UDC 613.96:616.12-008.331.1-053.6 https://doi.org/10.33619/2414-2948/132/35

CONTEMPORARY ADOLESCENT LIFESTYLE AND CARDIOVASCULAR HEALTH: THE INTERRELATIONSHIP OF BEHAVIORAL AND DIGITAL FACTORS

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СОВРЕМЕННЫЙ ОБРАЗ ЖИЗНИ ПОДРОСТКОВ И СОСТОЯНИЕ ЗДОРОВЬЯ СЕРДЕЧНО-СОСУДИСТОЙ СИСТЕМЫ: ВЗАИМОСВЯЗЬ ПОВЕДЕНЧЕСКИХ И ЦИФРОВЫХ ФАКТОРОВ

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Abstract. Hypertension in adolescents has become an increasing global health concern, with rising prevalence associated with obesity, unhealthy dietary patterns, insufficient physical activity, prolonged sedentary behaviour, and changing digital lifestyles. Early elevation of blood pressure during adolescence may contribute to persistent cardiovascular dysfunction and increase the risk of hypertension and cardiovascular disease later in life. Although individual lifestyle factors have been extensively studied, the combined influence of behavioural, metabolic, and digital environmental factors remains insufficiently integrated. This narrative review examines the relationships between dietary patterns, physical activity, sedentary behaviour, sleep disruption, psychological stress, and emerging digital technology exposure in relation to blood pressure regulation among adolescents. The review aims to evaluate how these interconnected lifestyle factors contribute to cardiovascular risk and identify potential pathways for early prevention. Current evidence indicates that adolescent blood pressure is influenced by multiple interacting pathways rather than a single behavioural factor. Poor dietary quality, reduced physical activity, obesity, inadequate sleep, and prolonged digital exposure may contribute to cardiovascular dysfunction through mechanisms including sympathetic nervous system activation, chronic inflammation, endothelial impairment, insulin resistance, and metabolic dysregulation. Traditional sedentary behaviours, such as television viewing, have evolved into more complex forms of digital engagement involving smartphones, social media, and online gaming, which may introduce additional cardiovascular challenges through cognitive stimulation, psychological stress, and sleep disruption. This review proposes that the modern adolescent lifestyle represents an emerging cardiovascular phenotype in which dietary imbalance, physical inactivity, digital exposure, sleep disruption, and psychological stress interact through shared physiological pathways. By integrating traditional lifestyle risk factors with the evolving impact of digital technologies, this review provides a broader framework for understanding adolescent hypertension and highlights the need for multidimensional prevention strategies.

Аннотация. Артериальная гипертензия у подростков стала одной из актуальных глобальных проблем здравоохранения, при этом её распространённость увеличивается и связана с ожирением, нездоровыми особенностями питания, недостаточной физической активностью, длительным малоподвижным образом жизни и изменениями в цифровом поведении. Раннее повышение артериального давления в подростковом возрасте может способствовать формированию стойких нарушений сердечно-сосудистой функции и увеличивать риск развития гипертензии и сердечно-сосудистых заболеваний в последующие периоды жизни. Несмотря на то, что отдельные факторы образа жизни широко изучались,

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Т. 12. №11 2026
https://doi.org/10.33619/2414-2948/132

совокупное влияние поведенческих, метаболических и цифровых факторов окружающей среды остаётся недостаточно комплексно изученным. Данный обзор литературы рассматривает взаимосвязи между особенностями питания, физической активностью, малоподвижным поведением, нарушениями сна, психологическим стрессом и воздействием современных цифровых технологий с точки зрения их влияния на регуляцию артериального давления у подростков. Цель обзора заключается в оценке того, каким образом взаимосвязанные факторы образа жизни способствуют развитию сердечно-сосудистого риска, а также в выявлении потенциальных путей ранней профилактики. Современные данные свидетельствуют о том, что уровень артериального давления у подростков определяется не одним отдельным поведенческим фактором, а сложным взаимодействием нескольких физиологических механизмов. Низкое качество питания, снижение физической активности, ожирение, недостаточная продолжительность сна и длительное использование цифровых устройств могут способствовать развитию сердечно-сосудистых нарушений через такие механизмы, как активация симпатической нервной системы, хроническое воспаление, нарушение функции эндотелия, инсулинорезистентность и метаболическая дисрегуляция. Традиционные формы малоподвижного поведения, такие как длительный просмотр телевизора, постепенно трансформировались в более сложные формы цифровой активности, включая использование смартфонов, социальных сетей и онлайн-игр. Эти виды активности могут создавать дополнительные сердечно-сосудистые риски за счёт усиленной когнитивной стимуляции, психологического стресса и нарушения режима сна. В данном обзоре предлагается рассматривать современный образ жизни подростков как формирующийся сердечно-сосудистый фенотип, при котором дисбаланс питания, недостаточная физическая активность, воздействие цифровых технологий, нарушения сна и психологический стресс взаимодействуют через общие физиологические пути. Объединяя традиционные факторы риска образа жизни с растущим влиянием цифровых технологий, данный обзор предлагает более широкую концептуальную модель для понимания подростковой гипертензии и подчёркивает необходимость разработки многоуровневых стратегий профилактики.

