

POPULATION STUDY ARTICLE



Effectiveness of a body shape index in predicting pediatric high blood pressure

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BACKGROUND: A body shape index (ABSI) is an emerging anthropometric indicator, challenging two traditional parameters: body mass index (BMI) and waist circumference (WC). We aimed to systematically compare and validate the capability of anthropometric indicators for determining pediatric high blood pressure (HBP).

METHODS: A total of 3150 participants aged 7–17 years were enrolled from Suzhou, China. Areas under the receiver operating characteristic curve (AUC) were obtained to evaluate the performance of anthropometric indicators in detecting HBP. DeLong's test was used to examine whether the AUCs of anthropometric indicators in contrast to BMI or original ABSI were statistically different. Furthermore, a meta-analysis was performed to combine results from this study and five similar articles from databases.

RESULTS: In Suzhou population, BMI exhibited the largest AUC (AUC = 0.705), followed by WC (AUC = 0.669) and original ABSI (AUC = 0.514). Modified ABSI (AUC: 0.537–0.681), although had slightly better performance than original ABSI, was still less valuable than BMI ($P < 0.05$), either in the total sample or in boys. The meta-analysis with 21108 children and adolescents subsequently confirms the results derived from Suzhou population.

CONCLUSIONS: In predicting pediatric HBP, original ABSI and modified ABSI underperform BMI and WC.

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IMPACT:

- The current study is the first to evaluate whether original ABSI or modified ABSI is comparable to BMI and WC for screening HBP in children and adolescents.
- In predicting pediatric HBP, original ABSI and modified ABSI do not perform as well as traditional anthropometric indicators, such as BMI and WC.
- BMI remains the optimal indicator in pediatric HBP screening.
- This study provides a theoretical basis for the early identification of HBP in children and adolescents by adopting effective predictors.

INTRODUCTION

High blood pressure (HBP) is recognized as one of the most critical risk factors for cardiovascular disease (CVD)¹, and it is gradually becoming more prevalent in youths². In China, it is reported that the systolic blood pressure (SBP) and diastolic blood pressure (DBP) of children and adolescents aged 7–17 years increased by 6.6 and 4.8 mmHg from 1991 to 2015, respectively, while the prevalence of HBP elevated from 5.7% to 12.8%³. A growing body of evidence indicates that persistent pediatric HBP greatly enhanced the risk of specific target organ damage, HBP, and even CVD in adulthood^{4,5}. Additionally, pediatric HBP is frequently asymptomatic, making it usually underdiagnosed and underestimated^{6,7}. Thus, early identification and effective intervention of HBP in children and adolescents are critical to their long-term health conditions.

In epidemiological studies, there is a dynamic linear relationship between HBP and the epidemic of obesity^{8,9}. The risk of HBP in obese children and adolescents is 4–10 times higher than their normal-weight counterparts¹⁰. In general, anthropometric indicators are convenient, practical measurements for clinical applications and routine public health screening for obesity and body shape¹¹. Body mass index (BMI) and waist circumference (WC) are the most common anthropometric indicators^{12,13}. However, as single rough indicators, these two parameters are limited in evaluating full-body (particularly abdominal obesity), potentially resulting in inadequate identification of HBP^{14,15}. For instance, BMI fails to discriminate among fat distributions¹³. At the same time, WC ignores the effect of height on BP; thus, it may misestimate the risk of HBP to some extent¹⁶.

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Table 1. Basic characteristics of Chinese children and adolescents.

