Gender-specific differences in related indicators of blood pressure in Chinese school-age children with overweight and obesity

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Research article

Keywords: Child obesity, Blood pressure, Pulse pressure, Mean arterial pressure, Gender

Posted Date: September 14th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-66745/v1>

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Abstract

Background

The effects of overweight and obesity on blood pressure in children may differ by sex. Previous studies have only shown the association between overweight and obesity and elevated blood pressure (EBP). The objective of this study is to further explore the association between elevated pulse pressure (EPP) and elevated mean arterial pressure (EMAP) and obesity in Chinese school-age children by gender.

Methods

We performed a cross-sectional study of 935 children between seven and twelve years old. Overweight and obesity were defined by body mass index and body composition. The adjusted population attributable risk was used to assess the effects of obesity on EBP, EPP and EMAP.

Results

The interaction of height or age and obesity was used to identify the effect of obesity on blood pressure independent of age and height. Boys with overweight and obesity had higher EBP, EPP and EMAP ($P < 0.05$). The multivariate logistic regression analysis showed that overweight and obesity had a greater impact on BP and MAP than PP, especially in boys [Odds ratio (OR) > 1]. EBP in 79% of boys and 76% of girls could be attributable to the visceral fat level. The interaction between blood pressure and height or age was modestly increased in children with overweight and obesity, especially in boys.

Conclusions

Independent of age and height, the effect of obesity on blood pressure was greater in boys than girls. Moreover, the effect was mainly on small arteries rather than large arteries.

Background

Previous pathophysiological and epidemiological evidence indicates that childhood hypertension is associated with essential hypertension in adults and harmful life-long cardiovascular events [1–3]. The global prevalence of hypertension in children is 4.00%, and the prevalence of hypertension in children with overweight or obesity is 4.99% and 15.27%, respectively [4]. The pooled prevalence of elevated blood pressure (EBP) is 9.8% in children and adolescents in China, and the prevalence of EBP in children with overweight or obesity is 15.5% and 34.1%, respectively [5]. Blood pressure (BP) is usually assessed as systolic blood pressure (SBP) and diastolic blood pressure (DBP). Alternative decomposition into pulse pressure (PP) and mean arterial pressure (MAP) localizes the changes to large and small arteries, respectively, and predicts incident cardiovascular events [6]. PP was calculated as SBP minus DBP. The increase in PP that occurs with advancing age is predominantly due to reduced arterial distensibility leading to decreased aortic compliance, which is the main risk factor for coronary heart disease and stroke [7]. MAP is an important blood pressure index that comprehensively considers SBP and DBP together, and is calculated as follows: $MAP = 1/3 \times SBP \text{ (mmHg)} + 2/3 \times DBP \text{ (mmHg)}$ [8]. MAP represents the steady flow of blood through the aorta and its arteries. Also, MAP is considered a surrogate marker for vascular stiffness resulting from loss of vascular elasticity [9].

Body mass index (BMI) is the standard diagnostic tool to assign overweight and obesity in children and adolescents, but BMI cannot determine the location of fat accumulation. Alternative measurements such as dual energy X-ray absorptiometry (DEXA) and skin fold thickness may be more precise, but are far more complex to use. Bioelectrical impedance analysis (BIA) is extensively used in epidemiological settings to evaluate body composition, which is noninvasive, low cost and reliable [10]. Therefore, the combination of BMI and BIA can accurately determine the characteristics of childhood obesity.

This study investigated the association between EBP, elevated pulse pressure (EPP), elevated mean arterial pressure (EMAP) and overweight/obesity in Chinese school-age children. A subgroup analysis was conducted to show the effect of gender on the relationship between blood pressure and overweight/obesity.

Methods

Study design and population

This cross-sectional study was conducted from October to November 2019. Based on data from the school health examination in 2018, 935 school-age children were selected between seven and twelve years old by a random sampling method from five primary schools, including 307

children of normal weight, 228 with overweight and 400 with obesity from rural and urban areas. A set of standardized questionnaires for students and parents assessed demographic characteristics, lifestyle, diet, learning and social skills, family environment, mother's pregnancy and feeding patterns during infancy, and parents' attitudes towards health knowledge and behavior. Students filled out questionnaires with the guidance of investigators. Parent questionnaires were filled out by the students' parents or guardians. The anthropometric measurements (weight, height, blood pressure and pulse) and body composition indicators (body fat mass, muscle mass, body fat percentage, visceral fat area, etc.) were measured by trained professionals. Informed consent was obtained from parents or guardians in verbal. The study was approved by the Ethics Committee of Henan University.

