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FEATURES OF SOME VEGETATIVE INDICATORS IN CHILDREN FROM MOUNTAIN AREAS

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Abstract

A comparative analysis was conducted to examine regional differences in selected vegetative parameters among primary school children and adolescents residing in the hypoxic conditions of the mountainous regions of the Chechen Republic, compared to their peers living in lowland (normoxic) areas. The study focused on key indicators of cardiovascular function—namely systolic and diastolic blood pressure (SBP, DBP) and heart rate (HR)—as well as parameters of carbohydrate metabolism, particularly fasting blood glucose levels. These physiological markers were assessed across two age groups to evaluate developmental dynamics and adaptation patterns in contrasting altitudinal environments. The findings revealed that children living in high-altitude zones exhibited significantly lower values in all measured vegetative parameters compared to their counterparts in the plains. Specifically, systolic and diastolic blood pressure, resting heart rate, and blood glucose concentrations were markedly reduced in the highland group, suggesting enhanced cardiovascular efficiency and improved metabolic regulation associated with chronic exposure to moderate hypoxia. These adaptations are likely mediated by long-term physiological adjustments, including increased parasympathetic tone, improved oxygen utilization, and more stable autonomic control of vital functions. Age-related trends in the development of these parameters were evident in both lowland and highland populations, reflecting normal maturational processes; however, the rate and trajectory of change appeared more pronounced in the mountain group, indicating an altitude-modulated pattern of physiological development. Notably, no statistically significant gender differences were observed in any of the studied vegetative parameters across either age group or residential zone. This absence of sexual dimorphism during childhood and early adolescence suggests that the influence of sex hormones on autonomic regulation and metabolic activity has not yet fully emerged, and that environmental factors—particularly hypoxia—play a dominant role in shaping physiological profiles at this stage of development.

Keywords: *hypoxia, normoxia , mountains, adaptation, children, adolescents, age, gender, pressure, pulse, glucose.*

I. Introduction

Climatic factors have a significant impact on the vegetative systems of the human body [1, 5, 6, 8]. Various climatic factors (lighting, temperature, humidity, gas content, day length and many others) cause adaptive restructuring in the body's systems. As a result of such restructuring and adaptation, the functional capabilities of the body can change. In particular, the body can better adapt, for example, to a lack of oxygen in the air, which is observed in a person living in a mountainous area [1].

Hypoxia or low oxygen content in the atmosphere is one of the main natural factors affecting the work of almost all physiological systems of the human body. First of all, the gas transport systems – the circulatory and respiratory systems – react to the lack of oxygen. The circulatory system is one of the first to react to the lack of oxygen in the air. The reaction of this system to a person's prolonged stay in hypoxic conditions has also been well studied. It has been established that under conditions of constant hypoxia, a number of adaptive changes in the functioning of the circulatory system occur in the body. These are, first of all, a decrease in pulse, blood pressure, an increase in cardiac output, minute blood volume, growth of the myocardium of the ventricles of the heart, etc. [5, 6].

Basically, the studies of the effects of hypoxia are conducted on the adult population. There are few works in the available literature devoted to the study of vegetative parameters, in particular, the circulatory system, metabolism in children during ontogenesis [5]. Many works on the study of vegetative indicators were conducted under normoxia conditions . How the circulatory system and carbohydrate metabolism react in children, constantly living in conditions of mountain hypoxia, has not been sufficiently studied. Whether the same patterns of adaptation of the circulatory system and metabolism in children, which were found in the adult population living in conditions of mountain hypoxia, are manifested, is unknown. These issues are of practical and theoretical interest.

Objective : To study some parameters of the circulatory system and carbohydrate metabolism in children under conditions of normoxia and hypoxia.

II. Methods

Research materials. The research was conducted in the village of Benoy -Vedeno (Gymnasium No. 1) and in the city of Grozny (Gymnasium No. 14).

A total of 80 schoolchildren aged 9-15 years were examined. Of these, 38 schoolchildren were from the mountainous region and 42 schoolchildren from the flatland region. Schoolchildren from the mountainous and flatland regions were divided into 2 age groups: Group 1 - junior school age (9, 10 years); Group 2 - senior school age (14, 15 years). Oral consent was obtained from the parents of the schoolchildren involved in the study for their children to participate in the survey.