Ключевые слова: здоровье подростков; сердечно-сосудистое здоровье; артериальная гипертензия у подростков; цифровой образ жизни; поведенческие факторы риска.

Keywords: adolescent health; cardiovascular health; adolescent hypertension; digital lifestyle; behavioural risk factors.

Once considered predominantly a condition of adulthood, hypertension is increasingly recognized as a significant health challenge during adolescence, with rising prevalence worldwide. A systematic review and meta-analysis including more than 440,000 children from 21 countries reported that the prevalence of hypertension among children and adolescents nearly doubled between 2000 and 2020. The pooled prevalence was estimated at 4.28% based on office blood pressure measurements, while sustained hypertension reached 6.67% when combined diagnostic approaches were applied. Higher prevalence was observed in low- and middle-income countries compared with high-income regions, emphasizing significant global disparities. Moreover, excess body weight represents an important risk factor, with overweight and obesity substantially increasing the likelihood of hypertension during childhood [1-3].

This increasing trend is closely associated with changes in dietary patterns, physical activity levels, obesity prevalence, and sedentary behaviours [4].

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https://doi.org/10.33619/2414-2948/132

Physical inactivity remains one of the leading behavioural risk factors for non-communicable diseases, while childhood obesity has increased substantially over recent decades, contributing to the earlier emergence of cardiovascular risk factors [5; 6].

Blood pressure during adolescence is influenced by both genetic and environmental factors. Although genetic predisposition cannot be modified, lifestyle behaviours including diet quality, physical activity, body weight, sleep duration, and screen exposure provide important opportunities for prevention. Elevated blood pressure during adolescence is associated with increased risk of hypertension and cardiovascular disease later in life, emphasizing the importance of early intervention [7; 8].

Among modifiable factors, diet and physical activity remain the most extensively studied. Diets high in sodium, refined sugars, and ultra-processed foods are associated with increased blood pressure, whereas diets rich in fruits, vegetables, whole grains, and low-fat dairy products support vascular health. Regular physical activity improves cardiovascular function through enhanced endothelial function, improved insulin sensitivity, and reduced arterial stiffness [9-12].

The adolescent digital environment has also undergone major transformation. Unlike traditional sedentary behaviours, modern digital exposure may affect cardiovascular health through reduced physical activity, impaired sleep, psychological stress, and prolonged sympathetic nervous system activation. Since Sugiyama et al. (2007) identified television viewing as an independent predictor of elevated systolic blood pressure, smartphones, tablets, social media, and online gaming have become increasingly important sources of screen exposure due to their interactive and continuous use patterns, particularly during evening hours [13].

Although previous studies have examined individual lifestyle factors, the combined influence of diet, physical activity, sedentary behaviour, and digital exposure remains insufficiently integrated. This review synthesizes current evidence on lifestyle determinants of adolescent blood pressure while examining the emerging role of digital technologies as potential cardiovascular risk factors.

Diet, Physical Activity and Blood Pressure Regulation in Adolescents. Diet is one of the most important modifiable determinants of blood pressure during adolescence [14].

Nutritional intake influences cardiovascular health through several mechanisms, including sodium balance, vascular function, body weight regulation, insulin sensitivity, and systemic inflammation [15].

Adolescence is a particularly important period because eating habits established during these years often continue into adulthood [14].

Excessive sodium intake remains one of the most consistent dietary risk factors for hypertension. High sodium consumption increases blood volume and vascular resistance, leading to elevated blood pressure [16].