Measurements

Height and weight were measured by using standard methods with a metric scale to the nearest 0.1 cm and 0.1 kg with school-aged children wearing light clothing and no shoes. Blood pressure was measured in triplicate at 30-s intervals by using an electronic sphygmomanometer (Omron HEM-7136) and the mean was used for analysis. Body fat, muscle mass, protein mass, body fat percentage, visceral fat area and visceral fat level were measured by using a bioelectrical impedance analyzer (JAWON ioi353). BMI was calculated as weight in kilograms divided by the square of height in meters.

Definitions

In this study, EBP and pre-EBP were defined as SBP and/or DBP $\geq$ age-, sex-, and height-specific 90th percentile and 95th percentile, according to the blood pressure cutoff for Chinese children at 3–17 years of age [11]. Overweight and obesity were defined using the sex- and age-specific BMI criteria, that is, BMI percentile at least 85th and 95th, respectively [12]. Because there is no unified diagnostic standard, elevated pulse pressure (EPP) and elevated mean arterial pressure (EMAP) were defined as PP and MAP $\geq$ 90th percentile of data from this study. For boys aged 6–18 years, body fat percentage (FAT%) $\geq$ 20%, 25% and 30% were mild, moderate and severe obesity, respectively. For girls aged 6–14 years, FAT% $\geq$ 25%, 39% and 35% were mild, moderate and severe obesity, respectively [13].

Statistical analysis

Categorical variables are represented with frequencies (%). Continuous variables are represented as mean $\pm$ standard deviation or median (interquartile range) according to whether the continuous variable exhibited homogeneity of variance and normal distribution. Mann-Whitney Wilcoxon and Student's *t* tests were used to compare differences among the categories for continuous data. Pearson's chi-square, Fisher's exact and linear by-linear tests were used to compare differences among the category data. Multivariate logistic regression analysis was used to determine the independent effect of overweight and obesity on the risk of EBP, EPP and EMAP with the adjustment of age, sex, setting, height and heart rate. The population attribution risk (PAR) was obtained using the formula defined by Bruzzi [14], which was suitable for case-control studies. In the formula, $P_j = D_j / D$, *D* is the total number of cases; stratum *j*, namely stratum 1, 2, ... *j* of the exposure factor level; *D_j* is the number of cases in the stratum *j*; *P_j* is the ratio of the number of cases in the stratum *j* to the total number of cases; *R_j* is the odds ratios in the stratum *j* compared with stratum 1 adjusting after for confounding factors.

The correlations between SBP, DBP, PP, MAP and BMI, FAT%, visceral fat area were statistically evaluated as continuous measures, using Spearman's rank correlation of a non-normal distribution or Pearson's correlation tests. The interactions of height-obesity and age-obesity were used to identify the modification of obesity on the relationship between blood pressure and height or age, respectively, by the presence of dichotomous BMI obesity status. The tendencies of modification were reported as mean with standard error.

The SPSS 21.0 (IBM, Armonk, NY, USA) and GraphPad Prism 6.0 (San Diego, California, USA) were used to perform the statistical analysis in this study. A two-tailed *P* value of less than 0.05 was defined as statistically significant.

Results

Characteristics of participants

A total of 935 school-age children (546 boys and 389 girls) were included in this analysis, aged 7 to 12 years. The detailed characteristics of the normal weight and overweight/obesity participants are presented in Table 1. Compared with normal weight subjects, children with overweight and obesity were older, mostly urban children; had higher BMI, heart rate, SBP, DBP, PP and MAP; higher body fat, muscle mass, protein mass, FAT%, visceral fat area and visceral fat level (*P* < 0.05). Compared with boys, girls with overweight and obesity had a higher heart rate, body fat and FAT%; lower SBP, PP, muscle mass, protein mass, visceral fat area and visceral fat level (*P* < 0.05).