The parameters of the cardiovascular system and sugar level were compared taking into account the gender, age and climate zone of residence of the children. The mountain village of Benoy -Vedeno was chosen as a mountain climate zone with constant hypoxia . This village is located at an altitude of about 700 meters above sea level (695 m). Such an altitude is considered in the literature as low mountains. Children living here are constantly in conditions of low oxygen content in the atmosphere. The flat zone, with a normal oxygen level, was represented by the city of Grozny, which is located at an altitude of 160 m above sea level. The difference between the altitudes of these two zones is slightly more than 500 meters.

Research methods. All studies were conducted in the morning, 2.5-3 hours after eating. The subject's blood pressure, heart rate and blood glucose level were measured in a state of physiological rest. A non-invasive glucometer Omelon-B2. Device Omelon A-1. Manufacturer of the device - Kursk OJSC "Pribor", Russia, 305040, Kursk, st. Zapolnaya, 47, OJSC "Pribor".

The device measures blood pressure, heart rate and blood glucose level. In this case, glucose measurement in peripheral blood is performed non-invasively . The sugar level is determined automatically by the device based on systolic and diastolic pressure readings. The calculation method is described in detail in the device manual. The device displays all vegetative parameters studied (systolic pressure, diastolic pressure, heart rate, sugar level) on the display.

III. Results

Blood pressure, heart rate and glucose level in schoolchildren from lowlands and plains. The study of the parameters of the circulatory system in children of two age groups living in different climatic zones shows that living conditions have a significant impact on the features of physiological processes in the body of children. In children of the younger age group (Table 1) living in highlands, in conditions of hypoxia, such parameters of the cardiovascular system as pulse (HR), systolic and diastolic pressure were significantly lower (Table 1; Fig. 1, 2). Probably, low HR and BP in mountain children can be interpreted as a result of adaptation to hypoxia.

It is a well-known fact that under hypoxic conditions, the muscular wall of the heart hypertrophies, especially the left ventricle of the heart. This leads to an increase in cardiac output of blood into the aorta. Apparently, the heart contracts less frequently under hypoxic conditions, as evidenced by the decrease in heart rate in children, due to an increase in cardiac output of blood, minute volume of blood, it works in a more economical mode, thereby getting more time for a break. Perhaps changes occur not only in the heart itself, but also in the vascular bed. The walls of blood vessels become more elastic and their tone increases. This explains the fact that mountain children have lower systolic and diastolic pressure . According to our data, the examined children in the mountainous zone show adaptive changes in the functioning of the circulatory system and heart, which are found in adults living permanently in conditions of mountain hypoxia [5, 6]. Apparently,

To compensate for the lack of oxygen in the blood, the child's body improves the mechanical pumping functions of the heart and reduces the resistance to blood flow in the vessels, improving the tone and permeability of blood vessels.

Table 1 Blood pressure and heart rate in children of the Moscow School of Health in the village of Benoy -Vedeno and the city of Grozny

Residential area	Systolic pressure, mmHg	Diastolic pressure, mmHg	Heart rate, bpm
s. Benoy -Vedeno	99.5±1.61	67.2±1.84	67.3±1.18
Grozny city	120.3±1.45	86.4±2.74	75.6±2.13
r	< 0.001***	< 0.001***	< 0.01**

