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

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**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 (ABSI) 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 to 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 analyzed by sex using the receiver operating characteristic (ROC) 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 is an accurate and practical screening tool to predict high BP among Malaysian adolescents alongside BMI.

**Strengths and limitations of this study**

- Sex-specific analysis of ROC was conducted as body composition differed significantly between men and women.
- Two separate analyses using the 90th and 95th percentile cut-offs for differentiating high BP were performed, which allowed a better comparison of the predictive power of anthropometric indices to detect high BP in adolescents.
- Causal association between anthropometric indices and high BP cannot be determined because of the cross-sectional study design.
- Confounding effects of the potential covariates such as age, physical activity level, family hypertension history and obesity were not determined in this study.

## Introduction

Hypertension has been recognized 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 blood pressure tracks well from childhood to adulthood, yet pediatric 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 emphasized in pediatric 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 tenfold 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 mmHg.[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] 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, Yan and Cheung[19] proposed that BMI was sufficient to predict BP in adolescents, while no association between ABSI and BP was observed.

Given the marked increase of pediatric 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 analyze 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. Up to date, very few studies performed ROC analysis and compared several anthropometric indices in Asian adolescent populations.[15] 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. Adolescents who had medical conditions (e.g. sleep disorders, diabetes, thyroid disease and CVDs), neurological or psychiatric disorders (e.g. autism spectrum disorders, anxiety and depression), learning disabilities or developmental delays were excluded from the study. Five hundred sixty eligible adolescents were recruited and 513 of them agreed to participate in this study.

Before the commencement of the study, ethics approval was obtained from the Ethics Committee for Research Involving Human Subject of Universiti Putra Malaysia [Reference No. FPSK(EXP16) P186]. 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, IL, USA) and a SECA portable stadiometer 213 (SECA, Hamburg, Germany), respectively. The World Health Organization (WHO) AnthroPlus software version 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.[21] 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, NC, 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.[22] Besides, WHtR was computed by dividing WC (cm) by height (cm). Abdominal obesity was classified as WHtR ≥0.5.[23] ABSI of adolescents was calculated using the formula proposed by Xu, Yan and Cheung[19] as shown below, with WC and height measured in meter. Higher ABSI indicated a greater fraction of visceral fat to body size.

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

**Blood pressure measurement**

Blood pressure 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), pre-hypertension (≥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.[24] For ROC analysis, adolescents were separated into two BP categories: group A included those with normal BP (<95th percentile: normal and pre-hypertension) 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: pre-hypertension and hypertension stages 1 and 2).

**Statistical analysis**

All data were analyzed using the IBM SPSS Statistics 24 (IBM Corp., Armonk, NY, USA). The descriptive data on body composition and BP of adolescents were summarized 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 pre-hypertension and hypertension among the adolescents. The area under the curve (AUC) was used to summarize 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.[25] 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).[26] 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%.[27] 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, waist circumference, and blood pressure 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 pre-hypertension (19.1%), whereas 11.9% of them were at hypertension stage 1 or 2.

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

| Variables | n (%) | | |
|---|---|---|---|
| | **Total (n=513)** | **Males (n=211)** | **Females (n=302)** |
| **BMI-for-age z-score** | 0.25 ± 1.52 | 0.41 ± 1.60 | 0.13 ± 1.45 |
| Mean ± SD (Range) | (-3.95 – 4.6) | (-3.95 – 4.16) | (-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)** | 69.83 ± 10.57 | 71.35 ± 11.08 | 68.77 ± 10.08 |
| Mean ± SD (Range) | (52.50 – 111.0) | (52.6 – 111.0) | (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** | 0.45 ± 0.06 | 0.45 ± 0.07 | 0.44 ± 0.06 |
| Mean ± SD (Range) | (0.32 – 0.71) | (0.32 – 0.68) | (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** | 0.1389 ± 0.0074 | 0.1402 ± 0.0005 | 0.1379 ± 0.0004 |
| Mean ± SD (Range) | (0.12 – 0.17) | (0.13 – 0.17) | (0.12 – 0.16) |
| **Systolic BP** | 113.4 ± 14.4 | 116.2 ± 14.7 | 111.4 ± 13.9 |
| Mean ± SD (Range) | (79.0 – 159.0) | (82.0 – 159.0) | (79.0 – 155.5) |
| **Diastolic BP** | 67.1 ± 9.8 | 65.5 ± 9.6 | 68.2 ± 9.9 |
| Mean ± SD (Range) | (63.8 – 35.0) | (42.0 – 92.6) | (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) |