Table 1
Blood Pressure-Related Indexes and Body Composition Characteristics of School-Age Children (n = 935)

Variables	Normal weight (n = 307)	Overweight/obesity (n = 628)	P value	Overweight/obesity		P value
				Boys (n = 378)	Girls (n = 250)	
Setting			0.002			0.229
Urban	140 (45.60)	356 (56.69)		221 (58.47)	134 (53.60)	
Rural	167 (54.40)	273 (43.31)		157 (41.53)	116 (46.40)	
Age (years)	9.17 (8.53–10.85)	10.00 (8.90–11.21)	< 0.0001	10.13 (8.82–11.35)	9.79 (8.95–11.01)	0.124
Height (cm)	138.51 ± 9.95	144.97 ± 9.38	< 0.0001	145.22 ± 9.28	144.60 ± 9.54	0.420
BMI (kg/m ²)	17.40 (16.30–18.60)	23.00 (20.90–25.40)	< 0.0001	23.40 (21.18–25.60)	22.40 (20.70–25.10)	0.057
Heart rate (bpm)	95 ± 13	100 ± 14	< 0.0001	99 ± 14	102 ± 13	0.003
SBP (mm Hg)	94.33 (89.00–101.67)	104.67 (97.67–112.50)	< 0.0001	106.38 ± 10.82	103.91 ± 12.1	0.008
DBP (mm Hg)	63.67 (59.00–69.33)	69.00 (62.67–75.67)	< 0.0001	70.11 ± 9.24	69.72 ± 9.66	0.606
PP (mm Hg)	31.33 (26.00–35.33)	34.67 (29.33–41.17)	< 0.0001	36.26 ± 8.62	34.19 ± 9.27	0.004
MAP (mm Hg)	74.70 ± 7.80	81.77 ± 9.21	< 0.0001	82.20 ± 8.91	81.12 ± 9.62	0.147
Body fat (kg)	4.40 (2.85–5.90)	11.60 (8.10–15.40)	< 0.0001	11.00 (7.10–14.43)	12.70 (2.30–3.20)	< 0.0001
Muscle mass (kg)	27.36 ± 5.76	34.55 ± 6.40	< 0.0001	35.96 ± 6.17	32.41 ± 6.15	< 0.0001
Protein (kg)	6.27 ± 1.42	7.60 ± 1.34	< 0.0001	7.98 ± 1.24	7.03 ± 1.27	< 0.0001
FAT (%)	13.40 ± 5.84	23.87 ± 5.94	< 0.0001	21.90 (17.15–25.90)	26.80 (24.00–30.80)	< 0.0001
Visceral fat area (cm ²)	25.00 (23.00–30.00)	58.00 (38.75–72.00)	< 0.0001	69.00 (55.00–80.00)	37.00 (29.00–54.75)	< 0.0001
Visceral fat level [#]			< 0.0001			< 0.0001
Subcutaneous/balanced	293 (100.00)	477 (76.81)		267 (71.39)	210 (85.02)	
Critical visceral obesity	0	90 (14.49)		62 (16.58)	28 (11.34)	
Visceral obesity	0	54 (8.70)		45 (12.03)	9 (3.64)	
Data are median (interquartile range) or no. (%).						
[#] Partial data deletion.						
BMI, body mass index; SBP, systolic blood pressure; DBP, diastolic blood pressure; PP, pulse pressure; MAP, mean arterial pressure; FAT%, body fat percentage.						

The distribution of EBP, EPP and EMAP in children with overweight and obesity

Compared with normal BMI children, participants with overweight/obesity had higher EBP, EPP and EMAP proportions ($P < 0.05$), especially for boys. In addition, as BMI increased in boys the proportion of normal BP, PP and MAP decreased, and the proportion of EBP, EPP and EMAP increased. Among girls, only BP and MAP indicated the same trend (Table S1). In particular, with an increase of BMI, BP showed a linear increasing trend in both boys and girls ($P < 0.05$). Similarly, compared with children of normal FAT% and visceral fat levels, participants with overweight and obesity had higher EBP, EPP and EMAP proportions (Table S2 and Table S3). Moreover, FAT% and visceral fat levels seem to be

more sensitive than BMI; with an increase of FAT% and visceral fat levels, the proportion of EPP in girls with overweight and obesity also showed an increasing trend compared with girls of normal weight.

Adjusted population attributable risk of overweight/obesity for EBP, EPP and EMAP

The associations of overweight and obesity with EBP, EPP and EMAP were evaluated by multivariate logistic regression analysis. Compared with normal weight, overweight and obesity were associated with EBP, EPP and EMAP after adjusting for age, sex, setting, height and heart rate. Especially in boys, as BMI increased this association gradually increased. However, overweight and obesity were only associated with EBP and EMAP of school-age girls after adjusting for age, setting, height and heart rate. Because the EPP group of girls was not accompanied by visceral obesity, logistic regression analysis did not show results (Table S4).