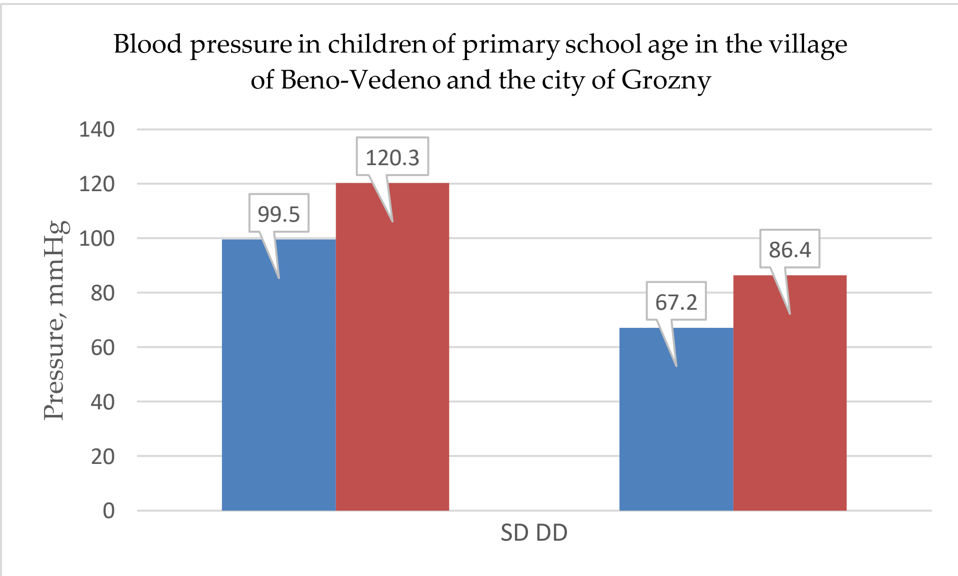

Fig. 1. Systolic and diastolic pressure in children of the Moscow region living in different natural zones

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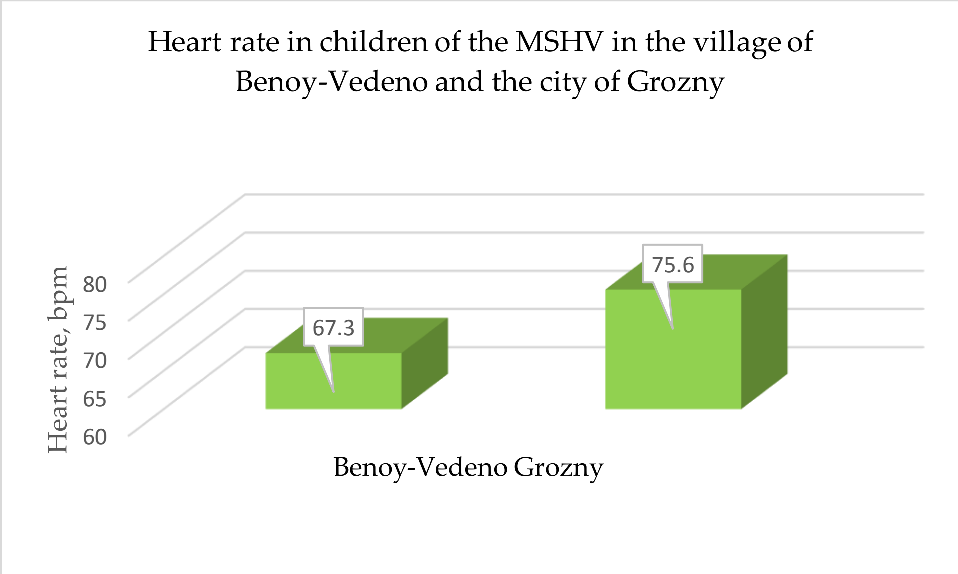

Fig. 2. Heart rate in children living in plains and lowlands

A study of blood glucose levels in mountain and plain children aged 7 to 11 years revealed significantly lower blood glucose concentrations in lowland children (Table 2, Fig. 3). From the point of view of the physiological norm, a constant low blood glucose level within the normative limits can be considered a useful adaptation of the body.

Table 2 Blood glucose levels in schoolchildren of the Moscow School of Economics living in the plains and lowlands of the Czech Republic

Residential area	Glucose, mmol /l
S. Benoy -Vedeno	3.0± 0.15
Mr. Grozny	3.6± 0.13
r	< 0.01**

The explanation of the possible mechanism of such a decrease is quite controversial. There are data or assumptions that the decrease in blood glucose in mountain dwellers may be caused by the fact that they cultivate a predominantly protein diet [7].

