BMJ Open

Comparisons of body mass index, waist circumference, waist-to-height ratio and a body shape index (ABSI) in predicting high blood pressure among Malaysian adolescents: a cross-sectional study

Joyce Ying Hui Tee,[1] Wan Ying Gan ,[1] Poh Ying Lim[2]

To cite: Tee JYH, Gan WY, Lim PY. Comparisons of body mass index, waist circumference, waist-to-height ratio and a body shape index (ABSI) in predicting high blood pressure among Malaysian adolescents: a cross-sectional study. *BMJ Open* 2020;**10**:e032874. doi:10.1136/bmjopen-2019-032874

► Prepublication history for this paper is available online. To view these files, please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2019-032874).

Received 10 July 2019
Revised 11 November 2019
Accepted 09 December 2019

Check for updates

[1]Department of Nutrition and Dietetics, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Serdang, Malaysia
[2]Department of Community Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, Serdang, Malaysia

Correspondence to
Dr Wan Ying Gan;
wanying@upm.edu.my

ABSTRACT

Objective To compare the performance of different anthropometric indices including body mass index (BMI), waist circumference (WC), waist-to-height ratio (WHtR) and a body shape index to predict high blood pressure (BP) in adolescents using the 90th and 95th percentiles as two different thresholds.

Design Cross-sectional study.

Setting Probability proportionate to size was used to randomly select two schools in Selangor state, Malaysia.

Participants A total of 513 adolescents (58.9% women and 41.1% men) aged 12–16 years were recruited.

Primary and secondary outcome measures Weight, height, WC and BP of the adolescents were measured. The predictive power of anthropometric indices was analysed by sex using the receiver operating characteristic curve.

Results BMI and WHtR were the indices with higher areas under the curve (AUCs), yet the optimal cut-offs to predict high BP using the 95th percentile were higher than the threshold for overweight/obesity. Most indices showed poor sensitivity under the suggested cut-offs. In contrast, the optimal BMI and WHtR cut-offs to predict high BP using the 90th percentile were lower (men: BMI-for-age=0.79, WHtR=0.46; women: BMI-for-age=0.92, WHtR=0.45). BMI showed the highest AUC in both sexes but had poor sensitivity among women. WHtR presented good sensitivity and specificity in both sexes.

Conclusions These findings suggested that WHtR might be a useful indicator for screening high blood pressure risk in the routine primary-level health services for adolescents. Future studies are warranted to involve a larger sample size to confirm these findings.

Strengths and limitations of this study

- Sex-specific analysis of receiver operating characteristic was conducted.
- Two separate analyses using the 90th and 95th percentile cut-offs for differentiating high blood pressure (BP) were performed.
- Causal association between anthropometric indices and high BP cannot be determined.
- Confounding effects of the potential covariates such as age, physical activity level, family hypertension history and obesity were not determined.

INTRODUCTION

Hypertension has been recognised as the leading risk factor for global disease burden. It is the most common medical condition that is linked to cardiovascular diseases (CVDs), which is the main source of mortality around the world.[1] In 2015, the global prevalence of raised blood pressure (BP) was 24.1% in men and 20.1% in women.[2] In Malaysia, one in three Malaysian adults is hypertensive.[3] Strong evidence suggested that raised BP tracks well from childhood to adulthood, yet paediatric hypertension remains largely underdiagnosed. Moreover, no data regarding the national prevalence of hypertension among Malaysian adolescents have been reported. This could probably be due to a more complicated classification of BP that varies with age, sex and height, while routine BP screening was not emphasised in paediatric clinics.

Many studies discovered the rising trend of hypertension in children and adolescents was attributed to the obesity epidemic.[4 5] Obese adolescents were found to have a fourfold to 10-fold higher risk of developing hypertension.[6] Even in normal-weight adolescents, the odds of having hypertension increased with z-scores of body mass index (BMI) adjusted for age, sex and height.[7] A large cohort of healthy adolescents from Israel found that every increase in a unit of BMI was associated with an increased risk of systolic BP above 130 mm Hg.[8] These results concurrently supported the established association of hypertension and excess adiposity, yet the relation with the distribution of body fat remains controversial.[9 10] Thus, the relationships are not fully understood. There are lack of data on the relationship between body fat distribution and the risk of high BP among Malaysian adolescents. In addition, the universal BMI classification system to define obesity in children and adolescents may not accurately capture the comparable levels of body fatness of different ethnic groups. In contrast, waist circumference (WC) was proposed as an alternative to BMI when examining body composition and disease risk because of its sensitivity towards body size, body fat percentage and fat distribution.[11] Previous data have shown that WC was a better predictor of metabolic morbidities such as hypertension and impaired blood glucose in adolescents.[12 13]

Recently, waist-to-height ratio (WHtR) was suggested as a simpler indicator of abdominal obesity that has greater practical advantages than BMI and WC.[14] Several reviews highlighted the superiority of WHtR in predicting cardiometabolic risks among adults and adolescents, while its interpretation can be applied to different ethnic groups and does not require sex-dependent or age-dependent cut-offs.[15 16] Despite so, some studies showed that different anthropometric indices did not differ in their predictive abilities for CVD risk factors.[17 18] On the other hand, a body shape index (ABSI) as an indicator of body volume (corresponds to the fraction of abdominal fat to peripheral tissue) was found to predict high BP better than WC and BMI in Portuguese adolescents.[9] However, Xu *et al*[19] proposed that BMI was sufficient to predict BP in adolescents, while no association between ABSI and BP was observed. Overall, practical tools are needed to be established in determining the risk of high BP in a quick and accurate manner among adolescents.