The PAR of EBP and EMAP attributable to overweight and obesity was greater than that of EPP. Moreover, for boys, overweight and obesity accounted for more PAR for EBP, EPP and EMAP. EBP in about 78% of children overall (79% of boys and 76% of girls) could be attributed to visceral fat level, and EBP in about 71% of children overall (76% of boys and 65% of girls) could be attributed to BMI. Visceral fat level accounted for PAR of EBP more so than BMI. However, BMI was superior to FAT% and visceral fat level in estimating the PAR of EPP and EMAP (Table 2).

Table 2
Adjusted Population Attributable Risk of Overweight/obesity for Elevated BP, PP and MAP

	No. of pre- EBP/EBP	No. of overweight	No. of obesity	PAR%	No. of EPP	No. of overweight	No. of obesity	PAR%	No. of EMAP	No. of overweight	No. of obesity	PAR%
Overall												
BMI	329	72	198	71	96	24	60	64	93	18	68	80
FAT%				68				49				64
Visceral fat level				78				18				72
Boys												
BMI	194	41	126	76	66	17	42	66	53	9	41	82
FAT%				76				57				74
Visceral fat level				79				30				72
Girls												
BMI	135	31	72	65	30	7	18	61	40	9	27	78
FAT%				57				38				45
Visceral fat level				76				—				57
EBP, elevated blood pressure; EPP, elevated pulse pressure; EMAP, elevated mean arterial pressure; PAR, population-attributable risk.												

Correlation of overweight and obesity with BP, PP and MAP

The BMI, FAT% and visceral fat area of school-age children strongly correlated with SBP and MAP, especially for boys, and the correlation coefficients $r > 0.5$. Moreover, BMI and visceral fat area were consistent, and both showed strong correlation with BP, PP and MAP (Table S5).

The effects of obesity on SBP, DBP, PP and MAP with different height and age

SBP, PP and MAP of school-age children increased with height, regardless of gender. But changes in DBP with height were more complicated. The relationship between blood pressure and height was augmented comparably in children with overweight and obesity (based on BMI) (Fig. 1). SBP, DBP, PP and MAP were higher with age in boys, especially for boys with overweight and obesity. But only SBP and PP increased with age, while DBP and MAP showed complex trends among girls. Similarly, the interaction between blood pressure and age in children with overweight and obesity was also increased (Fig. 2).

Discussion

We investigated the gender difference in the relationship of overweight and obesity with BP, PP and MAP in Chinese school-age children. We found that boys with overweight and obesity were more likely to have higher EBP, EPP and EMAP, and overweight and obesity had a greater impact on BP and MAP than PP, especially in boys. Body fat percentage and visceral fat level were better indicators to evaluate the effect of obesity on blood pressure than BMI in girls. The interaction between blood pressure and height or age was moderately increased in children with overweight and obesity, especially in boys.

EBP in children and adolescents is a growing health problem, along with the worldwide increase in obesity. EBP in childhood is correlated with hypertension and risk of cardiovascular disease (CVD) in adulthood, and this relationship strengthens with age [1]. Primary hypertension in children is associated with other risk factors for CVD, including hyperlipidemia and insulin resistance [2]. Children may also suffer damage to organs from hypertension, including left ventricular hypertrophy and pathological vascular changes [15]. PP and MAP increase with age. EBP, EPP and EMAP can cause loss of vascular elasticity, leading to vascular stiffness in adults, which predicts incident CVD events. PP is determined by large artery stiffness and flow pulsatility, whereas MAP is determined by small resistance arterial function and cardiac output, and which may provide additional insight into the underlying pathophysiology of elevated BP [16]. The effect of obesity on MAP is greater than PP in our study, indicating that childhood obesity can lead to increased vascular resistance of small arteries rather than stiffness of large arteries.