Variables	Total (n = 3150)			Boys (n = 1602)			Girls (n = 1548)		
	Non-HBP	HBP	P	Non-HBP	HBP	P	Non-HBP	HBP	P
Children and adolescents									
Number (n, %)	2795 (88.73)	355 (11.27)		1388 (86.64)	214 (13.36)		1407 (90.89)	141 (9.11)	
Age (year)	11.98 ± 3.12	12.44 ± 3.08	0.009	12.04 ± 3.15	12.66 ± 3.21	0.008	11.92 ± 3.09	12.10 ± 2.83	0.503
SBP (mmHg)	105.70 ± 10.97	127.90 ± 10.80	<0.001	108.20 ± 11.60	130.60 ± 11.02	<0.001	103.30 ± 9.72	124.00 ± 9.13	<0.001
DBP (mmHg)	60.80 ± 7.11	72.62 ± 8.74	<0.001	60.61 ± 7.14	72.11 ± 8.80	<0.001	60.99 ± 7.07	73.40 ± 8.63	<0.001
Weight (kg)	44.22 ± 15.97	54.20 ± 20.55	<0.001	46.81 ± 17.71	58.16 ± 22.19	<0.001	41.66 ± 13.57	48.21 ± 16.08	<0.001
Height (cm)	150.20 ± 16.61	153.00 ± 16.84	0.003	152.40 ± 18.24	155.50 ± 18.08	0.021	148.00 ± 14.49	149.20 ± 13.99	0.329
BMI (kg/m ²)	18.94 ± 3.69	22.29 ± 5.01	<0.001	19.39 ± 3.87	23.08 ± 5.06	<0.001	18.49 ± 3.45	21.08 ± 4.69	<0.001
WC (cm)	65.15 ± 10.67	72.94 ± 13.84	<0.001	67.53 ± 11.37	76.62 ± 14.40	<0.001	62.79 ± 9.36	67.34 ± 10.82	<0.001
ABSI (m ^{11/6} /kg ^{2/3})	0.08 ± 0.00	0.07 ± 0.01	0.217	0.08 ± 0.00	0.08 ± 0.00	0.911	0.07 ± 0.01	0.07 ± 0.01	0.006
Children									
Number (n, %)	1738 (89.40)	206 (10.60)		855 (87.87)	118 (12.13)		883 (90.94)	88 (9.06)	
Age (year)	9.89 ± 1.70	10.21 ± 1.67	0.011	9.90 ± 1.70	10.17 ± 1.76	0.108	9.88 ± 1.69	10.26 ± 1.56	0.042
SBP (mmHg)	101.70 ± 9.81	123.20 ± 8.92	<0.001	103.00 ± 9.93	124.60 ± 9.37	<0.001	100.50 ± 9.54	121.40 ± 7.95	<0.001
DBP (mmHg)	59.28 ± 6.98	71.45 ± 9.10	<0.001	59.13 ± 7.04	70.85 ± 9.14	<0.001	59.43 ± 6.92	72.25 ± 9.03	<0.001
Weight (kg)	35.79 ± 11.16	43.11 ± 14.80	<0.001	36.92 ± 11.60	44.55 ± 15.32	<0.001	34.69 ± 10.60	41.18 ± 13.92	<0.001
Height (cm)	140.60 ± 12.43	142.50 ± 13.03	0.037	140.80 ± 12.24	142.90 ± 13.66	0.089	140.30 ± 12.61	142.00 ± 12.19	0.248
BMI (kg/m ²)	17.72 ± 3.19	20.67 ± 4.59	<0.001	18.23 ± 3.35	21.19 ± 4.37	<0.001	17.23 ± 2.94	19.99 ± 4.82	<0.001
WC (cm)	61.18 ± 9.21	67.48 ± 11.39	<0.001	63.34 ± 9.96	70.41 ± 12.11	<0.001	59.09 ± 7.87	63.55 ± 9.03	<0.001
ABSI (m ^{11/6} /kg ^{2/3})	0.08 ± 0.00	0.08 ± 0.01	0.090	0.08 ± 0.00	0.08 ± 0.00	0.889	0.08 ± 0.00	0.07 ± 0.01	0.001
ABSI-ch (m ^{21/20} /kg ^{2/5})	0.15 ± 0.01	0.15 ± 0.01	<0.001	0.15 ± 0.01	0.16 ± 0.01	<0.001	0.15 ± 0.01	0.15 ± 0.01	0.193
Adolescents									
Number (n, %)	1057 (87.65)	149 (12.35)		533 (84.74)	96 (15.26)		524 (90.81)	53 (9.19)	
Age (year)	15.42 ± 1.41	15.52 ± 1.52	0.417	15.48 ± 1.40	15.72 ± 1.47	0.124	15.35 ± 1.42	15.15 ± 1.54	0.329
SBP (mmHg)	112.20 ± 9.57	134.50 ± 9.75	<0.001	116.50 ± 8.98	137.90 ± 8.11	<0.001	107.90 ± 8.12	128.20 ± 9.42	<0.001
DBP (mmHg)	63.30 ± 6.60	74.24 ± 7.97	<0.001	62.98 ± 6.64	73.66 ± 8.14	<0.001	63.62 ± 6.54	75.30 ± 7.62	<0.001
Weight (kg)	58.07 ± 12.67	69.54 ± 17.28	<0.001	62.67 ± 13.86	74.88 ± 17.39	<0.001	53.40 ± 9.25	59.87 ± 12.23	<0.001
Height (cm)	166.00 ± 8.43	167.60 ± 8.59	0.033	171.10 ± 7.64	171.10 ± 7.59	0.982	160.90 ± 5.55	161.30 ± 6.42	0.601
BMI (kg/m ²)	20.94 ± 3.59	24.52 ± 4.70	<0.001	21.27 ± 3.92	25.42 ± 4.90	<0.001	20.60 ± 3.19	22.90 ± 3.86	<0.001
WC (cm)	71.67 ± 9.67	80.48 ± 13.41	<0.001	74.26 ± 10.21	84.26 ± 13.31	<0.001	69.02 ± 8.30	73.64 ± 10.68	0.001
ABSI (m ^{11/6} /kg ^{2/3})	0.07 ± 0.01	0.07 ± 0.00	0.581	0.07 ± 0.00	0.01 ± 0.00	0.244	0.07 ± 0.01	0.07 ± 0.00	0.454
ABSI-ad1 (m ^{7/5} /kg ^{1/2})	0.12 ± 0.01	0.12 ± 0.01	<0.001	0.12 ± 0.01	0.12 ± 0.01	<0.001	0.11 ± 0.01	0.12 ± 0.01	0.202
ABSI-ad2 (m ^{27/20} /kg ^{9/20})	0.14 ± 0.01	0.14 ± 0.01	<0.001	0.14 ± 0.01	0.15 ± 0.01	<0.001	0.14 ± 0.01	0.14 ± 0.01	0.347