BMI: body mass index; WC: waist circumference; WHtR: Waist-to-height ratio; ABSI: a body shape index; BP: blood pressure; SD: standard deviation.

**ROC analysis based on group A**

Table 2 summarizes 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 pre-hypertensive adolescents were grouped in the normal BP group (normal and pre-hypertensive) 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.

**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* | Cut-off value | Sensitivity (%) | Specificity (%) | Youden index |
|---|---|---|---|---|---|---|
| **Total (n = 513)** | | | | | | |
| BMI-for-age z-score | 0.835 (0.782 – 0.889) | <0.001 | 1.47 | 68.9 | 83.6 | 0.525 |
| WC percentile | 0.828 (0.768 – 0.888) | <0.001 | 73.0 | 80.3 | 72.1 | 0.525 |
| WHtR | 0.823 (0.759 – 0.887) | <0.001 | 0.44 | 90.2 | 63.7 | 0.539 |
| ABSI | 0.735 (0.662 – 0.809) | <0.001 | 0.14 | 68.9 | 71.5 | 0.403 |
| **Males (n = 211)** | | | | | | |
| BMI-for-age z-score | 0.817 (0.723 - 0.912) | <0.001 | 1.87 | 69.2 | 84.3 | 0.536 |
| WC percentile | 0.781 (0.671 – 0.891) | <0.001 | 78.0 | 57.7 | 90.8 | 0.485 |
| WHtR | 0.789 (0.675 – 0. 903) | <0.001 | 0.52 | 65.4 | 87.6 | 0.530 |
| ABSI | 0.709 (0.577 – 0.841) | <0.001 | 0.15 | 65.4 | 85.4 | 0.508 |
| **Females (n = 302)** | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| BMI-for-age z-score | 0.854 (0.793 – 0.916) | <0.001 | 1.18 | 71.4 | 83.5 | 0.549 |
| WC percentile | 0.863 (0.798 – 0.927) | <0.001 | 73.0 | 85.7 | 74.2 | 0.599 |
| WHtR | 0.854 (0.781 – 0.927) | <0.001 | 0.45 | 94.3 | 65.9 | 0.602 |
| ABSI | 0.756 (0.670 – 0.843) | <0.001 | 0.14 | 82.9 | 62.9 | 0.458 |

BMI: body mass index; WC: waist circumference; WHtR: Waist-to-height ratio; ABSI: a body shape index; ROC: receiver operating characteristic; AUC: area under the curve; CI: confidence interval.

**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 pre-hypertensive 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 was the highest in both sexes, followed by WHtR, WC and ABSI in women and WC, WHtR and ABSI in men. 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 70th percentile for men and the 72nd 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 from 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%).

