Hypertension Research (2018) 41, 135–140

www.nature.com/hr

ORIGINAL ARTICLE

High blood pressure and its relationship to adiposity in a school-aged population: body mass index vs waist circumference

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High blood pressure (HBP) is a major concern in pediatric populations. Adiposity is highly related to HBP in youths; however, whether body mass index (BMI) or waist circumference (WC) is more strongly associated with HBP in this population is unclear. This cross-sectional study, involving schoolchildren between 10 and 17 years of age from public and private schools, assessed direct measurements of BMI, WC and blood pressure. The socioeconomic level, sedentary behavior, physical activity, alcohol consumption and smoking history were obtained through a questionnaire. A Pearson's correlation and linear regression were used. In total, 1011 adolescents with a mean age of 13.1 (+2.3) years were evaluated. The prevalence of overweight/obesity was 27.7%, and the percentage of abdominal obesity was 19.3%. Adolescent boys and girls who had overweight/obesity or abdominal obesity had higher systolic and diastolic blood pressure (BP) values compared with eutrophic adolescents or those without abdominal obesity. In general, both BMI and WC were related to BP, but WC was more strongly correlated with BP than BMI. In conclusion, although both BMI and WC were related to HBP, WC was more strongly associated with blood pressure in young people.
Hypertension Research (2018) **41,** 135–140; doi:10.1038/hr.2017.93; published online 26 October 2017

Keywords: adiposity; blood pressure; body mass index; students; waist circumference

INTRODUCTION

High blood pressure (HBP) is alarmingly common in the world population, and it is the main factor associated with cardiovascular death and morbidity in both developed and developing countries.[1] Hypertension observed in adults has a high chance of having its onset in infancy, as children with HBP are more likely to become hypertensive adults.[2]

Obesity is defined as an excess of body fat[3] and is a major determinant of HBP in youth.[4] Fujii *et al.*[5] observed that the presence of abdominal obesity together with high levels of high-sensitivity C-reactive protein was associated with an elevated level of new-onset hypertension in the general population. Obese children and adolescents have a higher blood pressure compared with lean subjects, increasing the risk of cardiovascular events in adulthood.[6] Therefore, easy adiposity indicators, such as body mass index (BMI) and waist circumference (WC), have been used in practice. Both indicators have been associated with cardiovascular risk in young people[6] and have shown better reliability compared with other indicators, such as waist-to-hip and waist-to-height ratios.[7–9] In addition, these indicators have widely acceptable cutoff points, improving the interpretation of the results.[10]

In adults, general adiposity assessed by BMI had a stronger association with blood pressure than central adiposity measured by WC.[11] However, whether similar results are observed in children is unclear. It is possible that WC is more related to HBP than BMI in children and adolescents,[12,13] given that sympathetic activation is an important factor for the development of HBP in young populations.[14] Furthermore, whether the association between HBP and adiposity differs between genders in adolescents is still unknown, although several risk factors are different between the sexes.[15] Thus, the aim of this study was to assess the relationship between central and overall adiposity and HBP in adolescents and the influence of gender on this health outcome.

METHODS

Sample selection and inclusion criteria

According to the City Education Department of Presidente Prudente, there are ~37 000 students regularly enrolled in the public and private systems of education in the city. Of this total, 27 860 students are enrolled in primary

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Received 14 August 2016; revised 10 July 2017; accepted 14 July 2017; published online 26 October 2017

school and 9105 in high school, with ~20% of students enrolled in private schools. The study sample consisted of students aged between 10 and 17 years (10–13 years ($n=563$); 14–17 years ($n=448$)) who were all regularly enrolled in public or private educational systems in the city.

The city of Presidente Prudente has 36 schools serving the specific population of this study.[16] Aiming to include students from all regions of the city (north, south, east, west and central), two schools were randomly chosen per region, in which all classes were evaluated. As not all regions contain private schools, two randomly selected private schools were assessed to meet the representative number of students in the private school system.

Study participants were: (I) adolescents aged 10–17 years; (II) enrolled in primary and high schools from public and private education systems; (III) were not using any medication to control heart rate or blood pressure; (IV) had not performed strenuous exercise for at least 24 h before evaluation; (V) had not consumed caffeinated beverages within 24 h before evaluation, and (VI) returned the informed consent allowing the adolescent to participate in the study, signed by a parent or guardian. This study was approved by the Ethics Research Committee of the Sao Paulo State University (CAAE: 21600613.4.0000.5402).