HBP high blood pressure, BMI body mass index, WC waist circumference, ABSI a body shape index.

ABSI-ch, a body shape index for Chinese children by Tong et al.²³; ABSI-ad1, a body shape index for Chinese adolescents by Tong et al.²³; ABSI-ad2, a body shape index for Chinese adolescents by Xu et al.¹¹.

Given this situation, a body shape index (ABSI) has been developed to standardize WC for BMI and height in recent years, estimating abdominal obesity independent of height, weight, or BMI^{17,18}. Therefore, ABSI was suggested to have additional predictive power to compensate for the existing deficiencies of the BMI and WC^{17,19}. Previous studies had shown that ABSI appeared to be a substantial risk factor for premature deaths¹⁷ and the onset of diabetes²⁰. A study found a strong association between ABSI and several cardiometabolic markers, such as total cholesterol, triglycerides, and low-density lipoprotein cholesterol²¹. However, the recent meta-analysis, including 24 retrospective cohort studies and 14 cross-sectional studies conducted in adults, showed that ABSI was superior to BMI and WC in predicting all-cause mortality but inferior in predicting HBP, CVD, and type 2 diabetes²².

Doubts existed that original ABSI, which was developed for American adults, might not be well suited to the rapidly developing body shape conditions of children and adolescents during puberty^{11,19}. Thus, Xu et al.¹¹ and Tong et al.²³ had created two modified ABSI equations by standard contour analysis, particularly for the Chinese pediatric population. In contrast to the abundant evidence of ABSI in adults, there are relatively few

historical studies exploring this novel indicator among children and adolescents. Meanwhile, regarding the predictive performance for HBP, comparisons between ABSI and traditional obesity measurement indicators, as well as original ABSI versus modified ABSI indicators, are not well-documented and far from conclusion. For example, some studies supported the usage of BMI instead of ABSI^{23–27}, whereas one study²⁸ among Portuguese concluded that ABSI was a better predictor of BP than BMI and WC.

Therefore, the current study were: (1) to compare the ability of different anthropometric indicators, including original ABSI, modified ABSI, BMI, and WC, in discriminating HBP by using school-based data from Suzhou, China; (2) to pool the results of similar studies to determine whether original ABSI or modified ABSI was the optimal predictor of HBP in children and adolescents by a subsequent meta-analysis.

MATERIALS AND METHODS

A cross-sectional study in Suzhou, China

Study design and population. The current study was a cross-sectional study, based on the national surveillance project of common diseases and health influencing factors of students in China, involving children and adolescents

Table 2. Predictive performance of anthropometric indicators for high blood pressure in the Suzhou population.