While children and adolescents are growing and developing their body composition is constantly changing. Age, gender and ethnic background all have some influence on body composition. Boys and girls have different developmental characteristics of adipose tissue and non-adipose tissue. BMI growth curve and body fat development characteristics are not completely consistent, and there are gender differences [17]. The body fat mass of boys increases year by year from the age of 6 to 12, and begins to decrease at the age of 13. However, the increased body fat of girls occurs early in life and is maintained during adolescence, which may be related to the increase of estrogen during puberty [18, 19]. Adolescent boys have more muscle mass than girls [20], but the visceral fat area of both boys and girls increases with age [21]. Obesity is not excess weight; it is excess adipose tissue [22]. Asians have a higher percentage of body fat at a lower BMI [23, 24]. Therefore, this study uses BMI, body fat percentage and visceral fat area or level to simultaneously assess the effect of obesity on blood pressure in order to obtain more accurate research results.

We found that blood pressure-related indicators and body composition differed among boys and girls with overweight and obesity. Regardless of whether BMI or body fat percentage or visceral fat level was used to evaluate the degree of obesity, as the degree of obesity increases, BP, PP and MAP increased linearly in boys. Using FAT% and visceral fat level to evaluate the effect of obesity on blood pressure is a better predictor than BMI in girls. Multivariate logistic regression analysis showed that overweight/obesity was an independent predictor of EBP and EMAP, especially for boys. Overweight and obesity accounted for more PAR of EBP and EMAP in boys. Our research results suggest that obesity is associated with elevated blood pressure through changes at the small and large artery levels, especially changes in small arteries. Moreover, the changes in small arteries were particularly prominent in boys with obesity. Several studies have suggested that arterial hypertension may originate early in life, and changes in microvascular structure represent a potential mechanism for the development of hypertension [25, 26]. Persistent obesity and elevated blood pressure may cause structural remodeling of the microvascular and macrovascular wall, which may further trigger arteriolar narrowing and increased large artery stiffness [27]. However, none of the above studies have noted that there are gender differences in the effects of obesity on blood vessels. This may contribute to the greater incidence of CVD events in men than in women.

SBP, DBP, PP and MAP as continuous variables showed a linear correlation with BMI, body fat percentage and visceral fat area. This linear relationship is particularly evident among boys. In order to exclude the effect of height and age on blood pressure, the relationship between obesity and blood pressure was grouped by height per 10 cm and age per year. The interaction between blood pressure and height or age in children with overweight and obesity was increased, especially for boys. However, as height and age increased, the blood pressure-related indicators in girls showed more complex trends. The average blood pressure of children gradually increases with age. The trend of increasing blood pressure in boys and girls is that SBP is greater than DBP, but the growth rate of boys is greater than that of girls. Therefore, the phenomenon that blood pressure rises with age is mainly related to growth and development, and is a concomitant phenomenon of growth and development of children. One study found that early life risk factors, including birth weight, gestational age, and socioeconomic position, are associated with SBP but not with (or more weakly with) DBP [28]. Our results also suggest that the correlation between obesity and SBP is higher than that with DBP. The associations of adiposity measured in childhood (9–12 years) with cardiovascular risk factors in adolescence (15–16 years) were stronger in boys than girls [29]. Therefore, the gender difference in the effect of obesity on blood pressure may be related to hormone levels in adolescence, or related to the distribution of body fat. That is, preferentially more subcutaneous and “safe” weight is gained in girls than boys [30]. Males develop earlier and more severe hypertension than females [31]. Therefore, early detection and management of boyhood obesity may effectively reduce the incidence of hypertension in adulthood.

This study has some limitations. First, the cross-sectional design does not show a trend in the effect of obesity on elevated blood pressure in different genders. Second, the relatively small sample sizes may prevent us from estimating accurate statistical values. Finally, our research was restricted to Chinese children and adolescents aged 7–12, so the conclusions of the study may not apply to other races and age groups.

Conclusions

In conclusion, our study indicates that the effect of overweight and obesity on blood pressure is greater in boys than girls, and this effect is not affected by age and height. The effect of overweight and obesity on blood pressure was mediated mainly through small rather than large arteries.

Abbreviations

EBP: elevated blood pressure; EPP: elevated pulse pressure; EMAP: elevated mean arterial pressure; SBP: systolic blood pressure; DBP: diastolic blood pressure; BMI: body mass index; DEXA: X-ray absorptiometry; BIA: bioelectrical impedance analysis; FAT%: body fat percentage; PAR: population attribution risk; CVD: cardiovascular disease; OR: odds ratio.

Declarations

Availability of data and materials

The datasets generated during and/or analyzed during the current study are not publicly available but are available from the corresponding author upon reasonable request.