Individual responses to sodium restriction may vary, highlighting the importance of personalized dietary approaches [17].

Modern diets rely heavily on processed foods, fast food, packaged snacks, and sugar-sweetened beverages, making it difficult for many adolescents to remain within recommended sodium limits [18].

The adverse effects of sodium appear particularly pronounced among overweight adolescents and those with a family history of hypertension [19].

Conversely, diets rich in potassium, magnesium, calcium, dietary fibre, and antioxidants support healthy blood pressure regulation. Higher dietary potassium intake and a more favourable sodium-to-potassium ratio have been associated with lower cardiovascular risk, whereas excessive sodium intake has been linked to adverse cardiovascular outcomes. Fruits, vegetables, legumes, whole grains, and low-fat dairy products improve endothelial function and help counteract some of

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https://doi.org/10.33619/2414-2948/132

the harmful effects of excessive sodium. The Dietary Approaches to Stop Hypertension (DASH) diet has consistently demonstrated beneficial effects on blood pressure in adults and is increasingly recommended for adolescents at elevated cardiovascular risk. By emphasising minimally processed foods and reducing sodium intake, the DASH dietary pattern provides a practical framework for long-term cardiovascular prevention [20; 21].

Adapted conceptually from evidence supporting early cardiovascular prevention strategies [22].

Body weight represents an important link between diet and hypertension. Obesity contributes to elevated blood pressure through activation of the sympathetic nervous system, increased inflammation, insulin resistance, and stimulation of the renin–angiotensin–aldosterone system. Nevertheless, contemporary evidence suggests that improving dietary quality and increasing physical activity may reduce cardiovascular risk even before substantial weight loss occurs, reinforcing the importance of healthy lifestyle behaviours rather than focusing solely on body mass index [23].

Regular physical activity is one of the most effective non-pharmacological interventions for preventing and managing hypertension during adolescence [21; 24].

Exercise improves cardiovascular function through several complementary physiological mechanisms, including enhanced endothelial function, increased nitric oxide production, improved insulin sensitivity, reduced arterial stiffness, and lower sympathetic nervous system activity. Together, these adaptations improve vascular health and reduce both systolic and diastolic blood pressure (Figure 1).