Sample calculation

The estimated sample adopted a maximum prevalence of 50% of outcome, commonly used in epidemiological studies.[17] Given that Presidente Prudente has a student population of ~37 000 students, the confidence interval was 95% and the maximum tolerable error rate 4%, which provided a simple random sample of 591 adolescents. However, because the study was carried out by conglomerates, the design effect correction of 1.5 showed a minimum size of 886 subjects. Anticipating possible sample losses of 10%, 975 subjects were required for the survey.

Data Collection

A questionnaire was used to assess sedentary behavior, physical activity engagement, smoking habits, alcohol consumption, and socioeconomic status. It was applied in classrooms provided by the school, by previously trained researchers.

Anthropometry

All participants were barefoot and wore light clothing for the evaluations. Body weight, height and WC were assessed. For the assessment of body weight, a digital scale (Plenna, São Paulo, Brazil) accurate to 0.1 kg was used. Height was measured using a portable stadiometer (Sanny; American Medical do Brasil, São Paulo, Brazil) with a maximum extension of 2.2 m and 0.1 cm precision. From these two measures, the BMI was calculated using body mass divided by the height squared. Measurements of WC were obtained in duplicate, at the middle point between the iliac crest and the last rib, and at the end of normal expiration, using an inextensible metallic tape with a precision of 0.1 cm (Sanny; American Medical do Brasil).[18] The final WC value of the adolescents was determined by the average of the two measures.

The anthropometric measurements were performed in a separate room, provided by the schools participating in the study. To avoid any possible embarrassment during the anthropometric assessment, it was carried out by researchers of the same sex as the evaluated subject.

Definition of obesity and abdominal obesity

To define overall obesity in the sample, the adolescents were classified according to Cole *et al.*,[19] considering BMI values according to age and gender, defined as normal weight or overweight (overweight and/or obesity).

For the abdominal obesity definition, the participants in the sample were classified by values of WC, conforming to Taylor *et al.*[20] This criteria defines individuals as 'having' or 'not having' abdominal obesity according to the age and gender of the children and adolescents.

Blood pressure measurement

Measurements of BP were collected two times, in a location with controlled environmental factors such as temperature, humidity and noise. The individual was in a seated position with their torso leaning against the chair and arms relaxed, with a minimum rest of 5 min before each measurement and a 10 min interval between the first and second measurements. The average of the two measurements was considered for SBP and DBP values. An oscillometric electronic device was used (OMRON, model HEM 742; Omron Healthcare, Hoofddorp, Netherlands), which was previously validated for use in this population,[21] and the appropriate cuff sizes were chosen according to the wide range of ages and body sizes of the sample.

Sedentary behavior

Sedentary behavior was assessed through the number of hours a week that the adolescents used electronic devices such as televisions, computers or video games during leisure time. School-aged children and adolescents spend prolonged hours in sedentary activities while studying, and this behavior was common in all of the samples of this study conducted in the school environment. Thus, to determine the levels of sedentary behavior, leisure activities outside school hours were chosen. High levels of sedentary behavior were considered in those adolescents who reported a sum of television, video game and computer use of 22 h or more per week.[22]

Physical activity engagement

The habitual practice of physical activity was assessed using the questionnaire developed by Baecke *et al.*[23] validated for use in Brazilian adolescents.[24] This questionnaire aims to assess habitual physical activity through three different domains (physical activity at school, physical activity during leisure/occupational and sports activities outside school), and the sum of these three areas indicates the total practice of physical activity score.

For each of the three domains of physical activity, as well as the total score, the final product presented by the questionnaire is a dimensionless score. Thus, the cutoff point for classification of sufficient or insufficient physical activity was defined in an arbitrary manner by the investigators. Those individuals situated in the highest quartile for physical activity were classified as sufficiently active (fourth quartile (active enough)), and insufficiently active subjects were those in the first three quartiles (Q1, Q2 and Q3).

