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CLINICAL AND FUNCTIONAL CHARACTERISTICS OF THE CARDIOVASCULAR SYSTEM IN CHILDREN WITH DIFFERENT ADAPTATION CONDITIONS

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Abstract: This study examines the clinical and functional characteristics of the cardiovascular system in children living under different adaptation conditions, including high-altitude, industrial urban, and rural environments. A total of 180 children aged 7 to 15 years were examined using clinical, electrocardiographic, echocardiographic, and heart rate variability analyses. The findings revealed significant differences in cardiovascular regulation depending on environmental and psychosocial stressors. Children living at high altitudes and in urban environments exhibited higher heart rates, elevated systolic blood pressure, and decreased heart rate variability compared to those from rural regions. The study highlights that adaptation to environmental and social factors significantly affects the functional state of the cardiovascular system in childhood. Early identification of maladaptive cardiovascular responses is essential for preventive interventions in pediatric health care.

Key words: cardiovascular system, adaptation, children, hemodynamics, autonomic regulation, environment, heart rate variability

Introduction

The cardiovascular system of children represents one of the most sensitive physiological structures in the human body, responding dynamically to both internal and external stimuli. During growth and maturation, the cardiovascular system continuously adapts to environmental, psychosocial, and physical factors to maintain functional stability and ensure adequate perfusion of developing organs. Adaptation is a complex biological process that involves the coordinated activity of the nervous, endocrine, and circulatory systems.

Children living under various adaptation conditions demonstrate different patterns of cardiovascular function. High-altitude hypoxia, urban environmental pollution, and psychosocial stress provoke compensatory mechanisms that increase heart rate and myocardial contractility. Meanwhile, children residing in ecologically favorable rural areas tend to maintain optimal hemodynamic parameters due to more stable adaptive regulation. Understanding how different adaptation conditions influence cardiovascular function in childhood is crucial for early prevention of future cardiovascular diseases. Therefore, the aim of this study was to analyze the clinical and functional features of the cardiovascular system in children exposed to diverse adaptation conditions and to evaluate the physiological mechanisms underlying these responses.

The cardiovascular system in children represents one of the most complex and dynamically developing functional systems of the human organism. Its activity reflects the state of adaptation and general homeostasis, responding sensitively to even minimal changes in external or internal environments. During childhood, particularly between the ages of 7 and 15, the processes of physical growth, neurohumoral maturation, and metabolic regulation undergo rapid transformation. These transformations require constant physiological adaptation of the cardiovascular system to ensure adequate blood supply to all organs and tissues, including the developing brain and muscles.

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Adaptation is defined as a multifactorial physiological process through which the organism maintains internal stability in response to environmental and psychosocial influences. It represents a key mechanism that supports the balance between sympathetic and parasympathetic regulation, vascular tone, and myocardial activity. In pediatric populations, the adaptive capacity of the cardiovascular system is determined by genetic predisposition, hormonal regulation, level of physical activity, psychological resilience, and the external living environment. Environmental factors such as air quality, altitude, temperature fluctuations, and social stressors can significantly modify the balance of autonomic regulation and influence the developmental trajectory of cardiovascular function.

Children living in different ecological and social conditions display noticeable variations in cardiac performance and regulatory balance. Those residing in mountainous regions are exposed to hypobaric hypoxia, which induces a compensatory increase in heart rate, cardiac output, and myocardial contractility to maintain oxygen homeostasis. Urban children, who are frequently subjected to pollution, chronic noise, limited physical activity, and psychosocial tension, tend to exhibit elevated blood pressure and a predominance of sympathetic nervous system activity. In contrast, rural environments, characterized by cleaner air, natural physical activity, and lower stress levels, usually promote stable cardiovascular adaptation with optimal autonomic balance.