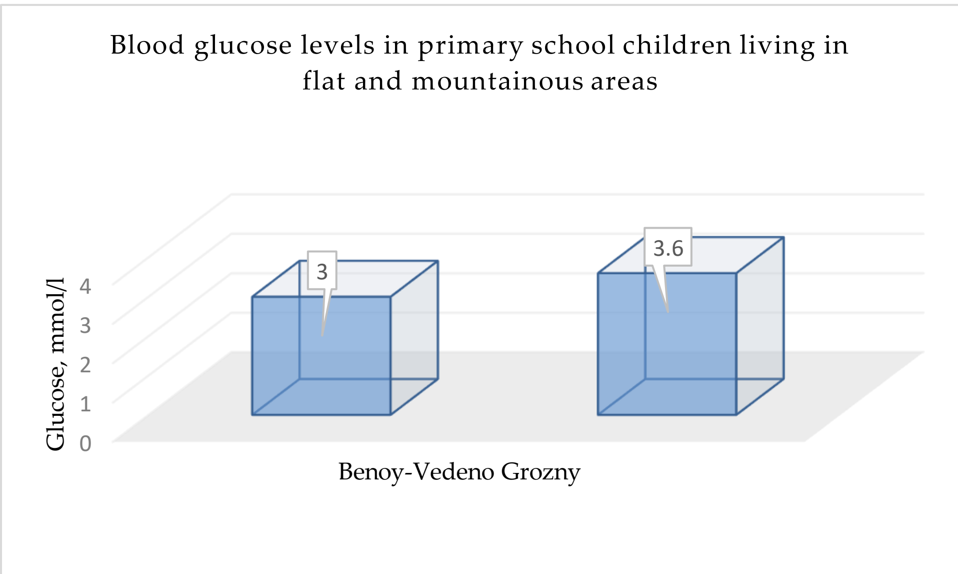

Fig. 3. Blood sugar levels in primary school children living in the plains and lowlands

Carbohydrates do not play a major role in the diet of mountain dwellers. It should also be remembered that the activity of the parasympathetic link in the mountains in regulating vegetative functions and metabolism increases, which, apparently, also affects the characteristics of metabolism.

The study of the same parameters of the circulatory system and carbohydrate metabolism in adolescence confirms the patterns identified above. Thus, in mountain children of adolescence, all the studied parameters were reliably reduced - systolic and diastolic pressure, pulse and blood sugar level (Tables 3, 4).

Table 3 Heart rate and blood pressure in children of the village of Benoy -Vedeno and the city of Grozny

Residential area	BP, mmHg	DD, mmHg	Heart rate, bpm
s. Benoy -Vedeno	103.4±0.99	68.1±2.02	68.2±1.33
Grozny city	118.6±1.28	81.2±2.05	82.1±1.43
r	< 0.001***	< 0.001***	< 0.001***

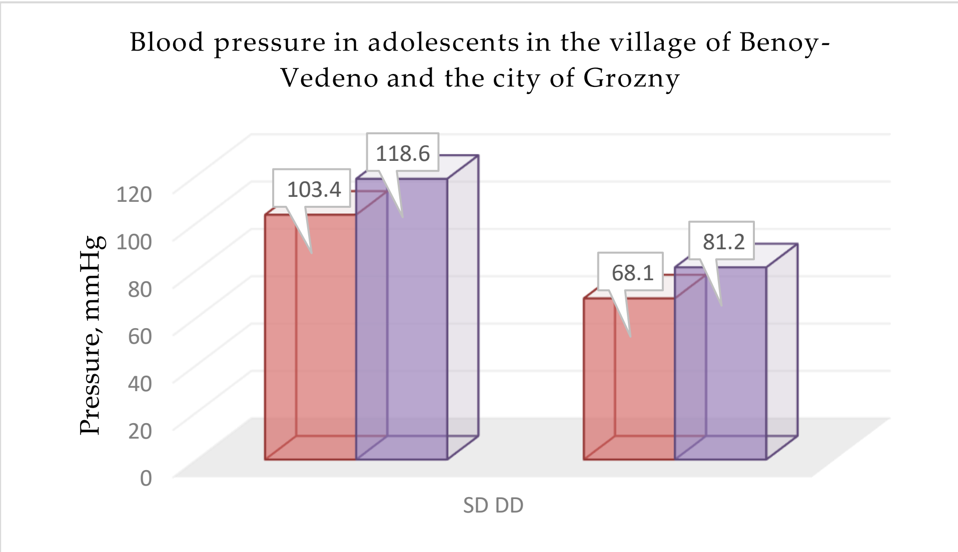

Fig. 4. Blood pressure in adolescents in the flat and mountainous areas of the Czech Republic

Systolic and diastolic pressure are statistically significantly higher in adolescents living on the plain, i.e. in the city of Grozny (Table 3; Fig. 4). Heart rate was also significantly lower in adolescents living in mountainous areas (Table 3; Fig. 5).