Given the marked increase of paediatric hypertension alongside with the drastic rise of childhood obesity, early detection of high BP via screening using anthropometric indices in adolescents could be an effective prevention of future hypertension and CVD risk. In order to analyse the discrimination abilities of anthropometric indices, the use of receiver operating characteristic (ROC) analysis has been recommended.[20] Cut-off values of anthropometric indices for predicting high BP could be established by running ROC analysis, which is invariably useful in screening. However, studies from different countries and ethnicities have variations in the conclusions regarding the superiority of one or the other anthropometric indices and the related cut-off values to identify high BP. It is believed that ethnic variation among population from different regions might need different cut-off values and the use of different anthropometric indices to predict high BP.

Up to date, very few studies performed ROC analysis and compared several anthropometric indices in Asian adolescent populations.[15] While early detection of high BP is possible through conducting routine anthropometric assessment in school settings, more scientific data need to be compiled to establish which indices and at which cut-off values of the indices should be used to identify adolescents with high risk of hypertension. To the best of our knowledge, no previous studies in Malaysia or neighbouring Southeast Asian countries have investigated the best indicator for high BP and locally appropriate cut-off value for the prediction of high BP among adolescents. Therefore, the present study aimed to compare the predictive power of different anthropometric indices for high BP while also to determine the optimal cut-off values for differentiating high BP among Malaysian adolescents.

MATERIALS AND METHODS

Study design and population

This was a cross-sectional study involving Malaysian adolescents aged between 12 and 16 years. The probability proportionate to size was used as the sampling method, in which two government secondary schools in Selangor state were randomly selected. The estimated sample size of 395 was calculated using the one proportion formula based on the prevalence of hypertension of 11.6% among 13–17 years old Malaysian adolescents in a local study,[21] considering power of 90%, precision of 0.05, significance level of 0.05, design effect of 2.0 and expected response rate of 80%. Adolescents who had medical conditions (eg, sleep disorders, diabetes, thyroid disease and CVDs), neurological or psychiatric disorders (eg, autism spectrum disorders, anxiety and depression), learning disabilities or developmental delays were excluded from the study (n=5). Five hundred and sixty eligible adolescents were recruited and 513 of them agreed to participate in this study.

Approval to conduct the study was obtained from the Ministry of Education, Selangor Department of Education, as well as from the principals of the selected schools. Prior to data collection, all eligible adolescents were explained about the study's objectives and the activities they would be involved in, with an information sheet provided. A set of parent's and adolescent's consent forms were taken home by the adolescents. All the completed forms were collected back on the next day. Adolescents who returned the parent's and adolescent's consent form were recruited into this study. Each of them underwent both anthropometric and BP measurements.

Anthropometric measurements

All measurements were taken twice to obtain the average value for further data analysis. Adolescents' body weight and height were taken in light clothing and without shoes by using a TANITA weighing scale THD-306 (TANITA Corporation, Arlington Heights, Illinois, USA) and a SECA portable stadiometer 213 (SECA, Hamburg, Germany), respectively. The WHO AnthroPlus software V.1.0.4 (WHO, Geneva, Switzerland) was used to calculate the BMI-for-age z-score (BAZ) of the adolescents. They were further classified into several categories of body weight status according to the WHO Growth Reference 2007.[22] In terms of WC, adolescents were requested to fold their arms in front of their chest in a relaxed standing position while the measurements were taken using a Lufkin executive diameter pocket tape (Apex Tool Group, Apex, North Carolina, USA). According to the WC percentile chart for Malaysian childhood population, a WC of >90th percentile was used as the cut-off point to define abdominal obesity.[23] Besides, WHtR was computed by dividing WC (cm) by height (cm). Abdominal obesity was classified as WHtR ≥0.50.[24] ABSI of adolescents was calculated using the formula proposed by Xu *et al*[19] as shown below, with WC and height measured in metre. Higher ABSI indicated a greater fraction of visceral fat to body size.

$$ABSI = \frac{WC}{BMI^{0.45} \times Height^{0.55}}$$

BP measurement

BP was measured using a digital sphygmomanometer (Omron Model IA2 blood pressure monitor, Omron, Kyoto, Japan). Adolescents were asked to sit relaxed on a chair with their arms supported comfortably at the vertical level. They were classified as normal BP (<90th percentile), prehypertension (≥90th to <95th percentile), stage 1 (95th to 99th percentile) and stage 2 hypertension (>99th percentile) using the normative tables of BP based on age and sex adjusted for height percentiles.[25] For ROC analysis, adolescents were separated into two BP categories: group A included those with normal BP (<95th percentile: normal and prehypertension) and high BP (≥95th percentile: hypertension stages 1 and 2) and group B included those with normal BP (<90th percentile: normal) and high BP (≥90th percentile: prehypertension and hypertension stages 1 and 2).

Statistical analysis

All data were analysed using the IBM SPSS Statistics V.24. The descriptive data on body composition and BP of adolescents were summarised in the total sample and by sexes. ROC analysis was employed to compare the predictive power of different body composition indices in differentiating the classification of prehypertension and hypertension among the adolescents. The area under the curve (AUC) was used to summarise the predictive power of these measures for high BP. An AUC of 1 reflected a perfectly accurate test, whereas 0.5 suggested that the test has no discriminatory ability. An AUC <0.7 was considered as poor, 0.7–0.8 as acceptable, 0.8–0.9 as good and >0.9 as excellent.[26] The optimal cut-off values of the anthropometric indices to predict high BP were estimated based on the largest value of the Youden index (J=SE+Sp−1).[27] Sensitivity, specificity and the Youden index were used to evaluate the validity of different indices in predicting high BP. The acceptable level of sensitivity and specificity of screening tests adopted in this study was 70.0%.[28] The level of significance for all tests was set at p<0.05.

Patient and public involvement

Study participants were generally healthy adolescents and no patients were involved in the study. Adolescents and their parents were not involved in the design and conduct of the study. The individual results such as weight, height, WC and BP were recorded into individual health information, and this information was given back to the adolescents on the same day of data collection.