**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* | Cut-off value | Sensitivity (%) | Specificity (%) | Youden index |
|---|---|---|---|---|---|---|
| **Total (n = 513)** | | | | | | |
| BMI-for-age z-score | 0.793 (0.750 – 0.836) | <0.001 | 0.79 | 71.1 | 76.6 | 0.476 |
| WC percentile | 0.781 (0.737 – 0.825) | <0.001 | 73.0 | 66.0 | 80.2 | 0.463 |
| WHtR | 0.781 (0.736 – 0.826) | <0.001 | 0.44 | 74.2 | 71.5 | 0.457 |
| ABSI | 0.688 (0.637 – 0.739) | <0.001 | 0.14 | 57.2 | 74.3 | 0.315 |
| **Males (n = 211)** | | | | | | |
| BMI-for-age z-score | 0.808 (0.744 – 0.872) | <0.001 | 0.79 | 79.7 | 70.7 | 0.504 |
| WC percentile | 0.788 (0.720 – 0.857) | <0.001 | 72.0 | 70.5 | 78.9 | 0.492 |
| WHtR | 0.799 (0.732 – 0.865) | <0.001 | 0.46 | 70.3 | 80.3 | 0.506 |
| ABSI | 0.730 (0.650 – 0.809) | <0.001 | 0.14 | 70.3 | 72.1 | 0.424 |
| **Females (n = 302)** | | | | | | |
| BMI-for-age z-score | 0.786 (0.729 – 0.843) | <0.001 | 0.92 | 63.2 | 84.5 | 0.477 |
| WC percentile | 0.777 (0.719 – 0.835) | <0.001 | 70.0 | 63.1 | 81.2 | 0.443 |
| WHtR | 0.768 (0.708 – 0.828) | <0.001 | 0.45 | 71.6 | 72.9 | 0.445 |
| ABSI | 0.665 (0.598 – 0.731) | <0.001 | 0.14 | 54.9 | 70.0 | 0.248 |

BMI: body mass index; WC: waist circumference; WHtR: Waist-to-height ratio; ABSI: a body shape index; ROC: receiver operating characteristic; AUC: area under the curve; CI: confidence interval.

**Discussion**

This study analyzed 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.[28–30] 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.*[28] who reported WC cut-off values.

Using the ≥95th percentile threshold to define high BP, we found that anthropometric indices had relatively lower sensitivities (<70.0%) in predicting, 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).[21] 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 pre-hypertensive adolescents with excess adiposity. In the pre-hypertension 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 pre-hypertensive 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.[31] In addition, emerging data from cohort studies showed that pre-hypertension increased the risk of CVD over time, even after adjusting for multiple cardiovascular risk factors.[32,33] Given the strong tracking of BP from childhood to adulthood, careful attention should be given to pre-hypertensive 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 pre-hypertensive adolescents. These findings replicated previous studies on the use of the 90th percentile for raised BP in adolescents of different ethnic groups.[6,34] 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. Altogether, these results suggest that WHtR is the most accurate indicator to predict the presence of elevated BP alongside BMI.

Studies found that BMI and WC were good predictors of elevated BP in adolescents.[9,34] However, both indices exhibited low sensitivity in discriminating individuals with high BP.[35,36] 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 percent 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.[37,38] Thus, screening by BMI alone could potentially lead to 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.[28] 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.[39,40] 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.[41]

Findings from various Asian countries concurrently supported the superiority of WHtR over WC and BMI in predicting hypertension among adolescents.[41] 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.[42,43] 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.[44] 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.[45,46] 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.[47]

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.[36,48] 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[36] as well as metabolic syndrome[48] and CVD risk among adolescents.[49] 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.[50] 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.[51] 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.[52,53] 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.[54,55] Similar results were found in adults whereby ABSI had the smallest odds ratio and AUC for the prediction of hypertension.[56,57]

Based on the results of systematic review and meta-analysis, Ji, Zhang and An[58] 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,[52] it was suggested that age should be considered when assessing the mortality risk of different populations. In relation to hypertension, Cheung[59] 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. Other researcher 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.[60] Therefore, it is possible that these limitations confined the predictability of ABSI for hypertension in our study.

Several limitations inherent to this study are worth noting. Firstly, 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. Secondly, 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. Thirdly, generalization of findings should be done cautiously as the study samples were randomly selected from Selangor state only. 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 is an accurate and useful screening tool for predicting high BP in 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.

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**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.

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**Competing interests** None declared.

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**Data availability** The dataset analysed in this study is available from the corresponding author upon a reasonable request.