Ethics approval and consent to participate

All parents of children gave their written consent for their participation in the study. This study received approval from the Henan University Ethical Review Board (Protocol ID HUSOM2019-266), and it conformed to the ethics guidelines of the Declaration of Helsinki.

Consent for publication

Not applicable.

Competing interests

The authors declare that they do not have any conflicts of interests.

Funding

This study was supported by Program for Innovative Talents of Science and Technology in Henan Province (No.18HASTIT048), Kaifeng Science and Technology Major Project (18ZD008), Supporting grant of Bioinformatics Center of Henan University (No.2018YLJC01; No.2019YLXKJC01; No.2019YLXKJC04), Program of interdiscipline plan based on first class disciplines (No.2019YLXKJC02). Student Innovation and Entrepreneurship Training Program of Henan University (No. 202010475082). And all the financial expenditure of this study comes from the above programs.

Authors' contributions

All authors materially participated in the study and manuscript preparation. ZL, HHM and YSJ participated in the design and the data analysis of the study. ZL and HHM drafted the manuscript. QN, DY, QL, LJJ, LY, HYS, LZ Y and PHS collected and managed data. JSP and GXQ reviewed and edited the manuscript. ZL supervised the research process. All authors approved the final article.

Acknowledgements

Not applicable.

References

1. Chen X, Wang Y. Tracking of blood pressure from childhood to adulthood: a systematic review and meta-regression analysis. *Circulation*. 2008;117:3171–80.
2. Martino F, Puddu PE, Pannarale G, Colantoni C, Martino E, Zanoni C, et al. Hypertension in children and adolescents attending a lipid clinic. *Eur J Pediatr*. 2013;172:1573–9.