RESULTS

The anthropometric characteristics and BP of the adolescents in the full sample and by sex are shown in table 1. Based on the classifications of BMI-for-age, one in three of the adolescents was overweight or obese (32.6%). The prevalence of abdominal obesity based on WC and WHtR classifications were 14.0% and 18.5%, respectively. Almost one-fifth of the adolescents were classified as prehypertension (19.1%), whereas 11.9% of them were at hypertension stage 1 or 2.

ROC analysis based on group A

Table 2 summarises the results of the ROC analysis of various anthropometric indices with high BP (≥95th percentile) among adolescents. These findings were based on group A whereby prehypertensive adolescents were grouped in the normal BP group (normal and prehypertensive) versus the high BP group (hypertension stages 1 and 2). Overall, the AUCs of BMI-for-age, WC and WHtR (range from 0.81 to 0.86) indicated good predictive power in assessing high BP of adolescents, whereas the AUC of ABSI in the total sample was less than 0.8, showing an acceptable level of predictive power. In men, the AUC of BMI was the highest (0.817), followed by WHtR (0.789), WC (0.781) and ABSI (0.709). As for the women, WC (0.863) showed the highest AUC, whereas BMI and WHtR had the same AUC (0.854) with the lowest for ABSI (0.756). Based on the Youden index, the optimal cut-off values of BMI-for-age for predicting high BP were 1.87 in men and 1.18 in women, whereas for WC were the 78th percentile for men and the 73rd percentile for women. Optimal WHtR cut-off values were 0.52 for men and 0.45 for women, whereas ABSI cut-off values to identify hypertensive adolescents were 0.15 for men and 0.14 for women. In the full sample and the women group, WHtR has the highest sensitivity (>90.0%) in identifying hypertensive adolescents, whereas BMI-for-age showed the highest specificity (>80.0%) in identifying those with normal BP. Most indices did not show an acceptable level of sensitivity (<70.0%) for the prediction of high BP in men, while the index with the highest specificity was WC. When further analysis was performed by comparing the AUC values of WHtR with other anthropometric indices for both sexes, only ABSI showed a significant difference with WHtR.

ROC analysis based on group B

Table 3 shows the results of the ROC analysis of various anthropometric indices with high BP (≥90th percentile) based on group B, whereby prehypertensive and hypertensive adolescents were grouped together in the high BP group. The AUCs of BMI (0.793), WC (0.781) and WHtR (0.781) showed acceptable to good predictive power for high BP, except for ABSI (<0.70). The AUC of BMI-for-age

Table 1 Mean, SD, range and classifications of BMI-for-age, WC, WHtR, ABSI and blood pressure of adolescents (n=513)

	N (%)		
Variables	**Total (n=513)**	**Males (n=211)**	**Females (n=302)**
BMI-for-age z-score mean±SD (range)	0.25±1.52 (–3.95–4.6)	0.41±1.60 (–3.95–4.16)	0.13±1.45 (–3.64–3.95)
Thinness	35 (6.8)	16 (7.6)	19 (6.3)
Normal	311 (60.6)	114 (54.0)	197 (65.2)
Overweight	93 (18.1)	40 (19.0)	53 (17.5)
Obesity	74 (14.5)	41 (19.4)	33 (11.0)
WC (cm) mean±SD (range)	69.83±10.57 (52.50–111.0)	71.35±11.08 (52.6–111.0)	68.77±10.08 (52.0–108.0)
Normal	441 (86.0)	179 (84.8)	262 (86.8)
Abdominal obesity	72 (14.0)	32 (15.2)	40 (13.2)
WHtR mean±SD (range)	0.45±0.06 (0.32–0.71)	0.45±0.07 (0.32–0.68)	0.44±0.06 (0.32–0.71)
Normal	418 (81.5)	163 (77.3)	418 (81.5)
Abdominal obesity	95 (18.5)	48 (22.7)	95 (18.5)
ABSI mean±SD (range)	0.1389±0.0074 (0.12–0.17)	0.1402±0.0005 (0.13–0.17)	0.1379±0.0004 (0.12–0.16)
Systolic BP mean±SD (range)	113.4±14.4 (79.0–159.0)	116.2±14.7 (82.0–159.0)	111.4±13.9 (79.0–155.5)
Diastolic BP mean±SD (range)	67.1±9.8 (63.8–35.0)	65.5±9.6 (42.0–92.6)	68.2±9.9 (35.0–98.8)
BP classification			
Normal (<90th percentile)	354 (69.0)	147 (69.7)	207 (68.5)
Prehypertension (≥90th to <95th percentile)	98 (19.1)	38 (18.0)	60 (19.9)
Hypertension stage 1 (95th to 99th percentile)	43 (8.4)	21 (10.0)	22 (7.3)
Hypertension stage 2 (>99th percentile)	18 (3.5)	5 (2.4)	13 (4.3)

ABSI, a body shape index; BMI, body mass index; BP, blood pressure; WC, waist circumference; WHtR, waist-to-height ratio.

was the highest in both sexes, followed by WHtR, WC and ABSI in men and WC, WHtR and ABSI in women. For the prediction of high BP, the optimal cut-off values of BMI-for-age were 0.79 and 0.92 in men and women, respectively. The optimal WC cut-off points used to discriminate high BP were the 72nd percentile for men and the 70th percentile for women, whereas WHtR cut-off points were 0.46 in men and 0.45 in women. ABSI cut-off values to identify hypertensive adolescents were 0.14 in both sexes. WHtR consistently showed good sensitivity and specificity (>70.0%) in predicting high BP for both sexes and the full sample. The highest percentage of hypertensive adolescents could be identified based on WHtR in women (sensitivity: 71.6%) and BMI-for-age in men (sensitivity: 79.7%). On the other hand, BMI-for-age showed the highest specificity (84.5%) in women, whereas WHtR had the highest specificity in men (80.3%). Further analysis was performed to compare the AUC values of WHtR with other anthropometric indices for both sexes. Only ABSI showed a significant difference with WHtR. Overall, considering the results of AUC, sensitivity, specificity and Youden index, WHtR was considered as the best anthropometric indices in predicting high BP among Malaysian adolescents alongside BMI.