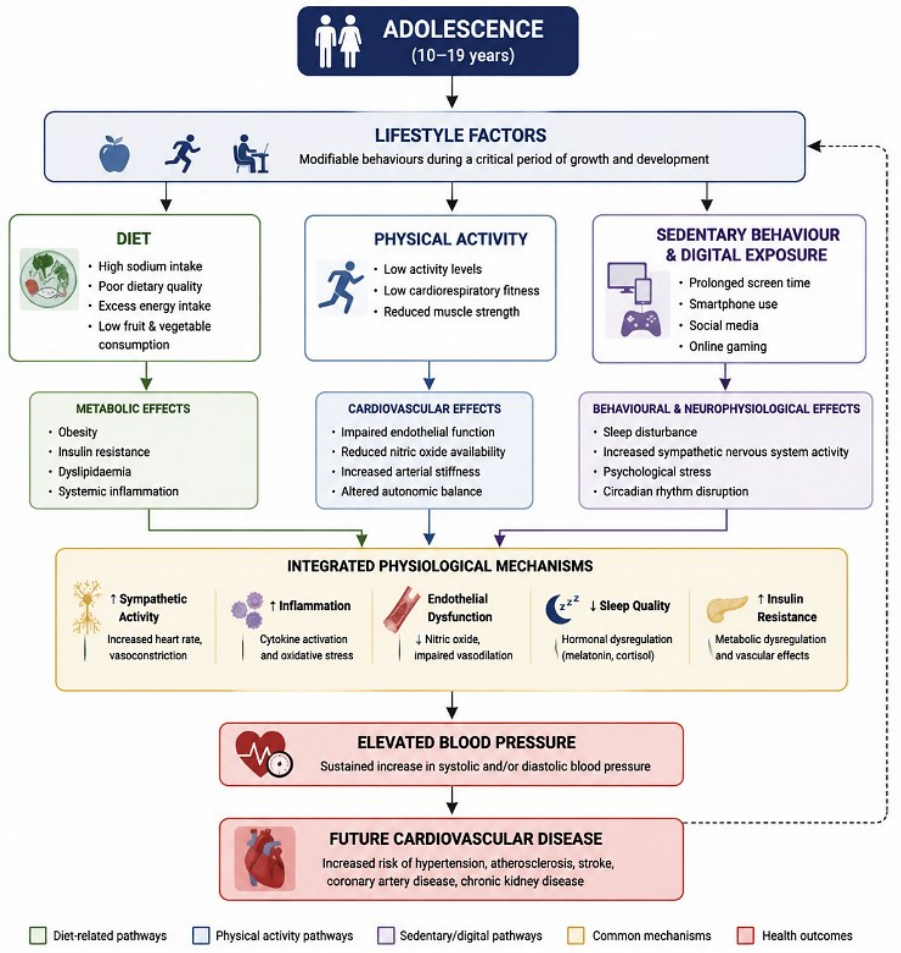


Figure 1. Conceptual framework illustrating proposed interactions between lifestyle factors and cardiovascular pathways; arrows represent associations supported by current evidence rather than confirmed causal relationships

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https://doi.org/10.33619/2414-2948/132

The World Health Organization (WHO) recommends that children and adolescents accumulate at least 60 minutes of moderate-to-vigorous physical activity daily, incorporating vigorous aerobic activities and muscle-strengthening exercises on at least three days per week. Unfortunately, international surveillance studies indicate that more than 80% of adolescents fail to achieve these recommendations, particularly among older teenagers and girls [6].

Aerobic exercise, including brisk walking, cycling, swimming, football, basketball, and running, has demonstrated the strongest evidence for blood pressure reduction [25].

Regular participation strengthens the heart, allowing it to pump blood more efficiently while reducing resting heart rate and peripheral vascular resistance. Resistance training also contributes positively when appropriately supervised, improving muscular strength, metabolic health, and insulin sensitivity without increasing long-term blood pressure. Beyond its direct cardiovascular effects, exercise also reduces several secondary risk factors associated with hypertension [26].

Physically active adolescents generally have healthier body composition, improved sleep quality, lower stress levels, and reduced symptoms of anxiety and depression. These indirect benefits further contribute to improved autonomic regulation and healthier blood pressure profiles (Table).

Table

LIFESTYLE FACTORS, BIOLOGICAL MECHANISMS, AND CARDIOVASCULAR CONSEQUENCES ASSOCIATED WITH ADOLESCENT BLOOD PRESSURE REGULATION

Lifestyle factor	*Biological mechanism*	*Molecular mediator*	*Cardiovascular consequence*
High sodium diet	Fluid retention	RAAS activation	↑ BP
Sedentary behaviour	Endothelial dysfunction	Nitric oxide reduction	↑ vascular resistance
Smartphone use	Sleep disruption	Melatonin/cortisol imbalance	↑ BP
Obesity	Chronic inflammation	Cytokines	↑ cardiovascular risk

Recent studies suggest that even relatively small increases in daily activity, such as active commuting to school, recreational sports, or replacing sedentary leisure time with outdoor activities, may produce measurable cardiovascular benefits. Consequently, encouraging lifelong exercise habits during adolescence may represent one of the most cost-effective strategies for reducing the future burden of cardiovascular disease.

Sedentary Behaviour: From Television to Smartphones. While increasing physical activity remains essential, modern research recognises that reducing sedentary behaviour has become an increasingly important public health priority. Sedentary behaviour refers to waking activities performed while sitting or reclining that require very little energy expenditure. Traditionally, television viewing was the principal source of sedentary recreation among adolescents. However, smartphones, tablets, streaming platforms, online gaming, and social media have fundamentally transformed how young people spend their leisure time. Recent evidence suggests that different forms of sedentary behaviour, including screen-based activities, are associated with adverse cardiovascular outcomes and may contribute to elevated blood pressure among adolescents [27].

The study by Sugiyama et al. (2007) was among the first to demonstrate an independent relationship between sedentary behaviour and blood pressure in adolescents [13].

Using data from the U.S. National Health and Nutrition Examination Survey (NHANES), the investigators reported that each additional hour of sedentary activity was associated with an increase of approximately 0.2 mm Hg in systolic blood pressure", while television viewing alone was associated with an increase of approximately 0.5 mm Hg per hour among adolescents aged 12–15 years. Importantly, these associations remained significant even after adjusting for body mass index,

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https://doi.org/10.33619/2414-2948/132

suggesting that prolonged sitting itself contributes to elevated blood pressure independently of obesity [13].

