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Influence of body mass index on blood pressure in children and adolescents: a cross-sectional school-based study

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Abstract

Background In recent years, the incidence of hypertension in children and adolescents has gradually increased, becoming a public health issue of global concern. Current evidence has established a correlation between body mass index (BMI) and blood pressure in adult populations, whereas the nature of this association remains inconclusive in pediatric population. Therefore, in this study, we explored the association between BMI and blood pressure in children and adolescents.

Methods This cross-sectional study included 8,157 children and adolescents aged 6–17 years in Zhangwu County, Liaoning Province. From February to September 2022, we collected the hypertension risk factor questionnaire and completed anthropometric measurements and blood pressure measurements. BMI was calculated as (weight (kg)/height $(m)^2$), and categorized into four groups: underweight, normal weight, overweight and obesity based on percentile thresholds. Blood pressure was classified into normal blood pressure, prehypertension, stage one hypertension, and stage two hypertension in accordance with the definition criteria of the American Academy of Pediatrics. One-way analysis of variance (ANOVA), Kruskal-Wallis test, chi-square test, and ordinal logistic regression analysis were all performed to explore the correlation between BMI and blood pressure. SPSS 27.0 statistical software and SPSS AU were used for statistical analysis.

Results The overall prevalence of hypertension was 20.4%, with a prevalence of 19.9% in boys and 20.8% in girls. The blood pressure categories increased with the elevation of BMI categories (all $P < 0.001$). A significant association between BMI categories and blood pressure categories was observed in both the unadjusted model (prehypertension: $OR = 5.01$, 95%CI: 4.52–5.55; stage one hypertension: $OR = 10.09$, 95%CI: 9.03–11.26; stage two hypertension: $OR = 108.54$, 95%CI: 91.05-129.38; all $P < 0.001$) and the model adjusted for age and smoking (prehypertension: $OR = 6.05$, 95%CI: 4.91–7.46; stage one hypertension: $OR = 12.20$, 95%CI: 9.86–15.08; stage two hypertension: $OR = 131.39$, 95%CI: 102.02–169.20; all $P < 0.001$).

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Conclusion Overweight and obesity may represent a potential risk factor for high blood pressure in the pediatric population. These findings underscore the importance of early weight management to mitigate the long-term risk of cardiovascular diseases.

Keywords Body mass index, Hypertension, Pediatric population, Risk factor

Introduction

Hypertension is a leading cause of cardiovascular disease and premature death worldwide [1]. Notably, its prevalence is increasing among children and adolescents [2, 3], which serves as an early indicator of future cardiovascular risk. Some studies have shown that childhood hypertension can cause early structural and functional damage to target organs such as the heart and blood vessels, increasing the likelihood of cardiovascular disease and reducing healthy life-years in adulthood [4–6].

Zhangwu County is located in the northernmost part of Liaoning Province, with a fragile ecological environment and challenging natural conditions. According to a large-scale epidemiological survey reported in 2003, the prevalence of hypertension among individuals under 30 years old was 12.2%, significantly higher than the national average during the same period [7]. However, elevated blood pressure in childhood is not necessarily permanent, and reversal before adulthood can substantially lower future cardiovascular risk [8].

Body mass index (BMI) is a widely used indicator for assessing obesity, with higher values generally associated with increased health risks and mortality rates [9, 10]. Although some studies show that controlling elevated BMI levels can reduce the incidence of hypertension in children [11, 12], other studies report that there is almost no correlation between BMI and hypertension, and even put forward the "obesity paradox", that is, higher BMI levels may not necessarily increase the risk of all-cause death in adults [13, 14].

Although some studies have explored the relationship between BMI and hypertension in children and adolescents, the generalizability of existing findings regarding BMI and hypertension in children and adolescents of different age groups, genders, and cultural backgrounds is still unclear. Given the increasing prevalence of early-onset hypertension in areas such as Zhangwu County, and the fact that childhood hypertension can be reversed before adulthood, it is crucial to identify modifiable risk factors such as BMI. Therefore, this study aims to explore the association between BMI and blood pressure in children and adolescents. The findings may provide scientific basis for targeted weight management and early prevention of high blood pressure to reduce long-term cardiovascular risk.