DISCUSSION

Easy-to-use screening tool for hypertension is the fundamental for the detection of adolescents at risk for early intervention. This study analysed the existing anthropometric indices for their predictive power of high BP in adolescents based on two different grouping methods. Comparable results were obtained from the ROC analysis using the ≥95th percentile cut-off points (group A) versus the ≥90th percentile (group B) to define high BP. Increasing evidence demonstrated the predictive power of different anthropometric indices for raised BP as defined by the ≥95th percentile systolic or diastolic BP in children and adolescents.[29–31] Yet, none of the studies established the optimal cut-off values of anthropometric measures in identifying those with high BP, except for Liang *et al*[29] who reported WC cut-off values. The current study reported the optimal cut-off values for the different anthropometric indices in identifying those adolescents with high BP. Given that the prevalence of hypertension appears to be increasing in adolescents, using a quick and accurate screening method in measuring BP level in this population has been considered important for public health actions.

Table 2 Area under ROC curve (AUC), optimal cut-off values, sensitivities, specificities and Youden index of anthropometric indices in predicting high blood pressure according to sex in group A

Body composition indices	AUC (95% CI)	P value	Cut-off value	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	Youden index	χ^2*	P value*
Total (n=513)								
BMI-for-age z-score	0.835 (0.782 to 0.889)	<0.001	1.47	68.9(0.556 to 0.798)	83.6 (0.798 to 0.869)	0.525	0.62	0.433
WC percentile	0.828 (0.768 to 0.888)	<0.001	73.0	80.3 (0.678 to 0.890)	72.1 (0.677 to 0.762)	0.525	0.15	0.703
WHtR	0.823 (0.759 to 0.887)	<0.001	0.44	90.2 (0.791 to 0.959)	63.7 (0.591 to 0.681)	0.539	–	–
ABSI	0.735 (0.662 to 0.809)	<0.001	0.14	68.9 (0.556 to 0.798)	71.5 (0.670 to 0.755)	0.403	19.63	<0.001
Males (n=211)								
BMI-for-age z-score	0.817 (0.723 to 0.912)	<0.001	1.87	69.2 (0.481 to 0.849)	84.3 (0.781 to 0.891)	0.536	2.38	0.123
WC percentile	0.781 (0.671 to 0.891)	<0.001	78.0	57.7 (0.372 to 0.760)	90.8 (0.855 to 0.944)	0.485	0.30	0.581
WHtR	0.789 (0.675 to 0. 903)	<0.001	0.52	65.4 (0.444 to 0.821)	87.6 (0.817 to 0.918)	0.530	–	–
ABSI	0.709 (0.577 to 0.841)	<0.001	0.15	65.4 (0.444 to 0.821)	85.4 (0.793 to 0.900)	0.508	10.35	0.001
Females (n=302)								
BMI-for-age z-score	0.854 (0.793 to 0.916)	<0.001	1.18	71.4 (0.535 to 0.848)	83.5 (0.784 to 0.877)	0.549	0.00	0.985
WC percentile	0.863 (0.798 to 0.927)	<0.001	73.0	85.7 (0.690 to 0.946)	74.2 (0.684 to 0.792)	0.599	0.19	0.667
WHtR	0.854 (0.781 to 0.927)	<0.001	0.45	94.3 (0.795 to 0.990)	65.9 (0.599 to 0.716)	0.602	–	–
ABSI	0.756 (0.670 to 0.843)	<0.001	0.14	82.9 (0.657 to0.928)	62.9 (0.568 to 0.687)	0.458	11.72	0.001

*Comparison of the AUC value of WHtR with the other anthropometric indices.
ABSI, a body shape index; AUC, area under the curve; BMI, body mass index; ROC, receiver operating characteristic; WC, waist circumference; WHtR, waist-to-height ratio.

Using the ≥95th percentile threshold to define high BP, we found that anthropometric indices had relatively lower sensitivities (<70.0%) in prediction, especially among the men. In both sexes, the optimal cut-off values of BMI-for-age to predict high BP were higher than the reference criteria used to identify overweight (BAZ ≥1).[22] Likewise, the optimal cut-off value of WHtR in male adolescents was above the common cut-off that defines abdominal obesity (WHtR ≥0.5). These results were due to the high proportion of prehypertensive adolescents with excess adiposity. In the prehypertension group, more than half of them were overweight or obese (based on the BMI-for-age), whereas more than one-third of the male adolescents (36.8%) were abdominally obese (based on the WHtR). Concurrently, a previous study showed that prehypertensive adolescents were more likely to be overweight and obese, with more than fourfold greater incidence rate of hypertension (up to 7% per year) as compared with those with normal BP.[32] In addition, emerging data from cohort studies showed that prehypertension increased the risk of CVD over time, even after adjusting for multiple cardiovascular risk factors.[33 34] Given the strong tracking of BP from childhood to adulthood, careful attention should be given to prehypertensive condition especially during adolescence. Hence, it is also suggested that more accurate prediction of high BP from anthropometric indices should be based on the 90th percentile threshold.

On the other hand, current results based on group B confirmed the significant ability of BMI, WC, WHtR and ABSI to discriminate both hypertensive and prehypertensive adolescents. These important findings replicated previous studies on the use of the 90th percentile for raised BP in adolescents of different ethnic groups.[6 35] The AUC of BMI-for-age was the highest, whereas the AUCs of WC and WHtR were comparable and performed similarly well to predict high BP in adolescents. However, BMI-for-age and WC showed low sensitivities in identifying women with high BP. Considering both sensitivity and specificity, WHtR appeared to be the best in discriminating high BP among men and women in this study. Altogether, these results suggest that WHtR is the most accurate indicator to predict the presence of elevated BP alongside BMI among adolescents in this study.