	AUC (95% CI)	P^a	P^b	Cut-off value	Sensitivity (95% CI)	Specificity (95% CI)	Youden Index
Children and adolescents							
Total							
BMI	0.705 (0.675, 0.735)	<0.001	Reference	20.10	63.94 (58.70, 68.90)	67.69 (65.90, 69.40)	0.316
WC	0.669 (0.638, 0.701)	<0.001	<0.001	70.70	52.68 (47.30, 58.00)	74.74 (73.10, 76.30)	0.274
ABSI	0.514 (0.481, 0.547)	Reference	<0.001	0.07	38.59 (33.50, 43.90)	66.94 (65.20, 68.70)	0.055
Boys							
BMI	0.720 (0.682, 0.758)	<0.001	Reference	20.62	51.06 (42.50, 59.60)	75.84 (73.50, 78.10)	0.269
WC	0.689 (0.649, 0.728)	<0.001	<0.001	69.90	66.36 (59.60, 72.70)	63.69 (61.10, 66.20)	0.301
ABSI	0.498 (0.456, 0.540)	Reference	<0.001	0.07	11.21 (7.30, 16.20)	93.16 (91.70, 94.40)	0.044
Girls							
BMI	0.672 (0.624, 0.720)	<0.001	Reference	20.03	52.17 (39.80, 64.40)	69.30 (66.90, 71.60)	0.215
WC	0.624 (0.574, 0.674)	0.186	<0.001	70.00	37.59 (29.60, 46.10)	81.88 (79.80, 83.90)	0.195
ABSI	0.575 (0.523, 0.627)	Reference	<0.001	0.07	56.74 (48.10, 65.00)	60.20 (57.60, 62.80)	0.169
Children							
Total							
BMI	0.707 (0.668, 0.745)	<0.001	Reference	20.10	51.46 (44.40, 58.50)	79.75 (77.80, 81.60)	0.312
WC	0.669 (0.628, 0.709)	<0.001	<0.001	65.90	50.49 (43.50, 57.50)	74.74 (72.60, 76.80)	0.252
ABSI	0.524 (0.479, 0.568)	Reference	<0.001	0.07	17.48 (12.60, 23.40)	91.02 (89.60, 92.30)	0.085
ABSI-ch	0.613 (0.570, 0.655)	0.034	<0.001	0.15	57.77 (50.70, 64.60)	63.64 (61.30, 65.90)	0.214
Boys							
BMI	0.707 (0.655, 0.759)	<0.001	Reference	19.56	63.56 (54.20, 72.20)	70.18 (67.00, 73.20)	0.337
WC	0.676 (0.622, 0.730)	<0.001	0.017	68.90	52.54 (43.10, 61.80)	76.61 (73.60, 79.40)	0.292
ABSI	0.504 (0.447, 0.560)	Reference	<0.001	0.08	58.47 (49.00, 67.50)	46.20 (42.80, 49.60)	0.047
ABSI-ch	0.647 (0.593, 0.700)	0.006	0.041	0.15	70.34 (61.20, 78.40)	55.79 (52.40, 59.20)	0.261
Girls							
BMI	0.700 (0.643, 0.758)	0.196	Reference	17.62	70.45 (59.80, 79.70)	62.63 (59.30, 65.80)	0.331
WC	0.651 (0.590, 0.711)	0.015	0.229	57.90	73.86 (63.40, 82.70)	50.17 (46.80, 53.50)	0.240
ABSI	0.591 (0.522, 0.660)	Reference	0.196	0.07	52.27 (41.40, 63.00)	66.48 (63.30, 69.60)	0.188
ABSI-ch	0.549 (0.483, 0.625)	0.393	0.814	0.15	35.23 (25.30, 46.10)	76.44 (73.50, 79.20)	0.117
Adolescents							
Total							
BMI	0.730 (0.684, 0.775)	<0.001	Reference	23.76	52.35 (44.00, 60.60)	82.59 (80.20, 84.80)	0.349
WC	0.702 (0.655, 0.749)	<0.001	0.006	70.80	75.17 (67.40, 81.90)	56.10 (53.00, 59.10)	0.313
ABSI	0.528 (0.476, 0.579)	Reference	<0.001	0.07	42.28 (34.20, 50.60)	66.23 (63.30, 69.10)	0.085
ABSI-ad1	0.624 (0.573, 0.675)	<0.001	<0.001	0.12	42.28 (34.20, 50.60)	79.00 (76.40, 81.40)	0.213
ABSI-ad2	0.642 (0.592, 0.692)	<0.001	<0.001	0.14	47.65 (39.40, 56.00)	76.82 (74.20, 79.30)	0.245
Boys							
BMI	0.747 (0.693, 0.800)	<0.001	Reference	24.54	56.25 (45.70, 66.40)	82.36 (78.90, 85.50)	0.386
WC	0.720 (0.663, 0.777)	<0.001	0.004	84.20	51.04 (40.60, 61.40)	84.24 (80.90, 87.20)	0.353
ABSI	0.543 (0.476, 0.610)	Reference	<0.001	0.08	37.50 (27.80, 48.00)	73.73 (69.80, 77.40)	0.112
ABSI-ad1	0.664 (0.600, 0.729)	<0.001	<0.001	0.12	54.17 (43.70, 64.40)	75.05 (71.10, 78.70)	0.292
ABSI-ad2	0.681 (0.618, 0.743)	<0.001	0.002	0.15	48.96 (38.60, 59.40)	82.55 (79.10, 85.70)	0.315
Girls							
BMI	0.685 (0.599, 0.770)	0.017	Reference	22.02	62.26 (47.90, 75.20)	74.24 (70.30, 77.90)	0.365
WC	0.637 (0.550, 0.724)	0.171	0.129	70.80	58.49 (44.10, 71.90)	67.94 (63.80, 71.90)	0.264
ABSI	0.542 (0.459, 0.624)	Reference	0.025	0.07	71.70 (57.70, 83.20)	42.94 (38.70, 47.30)	0.146
ABSI-ad1	0.537 (0.453, 0.621)	0.952	0.017	0.12	37.74 (24.80, 52.10)	71.95 (67.90, 75.80)	0.097
ABSI-ad2	0.556 (0.473, 0.639)	0.859	0.024	0.14	33.96 (21.50, 48.30)	79.58 (75.90, 83.00)	0.135

BMI body mass index, WC waist circumference, ABSI a body shape index, AUC area under the curve, ROC receiver operating characteristic. ABSI-ch, a body shape index for Chinese children by Tong et al.²³; ABSI-ad1, a body shape index for Chinese adolescents by Tong et al.²³; ABSI-ad2, a body shape index for Chinese adolescents by Xu et al.¹¹.