Numerous studies have shown that disturbances in the adaptive mechanisms of the cardiovascular system during childhood may contribute to the early formation of risk factors for hypertension, metabolic syndrome, and other chronic cardiovascular diseases in adulthood. Therefore, the functional assessment of cardiovascular parameters in children living under diverse adaptation conditions has both scientific and preventive importance. Understanding how different environmental contexts shape cardiovascular regulation allows for the early detection of maladaptive changes and the design of region-specific health programs aimed at supporting optimal child development.

The aim of the present study was to investigate the clinical and functional characteristics of the cardiovascular system in children living in high-altitude, industrial urban, and rural environments, and to identify how environmental and psychosocial adaptation factors influence cardiovascular regulation and autonomic balance.

Materials and Methods

The study was conducted among 180 children aged 7–15 years, all of whom were healthy and not under any pharmacological treatment. Participants were divided into three equal groups based on their living conditions. The first group included children residing in high-altitude regions, characterized by low oxygen availability. The second group consisted of children living in industrial urban areas, exposed to increased psychosocial and environmental stress. The third group comprised children from rural areas with favorable ecological conditions, serving as the control group.

All participants underwent a comprehensive clinical and instrumental evaluation. Heart rate and arterial blood pressure were measured at rest using standard techniques. Electrocardiography was performed to analyze rhythm and conduction parameters, while echocardiography provided data on cardiac output, myocardial contractility, and ejection fraction. Heart rate variability (HRV) was analyzed to assess the state of autonomic regulation and the balance between sympathetic and parasympathetic activity.

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The obtained data were processed statistically using SPSS 25.0 software. Mean values and standard deviations were calculated for each variable, and intergroup differences were evaluated using Student's t-test and one-way ANOVA. Correlation analysis was applied to identify relationships between adaptation factors and cardiovascular parameters. Statistical significance was considered at $p < 0.05$.

Results

The study identified clear and statistically significant differences in cardiovascular function among children living in different environmental conditions. Children residing at high altitudes exhibited an increased resting heart rate averaging 92.4 ± 6.3 beats per minute, compared with 83.8 ± 5.1 in rural children. This reflected a compensatory increase in cardiac output to counteract hypoxic conditions. The ejection fraction was also slightly elevated in high-altitude children (71.2 ± 3.1%) compared with the control group (68.5 ± 2.9%), confirming a state of functional myocardial hyperactivity.

Urban children showed a moderate rise in heart rate and a notable increase in systolic blood pressure (114.5 ± 7.2 mmHg) compared with rural children (106.3 ± 6.4 mmHg). Electrocardiographic findings in the urban group more frequently revealed sinus tachycardia and nonspecific ST-T changes, while heart rate variability analysis demonstrated reduced parasympathetic modulation and a predominance of sympathetic activity. These results indicate that long-term psychosocial and environmental stress leads to functional tension in autonomic regulation.

Children from rural areas displayed optimal cardiovascular performance, with normal heart rate, stable blood pressure, and balanced HRV indicators. Their results represented the most physiologically favorable adaptation profile, characterized by efficient regulation and high autonomic flexibility.

Discussion

The findings of this study emphasize that adaptation conditions have a direct and measurable effect on cardiovascular regulation in childhood. The physiological responses observed in high-altitude children correspond to the body's natural compensatory mechanisms under conditions of decreased oxygen tension. Increased heart rate and myocardial contractility are essential to maintain oxygen delivery to tissues; however, persistent overactivation may lead to functional strain if prolonged.

In urban children, chronic exposure to psychosocial stress, environmental pollutants, and reduced physical activity results in altered autonomic regulation, characterized by sympathetic predominance and lower heart rate variability. Such a regulatory imbalance reflects an early stage of maladaptation that can evolve into preclinical cardiovascular dysfunction. In contrast, rural children living in stable ecological and emotional environments demonstrate balanced autonomic control and optimal hemodynamic parameters, which indicate efficient adaptation and cardiovascular stability.

These findings support the concept that adaptation is not merely a passive response but an active and energy-dependent process involving complex regulatory interactions. Monitoring cardiovascular function in children from different environments allows for the early detection of maladaptive patterns and helps to guide preventive interventions, including physical training, stress management, and ecological health promotion.