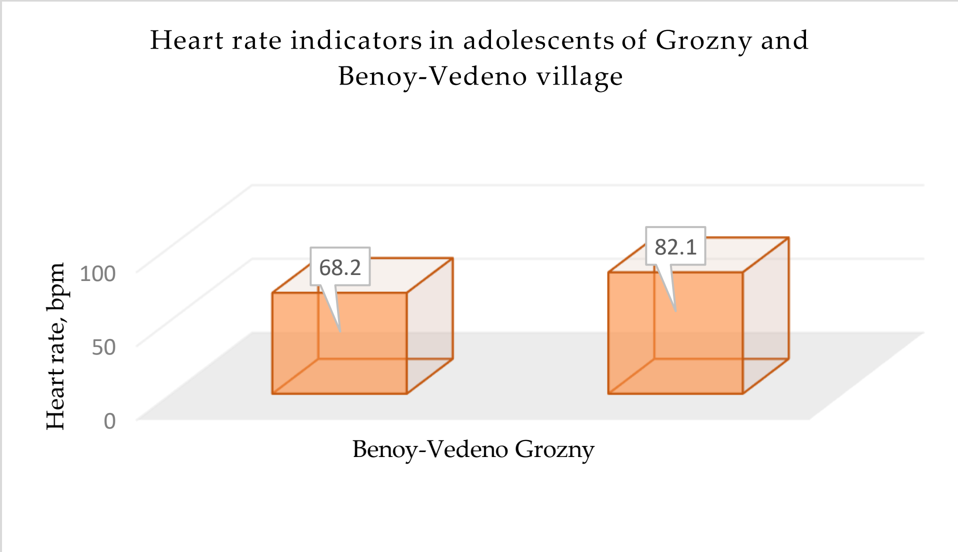

Fig. 5. Pulse in adolescent children in lowlands and plains

As for the blood sugar level of adolescents, it was statistically significantly lower in mountain adolescents (Table 4, Fig. 6).

Table 4 Blood sugar levels in schoolchildren in the plains and mountains

Residential area	Sugar, mmol /l
s. Benoy -Vedeno	3.7±0.14
Grozny city	4.3±0.15
r	< 0.05*

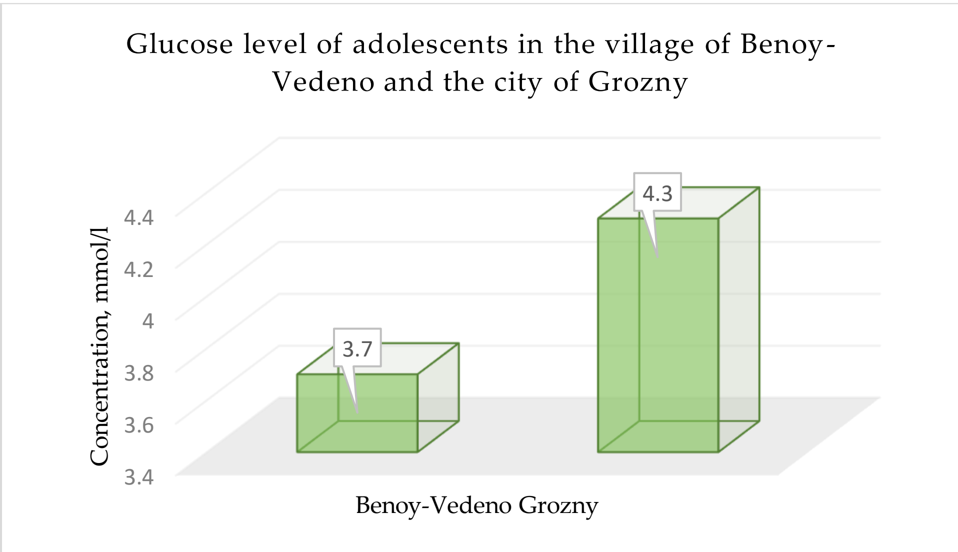

Fig. 6. Blood sugar levels in children and adolescents in lowlands and plains

Thus, children's living in hypoxic conditions causes adaptive changes in the circulatory system and carbohydrate metabolism.

Age-related changes in blood pressure, heart rate, and sugar levels in mountain and flat areas. Studies of the effect of age on blood pressure, heart rate, and glucose levels in children in the mountain and flat areas of the Chechen Republic show that there were no age-related changes in heart rate and blood pressure in mountain children (Table 5), but glucose levels increased significantly (Table 6). A slight, although not reliable, increase was noted in systolic pressure (Table 5). Heart rate and diastolic pressure changed almost little (Table 5).