Smoking habits and alcohol consumption

Smoking habits and alcohol consumption were verified through questions adapted from the Global School-based Student Health Survey.[25] This type of instrument reports the use of alcohol and tobacco by adolescents in the previous month. Adolescents who reported alcohol consumption on at least 1 day a week of 2 doses or 2 days a week with 1 dose per day (each dose is 250 ml) or who had smoked in the previous 30 days were considered as having the respective risk behavior.

Socioeconomic status

The economic status of the families was determined by the 'Criteria for Economic Classification of Brazil' established in 2011 by the Brazilian Association of Companies and Research (ABEP), according to the database of a survey conducted in 2009 by the Brazilian Institute of Public Opinion and Statistics (2011).[26] The questionnaire was completed by the student in the classroom, with the help of a researcher, taking into account the level of education of the household head, as well as the presence and quantity of certain rooms and items in the analyzed home (TV color, videocassette or DVD, radio, bathroom, car, washing machine, housemaids, fridge and freezer), and established the following ratings for economic conditions: A1, A2, B1, B2, C1, C2, D and E. After classification of the subject through the instrument for measuring economic class, the sample was further subdivided into high economic class, including categories A1, A2 and B1, middle economic class, including B2 and C1, and low economic class, including categories C2, D and E.

Statistical analysis

The sample characterization variables are described as the mean and s.d. As the pubertal stage was not assessed, analyses stratified by age (10–13 years and 14–17 years) were performed to limit the influence of maturation in the

Table 1 Characterization of the sample according to anthropometric indicators

	Boys (n = 454)						Girls (n = 557)					
	Normal weight	*Overweight*	*P-value*	*Normal WC*	*Abdominal obesity*	*P-value*	*Normal weight*	*Overweight*	*P-value*	*Normal WC*	*Abdominal obesity*	*P-value*
Age (years)	13.1 (2.3)	12.4 (2.2)	0.005	13.1 (2.4)	12.00 (1.9)	≤0.001	13.5 (2.2)	12.8 (2.3)	0.001	13.5 (2.2)	12.6 (2.4)	0.002
Weight (kg)	44.8 (12.9)	62.0 (14.5)	≤0.001	46.7 (13.7)	61.9 (12.9)	≤0.001	45.7 (10.8)	63.3 (15.4)	≤0.001	47.0 (11.4)	65.4 (16.7)	≤0.001
Height (cm)	155.2 (13.9)	156.0 (12.1)	0.549	155.4 (13.8)	155.2 (11.6)	≤0.001	156.0 (12.1)	155.7 (12.2)	0.813	155.7 (11.9)	156.9 (13.0)	0.398
BMI (kg/m^2)	18.2 (2.4)	25.2 (3.8)	≤0.001	18.9 (3.3)	25.2 (3.3)	≤0.001	18.5 (2.4)	25.7 (3.5)	≤0.001	19.1 (3.0)	26.2 (4.1)	≤0.001
WC (cm)	64.5 (6.4)	79.5 (8.3)	≤0.001	65.3 (6.7)	83.0 (7.1)	≤0.001	64.0 (5.9)	78.9 (9.4)	≤0.001	64.6 (6.0)	82.7 (8.1)	≤0.001
SBP (mm Hg)	114.4 (2.2)	118.5 (2.3)	0.003	114.8 (13.7)	118.6 (12.9)	0.019	115.5 (12.8)	119.9 (13.3)	≤0.001	115.8 (12.6)	120.5 (14.2)	0.002
DBP (mm Hg)	65.5 (9.1)	69.2 (10.9)	≤0.001	65.7 (9.4)	70.1 (10.7)	≤0.001	66.5 (8.5)	71.0 (9.3)	≤0.001	66.9 (8.6)	71.2 (9.4)	≤0.001

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; WC, waist circumference.

analyses. The correlation between systolic and diastolic blood pressure with BMI and WC was verified by the Pearson's correlation. The magnitude of the relationship in the unadjusted and adjusted analysis (age, socioeconomic level, smoking status, alcohol consumption, sedentary behaviors and physical activity) was observed through linear regression. The adopted confidence interval was 95%, and the significance level was 5%. The statistical program used was SPSS version 15.0.

RESULTS

The study included 1011 adolescents with a mean age of 13.1 (±2.3) years. The prevalence of overweight adolescents was 27.7%, including 28.9% male adolescents and 26.6% female adolescents ($P=0.463$). The prevalence of abdominal obesity was 19.3%. The prevalence of abdominal obesity was slightly higher in male adolescents, 19.7%, compared with female adolescents, 18.9% ($P=0.821$).