^aComparison of ABSI with other anthropometric indicators.

^bComparison of BMI with other anthropometric indicators.

aged 7–17 years from Suzhou, Jiangsu Province. This study adopted a method of multistage, stratified random cluster-sampling from September to October 2019, which was conducted in three steps: firstly, two counties (cities, districts) were selected as the initial sampling unit in Suzhou; secondly, two streets (townships and towns) were selected from each county (city,

district); finally, one primary school, one junior high school, and one senior high school were selected from each street (township and town), and all students in two classes were randomly selected from each grade. After excluding incomplete data and students with serious organ diseases, physical disabilities, developmental abnormalities, and other serious metabolic

diseases, 3150 children (aged 7–12 years) and adolescents (aged 13–17 years) agreed to participate in the study.

For the recruited participants, informed consent forms in writing duly signed by their guardians were collected before their examination. The project was reviewed by the ethics committees of Suzhou Center for Disease Prevention and Control. All works were carried out with the consent of the students and their parents.

Anthropometric measurements. All measurements were carried out by professionally trained health professionals, using the same equipment and following the same procedures to ensure accuracy. When measuring height and weight, participants were asked to wear light clothing, remove their shoes and hats, and stand erect with heels together with an accuracy of 0.1 cm and 0.1 kg, respectively. WC was measured by exposing the abdomen and breathing gently, using soft anthropometric tape and circumscribing it horizontally around the midpoint between the lower border of the 12 ribs and the upper edge of the iliac crest on both sides precision of 0.1 cm. BMI was calculated as weight (kg) divided by the square of the height (m), and original ABSI was calculated using the following Eq. (1)¹⁷. Two modified ABSI, ABSI-ch for children and ABSI-ad1 for adolescents, were calculated using the following Eqs. (2) and (3) by Tong et al.²³, while another modified ABSI, ABSI-ad2, was calculated for adolescents using the following Eq. (4) by Xu et al.¹¹.

$$\text{ABSI} = \frac{\text{WC}}{\text{BMI}^{2/3} \text{height}^{1/2}} \quad (1)$$

$$\text{ABSI - ch} = \frac{\text{WC}}{\text{BMI}^{2/5} \text{height}^{3/4}} \quad (2)$$

$$\text{ABSI - ad1} = \frac{\text{WC}}{\text{BMI}^{1/2} \text{height}^{3/5}} \quad (3)$$

$$\text{ABSI - ad2} = \frac{\text{WC}}{\text{BMI}^{0.45} \text{height}^{0.55}} \quad (4)$$

BP measurement. Surveyors were in strict accordance with the standard requirements to measure BP using an Electronic Blood Pressure Monitor (Omron HBP-1300) of the right size for children and adolescents. All participants were told to sit upright with their backs supported and relax for 15 min simultaneously. The cuff was placed on the non-dominant arm at the heart level, with the balloon's midline above the brachial pulse. BP was measured twice, and participants rested for at least 2 min between measurements. The average of the two measurements as the final result was recorded. When the difference in BP between two measurements exceeded 10 mmHg, additional measurements were taken, and two similar blood pressure measurements were averaged.

HBP levels were defined as SBP and/or DBP above 95th percentile according to age, sex, and percentile of height, based on the Chinese standard "Reference of screening for elevated Blood pressure among children and adolescents aged 7~18 years" (WS/T 610-2018)²⁹.

Statistical analysis. The basic information about the participants was described in the total sample and by age and sex. Continuous and categorical variables were expressed as [mean ± standard deviation (SD)] and *n* (%) and were correspondingly compared by using Student's *t*-test and Chi-square test, respectively. Receiver operating characteristic (ROC) curves analysis was used to compare the validity of different anthropometric indicators in predicting HBP, resulting in the area under the curve (AUC), corresponding 95% confidential interval (95% CI), cut-off value, sensitivity, and specificity. AUC > 0.7 indicates acceptable screening power³⁰. Meanwhile, DeLong's test was used to examine whether the AUCs of anthropometric indicators contrast to BMI or original ABSI was meaningfully different³¹. The Youden index was calculated to determine the optimal cut-off values for different indicators. A two-tailed *P* value < 0.05 was considered to be statistically significant. All analyses were conducted using SAS statistical software (version 9.4, SAS Institute).