Although the increase in blood pressure observed in the study was modest, its significance lies in the cumulative effect across populations. Even small increases in average systolic blood pressure can substantially increase the long-term risk of stroke and cardiovascular disease [28].

Even small increases in average systolic blood pressure can substantially increase the long-term incidence of hypertension, stroke, and cardiovascular disease. Since the publication of this landmark study, patterns of sedentary behaviour have changed dramatically. Television is no longer the dominant form of screen-based entertainment. Adolescents now spend considerably more time using smartphones and tablets, frequently engaging with multiple devices simultaneously. Consequently, the cardiovascular implications of sedentary behaviour have become more complex.

Television Versus Smartphones: A New Cardiovascular Challenge. Television and smartphones share one important characteristic: both encourage prolonged sitting. However, smartphones differ from television in several important respects that may amplify their influence on cardiovascular health. Television viewing is generally passive and occurs during defined periods. Smartphone use, by contrast, is highly interactive, portable, and continuous throughout the day. Modern adolescents use smartphones not only for entertainment but also for communication, education, gaming, shopping, and social networking (Figure 2). Frequent notifications, messaging, and social media interactions create repeated episodes of cognitive and emotional stimulation that rarely occur during passive television viewing [29].

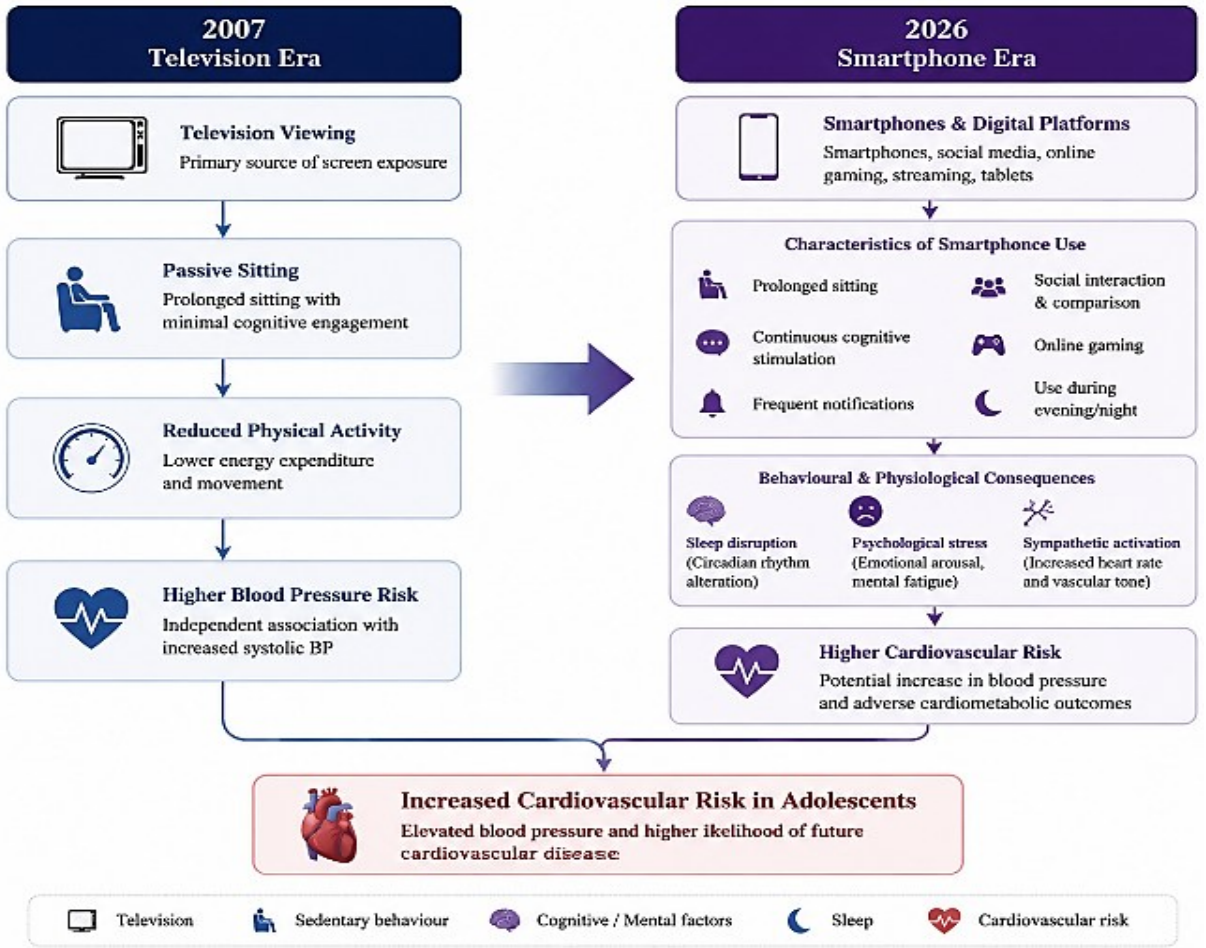


Figure 2. Transition of sedentary behaviour from television to smartphones and associated cardiovascular risk pathways in adolescents

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https://doi.org/10.33619/2414-2948/132

This distinction is clinically relevant because psychological stimulation activates the sympathetic nervous system, increasing heart rate, vascular resistance, and blood pressure. Studies conducted during the past decade suggest that prolonged smartphone use is associated with elevated resting heart rate, reduced heart rate variability, poorer sleep quality, and increased symptoms of anxiety. Although causality has not yet been conclusively established, these findings indicate that smartphones may influence blood pressure through mechanisms extending beyond physical inactivity alone. Another important difference concerns behavioural patterns. Television viewing often ends when a programme finishes, whereas smartphones encourage frequent, repeated checking throughout the day. This persistent engagement reduces opportunities for physical movement and mental recovery while maintaining a state of continuous physiological arousal. Consequently, smartphones may represent a more significant cardiovascular risk factor than traditional television viewing.

Sleep, Psychological Stress and Blood Pressure. One of the most important developments in recent hypertension research has been the recognition that sleep quality mediates many of the cardiovascular effects associated with digital technology. Healthy sleep plays a crucial role in regulating blood pressure because normal physiological processes produce a decline in blood pressure during the night, allowing the cardiovascular system to recover. Adolescents who consistently obtain insufficient or poor-quality sleep frequently exhibit higher daytime blood pressure and greater sympathetic nervous system activity [30].