Methods

Study population

This study used stratified random cluster sampling to recruit all students aged 6–17 years from four schools in Zhangwu County, Liaoning Province, namely Dade Nine-year School, Houxinqiu Nine-year School, Wufeng Nine-year School, and Yucai Nine-year School. Among the initial 8,511 participants, 187 were excluded due to incomplete questionnaires. Subsequently, 167 participants were removed from the study as they were unable to complete all measurements of blood pressure, height, and weight. Consequently, a total of 8,157 participants were included in the study. The selection process of the study participants is shown in Fig. 1.

Anthropometric measurements and blood pressure measurements of the selected participants were collected by 6 trained registered clinicians and nurses after 7 days of professional training. Our screening program was approved by the Zhangwu County Government, Zhangwu County Health Bureau, Zhangwu County Education Bureau and Zhangwu County Center for Disease Prevention and Control. The "Prevention and Treatment of Hypertension in Children and Adolescents in Zhangwu County" has been listed as a formal proposal by the People's Congress of Zhangwu County. All the local schools involved were also coordinated, and a questionnaire survey was conducted after consent obtained from each student' primary guardian. Only with the consent of the students can the guardians provided written consent on their behalf. The information provided in the questionnaire is strictly confidential and strictly adheres to the personal information protection system.

Questionnaire data

A structured questionnaire was designed to investigate the potential risk factors for hypertension in children and adolescents. The questionnaire mainly encompasses two sections: basic demographic information and lifestyle habits. The basic demographic information collects data on age, gender, race, and student source. Lifestyle habits mainly assess habits such as smoking and drinking. The personnel used the network background system to monitor the completion status of the questionnaire in real-time. After collecting the questionnaire, the project team personnels were responsible for reviewing it, eliminating invalid questionnaires, and ensuring the reliability of the questionnaire.