Meta-analysis

Search strategy. Systematic research was conducted on papers published in Medline, PubMed, Embase, Scopus, Ovid, and Web of Science databases and involved in BMI, WC, original ABSI, and modified ABSI in screening HBP

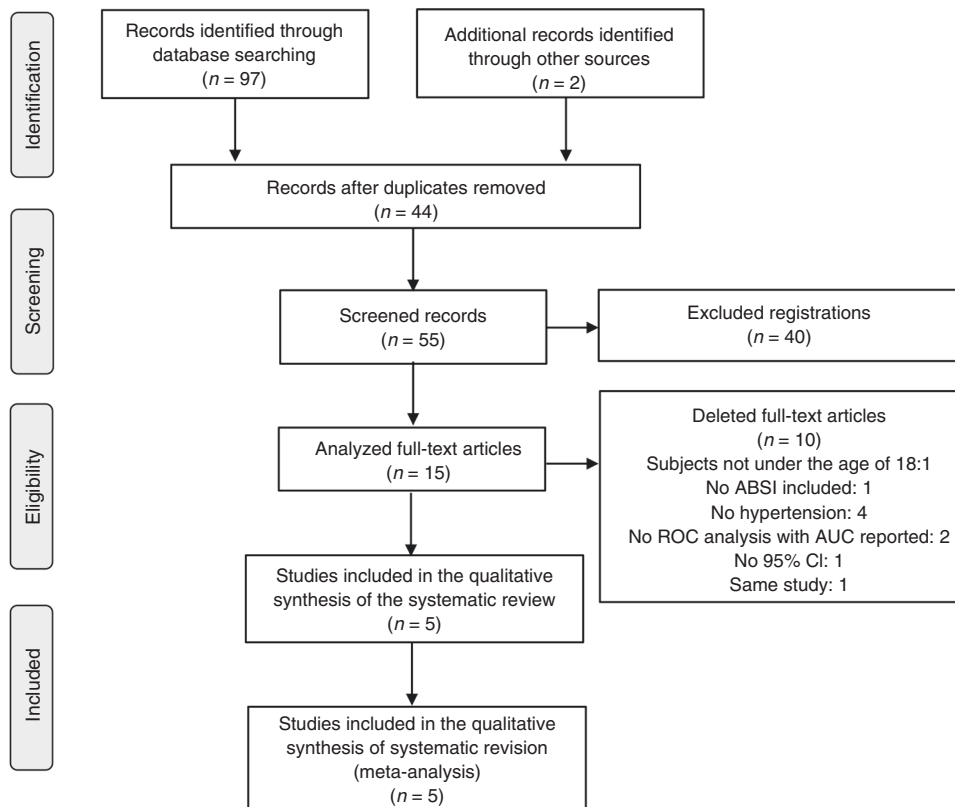


Fig. 1 Flow chart of study selection for the meta-analysis. ABSI a body shape index, ROC receiver operating characteristic, AUC area under the curve, CI confidential interval.

Table 3. Basic characteristics of included studies in the meta-analysis.

Authors	Country	Ethnicity	Design	Subjects		Age range	Equation of ABSI	Outcomes and discriminatory criteria	
				Total	Boys				Girls
Tong et al. (2019) ²³	China	Chinese	Cross-sectional	1387	706	681	7–17	(1–3)	Hypertension (≥ 95 th percentile)
Silva et al. (2019) ²⁷	Brazil	Brazilian	Cross-sectional	1069	499	570	12–17	(1, 4)	Blood pressure (> 90 th percentile or SBP/DBP $\geq 120/80$ mmHg)
Perona et al. (2019) ²⁴	Spain	Spanish	Cross-sectional	981	456	525	11–16	(1)	Hypertension (SBP/DBP $\geq 130/85$ mmHg)
Tee et al. (2020) ²⁵	Malaysia	Malaysian	Cross-sectional	513	211	302	12–16	(4)	High blood pressure (≥ 95 th percentile)
Yazdi et al. (2020) ²⁶	Iran	Iranian	Cross-sectional	14008	7091	6917	7–18	(1)	Hypertension (> 95 th percentile)
Current study	China	Chinese	Cross-sectional	3150	1602	1548	7–17	(1–4)	High blood pressure (≥ 95 th percentile)

SBP systolic blood pressure, DBP diastolic blood pressure.

up to June 20, 2021. Researchers used the following search strategies: (body mass index OR BMI) AND (waist circumference OR WC) AND (a body shape index OR ABSI) AND (anthropometric indexes) AND (high blood pressure OR HBP OR hypertension OR elevated blood pressure) AND (child OR children OR adolescents OR teenager OR young) AND (receiver operating characteristic curve OR ROC OR area under curve OR AUC).