Table 1 presents the descriptive variables of the sample according to the anthropometric indicators used in this study. Overweight boys and girls were younger and had higher weight, BMI, WC, SBP and DBP compared with their normal weight peers. Similar results were observed comparing adolescent boys and girls with and without abdominal obesity. An increase of 0.26 and 0.21 mm Hg for systolic and diastolic BP, respectively, was observed for each 1 kg/m^2 increase in BMI, and for each centimeter increase in WC, systolic and diastolic BP increased by 0.44 and 026 mm Hg, respectively.

In adolescent boys and girls of 10–13 years, a positive correlation among SBP, BMI and WC and among DBP, BMI and WC was observed. In adolescents aged 14–17 years, the SBP was correlated with WC in boys, while SBP and DBP were correlated with BMI and WC in girls (Table 2).

The crude multivariate analysis tested the magnitude of the relationship between anthropometric indicators and the SBP and DBP in adolescent boys and girls. Both anthropometric indicators presented positive relationships with SBP and DBP in adolescents from 10 to 13 years. In male adolescents aged 14–17 years, BMI was not related to SBP; neither the BMI nor WC had a relationship with DBP in boys aged 14–17 years (Table 3).

The adjusted analyses in Table 4 indicate that relations between anthropometric indicators and the SBP values remained connected in the first statistical model, even after adjusting for confounding variables: socioeconomic level, smoking status, alcohol consumption, physical activity and sedentary behavior, in both sexes (with the exception of BMI in boys aged 14–17 years). In the second model, when WC was entered as an adjustment factor for BMI, the significance observed between SBP and BMI was lost in both genders. On the other hand, when BMI was entered as an adjustment factor for WC, no reduction in the relationship between WC and SBP was observed.

Table 5 shows the relationship between anthropometric indicators and DBP in adolescents. In adolescents aged 10–13 years, a relationship between anthropometric indicators and DBP was observed. However, this relationship was not observed in boys aged 14–17 years, only in girls and the total sample of adolescents aged 14–17 years.

In adolescents aged 10–13 years, it was observed that after WC entry as an adjustment factor, there was a loss of the relationship between BMI and DBP in both sexes, which did not occur in adolescents aged 14–17 years. In relation to WC with DBP, there were no changes in the variables that were established in the first model after insertion of BMI as an adjustment.

Table 2 Correlation between anthropometric indicators and SBP and DBP in adolescents

	BMI		*WC*	
	r	P*-value*	r	P*-value*
10–13 years				
Boys				
SBP	0.31	⩽0.001	0.39	⩽0.001
DPB	0.21	⩽0.001	0.28	⩽0.001
Girls				
SBP	0.27	⩽0.001	0.30	⩽0.001
DPB	0.33	⩽0.001	0.33	⩽0.001
14–17 years				
Boys				
SBP	0.12	0.121	0.22	0.002
DPB	0.13	0.100	0.08	0.302
Girls				
SBP	0.18	0.004	0.24	⩽0.001
DPB	0.33	⩽0.001	0.29	⩽0.001

Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; WC, waist circumference.

Table 3 Crude analysis between anthropometric indicators and blood pressure in adolescents

	Boys		*Girls*		*Total*	
	β	*CI (95%)*	β	*CI (95%)*	β	*CI (95%)*
Systolic blood pressure						
10–13 years						
BMI	**0.86**	**0.55; 1.17**	**0.88**	**0.52; 1.24**	**0.86**	**0.62; 1.10**
WC	**0.46**	**0.33; 0.60**	**0.40**	**0.24; 0.55**	**0.50**	**0.37; 0.62**
14–17 years						
BMI	0.41	−0.11; 0.94	**0.52**	**0.17; 0.88**	**0.48**	**0.18; 0.77**
WC	**0.35**	**0.12; 0.57**	**0.34**	**0.17; 0.49**	**0.41**	**0.30; 0.52**
Diastolic blood pressure						
10–13 years						
BMI	**0.49**	**0.21; 0.77**	**0.74**	**0.49; 0.99**	**0.60**	**0.41; 0.79**
WC	**0.29**	**0.17; 0.41**	**0.31**	**0.21; 0.42**	**0.30**	**0.22; 0.38**
14–17 years						
BMI	0.29	−0.05; 0.63	**0.66**	**0.42; 0.89**	**0.54**	**0.34; 0.73**
WC	0.07	−0.07; 0.22	**0.27**	**0.16; 0.38**	**0.20**	**0.10; 0.28**

Abbreviations: BMI, body mass index; CI, confidence interval; WC, waist circumference.
The bold entries mean that these results were statistically significant ($P < 0.05$).