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STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

| | Item No | Recommendation | Page No |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 2 |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 3-5 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 5 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 5 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 5-6 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants | 5 |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 6-7 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 6-7 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 5 |
| Study size | 10 | Explain how the study size was arrived at | 5 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 6-7 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 7 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | - |
| | | (*c*) Explain how missing data were addressed | - |
| | | (*d*) If applicable, describe analytical methods taking account of sampling strategy | - |
| | | (*e*) Describe any sensitivity analyses | 7 |
| **Results** | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 5 |
| | | (b) Give reasons for non-participation at each stage | 5 |
| | | (c) Consider use of a flow diagram | - |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | 8 |
| | | (b) Indicate number of participants with missing data for each variable of interest | 8 |
| Outcome data | 15* | Report numbers of outcome events or summary measures | 8 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 9-12 |

| | | | |
|---|---|---|---|
| | | (*b*) Report category boundaries when continuous variables were categorized | 9-12 |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | 9-12 |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 9-12 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 13 |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | 17 |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 13-17 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 17 |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 18 |

*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

# 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

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**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**

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**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 (ABSI) 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 to 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 analyzed by sex using the receiver operating characteristic (ROC) 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 ROC was conducted.
- Two separate analyses using the 90th and 95th percentile cut-offs for differentiating high 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 recognized 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 blood pressure tracks well from childhood to adulthood, yet pediatric 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 emphasized in pediatric 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 tenfold 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 mmHg.[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, Yan and Cheung[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 pediatric 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 analyze 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 neighboring 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 (e.g. sleep disorders, diabetes, thyroid disease and CVDs), neurological or psychiatric disorders (e.g. autism spectrum disorders, anxiety and depression), learning disabilities or developmental delays were excluded from the study (n=5). Five hundred sixty eligible adolescents were recruited and 513 of them agreed to participate in this study.

Before the commencement of the study, ethics approval was obtained from the Ethics Committee for Research Involving Human Subject of Universiti Putra Malaysia [Reference No. FPSK(EXP16) P186]. 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, IL, USA) and a SECA portable stadiometer 213 (SECA, Hamburg, Germany), respectively. The World Health Organization (WHO) AnthroPlus software version 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, NC, 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 ≥0.5.[24] ABSI of adolescents was calculated using the formula proposed by Xu, Yan and Cheung[19] as shown below, with WC and height measured in meter. Higher ABSI indicated a greater fraction of visceral fat to body size.

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

**Blood pressure measurement**

Blood pressure 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), pre-hypertension (≥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 pre-hypertension) 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: pre-hypertension and hypertension stages 1 and 2).

**Statistical analysis**

All data were analyzed using the IBM SPSS Statistics 24 (IBM Corp., Armonk, NY, USA). The descriptive data on body composition and BP of adolescents were summarized 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 pre-hypertension and hypertension among the adolescents. The area under the curve (AUC) was used to summarize 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, waist circumference, and blood pressure 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 pre-hypertension (19.1%), whereas 11.9% of them were at hypertension stage 1 or 2.

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

| Variables | n (%) | | |
|---|---|---|---|
| | **Total (n=513)** | **Males (n=211)** | **Females (n=302)** |
| **BMI-for-age z-score** | 0.25 ± 1.52 | 0.41 ± 1.60 | 0.13 ± 1.45 |
| Mean ± SD (Range) | (-3.95 – 4.6) | (-3.95 – 4.16) | (-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)** | 69.83 ± 10.57 | 71.35 ± 11.08 | 68.77 ± 10.08 |
| Mean ± SD (Range) | (52.50 – 111.0) | (52.6 – 111.0) | (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** | 0.45 ± 0.06 | 0.45 ± 0.07 | 0.44 ± 0.06 |
| Mean ± SD (Range) | (0.32 – 0.71) | (0.32 – 0.68) | (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** | 0.1389 ± 0.0074 | 0.1402 ± 0.0005 | 0.1379 ± 0.0004 |
| Mean ± SD (Range) | (0.12 – 0.17) | (0.13 – 0.17) | (0.12 – 0.16) |
| **Systolic BP** | 113.4 ± 14.4 | 116.2 ± 14.7 | 111.4 ± 13.9 |
| Mean ± SD (Range) | (79.0 – 159.0) | (82.0 – 159.0) | (79.0 – 155.5) |
| **Diastolic BP** | 67.1 ± 9.8 | 65.5 ± 9.6 | 68.2 ± 9.9 |
| Mean ± SD (Range) | (63.8 – 35.0) | (42.0 – 92.6) | (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) |

BMI: body mass index; WC: waist circumference; WHtR: Waist-to-height ratio; ABSI: a body shape index; BP: blood pressure; SD: standard deviation.