Table 5 BP and HR in children MShV and PV with. Benoy -Vedeno

Age group	SD , mmHg	DD , mmHg	Heart rate, bpm
MSHV	10 0.1±1.47	69.4±1.76	67.5±1.12
PV	103.3±1.11	68.2±1.34	68.4±1.23
r	> 0.05	> 0.05	> 0.05

Table 6 Glucose levels in children with MSHV and PV in s.Benoy -Vedeno

Age group	Sugar, mmol /l
MSHV	3.0±0.11
PV	3.7±0.14
r	<0.01**

Thus, one of the vegetative parameters with age in mountain children, in particular, the sugar level, changed significantly, and the parameters of the circulatory system - blood pressure and heart rate - although they increased, the changes did not reach statistical significance. The increase in blood pressure, heart rate and sugar levels is probably explained by age-related changes in the cardiovascular system, hormonal status and metabolism of children [4].

In the plains, significant age-related changes in vegetative indices were more pronounced in children than in the mountains (Tables 7, 8). A slight, unreliable increase in arterial pressure and a significant increase in heart rate in adolescence were noted (Table 7).

Table 7
Blood pressure and heart rate in schoolchildren of the Moscow School of Higher Education and the Moscow School of Higher Education in Grozny

Group	SD , mmHg	DD , mmHg	Pulse, bpm
MSHV	110.2±1.26	8 0 ,7±3,12	75.0±2.32
PV	118.1±1.76	81.4±2.25	82.5±2.43
r	> 0.05	> 0.05	< 0.05*

Another vegetative parameter, glucose level, also shows a significant increase with age on the plain (Table 8).

Table 8
Changes in sugar levels with age in schoolchildren in Grozny

Group	Glucose, mmol /l
MSHV	3.6±0.12
PV	4.2±0.15
r	< 0.01**

Thus, both on the plain and in the mountains, there is a tendency for the cardiovascular system and blood sugar levels to increase with age in children. According to our data, this growth is smoother in the mountains. Apparently, under hypoxic conditions, growth processes have their own distinctive features. Perhaps the influence of the urban environment is at play, since individual indicators of vegetative functions vary greatly among city dwellers . Probably, in different climatic zones, growth processes can be mediated by the influence of many factors [4, 6].

Gender differences in blood pressure, heart rate and glucose in schoolchildren of the lowland and lowland areas. The work also examined the effect of hypoxia on gender-specific features of the functioning of the circulatory system and carbohydrate metabolism in children of two age periods – lowland and lowland (Tables 9-16). Thus, it was found that all the studied parameters characterizing the functioning of the circulatory system – blood pressure, heart rate and glucose – had no reliable gender differences in children living either in the lowlands or on the plain (Table 9).

Table 9 Gender differences in blood pressure and heart rate in children MShV s. Benoy - Vedeno

Floor	SD , mmHg	DD , mmHg	Pulse, bpm
Girls	100.1±1.36	65.3±2.13	67.4±1.39
Boys	99.7±1.67	64.5 ±2.55	66.3±1.47
r	> 0.05	> 0.05	> 0.05

Table 10 Glucose level in children MShV s. Benoy -Vedeno

Floor	Sugar, mmol /l
Girls	2.8±0.16
Boys	3.2±0.15
r	>0.05

It should be noted that gender differences in the parameters of physiological systems in children of primary school age may be completely absent [3, 4].

Blood glucose concentration in primary school children of the village of Benoy - Vedeno (Table 10): boys have higher sugar levels, although not reliably. Higher sugar levels in boys may be explained by metabolic peculiarities, although the subtle mechanisms of increasing levels are not entirely clear.

Gender differences in vegetative indices in adolescent children. As can be seen from the following tables 11 and 12, arterial pressure, heart rate and sugar levels in adolescent children living in the mountains also do not show gender differences.