3. Urbina EM, Houry PR, McCoy C, Daniels SR, Kimball TR, Dolan LM. Cardiac and vascular consequences of pre-hypertension in youth. *J Clin Hypertens (Greenwich)*. 2011;13:332–42.
4. Song P, Zhang Y, Yu J, Zha M, Zhu Y, Rahimi K, et al. Global prevalence of hypertension in children: a systematic review and meta-analysis. *JAMA Pediatr*. 2019;173:1–10.
5. Wang L, Song L, Liu B, Zhang L, Wu M, Cao Z, et al. Trends and status of the prevalence of elevated blood pressure in children and adolescents in China: a systematic review and meta-analysis. *Curr Hypertens Rep*. 2019;21:88.
6. Zachariah JP, Wang Y, Penny DJ, Baranowski T. Relation between lead exposure and trends in blood pressure in children. *Am J Cardiol*. 2018;122:1890–5.
7. Avolio AP, Kuznetsova T, Heyndrickx GR, Kerkhof PLM, Li JK. Arterial flow, pulse pressure and pulse wave velocity in men and women at various ages. *Adv Exp Med Biol*. 2018;1065:153–68.
8. Kodama S, Horikawa C, Fujihara K, Yoshizawa S, Yachi Y, Tanaka S, et al. Meta-analysis of the quantitative relation between pulse pressure and mean arterial pressure and cardiovascular risk in patients with diabetes mellitus. *Am J Cardiol*. 2014;113:1058–65.
9. Guo C, Qin P, Li Q, Zhang D, Tian G, Liu D, et al. Association between mean arterial pressure and risk of type 2 diabetes mellitus: The Rural Chinese Cohort Study. *Prim Care Diabetes*. 2020; pii: S1751-9918(19)30278-5.
10. Marra M, Sammarco R, De Lorenzo A, Iellamo F, Siervo M, Pietrobelli A, et al. Assessment of body composition in health and disease using bioelectrical impedance analysis (BIA) and dual energy X-ray absorptiometry (DXA): a critical overview. *Contrast Media Mol Imaging*. 2019; 2019:3548284.
11. Fan H, Yan YK, Mi J. Updating blood pressure reference for Chinese children aged 3–17 years [in Chinese]. *Chin J Hypertens*. 2017;25:428–38.
12. Group of China obesity task force. Body mass index reference norm for screening overweight and obese in Chinese children and adolescents. *Chin J Epidemiol*. 2004;25:97–102.
13. Disease Prevention and Control Bureau of the Ministry of Health of the People's Republic of China. Guidelines for the prevention and control of overweight and obese among school-age children and adolescents in China. Beijing: People's Medical Publishing House; 2007. p. 6.
14. Bruzzi P, Green SB, Byar DP, Brinton LA, Schairer C. Estimating the population attributable risk for multiple risk factors using case-control data. *Am J Epidemiol*. 1985;122:904–14.
15. Riley M, Hernandez AK, Kuznia AL. High blood pressure in children and adolescents. *Am Fam Physician*. 2018;98:486–94.
16. Zachariah JP, Graham DA, de Ferranti SD, Vasan RS, Newburger JW, Mitchell GF. Temporal trends in pulse pressure and mean arterial pressure during the rise of pediatric obesity in US children. *J Am Heart Assoc*. 2014;3:e000725.
17. Chen FF, Liu JT, Huang GM, Mi J, China Children and Adolescents Cardiovascular Health Research Project Group (for the CCACH Collaboration Group). Developmental characteristics on body composition in Chinese urban children and adolescents aged 3–17 years old [in Chinese]. *Zhonghua Liu Xing Bing Xue Za Zhi*. 2020;41:213–9.
18. Chen F, Liu J, Yan Y, Mi J. China Child and Adolescent Cardiovascular Health (CCACH) Study Group. Abnormal metabolic phenotypes among urban Chinese children: epidemiology and the impact of DXA-measured body composition. *Obesity (Silver Spring)*. 2019;27:837–44.
19. Lizana PA, Paula CV, Araya L, Aguilera F, Mora M. Obesity, body fat distribution, and physical activity in school-age Children: an urban and rural comparison in Valparaíso, Chile. *Biomed Environ Sci*. 2016;29:834–9.
20. Bredella MA. Sex Differences in Body Composition. *Adv Exp Med Biol*. 2017;1043:9–27.
21. Satake E, Nakagawa Y, Kubota A, Saegusa H, Sano S, Ohzeki T. Age and sex differences in fat distribution in non-obese Japanese children. *J Pediatr Endocrinol Metab*. 2010;23:873–8.
22. Gungor NK. Overweight and obesity in children and adolescents. *J Clin Res Pediatr Endocrinol*. 2014;6:129–43.
23. Wang J, Thornton JC, Russell M, Burastero S, Heymsfield S, Pierson RN Jr. Asians have lower body mass index (BMI) but higher percent body fat than do whites: comparisons of anthropometric measurements. *Am J Clin Nutr*. 1994;60:23–8.
24. Ehtisham S, Crabtree N, Clark P, Shaw N, Barrett T. Ethnic differences in insulin resistance and body composition in United Kingdom adolescents. *J Clin Endocrinol Metab*. 2005;90:3963–9.
25. Levy BI, Ambrosio G, Pries AR, Struijker-Boudier HA. Microcirculation in hypertension: a new target for treatment? *Circulation*. 2001;104:735–40.
26. Bizzarri C, Pedicelli S, Romanzo A, Bocchini S, Bottaro G, Cianfarani S, et al. The impact of IGF-I, puberty and obesity on early retinopathy in children: a cross-sectional study. *Ital J Pediatr*. 2019;45:52.
27. Kochli S, Endes K, Steiner R, Engler L, Infanger D, Schmidt-Trucksass A, et al. Obesity, high blood pressure, and physical activity determine vascular phenotype in young children. *Hypertension*. 2019;73:153–61.
28. Lawlor DA, Davey Smith G. Early life determinants of adult blood pressure. *Curr Opin Nephrol Hypertens*. 2005;14:259–64.

29. Lawlor DA, Benfield L, Logue J, Tilling K, Howe LD, Fraser A, et al. Association between general and central adiposity in childhood, and change in these, with cardiovascular risk factors in adolescence: prospective cohort study. *BMJ*. 2010;341:c6224.
30. Moran A, Jacobs DR Jr, Steinberger J, Steffen LM, Pankow JS, Hong CP, et al. Changes in insulin resistance and cardiovascular risk during adolescence: establishment of differential risk in males and females. *Circulation*. 2008;117:2361–8.
31. Ahmed S, Hu R, Leete J, Layton AT. Understanding sex differences in long-term blood pressure regulation: insights from experimental studies and computational modeling. *Am J Physiol Heart Circ Physiol*. 2019;316:H1113-23.

Figures

Figure 1

The effect of interactions of height-obesity on blood pressure in school-age children.

Figure 2

The effect of interactions of age-obesity on blood pressure in school-age children.

Supplementary Files

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- [TableS3.docx](#)
- [TableS2.docx](#)
- [TableS1.docx](#)