DISCUSSION

BMI and WC were associated with higher SBP and DBP levels in both sexes, even after adjustment for confounders. However, WC was more strongly associated with HBP compared with BMI, especially in male adolescents.

Findings in the literature are not consistent regarding the association of WC with BP considering BMI. Song[27] observed that WC loses strength of association when adjusted for BMI in relation to BP in overweight and normal weight individuals. Moreover, Maximova *et al.*[28] reported that neither WC nor the waist-to-hip ratio ratio had a greater ability to identify hypertensive children when compared with BMI, and the general or abdominal adiposity rates obtained by DXA did not have a higher ability than BMI or WC to identify subjects with elevated BP. The same study ranks BMI favorably for use in public health and clinical contexts in pediatric populations and recommends monitoring the BP of this population, regardless of their body weight.

Although BMI cannot discriminate between adipose, bone and muscle tissues involved in body weight[29] and can therefore not be directly related to central adiposity,[30] lower reproducibility of the WC when compared with the BMI was observed.[31] The recent increase in mean BMI in children and adolescents has been accompanied by an even more pronounced increase in WC.[32] Thus, both may be associated with health outcomes.

In some studies, the association between central adiposity and BP was stronger in boys than in girls.[33,34] A longitudinal study found an association of BMI and WC with BP, being mediated by the age and sex of the individuals.[35] Among men, WC appears to be more important than BMI for BP prediction. On the other hand, BMI is more strongly associated with BP in women. Girls have less visceral fat than boys, and this difference may explain the lower strength of association between visceral fat and BP in girls, as the relationship between BP and fat distribution was observed regardless of the amount of body fat.[36] Similar findings were observed in hypertensive adults by Krzesinski *et al.*,[37] where no differences between gender were shown with regard to the relation of hypertension with abdominal obesity assessed by WC.

The relationship between obesity markers and blood pressure was not observed in males aged between 14–17 years. Puberty had been associated with a reduction in adipose tissue, especially in males. It is known that adipose tissue is responsible for releasing a number of cytokines, including leptin. This cytokine contributes to increases in the sympathetic nervous system and subsequently in human blood pressure.[38] In addition, gender differences in the regulation of the sympathetic nervous system were previously described in adults.[39] Weise *et al.*[40] showed an association between norepinephrine levels and testosterone in boys, which can also account for the lack of a relationship between obesity parameters and blood pressure in boys aged 14–17 years in our study. In addition, adolescents with early maturation have more cardiovascular risk factors, such as high BMI and WC, when compared with adolescents with late maturation,[41] which may contribute to the relationship between BMI and WC with more pronounced HBP in the age group between 10–13 years. Another aspect to be considered is that the level of physical activity could have a protective role in increasing blood pressure regardless of weight, which could contribute to the observed results.[42]

Zangh *et al.*[43] observed an increased risk of elevated BP in children and adolescents with low BMI but high WC, and their health risks were underestimated when assessed by BMI alone. Dimitriadis *et al.*[44] observed in a 6-year follow-up study that WC might be an independent predictor of coronary artery disease when compared with BMI and the waist-to-hip ratio in hypertensive adults. In this study, the relationship between BMI and BP was lost with the inclusion of WC. On the other hand, the relationship between WC and BP remained significant after the adjustment for BMI, suggesting that WC is a better independent predictor of BP than BMI.