Table 11 Heart rate and blood pressure in boys and girls PV s. Benoy -Vedeno

Floor	SD , mmHg	DD , mmHg	Pulse, bpm
Girls	102.3±1.01	70.2±2.06	70.4±1.29
Boys	105.0±1.05	6 6 ,5±1,88	66.3±2.04
r	>0 ,05	> 0.05	> 0.05

Table 12 Gender differences in blood sugar in adolescents with Benoy -Vedeno

Floor	Glucose, mmol /l
Girls	3.6±0.13
Boys	4.0±0.16
r	>0.05

Results of comparison of cardiovascular system parameters in adolescent girls and boys permanently living in conditions of mountain hypoxia: girls have a higher pulse rate, but not significantly so (Table 11). Systolic pressure is higher in adolescent boys.

A study of glucose in children of the opposite sex in this natural zone (Table 12) shows that its level is lower in girls, although these differences do not reach statistical significance.

significant gender differences in blood pressure, heart rate, and glucose levels in children of primary school age and adolescents living in normoxic conditions , that is, on the plain (Tables 13, 14, 15, 16).

In plains girls of the MShV, the heart rate level was higher (Table 13), and the glucose concentration, on the contrary, was lower than in boys (Table 14).

Table 13 SD, DD and HR in boys and girls MShV Grozny

Floor	SD , mmHg	DD , mmHg	Heart rate, bpm
Girls	121.2±1.42	91.3±4.17	78.4±3.28
Boys	119.4±1.78	83.5±4.94	71.9±3.47
r	> 0.05	> 0.05	> 0.05

Table 14 Blood sugar content in children of the Moscow School of Health in Grozny: gender differences

Floor	Sugar, mmol /l
Girls	3.5±0.11
Boys	3.6±0.12
r	>0.05

Hemodynamic parameters (blood pressure, heart rate) and blood sugar levels in adolescent children of the opposite sex living on the plain also did not show significant gender differences (Tables 15, 16).

Table 15 Heart rate, diabetes and diabetes in adolescents of Grozny: gender differences

Floor	SD , mmHg	DD , mmHg	Pulse, bpm
Girls	116.3±2.97	84.5±2.45	81.3±3.15
Boys	122.4±1.65	78.3±2.04	85.1±3.22
r	> 0.05	> 0.05	> 0.05

Table 16 Blood sugar level in boys and girls PV Grozny

Floor	Sugar, mmol /l
Girls	4.4±0.17
Boys	4.2±0.21
r	> 0.05

As for the absence of gender differences in glucose levels in children in all studied age groups on the plain (Tables 10, 12) and in the mountains (Tables 14, 16), this may be explained by the fact that blood glucose levels are one of the most strictly controlled physiological constants of the body. There is evidence that its concentration is little affected by gender differences [2]. This pattern is probably also observed in those living in different natural and climatic zones.

IV. Discussion

I. Subsection One

As follows from the results of the study, blood pressure and heart rate demonstrated reliable differences between children of different ages living both on the plain and in the lowlands. Blood pressure and heart rate were significantly lower in mountain schoolchildren. The parameter characterizing carbohydrate metabolism, the glucose level, was also lower in children in highlands. Thus, hypoxia caused adaptive changes in the functioning of the cardiovascular system and in the nature of metabolism in children in highlands. These adaptive changes indicate an increase in the economy and efficiency of the functioning of these vegetative systems.

The next question that was considered in the work concerned the presence of age and gender differences in blood pressure, heart rate and glucose in children of two natural zones. It turned out that age-related changes were mainly of a unidirectional nature and were presented by a larger number of parameters in lowland children. Gender differences in children were absent both on the plain and in the lowlands.

Hypoxia causes adaptations in some vegetative systems , which contributes to their more economical functioning. For adaptive adaptations to hypoxia, the child's body pays with structural and physiological reorganizations of organs and systems, similar to the body of an adult.

The results of the work can be used to evaluate the mechanisms of adaptive reorganization of the vegetative systems of the body of children of different ages and sexes living in different climatic zones with different partial pressure of oxygen in the air. Natural zones of Russia can differ in different regions and, probably, they can influence the nature of the manifestations of adaptations.

The obtained quantitative indicators of arterial pressure (systolic and diastolic), heart rate and blood glucose level in children of two age periods can be used as reference and reference when compiling a regional "Health Passport" of a schoolchild living in the republic. Knowledge of the features of the functioning of the circulatory system and carbohydrate metabolism of children in different natural conditions can be useful when organizing mental and physical activities for schoolchildren. The study reveals significant regional, age-related, and metabolic differences in key vegetative parameters—systolic and diastolic blood pressure (SBP, DBP), heart rate (HR), and blood glucose levels—among primary school children and adolescents living in the lowland (normoxic) and mountainous (hypoxic) regions of the Chechen Republic. These findings highlight the profound influence of chronic environmental hypoxia on autonomic regulation and metabolic homeostasis during critical periods of growth and development.

