acute hypoxia causes a person to lose self-control. In the initial period of exposure to hypoxia, the endocrine glands are activated, and prolonged exposure to mountain air depletes them.

Under the influence of oxygen deficiency, the size and weight of the adrenal glands increase, but under the continued exposure, their function decreases. Deep effects of oxygen deficiency cause serious violations.

Due to the migration to mountainous areas, mechanisms of adaptation are of great interest [1].

The mechanisms of human adaptation to the altitude, lack of oxygen and negative changes are understudied [6].

Therefore, the research purpose is to determine the state of the cardiovascular and respiratory systems of students living under the mountain hypoxia.

II. Material and research methods

In order to identify features of adaptation of the cardiovascular and respiratory systems of students to the insufficient oxygen content, in 2014–2018, we were conducting studies in the laboratory of Physiology and at the Center for Collective Use of Chechen State University from 2014 to 2018.

120 (60 girls and 60 boys) healthy full-time students of the Biology and Chemistry Department and the Agrotechnological Institute aged 19–21 years were studied.

According to the principle of analogues (by age, weight, and sex), taking into account the altitude of residence, three groups were formed. Each group consisted of 20 students:

1. The control group: girls and boys living at an altitude of 170 meters above the sea level (Grozny – plain);

2. Experimental group I: 40 students from Shatoy district (600 meters above the sea level, low mountains);

3. Experimental group II: 40 students of Sharoy district (1600 meters above the sea level, middle mountains).

Cardiovascular parameters were determined using a digital automatic tonometer OMRON M3 Expert.

An electrocardiograph Alton-03 was used to assess the heart parameters. The respiratory system parameters were assessed using the Diamant-S spirograph.

For statistical processing of research results, the computer program “Biostatistics” was used.

III. Research results

The results of our research on the effects of hypoxia on a heart rate and blood pressure are presented in Table 1. We can conclude that students living in the conditions of mountain hypoxia have a decreased heart rate and blood pressure.

The value of the maximum pressure in female students from the 1st and 2nd experimental groups was lower by 2.3 and 4.9 mm. Hg Art., in male students, it was lower by 1.1 and 3.6 mm. Hg Art., compared with the control group.

The decrease in the minimum pressure level was 1.5 and 4.3 mm and 1.7 and 4.5 mm in boys living in the lowlands and middle mountains.

Female students from Shatoy district had the heart rate which was lower by 2.0 beats per minute, female students from Sharoy district had the heart rate which was lower by 4.3 beats, and male students had the heart rate which was lower by 1.5 and 3.7 beats per minute. It is clear that they are within the physiological norm.

The decrease in the minimum pressure level was 1.5 and 4.3 mm and 1.7 and 4.5 mm in boys living in the lowlands and middle mountains.

TABLE I. CARDIOVASCULAR SYSTEM INDICATORS

Indicators	Altitude, m					
	170		*600 (low mountains)*		*1600 (middle mountains)*	
	Boys	*Girls*	*Boys*	*Girls*	*Boys*	*Girls*
Systolic pressure	122.1±3.50	118.9±3.32	121.0±3.38	116.6±3.29	118.5±3.29	114.0±3.14
Diastolic pressure	79.3±2.04	73.5±2.75	77.6±2.03	72.0±2.77	74.8±2.18	69.2±2.82
Heart rate, beats per minute	76.2±2.29	78.6±3.25	74.7±2,08	76.6±2.88	72.5±2.31	74.3±2.97

Female students from Shatoy district had the heart rate which was lower by 2.0 beats per minute, female students from Sharoy district had the heart rate which was lower by 4.3 beats, and male students had the heart rate which was lower by 1.5 and 3.7 beats per minute. It is clear that they are within the physiological norm.

Hypoxia causes a slight decrease in the heart rate, a decrease in atrial systole time and ventricular excitation coverage, prolongation of excitation from the atria to the ventricles and systole.

The duration of the P wave was shorter by 0.001 seconds in male and female students from the middle mountains. The PQ interval was longer by 0.002 and 0.003 seconds in girls and boys from Shatoy district and by 0.006 and 0.005 seconds in boys and girls from Sharoy district.

Excitation of the ventricles was faster by 0.002 seconds in female students of the second experimental group, and by 0.001 seconds in male students of the second experimental group.

The duration of the QRST interval was longer by 0.002 and 0.003 seconds in boys and girls of the 1st group; in the 2nd group, it was longer by 0.005 seconds. The results of the study of the respiratory system are presented in Tables 3 and 4.