Smartphone use during the evening interferes with healthy sleep in several ways [31; 32].

Blue light emitted from digital screens suppresses melatonin production, delaying sleep onset and disrupting circadian rhythms [33]. In addition, emotionally engaging activities such as social media, online gaming, and instant messaging maintain cognitive alertness when the body should be preparing for sleep [34].

Reduced sleep duration has been associated with increased cortisol secretion, endothelial dysfunction, impaired glucose metabolism, and higher risks of obesity, all of which contribute to elevated blood pressure. Recent sensor-based evidence from the ABCD Study demonstrated that greater smartphone use among adolescents was associated with reduced physical activity, increased sedentary time, delayed sleep onset, and reduced sleep duration [35].

Importantly, these behavioural risk factors rarely occur in isolation. Adolescents who spend prolonged periods using smartphones often engage in less physical activity, consume less healthy diets, and obtain insufficient sleep [36].

Consequently, hypertension should be viewed as the result of multiple interacting lifestyle behaviours rather than a single exposure. Current evidence therefore supports comprehensive prevention strategies that simultaneously promote healthy eating, regular exercise, adequate sleep, stress management, and responsible use of digital technologies.

Discussion

The evidence reviewed demonstrates that elevated blood pressure in adolescents results from complex interactions between multiple lifestyle-related factors rather than a single behavioural cause. Poor diet, insufficient physical activity, obesity, sedentary behaviour, inadequate sleep, and psychological stress frequently occur together and may amplify their effects on cardiovascular regulation. Therefore, adolescent hypertension should be viewed as the outcome of interconnected behavioural, metabolic, and physiological processes. Although genetic predisposition contributes to hypertension risk, lifestyle modification provides important opportunities for prevention. The mechanisms linking lifestyle behaviours to blood pressure involve multiple pathways, including metabolic dysfunction, inflammation, endothelial impairment, insulin resistance, and increased sympathetic nervous system activity. These processes may contribute to early cardiovascular changes

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https://doi.org/10.33619/2414-2948/132

that persist into adulthood. The landmark study by Sugiyama et al. (2007) identified sedentary behaviour, particularly television viewing, as an independent predictor of increased systolic blood pressure in adolescents. This finding shifted attention beyond obesity alone and highlighted the cardiovascular consequences of prolonged sitting. Although the observed increase in blood pressure was modest, small population-level changes may contribute to substantial long-term cardiovascular disease burden [13].