Several factors may explain the link between SBP and WC. There is a higher sensitivity of catecholamine in subcutaneous fat cells in the abdominal region.[45] The molecules released by hypertrophic fat cells acts in the formation of angiotensin, which affects diuresis and vasoconstrictor hormones.[46] Finally, there is increased cardiac sympathetic modulation to the heart, activated by leptin, which is released by adipokines.[47]

Table 4 Adjusted analysis between anthropometric indicators and systolic blood pressure in adolescents

	Boys		*Girls*		*Total*	
	β	*CI (95%)*	β	*CI (95%)*	β	*CI (95%)*
Systolic blood pressure						
10–13 years						
BMI[a]	**0.80**	**0.49;1.11**	**0.89**	**0.52;1.25**	**0.85**	**0.61;1.09**
BMI[b]	−0.44	−0.60; 0.50	−0.10	−0.77; 0.97	0.04	−0.42; 0.52
WC[a]	**0.44**	**0.30; 0.58**	**0.41**	**0.25; 0.56**	**0.42**	**0.32; 0.53**
WC[b]	**0.46**	**0.21; 0.71**	**0.37**	**0.01; 0.73**	**0.41**	**0.20; 0.61**
14–17 years						
BMI[a]	0.51	−0.04; 1.07	**0.50**	**0.14; 0.85**	**0.45**	**0.16; 0.75**
BMI[b]	−0.90	−1.92; 1.24	−0.27	−0.92; 0.38	−0.54	−1.08; 0.01
WC[a]	**0.38**	**0.15; 0.61**	**0.32**	**0.15; 0.48**	**0.33**	**0.20; 0.46**
WC[b]	**0.70**	**0.27; 1.12**	**0.42**	**0.11; 0.73**	**0.54**	**0.29; 0.78**

Abbreviations: BMI, body mass index; CI, confidence interval; WC, waist circumference.
[a]Model 1 = socioeconomic level, smoking status, alcohol consumption, sedentary behaviors and physical activity.
[b]Model 2 = adjusted by model 1 and BMI or WC.
The bold entries mean that these results were statistically significant ($P < 0.05$).

Table 5 Adjusted analysis between anthropometric indicators and diastolic blood pressure in adolescents

	Boys		*Girls*		*Total*	
	β	*CI (95%)*	β	*CI (95%)*	β	*CI (95%)*
Diastolic blood pressure						
10–13 years						
BMI[a]	**0.49**	**0.21; 0.77**	**0.71**	**0.47; 0.97**	**0.60**	**0.41; 0.78**
BMI[b]	−0.16	−0.66; 0.33	0.41	−0.20; 1.01	−0.05	−0.31; 0.43
WC[a]	**0.29**	**0.17; 0.41**	**0.30**	**0.20; 0.40**	**0.29**	**0.21; 0.37**
WC[b]	**0.26**	**0.07; 0.45**	**0.34**	**0.18; 0.50**	**0.29**	**0.17; 0.41**
14–17 years						
BMI[a]	0.31	−0.03; 0.66	**0.64**	**0.41; 0.88**	**0.55**	**0.36; 0.75**
BMI[b]	0.48	−0.19; 1.13	**0.60**	**0.15; 1.03**	**0.61**	**0.25; 0.97**
WC[a]	0.09	−0.06; 0.23	**0.27**	**0.15; 0.38**	**0.20**	**0.11; 0.29**
WC[b]	−0.07	−0.12;0.26	**0.17**	**0.01; 0.31**	**0.13**	**0.01; 0.25**

Abbreviations: BMI, body mass index; CI, confidence interval; WC, waist circumference.
[a]Model 1 = Socioeconomic level, smoking status, alcohol consumption, sedentary behaviors and physical activity.
[b]Model 2 = Adjusted by model 1 and BMI or WC.
The bold entries mean that these results were statistically significant ($P < 0.05$).

Practical applications of this study include that WC and BMI are easily collected measurements, both at school and in the home, which can diagnose potential risk factors for cardiometabolic problems at an early age. Limitations of this study should be considered. The cross-sectional design precludes causality inferences. We performed only two blood pressure assessments in a single day, and thus overestimates of BP values might have occurred.[48] Screen time was the only sedentary behavior analyzed, and whether similar results occur with other sedentary behaviors is not known. Maturation was not assessed. Although the results were stratified by age, the influence of maturational stage cannot be discarded. As positive aspects of this study, we note the representative sample and control for multiple confounders in the analyses of the association between HBP and BMI and WC. It is also worth noting that the stratification analyses by sex is an important aspect of the study.

In conclusion, our results showed that both BMI and WC had a positive relation with HBP in the pediatric population.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

We thank the National Council for Research and Development (CNPq, process number:442395/2014-0).

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