Studies found that BMI and WC were good predictors of elevated BP in adolescents.[9 35] However, both indices exhibited low sensitivity in discriminating individuals with high BP.[36 37] This could be due to the inability of BMI to measure fat distribution and differentiate adipose tissues and muscle mass. Previous findings also discovered the relatively weak association of BMI and per cent body fat in Asians as compared with other ethnic groups, and a large proportion of individuals with high body fat content remained undetectable based on their BMI.[38 39] Thus, screening by BMI alone could potentially lead to

Table 3 Area under ROC curve (AUC), optimal cut-off values, sensitivities, specificities and Youden index of anthropometric indices in predicting high blood pressure according to sex in group B

Body composition indices	AUC (95% CI)	P value	Cut-off value	Sensitivity (%) (95% CI)	Specificity (%) (95% CI)	Youden index	χ^2*	P value*
Total (n=513)								
BMI-for-age z-score	0.793 (0.750 to 0.836)	<0.001	0.79	71.1 (0.633 to 0.778)	76.6 (0.717 to 0.808)	0.477	1.45	0.228
WC percentile	0.781 (0.737 to 0.825)	<0.001	73.0	66.0 (0.581 to 0.732)	80.2 (0.756 to 0.842)	0.462	0.00	0.993
WHtR	0.781 (0.736 to 0.826)	<0.001	0.44	74.2 (0.666 to 0.807)	71.5 (0.664 to 0.761)	0.457	–	–
ABSI	0.688 (0.637 to 0.739)	<0.001	0.14	57.2 (0.491 to 0.650)	74.3 (0.691 to 0.784)	0.315	27.71	<0.001
Males (n=211)								
BMI-for-age z-score	0.808 (0.744 to 0.872)	<0.001	0.79	79.7 (0.674 to 0.883)	70.7 (0.626 to 0.778)	0.504	0.51	0.475
WC percentile	0.788 (0.720 to 0.857)	<0.001	72.0	70.3 (0.574 to 0.808)	78.9 (0.713 to 0.850)	0.492	0.62	0.430
WHtR	0.799 (0.732 to 0.865)	<0.001	0.46	70.3 (0.574 to 0.808)	80.3 (0.727 to 0.862)	0.506	–	–
ABSI	0.730 (0.650 to 0.809)	<0.001	0.14	70.3 (0.574 to 0.808)	72.1 (0.640 to 0.790)	0.424	8.82	0.003
Females (n=302)								
BMI-for-age z-score	0.786 (0.729 to 0.843)	<0.001	0.92	63.2 (0.526 to 0.726)	84.5 (0.787 to 0.890)	0.477	1.86	0.172
WC percentile	0.777 (0.719 to 0.835)	<0.001	70.0	63.2 (0.526 to 0.726)	81.2 (0.750 to 0.861)	0.443	0.52	0.471
WHtR	0.768 (0.708 to 0.828)	<0.001	0.45	71.6 (0.613 to 0.801)	72.9 (0.663 to 0.788)	0.445	–	–
ABSI	0.665 (0.598 to 0.731)	<0.001	0.14	54.7 (0.442 to0.649)	70.0 (0.632 to 0.761)	0.248	16.70	<0.001

*Comparison of the AUC value of WHtR with the other anthropometric indices.
ABSI, a body shape index; AUC, area under the curve; BMI, body mass index; ROC, receiver operating characteristic; WC, waist circumference; WHtR, waist-to-height ratio.

underestimation of obesity-related diseases including hypertension. Given the close link of excess visceral fat and metabolic complications, indicators that reflect abdominal obesity such as WC and WHtR may perform better in predicting cardiometabolic risks.[29] Nonetheless, WC is a height-dependent variable; thus, not all individuals with the same WC had a similar risk of disease. Consistent findings revealed a higher metabolic risk in shorter individuals than taller ones at a given WC.[40 41] Even with the use of sex-specific WC percentile adjusted for age, WC might overestimate the risk of hypertension in tall adolescents but underestimate risk in short adolescents since height is a risk factor of hypertension.[42]

Findings from various Asian countries concurrently supported the superiority of WHtR over WC and BMI in predicting hypertension among adolescents.[42] Similar results were demonstrated in a meta-analysis review focusing on the Asian population. Nevertheless, some studies showed the poor prediction of WHtR for hypertension in children and adolescents mainly in European countries.[43 44] The discrepancy of results could be due to ethnicity differences. As compared with Caucasians, the Asian population tends to have a greater amount of abdominal fat and total body fat but shorter height, which were associated with higher risk of hypertension through several mechanisms such as systemic inflammation, leptin resistance, hydrostatic blood vessel pressure and fat distribution around the kidneys.[45] Variations in term of genetic-environmental interaction, socioeconomic status, cultural influences and lifestyle-related risk factors such as salt intake and physical activity level across ethnicity groups could affect the findings.[46 47] Besides, the variation of WHtR across age might reduce its efficacy to detect abdominal fat in children undergoing pubertal growth, since the rapid increase in height was relatively greater than the increase in WC.[48] Hence, the use of WHtR as a simple tool to measure and interpret represents an advantageous alternative to screen for the risk of high BP not only in the clinical setting, but also at the community setting.

The current study found that the optimal cut-off points of BMI, WC and WHtR for the prediction of high BP were lower than the threshold to define obesity in adolescents, replicating the results of previous studies.[37 49] In the present study, the optimal WHtR cut-off values were 0.46 in men and 0.45 in women, which were close to the WHtR cut-off values (<0.5) reported by previous studies for the prediction of hypertension[37] as well as metabolic syndrome[50] and CVD risk among adolescents.[51] Although a WHtR of ≥0.5 was previously proposed as the universal cut-off value to assess abdominal obesity and cardiometabolic risk,[14] the cut-off of 0.5 resulted in poor sensitivity in predicting CVD risk among adolescents and may not be efficiently used across different ethnic groups.[52] Since Asians are naturally shorter in height than Europeans of the same age and sex, lower WHtR cut-off points may be required for better accuracy in predicting cardiometabolic risks in Asian children and adolescents.