Since 2007, patterns of sedentary behaviour have changed considerably, with smartphones, tablets, streaming platforms, online gaming, and social media replacing television as major sources of screen exposure. Unlike passive television viewing, smartphone use combines prolonged sitting with continuous cognitive engagement, emotional stimulation, social interaction, and frequent notifications. These characteristics may contribute to additional pathways involving sympathetic activation, psychological stress, and sleep disruption. Consequently, smartphone exposure represents an emerging cardiovascular challenge among adolescents. The impact of digital technology depends not only on total screen time but also on timing, purpose, and behavioural context. Late-night smartphone use, social media engagement, and gaming may have different physiological consequences compared with educational use. Future studies should therefore examine specific patterns of digital behaviour rather than treating screen exposure as a single risk factor.

Despite growing evidence, several limitations remain. A substantial proportion of current studies are observational and can demonstrate associations but cannot establish causality. Although smartphone use has been linked to reduced physical activity, poorer sleep, and increased psychological stress, a direct causal relationship with hypertension has not yet been fully confirmed. In addition, many studies rely on self-reported measures of diet, physical activity, and screen exposure, which may introduce measurement bias.

Future research should prioritize long-term adolescent cohort studies using objective measurements, such as wearable activity monitors, digital usage tracking, and continuous blood pressure monitoring. These studies should investigate how diet, physical activity, digital exposure, sleep, and psychological stress interact over time to influence cardiovascular health. Understanding these relationships will be essential for developing personalized prevention strategies to reduce the future burden of adolescent hypertension.

Conclusion

Hypertension among adolescents has emerged as an important global public health challenge. Although genetic predisposition contributes to cardiovascular risk, lifestyle behaviours represent major modifiable determinants of blood pressure during adolescence. Dietary quality, physical activity, body weight, sleep patterns, psychological stress, and sedentary behaviour interact through multiple physiological pathways to influence cardiovascular health. An integrated lifestyle approach is essential for preventing elevated blood pressure during adolescence. Healthy dietary patterns, such as DASH-style diets rich in fruits, vegetables, whole grains, legumes, and low-fat dairy products, together with regular physical activity, reduced sedentary behaviour, and adequate sleep, may contribute to improved cardiovascular outcomes. Modern digital technologies represent an emerging factor in adolescent cardiovascular health. Their effects are mediated through behavioural pathways, including reduced physical activity, sleep disruption, and psychological stress. However, the impact of digital technology depends on usage patterns, duration, and context rather than technology exposure alone. Future prevention strategies should combine healthy nutrition, regular exercise, sufficient sleep, stress management, and responsible digital technology use. Emerging tools, including wearable health technologies and artificial intelligence-based monitoring systems, may support personalised cardiovascular prevention, although further research is needed to establish their

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long-term effectiveness. Reducing the future burden of adolescent hypertension requires coordinated efforts among healthcare professionals, families, schools, communities, and policymakers. Promoting healthy behaviours during adolescence may provide long-term benefits for cardiovascular health across the lifespan.

Acknowledgements. I would like to sincerely express my deepest gratitude to Associate Professor Ulduz Gurbanova from the Institute of Molecular Biology, Ministry of Science and Education of the Republic of Azerbaijan, for all her support and guidance and for believing in me.

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Поступила в редакцию
09.09.2026 г.

Принята к публикации
16.09.2026 г.

Ссылка для цитирования:

Afandiyeva A. Contemporary Adolescent Lifestyle and Cardiovascular Health: The Interrelationship of Behavioral and Digital Factors // Бюллетень науки и практики. 2026. Т. 12. №11. С. 327-340. https://doi.org/10.33619/2414-2948/132/35

Cite as (APA):

Afandiyeva, A. (2026). Contemporary Adolescent Lifestyle and Cardiovascular Health: The Interrelationship of Behavioral and Digital Factors. *Bulletin of Science and Practice, 12*(11), 327-340. https://doi.org/10.33619/2414-2948/132/35

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