Two reviewers (W.G. and C.X.) made an independent primary screening of the title and abstract, and then obtained the relevant articles' full text to determine inclusion eligibility. Disagreements were discussed by the team or adjudicated by the third researcher (J.H.). References to related studies were browsed to identify additional valuable studies.

Inclusion/exclusion criteria. Articles were included if they satisfied the following criterias: (1) status of HBP was assessed; (2) subjects between 7 and 18 years old; (3) either original ABSI using Eq. (1) or modified ABSI using Eqs. (2–4) as mentioned above were calculated, and was compared to BMI; (4) AUC and corresponding 95%CI were reported. The language of articles was restricted to English. Duplicated articles based on the same study, conference abstracts, reviews, and intervention studies were not included.

Data extraction and quality assessments. Study characteristics of the included literature were extracted independently by two investigators (W.G. and C.X.), including the type of study design, sample size, country, ethnicity, the definition of HBP, equations of ABSI, as well as age, sex distribution of the included participants. Meanwhile, the AUC (95% CI) of each anthropometric indicator for identifying HBP was also extracted.

Furthermore, QUADAS-2 was used to evaluate the study quality³². The included study was evaluated in two aspects: risk of bias (patient selection, index test, reference standard, and flow and time) and applicability concerns (patient selection, index test, and reference standard). The study quality was described as "high," "low," or "unclear"³².

Statistical analysis. Stata 15.0 was used to pool AUCs and 95% CIs together. I^2 statistics and Cochrane's Q statistics were used to assess the heterogeneity³³. If there was no heterogeneity between studies ($I^2 \leq 50\%$ and $P \geq 0.1$), a fixed-effect model was used; otherwise, a random-effect model was applied. The standard deviation of the difference between BMI and other anthropometric indicators of AUC was calculated assuming a correlation of 0.95 (ref. ³⁴).

RESULTS

A cross-sectional study in Suzhou, China

Baseline characteristics of the participants. Table 1 demonstrates the basic characteristics of the Suzhou population according to HBP status. Among the 3150 participants, 1944 children aged 7–12 years and 1206 adolescents aged 13–17 years; meanwhile, boys accounted for 50.86%. The prevalence of HBP in the total sample, children, and adolescents were 11.27%, 10.60%, and 12.35%, respectively. Participants with HBP had significantly higher SBP, DBP, weight, BMI, and WC than participants without HBP (all $P < 0.05$). Interestingly, original ABSI and modified ABSI (i.e., ABSI-ch, ABSI-ad1, and ABSI-ad2) did not always differ between HBP and Non-HBP groups in the total sample or the subsets divided by age and sex.

ROC analysis of the anthropometric indicators for predicting HBP. As shown in Table 2, BMI had the highest AUC for HBP (AUC: 0.672–0.747), followed by WC (AUC: 0.624–0.720) and ABSI (AUC: 0.498–0.591). The optimal cut-off values for original ABSI, ABSI-ch, ABSI-ad1, and ABSI-ad2 were relatively small and quite close to each other. Although the predictive powers for HBP of ABSI-ch (AUC: 0.613, 95% CI: 0.570, 0.655) among children, ABSI-ad1 (AUC: 0.624, 95% CI: 0.573, 0.675), and ABSI-ad2 (AUC: 0.642, 95% CI: 0.592, 0.692) among adolescent, had significantly improved compared to original ABSI, they were still weaker than BMI ($P < 0.05$). Meanwhile, in girls, the ability of modified ABSI (i.e., ABSI-ch, ABSI-ad1, and ABSI-ad2) to predict HBP in contrast to original ABSI was not significantly improved.