Compared with other indices, ABSI presented the worst predictive power and sensitivity in identifying high BP of the adolescents in this study. ABSI was first proposed as an indicator to better reflect visceral fat over peripheral tissue; thus, it was found to be more associated with mortality hazards than BMI and WC in American adults.[53] However, findings from subsequent studies were largely inconsistent about the usefulness of ABSI especially in determining hypertension and CVD risk. While combined obesity measure such as ABSI presented greater predictability of mortality risk, some studies found that ABSI was not capable of identifying CVD, CVD risk and metabolic syndrome in the adult population.[54 55] In a study done among Portuguese adolescents, both systolic and diastolic BPs were better predicted by ABSI as compared with BMI and WC, but an unexpected inverse association of ABSI and BP was found.[9] Xu *et al*[19] highlighted that the result was due to the inappropriate scaling exponents of ABSI in adolescents plus the confounding effect of BMI. Yet, the newly corrected ABSI was neither correlated to adolescents' BP nor significantly differentiated to those with high BP, after adjusting for BMI.[19] Likewise, recent studies of adolescents failed to obtain significant association between ABSI and BP.[56 57] Similar results were found in adults whereby ABSI had the smallest OR and AUC for the prediction of hypertension.[58]

Based on the results of systematic review and meta-analysis, Ji *et al*[59] concluded that ABSI was superior in predicting premature mortality risk than BMI and WC, but it underperformed in predicting chronic diseases including hypertension. While the underlying mechanisms of these contrasting results for ABSI remained unknown, variations in age, sex and ethnicity might give rise to the discrete findings. Given that both mortality and ABSI increased significantly with age,[53] it was suggested that age should be considered when assessing the mortality risk of different populations. In relation to hypertension, Cheung[60] observed limited applicability of the original ABSI in the adult population of Indonesia, whereas the locally adapted ABSI performed slightly better yet less accurate than BMI and WC in predicting the incidence rate of hypertension. Cheung[60] also suggested that the same structure but different exponents of ABSI should be adopted for men and women for optimal performance, and it may not be applied uniformly across different populations. Therefore, it is possible that these limitations confined the predictability of ABSI for hypertension in our study.

In term of practical application, the findings of this study bring some points to be considered in future public health actions. First, it is important to have routine measurement for BP in school and clinic settings in order to improve the early detection, prevention and treatment of hypertension in adolescents. WHtR may serve as a simple and inexpensive screening tool to identify high BP among adolescents in schools and those at risk can be referred for further diagnostic evaluation in hospitals. Second, it is essential to develop and implement effective public health strategies to prevent and control prehypertension, hypertension and obesity among adolescents.

Several limitations inherent to this study are worth noting. First, the cross-sectional design of this study does not infer the causality of associations between anthropometric indices and high BP. In other words, the predictive power measured by the ROC analysis does not suggest the ability to predict the development of hypertension; it is rather indicative of the ability to detect the presence of hypertension. Second, the confounding effects from potential covariates such as age, physical activity level, family hypertension history and obesity could not be completely excluded since multiple factors were associated with the development of obesity and hypertension. In addition, pubertal status of the adolescents was not evaluated in this study. Third, generalisation of findings should be done cautiously as the study samples were randomly selected from Selangor state only. Further studies with larger samples should be conducted. On the contrary, the strengths of this study included the sex-specific analysis of ROC as body composition differed significantly between men and women. This study performed two separate analyses using the 90th and 95th percentile cut-offs for differentiating high BP, which allowed a better comparison of the predictive power of anthropometric indices to detect high BP in adolescents.

CONCLUSIONS

The findings of this study demonstrated that the high prevalence of hypertension was evident among Malaysian adolescents. As the first study to compare the prediction of high BP using two different cut-off points, we suggest that early detection of high BP by anthropometric screening in adolescents should be based on the 90th percentile BP cut-off to prevent underestimation of those at high risk of hypertension. WHtR might be a useful indicator for screening high BP risk in the school setting or in the routine primary-level health services for Malaysian adolescents alongside BMI, based on the optimal cut-off values of 0.45 in men and 0.46 in women. Unlike WC and BMI, WHtR is independent of age and sex, which provides greater convenience in terms of measurement and interpretation. Thus, WHtR can be practically used for fast and mass screening in clinical and community settings. Given its simplicity to measure and comprehend, WHtR has high potential value in the development of successful prevention and screening strategies for abdominal obesity and hypertension among adolescents.

Acknowledgements We greatly appreciate the schools and students for their participation and cooperation in this study.

Contributors All authors contributed to the study design, revising and improving the manuscript. JYHT carried out data collection, data analysis, data interpretation and drafted the manuscript. WYG and PYL contributed to data interpretation and provided a critical review of the manuscript.

Funding This study was supported by Putra Grant—Postgraduate Initiative (GP-IPS) from the Universiti Putra Malaysia, grant number GP/IPS/2017/9519900.

Competing interests None declared.

Patient consent for publication Obtained.

Ethics approval Ethics Committee for Research Involving Human Subject of Universiti Putra Malaysia (Reference No. FPSK(EXP16) P186).

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available upon reasonable request.