Table 3 shows that low atmospheric air pressure causes a significant increase in the level of blood oxyhemoglobin, an insignificant increase in lung ventilation and minor fluctuations in respiratory movements.

Thus, the concentration of oxyhemoglobin increased by 1.2 % ($P < 0.05$) in girls and by 1.3 % – in boys ($P < 0.05$) living in the middle mountains. The range of fluctuations in the number of respiratory movements in boys was 1.0 movements per minute, and in girls – 0.6 movements per minute.

The increase in lung ventilation in female students of the first and second groups was 0.09 and 0.90 liters, and among male peers – 0.38 and 0.45 liters.

The dynamics of the respiratory lung volumes in students living at different altitudes above the sea level is presented in Table 4.

TABLE II. EXCITABILITY AND CONDUCTIVITY OF THE HEART MUSCLE OF STUDENTS

Indicators	Altitude, m					
	170		*600 (low mountains)*		*1600 (middle mountains)*	
	Boys	*Girls*	*Boys*	*Girls*	*Boys*	*Girls*
P, c	0.090±0.0031	0.088±0.0051	0.089±0.0240	0.087±0.0038	0.086±0.0041	0.085±0.0058
PQ, c	0.145±0.0074	0.143±0.0040	0.148±0.0045	0.145±0.0039	0.150±0.0047	0.149±0.0037
QRS, c	0.069±0.0006	0.071±0.0038	0.070±0.0026	0.070±0.0040	0.068±0.0029	0.069±0.036
QT, c	0.341±0.0067	0.345±0.0069	0.343±0.0058	0.348±0.0063	0.346±0.0058	0.350±0.0060

TABLE III. RESPIRATORY SYSTEM INDICATORS

Indicators	Altitude, m					
	170		*600 (low mountains)*		*1600 (middle mountains)*	
	Boys	*Girls*	*Boys*	*Girls*	*Boys*	*Girls*
The number of respiratory movements per minute	15.0±0.62	15.6±0.59	15.4±0.63	15.2±0.53	14.6±0.64	15.8±0.68
Minute volume of breathing, liters per minute	8.55±0.4431	8.42±0.623	8.93±0.654	8.51±0.585	9.00±0.486	9.32±0.597
Percentage of hemoglobin converted to oxyhemoglobin	97.4±0.30	97.6±0.32	98.2±0.37	98.0±0.63	98.6±0.34*	98.7±0.36*

[a.] * – $P < 0.05$

TABLE IV. RESPIRATORY LUNG VOLUMES

Indicators	Altitude, m					
	170		*600 (low mountains)*		*1600 (middle mountains)*	
	Boys	*Girls*	*Boys*	*Girls*	*Boys*	*Girls*
LC, l	4.23±0.172	3.38±0.120	4.28±0.167	3.41±0.117	4.70±0.149	3.71±0.112
RLV ib, l	2.03±0.100	1.62±0.072	2.05±0.096	1.63±0.072	2.25±0.082	1.77±0.066
RLV ob,l	1.63±0.085	1.22±0.057	1.65±0.084	1.22±0.062	1.82±0.081	1.35±0.056
AO, l	0.57±0.022	0.54±0.031	0.58±0.023	0.56±0.028	0.63±0.020	0.59±0.031

The LC level in the experimental groups is slightly higher.

The indicators of LC, RLV and AO in male students living in low mountains increased by 0.05 l, 0.02 l, 0.02 l and 0.01 l.

The indicators of LC, RLV, and AO in female students living in the low mountains increased by 0.03 l, 0.01 l, 0.00 l and 0.02 l, respectively in compared with female students living in Grozny (3.38 l, 1.62 l, 1.22 l and 0.54 l). These indicators in young men living in the middle mountains increased by 0.47 l, 0.22 l, 0.19 l and 0.07 l, and in young women – by 0.33 l, 0.15 l, 0.13 l and 0.05 l, respectively

IV. CONCLUSION

Humans populated the highlands searching for new sources of energy and minerals, building sports and recreational facilities.

Studies on altitude hypoxia initiated by X. Saussure, P. Baer, I. M. Sechenov, A. Mosso, N. Tsuntzi, J. Haldane, J. Barcroft and N. N. Sirotinin contributed to the development of mountain physiology and medicine.

At the beginning of the 20th century, the idea on the use of mountain air for treating diseases of the respiratory tract and lungs suggested by N. N. Sirotinin was widely recognized.

Scientists continue to search for ways to increase functional capabilities of the body and improve athletic performance.