In primary school-aged children (6–10 years), systolic and diastolic blood pressure were significantly lower in those residing in mountainous areas compared to their peers in the lowlands. This hypotensive tendency in highland children is consistent with adaptive mechanisms triggered by prolonged exposure to reduced oxygen availability, including enhanced parasympathetic dominance, improved endothelial function, and lower peripheral vascular resistance. Similarly, resting heart rate was significantly lower in mountain-dwelling children, indicating increased cardiac efficiency and greater vagal tone—both hallmarks of successful physiological adaptation to high-altitude hypoxia. These cardiovascular adjustments likely contribute to energy conservation and optimized oxygen delivery in oxygen-scarce environments.

However, this pattern shifts with age. During adolescence (11–17 years), both blood pressure and heart rate were found to be lower in lowland schoolchildren compared to their highland counterparts. This reversal suggests that the developmental trajectory of cardiovascular regulation diverges between altitudes, possibly due to differential timing of pubertal maturation, hormonal influences, and cumulative exposure to environmental stressors. While younger highland children benefit from early-life hypoxic conditioning, adolescents in mountainous regions may experience increased sympathetic activation and cardiovascular strain as metabolic demands rise during growth spurts, partially counteracting earlier adaptive advantages.

Blood glucose levels demonstrated a consistent and significant reduction in children living in mountainous areas across both age groups. Whether in primary school or adolescence, highland residents exhibited lower fasting glycemia compared to lowland peers. This finding points to enhanced insulin sensitivity and more efficient glucose utilization in hypoxic conditions—potentially mediated by increased expression of hypoxia-inducible factors (HIFs), upregulation of glucose transporters (e.g., GLUT1 and GLUT4), and higher metabolic reliance on glycolysis. These metabolic adaptations support sustained energy production under low oxygen tension and may offer protective effects against insulin resistance later in life.

Age-related changes in vegetative parameters revealed important developmental trends. Although no significant age-related differences were observed in blood pressure between younger children and adolescents in either region—suggesting relative hemodynamic stability during growth—heart rate in lowland children showed a clear developmental decline: younger children had significantly higher HR than adolescents, reflecting the expected maturation of autonomic control with age. In contrast, this trend was less pronounced in highland children, possibly due to earlier stabilization of autonomic function induced by hypoxic exposure. Notably, blood glucose levels increased significantly with age in both lowland and mountain populations, with adolescents exhibiting higher concentrations than younger children. This age-dependent rise in glycemia likely reflects increasing metabolic demands, changes in body composition, and evolving dietary patterns during puberty.

Importantly, no statistically significant gender differences were found in any of the studied parameters—blood pressure, heart rate, or blood glucose concentration—across either age group or residential zone. This absence of sexual dimorphism during childhood and early adolescence suggests that the influence of sex hormones on autonomic and metabolic regulation has not yet reached a threshold sufficient to produce measurable divergence between boys and girls. Instead, environmental factors—particularly chronic mountain hypoxia—appear to exert a stronger influence on physiological profiles than gender at this developmental stage.

Overall, the findings demonstrate that long-term residence in high-altitude hypoxic conditions significantly modulates key vegetative functions in children and adolescents. These effects are not uniform across age groups, indicating that adaptation to hypoxia is a dynamic, life-stage-dependent process. The observed reductions in blood pressure, heart rate, and blood glucose levels in mountain-dwelling children reflect beneficial physiological remodeling that enhances oxygen delivery, conserves energy, and improves metabolic efficiency. Such adaptations underscore the remarkable plasticity of the developing organism in response to environmental challenges.

In conclusion, this comparative study emphasizes the necessity of considering regional and altitudinal factors when establishing physiological norms for pediatric populations. Clinical assessments, school health programs, and public health policies in mountainous regions should account for these adaptive differences to avoid misinterpretation of lower blood pressure or heart rate as pathological when they may, in fact, represent optimal functional states under hypoxic conditions. Future research should explore the long-term health implications of these early-life adaptations, including potential protective effects against cardiovascular and metabolic diseases in adulthood.

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