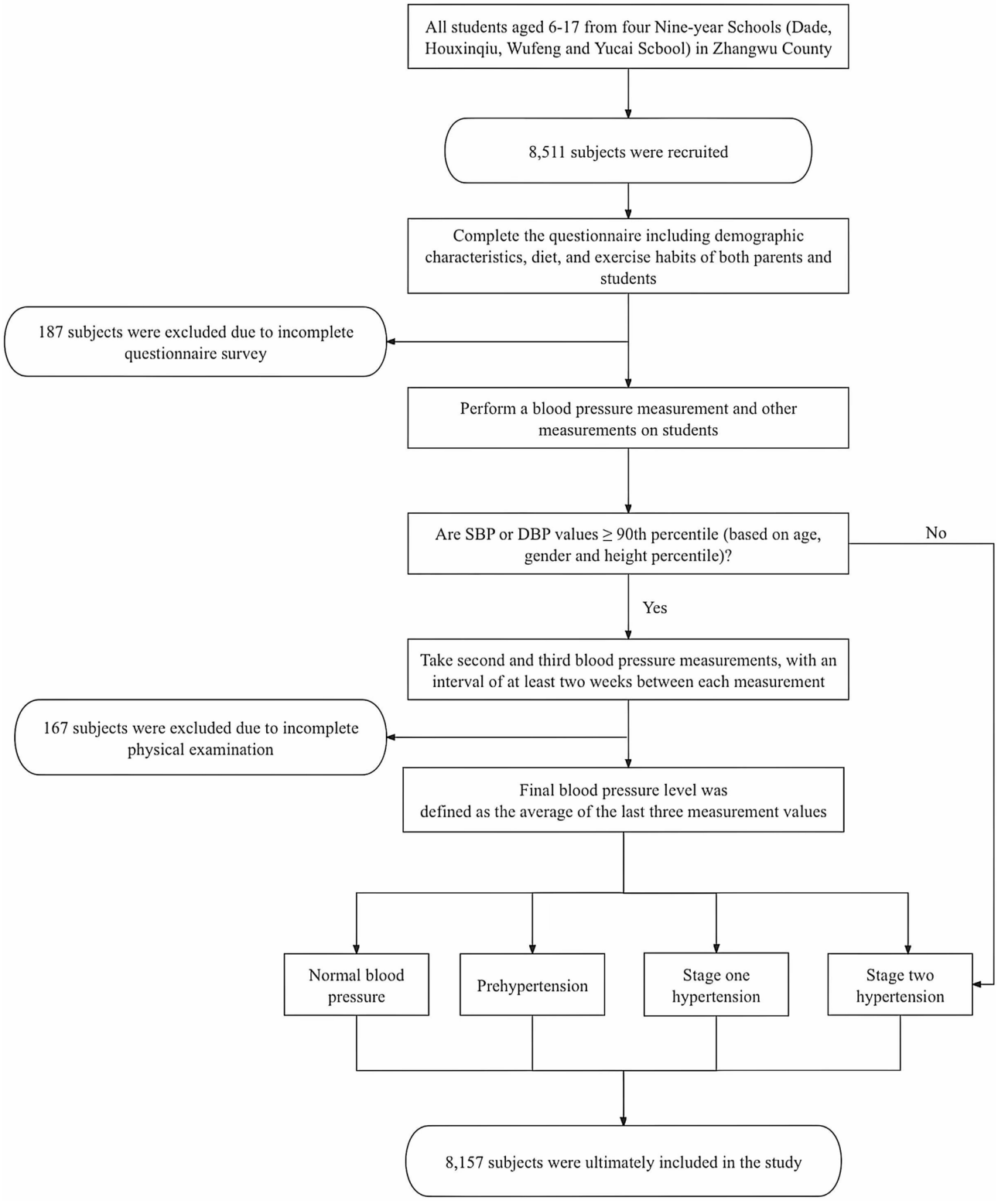

Fig. 1 Flow chart of the participants selection process

Body composition

Body weight and height were measured to an accuracy of 0.1 kg and 0.1 cm, respectively. All measurements were conducted using calibrated equipment. Participants were instructed to wear light clothing and remove their shoes prior to measurement [15]. Measurements were conducted in duplicate by trained staff. When the difference between the two measurements exceeded 0.5 kg for weight or 0.5 cm for height, a third measurement was taken to ensure accuracy.

BMI was calculated as (weight (kg)/height $(m)^2$). BMI classification for children and adolescents was defined as follows: underweight (BMI percentile ≤ 4.9), normal weight (BMI percentile 5.0-84.9), overweight (BMI percentile 85.0-94.9) and obesity (BMI percentile ≥ 95.0) [16].

Cardiovascular measurements

Blood pressure was measured using an Omron Electronic Blood Pressure Monitor (HEM-8613). Participants were instructed to avoid strenuous activity and emptied their bladder at least 30 min prior to measurement, then remained seated quietly for 3–5 min to achieve physiological stability [17]. Blood pressure was measured in triplicate at 2-minute intervals, and the average was recorded as the initial blood pressure. For participants whose mean systolic blood pressure (SBP) or diastolic blood pressure (DBP) exceeded the 90th percentile for their age, gender, and height were re-measured at least 2 weeks later. The third blood pressure measurement was then conducted 2 weeks after the second measurement. The final blood pressure value was calculated as the average of the three sets of measurements.

For children under 13 years old, normal blood pressure was characterized by SBP and DBP below the 90th percentile (on the basis of age, gender, and height). Prehypertension was defined as SBP and/or DBP ≥ 90th percentile and < 95th percentile or blood pressure ≥ 120/80 mm Hg to < 95th percentile, whichever was lower. Stage one hypertension was defined as SBP and/or DBP ranging from the 95th percentile to 12 mmHg above it, or within the range of 130/80 to 139/89 mmHg, whichever was lower. Stage two hypertension was identified when SBP and/or DBP exceeds 12 mmHg above the 95th percentile or reaches ≥ 140/90 mmHg [18]. For adolescents aged 13 years and above, normal blood pressure was less than 120/80 mmHg. Prehypertension was defined as a SBP of 120–129 mmHg with a DBP of less than 80 mmHg. Stage one hypertension was characterized by a SBP of 130–139 mmHg and a DBP of 80–89 mmHg. Stage two hypertension was defined when the blood pressure was 140/90 mmHg or higher [19].