**ROC analysis based on group A**

Table 2 summarizes 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 pre-hypertensive adolescents were grouped in the normal BP group (normal and pre-hypertensive) 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.

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

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| WHtR | 0.854 (0.781 – 0.927) | <0.001 | 0.45 | 94.3 (0.795 – 0.990) | 65.9 (0.599 – 0.716) | 0.602 | - | - |
| ABSI | 0.756 (0.670 – 0.843) | <0.001 | 0.14 | 82.9 (0.657 – 0.928) | 62.9 (0.568 – 0.687) | 0.458 | 11.72 | 0.001 |

BMI: body mass index; WC: waist circumference; WHtR: Waist-to-height ratio; ABSI: a body shape index; ROC: receiver operating characteristic; AUC: area under the curve; CI: confidence interval.

[#]Comparison of the AUC value of WHtR with the other anthropometric indices



**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 pre-hypertensive 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 was the highest in both sexes, followed by WHtR, WC and ABSI in women and WC, WHtR and ABSI in men. 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.

**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* | Cut-off value | Sensitivity (%) (95% CI) | Specificity (%) (95% CI) | Youden index | $\chi^{2\#}$ | $p^{\#}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | **Total (n = 513)** | | | | |
| BMI-for-age z-score | 0.793 (0.750 – 0.836) | <0.001 | 0.79 | 71.1 (0.633 – 0.778) | 76.6 (0.717 – 0.808) | 0.477 | 1.45 | 0.228 |
| WC percentile | 0.781 (0.737 – 0.825) | <0.001 | 73.0 | 66.0 (0.581 – 0.732) | 80.2 (0.756 – 0.842) | 0.462 | 0.00 | 0.993 |
| WHtR | 0.781 (0.736 – 0.826) | <0.001 | 0.44 | 74.2 (0.666 – 0.807) | 71.5 (0.664 – 0.761) | 0.457 | - | - |
| ABSI | 0.688 (0.637 – 0.739) | <0.001 | 0.14 | 57.2 (0.491 – 0.650) | 74.3 (0.691 – 0.784) | 0.315 | 27.71 | <0.001 |
| | | | | **Males (n = 211)** | | | | |
| BMI-for-age z-score | 0.808 (0.744 – 0.872) | <0.001 | 0.79 | 79.7 (0.674 – 0.883) | 70.7 (0.626 – 0.778) | 0.504 | 0.51 | 0.475 |
| WC percentile | 0.788 (0.720 – 0.857) | <0.001 | 72.0 | 70.3 (0.574 – 0.808) | 78.9 (0.713 – 0.850) | 0.492 | 0.62 | 0.430 |
| WHtR | 0.799 (0.732 – 0.865) | <0.001 | 0.46 | 70.3 (0.574 – 0.808) | 80.3 (0.727 – 0.862) | 0.506 | - | - |
| ABSI | 0.730 (0.650 – 0.809) | <0.001 | 0.14 | 70.3 (0.574 – 0.808) | 72.1 (0.640 – 0.790) | 0.424 | 8.82 | 0.003 |
| | | | | **Females (n = 302)** | | | | |
| BMI-for-age z-score | 0.786 (0.729 – 0.843) | <0.001 | 0.92 | 63.2 (0.526 – 0.726) | 84.5 (0.787 – 0.890) | 0.477 | 1.86 | 0.172 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| WC percentile | 0.777 (0.719 – 0.835) | <0.001 | 70.0 | 63.2 (0.526 – 0.726) | 81.2 (0.750 – 0.861) | 0.443 | 0.52 | 0.471 |
| WHtR | 0.768 (0.708 – 0.828) | <0.001 | 0.45 | 71.6 (0.613 – 0.801) | 72.9 (0.663 – 0.788) | 0.445 | - | - |
| ABSI | 0.665 (0.598 – 0.731) | <0.001 | 0.14 | 54.7 (0.442 – 0.649) | 70.0 (0.632 – 0.761) | 0.248 | 16.70 | <0.001 |

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



**Discussion**

Easy-to-use screening tool for hypertension is the fundamental for the detection of adolescents at risk for early intervention. This study analyzed 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.