Currently, hypoxytherapy has been widely used in clinics for treating nervous, cardiovascular and allergic diseases.

Despite the fact that hypoxia has been known for a long time, it is understudied. Even a slight decrease in the oxygen content in the atmospheric air causes disorders.

Hypoxia did not have a significant effect on the heart rhythm and arterial blood pressure of students.

The heart rhythm of the female students of the first and second groups was 76.6 and 74.3 beats per minute, whereas that of the male students was 74.7 and 72.5, and in the control group, the heart rhythm was 78.6 and 76.2, respectively.

The systolic pressure in the boys living at an altitude of 600 and 1600 m was 121.0 and 118.5 mm Hg. Art., and in the girls – 116.6 and 114.0 mm Hg. v. 170 m – 122.1 and 118.9.

The minimum blood pressure also decreased.

Our data are supported by research results [15]. According to E.V. Mateeva and N.I. Panteleev, the impact of hypoxia on the lack of oxygen causes a favorable reaction of the cardiovascular and respiratory systems of the body [7].

A decrease in the cardiovascular system is due to increased excitability of the vagus nerve.

All values characterizing the students' ECG are within the normal range. However, we identified tendencies to longer PQ and QT intervals and shorter P waves and QRS.

The PQ and QT values for girls of Sharoy district were 0.149 and 0.350 seconds, for boys – 0.150 and 0.346 s, and for residents of Grozny – 0.143 and 0.345; 0.145 and 0.341 respectively. Duration of the atrial systole and ventricular excitation coverage was 0.085 and 0.069 seconds in female residents of middle mountains, 0.086 and 0.068 s – in male residents of middle mountains, and 0.088 and 0.071 s; 0.090 and 0.069 s – in residents of the plain, respectively.

We did not find literary sources on the effects of mountain air on the duration of ECG intervals.

These changes are associated with a decrease in adrenaline production. With oxygen deficiency, hormone production decreases [20].

We studied the state of the respiratory system depending on the degree of exposure to hypoxia.

According to the results, hypoxia increases concentration of oxyhemoglobin, lung ventilation, LC and its constituent volumes and does not affect the amount of respiratory movements in experimental students. The higher the lack of oxygen, the more pronounced the changes.

An increase in the hemoglobin level was 0.4 and 0.8 % in female and male students living in the low mountains, 1.1 ($P < 0.05$) and 1.2 % ($P < 0.05$) in students living in the middle mountains.

Lung ventilation increased by 0.09 and 0.90 liters in girls and by 0.38 and 0.45 liters in boys.

The indicators of LC, RLV and AO increased by 0.05 l, 0.02 l, 0.02 l and 0.01 l in male students living in low mountains

The indicators of LC, RLV, and AO increased by 0.03 l, 0.01 l, 0.00 l and 0.02 l, respectively in female students living in the low mountains in compared with female students living in Grozny (3.38 l, 1.62 l, 1.22 l and 0.54 l). These indicators increased by 0.47 l, 0.22 l, 0.19 l and 0.07 l in young men, and by 0.33 l, 0.15 l, 0.13 l and 0.05 l in young women living in the middle mountains.

At an altitude of 1600 m, these values increased by 0.47 l, 0.22 l, 0.19 l and 0.07 l, while for female students – by 0.33 l, 0.15 l, 0.13 l and 0.05 l, respectively.

The fluctuation of the number of respiratory movements per minute at different heights was 0.6 for girls and 0.8 for boys.

Similar results were obtained by other researchers. M.O. Berova [8] identified the stimulating effect of hypoxia on the immune and respiratory systems.

According to various researchers, oxygen deficiency changes all the parameters of this system: external **respiration; gas exchange conditions; diffusion**; transport; use of oxygen by the tissues.

Apparently, a high level of oxyhemoglobin in the blood and minute respiratory volume is associated with a greater oxygen capacity of the blood, high affinity for hemoglobin and an increased respiratory volume of the lungs.

An increase in the vital capacity of the lungs and its constituent volumes is due to an increased inspiratory muscle

tone. Researchers say that the mountain people have larger chests, an increased vital capacity (by approximately 10 %) due to an increased muscle tone of the inhale [10].

We can conclude that under the influence of mountain hypoxia, students experience:

- an insignificant decrease in the heart rate and blood pressure;
- a slight decrease in the duration of contraction of the atria and excitation of the ventricles, an increase in the duration of excitation to the ventricles and their reduction;
- a significant increase in the level of oxyhemoglobin;
- a slight increase in the lung ventilation and lung capacity.

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