ORCID iD

Wan Ying Gan http://orcid.org/0000-0002-9016-3414

REFERENCES

1 Lozano R, Naghavi M, Foreman K, *et al*. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the global burden of disease study 2010. *Lancet* 2012;380:2095–128.
2 Zhou B, Bentham J, Di Cesare M, *et al*. Worldwide trends in blood pressure from 1975 to 2015: a pooled analysis of 1479 population-based measurement studies with 19·1 million participants. *Lancet* 2017;389:37–55.
3 Institute for Public Health. *The National Health and Morbidity Survey (NHMS) 2015. Non-communicable Disease, Risk Factors & Other Health Problems*. Volume 2. Institute for Public Health, National Institutes of Health, Ministry of Health Malaysia, 2015.
4 Kelly RK, Magnussen CG, Sabin MA, *et al*. Development of hypertension in overweight adolescents: a review. *Adolesc Health Med Ther* 2015;6:171–87.
5 da Silva KS, de Farias Júnior JC. Risk factors associated with high blood pressure in adolescents. *Rev Bras Med Esporte* 2007;2:213–6.
6 Koebnick C, Black MH, Wu J, *et al*. High blood pressure in overweight and obese youth: implications for screening. *J Clin Hypertens* 2013;15:793–805.
7 Tian C, Xu S, Wang H, *et al*. Blood pressure effects of adiposity in non-overweight children aged 6–17 years. *Ann Hum Biol* 2017;44:644–7.
8 Chorin E, Hassidim A, Hartal M, *et al*. Trends in adolescents obesity and the association between BMI and blood pressure: a cross-sectional study in 714,922 healthy teenagers. *Am J Hypertens* 2015;28:1157–63.
9 Duncan MJ, Mota J, Vale S, *et al*. Associations between body mass index, waist circumference and body shape index with resting blood pressure in Portuguese adolescents. *Ann Hum Biol* 2013;40:163–7.
10 Mushengezi B, Chillo P. Association between body fat composition and blood pressure level among secondary school adolescents in Dar ES Salaam, Tanzania. *Pan Afr Med J* 2014;19:327.
11 World Health Organization. *Waist circumference and waist-hip ratio: report of a WHO expert consultation*. Geneva: World Health Organization, 2011.
12 Lentferink YE, Elst MAJ, Knibbe CAJ, *et al*. Predictors of insulin resistance in children versus adolescents with obesity. *J Obes* 2017;2017:3793868.
13 Rodea-Montero ER, Evia-Viscarra ML, Apolinar-Jiménez E. Waist-to-height ratio is a better anthropometric index than waist circumference and BMI in predicting metabolic syndrome among obese Mexican adolescents. *Int J Endocrinol* 2014;2014:195407.
14 Ashwell M, Gibson S. Waist-to-height ratio as an indicator of 'early health risk': simpler and more predictive than using a 'matrix' based on BMI and waist circumference. *BMJ Open* 2016;6:e010159.
15 Yoo E-G. Waist-to-height ratio as a screening tool for obesity and cardiometabolic risk. *Korean J Pediatr* 2016;59:425–31.
16 Ashwell M, Gunn P, Gibson S. Waist-to-height ratio is a better screening tool than waist circumference and BMI for adult cardiometabolic risk factors: systematic review and meta-analysis. *Obes Rev* 2012;13:275–86.
17 Freedman DS, Kahn HS, Mei Z, *et al*. Relation of body mass index and waist-to-height ratio to cardiovascular disease risk factors in children and adolescents: the Bogalusa heart study. *Am J Clin Nutr* 2007;86:33–40.
18 Wormser D, Kaptoge S, Di Angelantonio E, *et al*. Separate and combined associations of body-mass index and abdominal adiposity with cardiovascular disease: collaborative analysis of 58 prospective studies. *Lancet* 2011;377:1085–95.
19 Xu Y, Yan W, Cheung YB. Body shape indices and cardiometabolic risk in adolescents. *Ann Hum Biol* 2015;42:70–5.
20 Browning LM, Hsieh SD, Ashwell M. A systematic review of waist-to-height ratio as a screening tool for the prediction of cardiovascular disease and diabetes: 0·5 could be a suitable global boundary value. *Nutr Res Rev* 2010;23:247–69.
21 Rampal L, KC N, Izzati IN, *et al*. Prevalence of hypertension among Malay adolescents in Putrajaya secondary schools, Malaysia, 2010 2011;7:53–60.
22 de Onis M, Onyango AW, Borghi E, *et al*. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* 2007;85:660–7.
23 Poh BK, Jannah AN, Chong LK, *et al*. Waist circumference percentile curves for Malaysian children and adolescents aged 6.0-16.9 years. *Int J Pediatr Obes* 2011;6:229–35.
24 McCarthy HD, Ashwell M. A study of central fatness using waist-to-height ratios in UK children and adolescents over two decades supports the simple message – 'keep your waist circumference to less than half your height'. *Int J Obes* 2006;30:988–92.
25 Ministry of Health. *Clinical practice guidelines: management of hypertension*. 4th edn. Ministry of Health Malaysia, 2013.
26 Hosmer D, Lemeshow S. *Applied logistic regression*. John Wiley and Sons, 2000.
27 Fluss R, Faraggi D, Reiser B. Estimation of the Youden index and its associated cutoff point. *Biom J* 2005;47:458–72.
28 Glascoe FP. Screening for developmental and behavioral problems. *Ment Retard Dev Disabil Res Rev* 2005;11:173–9.
29 Liang J-j, Chen Y-j, Jin Y, *et al*. Comparison of adiposity measures in the identification of children with elevated blood pressure in Guangzhou, China. *J Hum Hypertens* 2015;29:732–6.
30 Genovesi S, Antolini L, Giussani M, *et al*. Usefulness of waist circumference for the identification of childhood hypertension. *J Hypertens* 2008;26:1563–70.
31 Kromeyer-Hauschild K, Neuhauser H, Schaffrath Rosario A, *et al*. Abdominal obesity in German adolescents defined by waist-to-height ratio and its association to elevated blood pressure: the KiGGS study. *Obes Facts* 2013;6:165–75.
32 Falkner B, Gidding SS, Portman R, *et al*. Blood pressure variability and classification of prehypertension and hypertension in adolescence. *Pediatrics* 2008;122:238–42.
33 Huang Y, Wang S, Cai X, *et al*. Prehypertension and incidence of cardiovascular disease: a meta-analysis. *BMC Med* 2013;11:177.
34 Ishikawa Y, Ishikawa J, Ishikawa S, *et al*. Prehypertension and the risk for cardiovascular disease in the Japanese general population: the Jichi medical school cohort study. *J Hypertens* 2010;28:1630–7.
35 Beck CC, Lopes AdaS, Pitanga FJG. Anthropometric indicators as predictors of high blood pressure in adolescents. *Arq Bras Cardiol* 2011;96:126–33.
36 Li W-C, Chen I-C, Chang Y-C, *et al*. Waist-to-height ratio, waist circumference, and body mass index as indices of cardiometabolic risk among 36,642 Taiwanese adults. *Eur J Nutr* 2013;52:57–65.
37 Abbaszadeh F, Sarafraz N, Kafaei Atrian M, *et al*. Anthropometric indices in the prediction of hypertension in female adolescents. *Iran Red Crescent Med J* 2017;In Press.
38 Carpenter CL, Yan E, Chen S, *et al*. Body fat and body-mass index among a multiethnic sample of college-age men and women. *J Obes* 2013;2013:790654.
39 Nightingale CM, Rudnicka AR, Owen CG, *et al*. Patterns of body size and adiposity among UK children of South Asian, black African-Caribbean and white European origin: child heart and health study in England (Chase study). *Int J Epidemiol* 2011;40:33–44.
40 Schneider HJ, Klotsche J, Silber S, *et al*. Measuring abdominal obesity: effects of height on distribution of cardiometabolic risk factors risk using waist circumference and waist-to-height ratio. *Diabetes Care* 2011;34:e7.
41 Hsieh SD, Yoshinaga H. Do people with similar waist circumference share similar health risks irrespective of height? *Tohoku J Exp Med* 1999;188:55–60.
42 Song L, Shen L, Li H, *et al*. Height and prevalence of hypertension in a middle-aged and older Chinese population. *Sci Rep* 2016;6:39480.
43 Jung C, Fischer N, Fritzenwanger M, *et al*. Anthropometric indices as predictors of the metabolic syndrome and its components in adolescents. *Pediatr Int* 2010;52:402–9.
44 Bauer KW, Marcus MD, El ghormli L, *et al*. Cardio-metabolic risk screening among adolescents: understanding the utility of body