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 $\geq$ 1).[22] Likewise, the optimal cut-off value of WHtR in male adolescents was above the common cut-off that defines abdominal obesity (WHtR $\geq$ 0.5). These results were due to the high proportion of pre-hypertensive adolescents with excess adiposity. In the pre-hypertension 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 pre-hypertensive 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 pre-hypertension 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 pre-hypertensive 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 pre-hypertensive 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 percent 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 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 odds ratio and AUC for the prediction of hypertension.[58]

Based on the results of systematic review and meta-analysis, Ji, Zhang and An[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 blood pressure 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. Firstly, 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. Secondly, 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. Thirdly, generalization 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 blood pressure 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.

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**Competing interests** None declared.

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**Data availability** The dataset analysed in this study is available from the corresponding author upon a reasonable request.

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STROBE Statement—Checklist of items that should be included in reports of ***cross-sectional studies***

| | Item No | Recommendation | Page No |
|---|---|---|---|
| **Title and abstract** | 1 | (*a*) Indicate the study's design with a commonly used term in the title or the abstract | 1 |
| | | (*b*) Provide in the abstract an informative and balanced summary of what was done and what was found | 2 |
| **Introduction** | | | |
| Background/rationale | 2 | Explain the scientific background and rationale for the investigation being reported | 3-5 |
| Objectives | 3 | State specific objectives, including any prespecified hypotheses | 5 |
| **Methods** | | | |
| Study design | 4 | Present key elements of study design early in the paper | 5 |
| Setting | 5 | Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection | 5-6 |
| Participants | 6 | (*a*) Give the eligibility criteria, and the sources and methods of selection of participants | 5 |
| Variables | 7 | Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable | 6-7 |
| Data sources/ measurement | 8* | For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group | 6-7 |
| Bias | 9 | Describe any efforts to address potential sources of bias | 5 |
| Study size | 10 | Explain how the study size was arrived at | 6 |
| Quantitative variables | 11 | Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why | 6-7 |
| Statistical methods | 12 | (*a*) Describe all statistical methods, including those used to control for confounding | 8 |
| | | (*b*) Describe any methods used to examine subgroups and interactions | - |
| | | (*c*) Explain how missing data were addressed | - |
| | | (*d*) If applicable, describe analytical methods taking account of sampling strategy | - |
| | | (*e*) Describe any sensitivity analyses | 8 |
| **Results** | | | |
| Participants | 13* | (a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed | 6 |
| | | (b) Give reasons for non-participation at each stage | 6 |
| | | (c) Consider use of a flow diagram | - |
| Descriptive data | 14* | (a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders | 9 |
| | | (b) Indicate number of participants with missing data for each variable of interest | 9 |
| Outcome data | 15* | Report numbers of outcome events or summary measures | 9 |
| Main results | 16 | (*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included | 9-14 |

| | | | |
|---|---|---|---|
| | | (*b*) Report category boundaries when continuous variables were categorized | 9-14 |
| | | (*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period | - |
| Other analyses | 17 | Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses | 9-14 |
| **Discussion** | | | |
| Key results | 18 | Summarise key results with reference to study objectives | 14 |
| Limitations | 19 | Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias | 19 |
| Interpretation | 20 | Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence | 14-19 |
| Generalisability | 21 | Discuss the generalisability (external validity) of the study results | 19 |
| **Other information** | | | |
| Funding | 22 | Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based | 20 |

*Give information separately for exposed and unexposed groups.

**Note:** An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.