Statistical analysis

To prevent the disclosure of personal information of participants, the project used the "Hypertension Risk Factor Investigation Software", which was specially developed by the Software School of Northeastern University. The normally distributed quantitative data were presented as the means ± standard deviation, and comparisons between groups were performed via one-way analysis of variance (ANOVA). Non-normally distributed data were presented as the median (interquartile interval), and the Kruskal-Wallis test was used for comparisons between groups. Qualitative data were described by *n* (%), and the chi-square test was used for comparisons between groups. Subgroup analysis was conducted by gender (boys or girls) and age (6–12 years or 13–17 years). Ordinal logistic regression analysis was used to analyze the influencing factors, and the odds ratio (*OR*) along with the 95% confidence interval (*CI*) was calculated. $P < 0.05$ was considered statistically significant. Statistical analyses were performed with IBM® SPSS® Statistics, Version 27.0 (IBM Corporation, Armonk, New York).

Results

Baseline characteristics of participants are presented in Table 1. Among the 8,157 participants, 1,663 (20.4%) had hypertension, including 1,461 (17.9%) with stage one hypertension and 202 (2.5%) with stage two hypertension. The prevalence of hypertension was 19.9% (788/3,955) in boys and 20.8% (875/4,202) in girls. The participants had a mean age of 10.8 ± 2.5 years. The average BMI levels of the entire sample was 19.4 ± 4.7 kg/m^2. Significant intergroup differences were observed in age ($P = 0.017$), smoking status ($P = 0.013$) and BMI levels ($P < 0.001$).

The association between BMI categories and blood pressure categories are shown in Table 2. The distribution of BMI categories varied among different blood pressure categories ($P < 0.001$). Further, the prevalence of overweight and obesity was significantly higher among individuals with stage two hypertension than in other blood pressure categories. In the subgroup analysis, studies were categorized by gender and age. The results of the subgroup analysis are shown in Table S1 and Table S2. In the subgroup analysis by gender, significant associations between BMI categories and blood pressure categories were observed in both boys and girls (boys: $P < 0.001$; girls: $P < 0.001$). In the subgroup analysis by age, significant associations between BMI categories and blood pressure categories were found in both 6–12 years and 13–17 years subgroups (6–12 years: $P < 0.001$; 13–17 years: $P < 0.001$).

The association between BMI categories and SBP and DBP is shown Table 3. SBP and DBP values exhibited a consistent upward trend, increasing with the elevation of BMI categories. Specifically, underweight individuals had

Table 1 Characteristics of different blood pressure groups

Variable	Total (*n* = 8157)	Normal blood pressure (*n* = 5432)	Prehypertension (*n* = 1062)	Stage one hypertension (*n* = 1461)	Stage two hypertension (*n* = 202)	F/χ^2	*P*
Age, y	10.8 ± 2.5	10.8 ± 2.5	10.8 ± 2.5	11.0 ± 2.6	10.9 ± 2.4	3.39	0.017
Boys, n (%)	3955 (48.5)	2664 (49.1)	503 (47.4)	687 (47.0)	101 (50.0)	2.68	0.449
Race, n (%)							
Han nationality	6134 (75.2)	4070 (74.9)	812 (76.4)	1104 (75.6)	148 (73.2)	5.71	0.768
Mongolian nationality	1110 (13.6)	748 (13.8)	130 (12.3)	203 (13.9)	29 (14.4)		
Man nationality	835 (10.2)	560 (10.3)	110 (10.3)	140 (9.6)	25 (12.4)		
Others	78 (1.1)	54 (1.0)	10 (1.0)	14 (0.9)	0		
Student source, n (%)							
City	3561 (43.4)	2372 (43.7)	470 (44.3)	601 (41.1)	98 (48.5)	5.67	0.129
Countryside	4616 (56.6)	3060 (56.3)	592 (55.7)	860 (58.9)	104 (51.5)		
Smoking, n (%)	68 (0.8)	50 (0.9)	14 (1.3)	3 (0.2)	1 (0.5)	10.77	0.013
Drinking, n (%)	71 (0.9)	44(0.9)	15 (1.4)	12 (0.8)	0 (0.0)	5.66	0.130
BMI, kg/m^2	19.4 ± 4.7	18.6 ± 4.1	20.5 ± 5.1	20.9 ± 5.0	25.1 ± 7.0	787.79	<0.001