mass index, waist circumference and waist to height ratio. *Pediatr Obes* 2015;10:329–37.
45 Wang D, Li Y, Lee SG, *et al*. Ethnic differences in body composition and obesity related risk factors: study in Chinese and white males living in China. *PLoS One* 2011;6:e19835.
46 Cui J, Hopper JL, Harrap SB. Genes and family environment explain correlations between blood pressure and body mass index. *Hypertension* 2002;40:7–12.
47 Merlo J, Asplund K, Lynch J, *et al*. Population effects on individual systolic blood pressure: a multilevel analysis of the World Health Organization MONICA project. *Am J Epidemiol* 2004;159:1168–79.
48 Lo K, Wong M, Khalechelvam P, *et al*. Waist-to-height ratio, body mass index and waist circumference for screening paediatric cardio-metabolic risk factors: a meta-analysis. *Obes Rev* 2016;17:1258–75.
49 Febriana K, Nurani N, Julia M. Body mass index and waist-to-height ratio cut-offs as predictors of high blood pressure in adolescents. *Med J Indones* 2015;24:30–5.
50 Zhou D, Yang M, Yuan Z-P, *et al*. Waist-to-Height ratio: a simple, effective and practical screening tool for childhood obesity and metabolic syndrome. *Prev Med* 2014;67:35–40.
51 Matsha TE, Kengne A-P, Yako YY, *et al*. Optimal waist-to-height ratio values for cardiometabolic risk screening in an ethnically diverse sample of South African urban and rural school boys and girls. *PLoS One* 2013;8:e71133.
52 Zhao M, Bovet P, Ma C, *et al*. Performance of different adiposity measures for predicting cardiovascular risk in adolescents. *Sci Rep* 2017;7:43686.
53 Krakauer NY, Krakauer JC. A new body shape index predicts mortality hazard independently of body mass index. *PLoS One* 2012;7:e39504.
54 Wang H, Liu A, Zhao T, *et al*. Comparison of anthropometric indices for predicting the risk of metabolic syndrome and its components in Chinese adults: a prospective, longitudinal study. *BMJ Open* 2017;7:e016062.
55 Maessen MFH, Eijsvogels TMH, Verheggen RJHM, *et al*. Entering a new era of body indices: the feasibility of a body shape index and body roundness index to identify cardiovascular health status. *PLoS One* 2014;9:e107212.
56 Mameli C, Krakauer NY, Krakauer JC, *et al*. The association between a body shape index and cardiovascular risk in overweight and obese children and adolescents. *PLoS One* 2018;13:e0190426.
57 Giudici KV, Martini LA. Comparison between body mass index and a body shape index with adiponectin/leptin ratio and markers of glucose metabolism among adolescents. *Ann Hum Biol* 2017;44:489–94.
58 Chang Y, Guo X, Guo L, *et al*. The feasibility of two new anthropometric indices to identify hypertension in rural China. *Medicine* 2016;95:e5301.
59 Ji M, Zhang S, An R. Effectiveness of a body shape index (ABSI) in predicting chronic diseases and mortality: a systematic review and meta-analysis. *Obes Rev* 2018;19:737–59.
60 Cheung YB. "A Body Shape Index" in middle-age and older Indonesian population: scaling exponents and association with incident hypertension. *PLoS One* 2014;9:e85421.