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Conclusion

Children living under different adaptation conditions exhibit distinct clinical and functional profiles of the cardiovascular system. Those living in mountainous and industrial urban environments show elevated heart rate, increased myocardial contractility, and signs of sympathetic dominance, while rural children demonstrate balanced hemodynamics and autonomic regulation. Environmental, psychosocial, and physiological factors collectively determine the adaptive capacity of the cardiovascular system during childhood. Regular functional monitoring and early preventive measures are essential to ensure effective adaptation and reduce the risk of future cardiovascular disorders in pediatric populations.

The results of the present study clearly demonstrate that the cardiovascular system of children is closely dependent on environmental and psychosocial adaptation factors. Differences in heart rate, blood pressure, myocardial contractility, and heart rate variability among the examined groups confirm that the process of adaptation in childhood is highly dynamic and context-sensitive. The organism of a growing child, with its still-maturing autonomic and endocrine regulation systems, reacts to external conditions by developing specific compensatory strategies that ensure survival and functional balance. However, when these adaptation mechanisms are overburdened or chronically activated, functional strain may arise, which in turn can predispose to early cardiovascular dysfunctions.

Children living at high altitudes demonstrated physiological mechanisms of compensation aimed at maintaining oxygen supply in hypoxic conditions. This was expressed by an elevated heart rate, increased ejection fraction, and enhanced myocardial contractility. These changes are adaptive and, within physiological limits, beneficial for maintaining systemic oxygen transport. Nevertheless, prolonged exposure to hypoxia may contribute to energy imbalance in myocardial cells and can increase the risk of structural or metabolic remodeling if no adequate compensatory rest occurs.

Children from industrial urban environments exhibited a different adaptation model dominated by neurogenic and psychosocial stress. The data suggest that persistent exposure to noise, environmental pollution, and emotional overload contributes to the hyperactivation of the sympathetic nervous system and a reduction in parasympathetic influence. The reduction of heart rate variability and elevated systolic pressure indicate the presence of subclinical maladaptation, which may progress to sustained functional hypertension or stress-related cardiac alterations if uncorrected. These findings highlight the importance of regular cardiovascular screening, particularly in children living in urbanized regions, where chronic stress and reduced physical activity are prevalent.

In contrast, rural children, who represent the control model of favorable ecological and social adaptation, displayed balanced hemodynamic and autonomic parameters. Their cardiovascular systems demonstrated stability, efficiency, and high adaptive flexibility. The harmonious relationship between sympathetic and parasympathetic regulation indicates optimal physiological adaptation and reflects the protective effect of an environment with low stress levels, natural physical activity, and cleaner air. This confirms that ecological and psychosocial well-being serve as natural modulators of cardiovascular health in childhood.

The broader implication of these findings lies in their preventive and public health significance. Early identification of adaptive strain in the cardiovascular system allows for timely intervention before pathological changes develop. Schools and primary healthcare providers, particularly in urban and high-altitude regions, should integrate regular cardiovascular assessments—including

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heart rate variability analysis, blood pressure monitoring, and physical fitness evaluation—into pediatric screening programs. Such initiatives can provide valuable data for designing individualized health programs that enhance children's adaptive potential.

Moreover, public health strategies should prioritize environmental and psychosocial improvement, including measures to reduce pollution, promote physical activity, and implement stress management programs in educational settings. The integration of ecological awareness, physical education, and psychological resilience training into school curricula may significantly improve adaptive outcomes.

In conclusion, the study confirms that adaptation is not a static process but a continuous interaction between the organism and its environment. The cardiovascular system serves as a key indicator of this interaction, reflecting both physiological balance and early signs of maladaptation. Ensuring favorable conditions for the development of children—through environmental stability, emotional security, and regular preventive supervision—is one of the most effective means to promote lifelong cardiovascular health. Strengthening these adaptive capacities in childhood will not only prevent functional cardiovascular disturbances but also lay the foundation for healthier adult populations in the future.

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