BMI Body mass index

Table 2 Association between BMI categories and blood pressure categories

BMI categories	Blood pressure categories, n (%)				*H*	*P*
	Normal blood pressure	Prehyperhension	Stage one hypertension	Stage two hypertension		
Underweight	323 (5.9)	52 (4.9)	33 (2.3)	9 (4.5)	410.14	< 0.001
Normal weight	4549 (83.7)	789 (74.3)	1095 (74.9)	84 (41.6)		
Overweight	443 (8.2)	143 (13.5)	195 (13.3)	35 (17.3)		
Obesity	117 (2.2)	78 (7.3)	138 (9.4)	74 (36.6)		

BMI Body mass index

Table 3 Association between BMI categories and SBP and DBP

Blood pressure	Underweight	Normal weight	Overweight	Obesity	F/χ^2	*P*
DBP, mmHg	65.6 ± 7.8	68.2 ± 3.0	71.2 ± 8.1	73.6 ± 9.2	99.85	<0.001
SBP, mmHg	94.4 ± 9.0	104.7 ± 11.9	113.5 ± 12.2	124.2 ± 15.5	572.86	<0.001
High DBP and normal SBP, n (%)	11 (2.6)	257(3.9)	38 (4.7)	22 (5.4)	5.04	0.169
High SBP and normal DBP, n (%)	1 (0.2)	445 (6.8)	143 (17.5)	168 (41.3)	647.84	< 0.001
Either high DBP or high SBP, n (%)	18 (4.3)	950 (14.6)	254 (31.1)	256 (62.9)	751.82	< 0.001
Both high DBP and high SBP, n (%)	1 (0.2)	445 (7.1)	143 (19.2)	168 (49.3)	773.60	< 0.001

BMI Body mass index, *DBP* Diastolic blood pressure, *SBP* Systolic blood pressure, High DBP ≥ 90mmHg; High SBP ≥ 140mmHg

the lowest SBP levels at (94.4 ± 9.0) mmHg and DBP at (65.6 ± 7.8) mmHg. In contrast, obese participants demonstrated the highest SBP and DBP values, with means of (124.2 ± 15.5) mmHg and (73.6 ± 9.2) mmHg, respectively. Furthermore, it was observed that blood pressure categories increased with the elevation of BMI categories. This phenomenon was particularly found among participants with high SBP and normal DBP, as well as those who either had high DBP or high SBP alone, and both high DBP and high SBP (all $P < 0.001$).

Ordinal logistic regression models were conducted to explore the association between BMI categories and blood pressure categories. In the unadjusted model, a significant association was observed between BMI categories and blood pressure categories, indicating that higher BMI categories were significantly associated with increased odds of elevated blood pressure categories (prehypertension: $OR = 5.01$, 95%*CI*: 4.52–5.55; stage one hypertension: $OR = 10.09$, 95%*CI*: 9.03–11.26; stage two hypertension: $OR = 108.54$, 95%*CI*: 91.05-129.38, all $P < 0.001$). In the model adjusted for age and smoking status, the association was still observed (prehypertension: $OR = 6.05$, 95%*CI*: 4.91–7.46; stage one hypertension: $OR = 12.20$, 95%*CI*: 9.86–15.08; stage two hypertension: $OR = 131.39$, 95%*CI*: 102.02–169.20, all $P < 0.001$) (Table 4).

Discussion

This study demonstrated that BMI categories are associated with blood pressure categories, and higher BMI categories are linked to elevated blood pressure categories. These findings align with previous research and also highlight important distinctions in rural pediatric populations, particularly in Zhangwu County, where unique

Table 4 Ordinal logistic regression analysis of the association between BMI categories and blood pressure categories

	Unadjusted model		Adjusted model[a]	
Blood pressure classification	*OR* (95%*CI*)	*P*	*OR* (95%*CI*)	*P*
Normal blood pressure	Reference		Reference	
Prehypertension	5.01 (4.52-5.55)	<0.001	6.05 (4.91-7.46)	<0.001
Stage one hypertension	10.09 (9.03-11.26)	<0.001	12.20 (9.86-15.08)	<0.001
Stage two hypertension	108.54 (91.05-129.38)	<0.001	131.39 (102.02-169.20)	<0.001

[a]Age and smoking are adjusted in the adjusted model

dietary and lifestyle factors may exacerbate hypertension risk. The prevalence of hypertension in the overweight and obesity groups was significantly greater than that in the normal weight group, consistent with results from other studies [20–23].

The strong positive correlation between BMI and hypertension observed in this study underscores the critical role of obesity in pediatric blood pressure regulation. Mechanistically, increased adiposity may contribute to hypertension through multiple pathways, including increased sympathetic nervous system activity, activation of the renin-angiotensin-aldosterone system (RAAS), and chronic low-grade inflammation [24]. Additionally, excessive visceral fat deposition may impair endothelial function, leading to increased vascular resistance and elevated blood pressure [25]. Our findings further emphasize the dose-response relationship between BMI and hypertension. Notably, compared with their normal-weight counterparts, children with obesity present a markedly greater prevalence of stage two hypertension. This trend suggests that early intervention to address obesity could mitigate long-term cardiovascular risks in this vulnerable population [12].

While prior studies have established a general association between BMI and hypertension [26], our study uniquely contributes to the literature by focusing on a rural Chinese pediatric cohort. The prevalence of hypertension in this population (20.4%) exceeds rates reported in urban cohorts, which may reflect the impact of regional dietary habits, such as high salt and fat intake, combined with limited access to healthcare resources. Additionally, the observed gender and age differences in BMI-hypertension relationships align with findings from international studies [27, 28], which suggest that puberty-related hormonal changes may exacerbate blood pressure elevation, particularly in boys. However, our results challenge the "obesity paradox" observed in some adult studies, where higher BMI does not always correspond to increased cardiovascular risk [29]. This discrepancy underscores the need to differentiate between pediatric and adult hypertension pathophysiology's when interpreting BMI-related findings.

The results of this study have important implications for public health policy and clinical practice. First, routine BMI and blood pressure screenings should be implemented in schools to identify at-risk children early. Second, targeted interventions, such as promoting healthy eating and physical activity, are essential for reducing BMI and preventing the onset of hypertension. Third, specific strategies should be tailored for rural populations, addressing cultural and socioeconomic barriers to effective weight and blood pressure management.

Despite its strengths, this study has several limitations. The cross-sectional design precludes causal inference, and residual confounding from unmeasured variables, such as dietary sodium intake or genetic predispositions, may influence the results. Furthermore, the reliance on BMI as a sole measure of obesity overlooks other important factors, such as body composition and fat distribution. Beyond BMI, the waist-to-height ratio (WHtR) and relative fat mass (RFM) can serve as indicators to assess the weight status of students at school [30, 31]. Future longitudinal studies are needed to validate these findings and explore the long-term impact of early BMI reduction on cardiovascular outcomes. Additionally, the integration of biomarkers of inflammation or RAAS activity could provide deeper insights into the mechanisms linking BMI to hypertension.

Conclusion

This study indicates a potential association between overweight/obesity and high blood pressure in children and adolescents. These findings provide valuable insights for developing targeted prevention strategies and advancing our understanding of hypertension in pediatric population.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12889-025-25463-5.

Supplementary Material 1.

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Authors' contributions

XH designed the study and revised the manuscript. XJ and WJ wrote the first draft and conducted the data analysis. MZ provided research resources and coordinated contact. HZ, ZW and JL completed the physical examination and compiled the data. MT, WZ and ZZ designed and collected the questionnaires.

YZ participated in the production of diagrams and designed the table. XF revised the manuscript.

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Data availability
The raw data are available from the corresponding author (sophia_hxw@163.com) upon reasonable request.

Declarations

Ethics approval and consent to participate
This study was conducted in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Ethics Committee of General Hospital of Northern Theater Command (NO. Y (2022) 123). Written informed consent was obtained from all participants or their legal guardians prior to enrollment in the study. All procedures involving human participants adhered to the approved protocol and relevant guidelines.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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