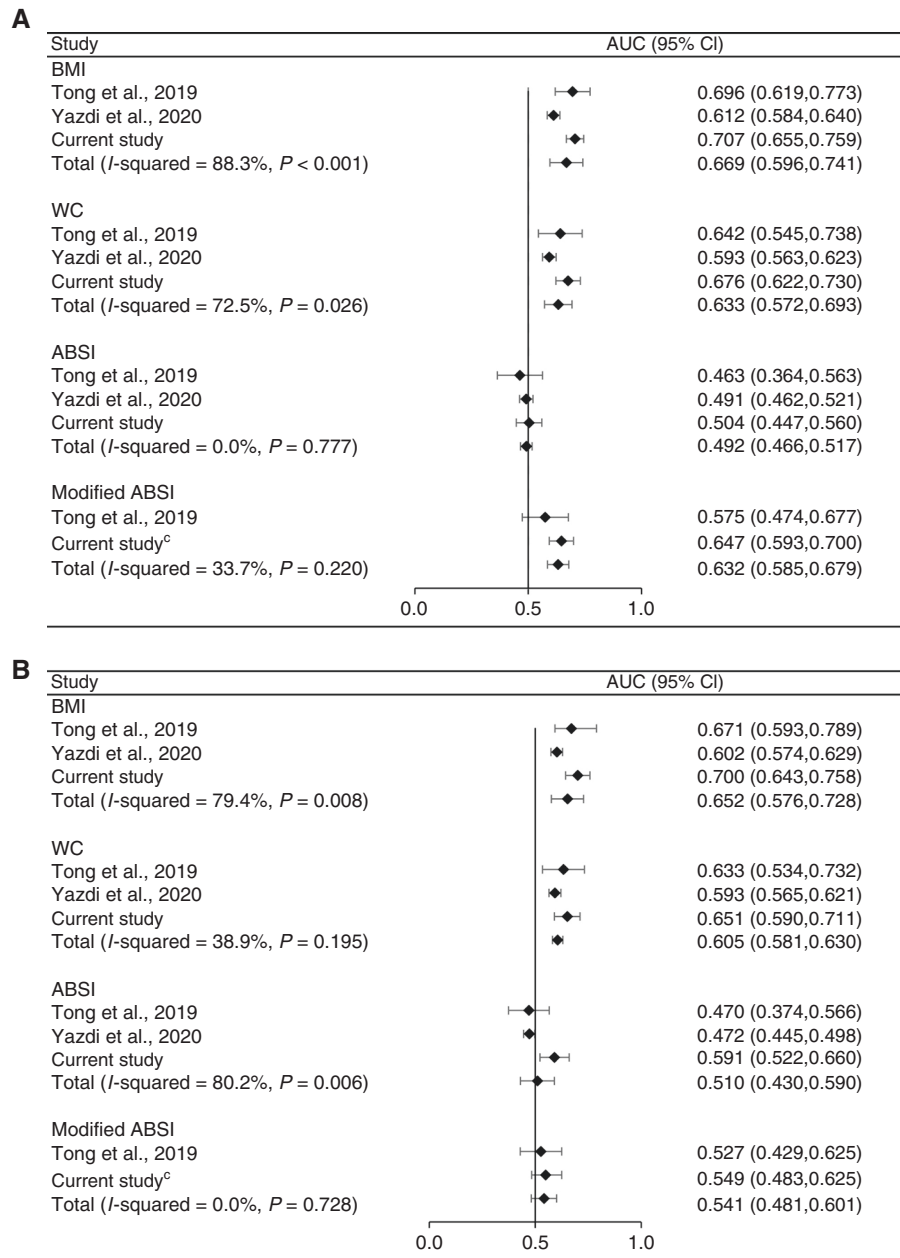


Fig. 2 The pooled area under the curve of anthropometric indicators for screening high blood pressure in children. Panel **A**: boys and panel **B**: girls. ^cUsed the modified ABSI equation for Chinese children by Tong et al.²³.

Meta-analysis

Eligible studies. According to the search strategy, we got 99 relevant articles, of which 44 were excluded for duplicate articles. After browsing the title and abstract, 40 papers were excluded because they were irrelevant to the research purpose. Fifteen papers were retained after full-text evaluation. For the two articles^{11,23} that adopted data from the same study, the report²³ with the larger sample size was finally included. Three papers^{21,28,35} were excluded because they did not report the results of AUC and 95% CI. Finally, five papers^{23–27} were included for the meta-analysis, and the selective process is shown in Fig. 1.

Characteristics of included papers and quality assessment. Table 3 presents the characteristics and outcome definitions of the current study and other five studies with 17958 participants aged 7–18 years. All included studies were published from 2018 to 2020 and had a cross-sectional design. In summary, three studies were

conducted in Asia^{23,25,26}, and the others were from South America²⁷ and Europe²⁴. In total, four papers^{23,24,26,27} analyzed original equation of ABSI (Eq. 1), two papers^{25,27} calculated ABSI using modified equation for adolescents (Eq. 4); another one²³ used a different modified equation for children (Eq. 2) and adolescents (Eq. 3), respectively. The quality assessment of included studies is shown in Table S1. The risk of bias for the current and other studies were evaluated as “low” in all domains. For studies that adopted original ABSI (Eq. 1)^{24,26} and a modified ABSI (Eq. 4)^{25,27} for Chinese adolescents, the results for assessing applicability were uncertain.

Figures 2 and 3 show the pooled AUCs of anthropometric indicators for screening HBP in children and adolescents by sex. Forrest plots present the pooled AUC values of BMI (AUC: 0.652–0.710), WC (AUC: 0.605–0.688), and ABSI (AUC: 0.492–0.547). In adolescents, the pooled AUC value for modified ABSI in boys was 0.646 (95% CI: 0.584, 0.709), and corresponding

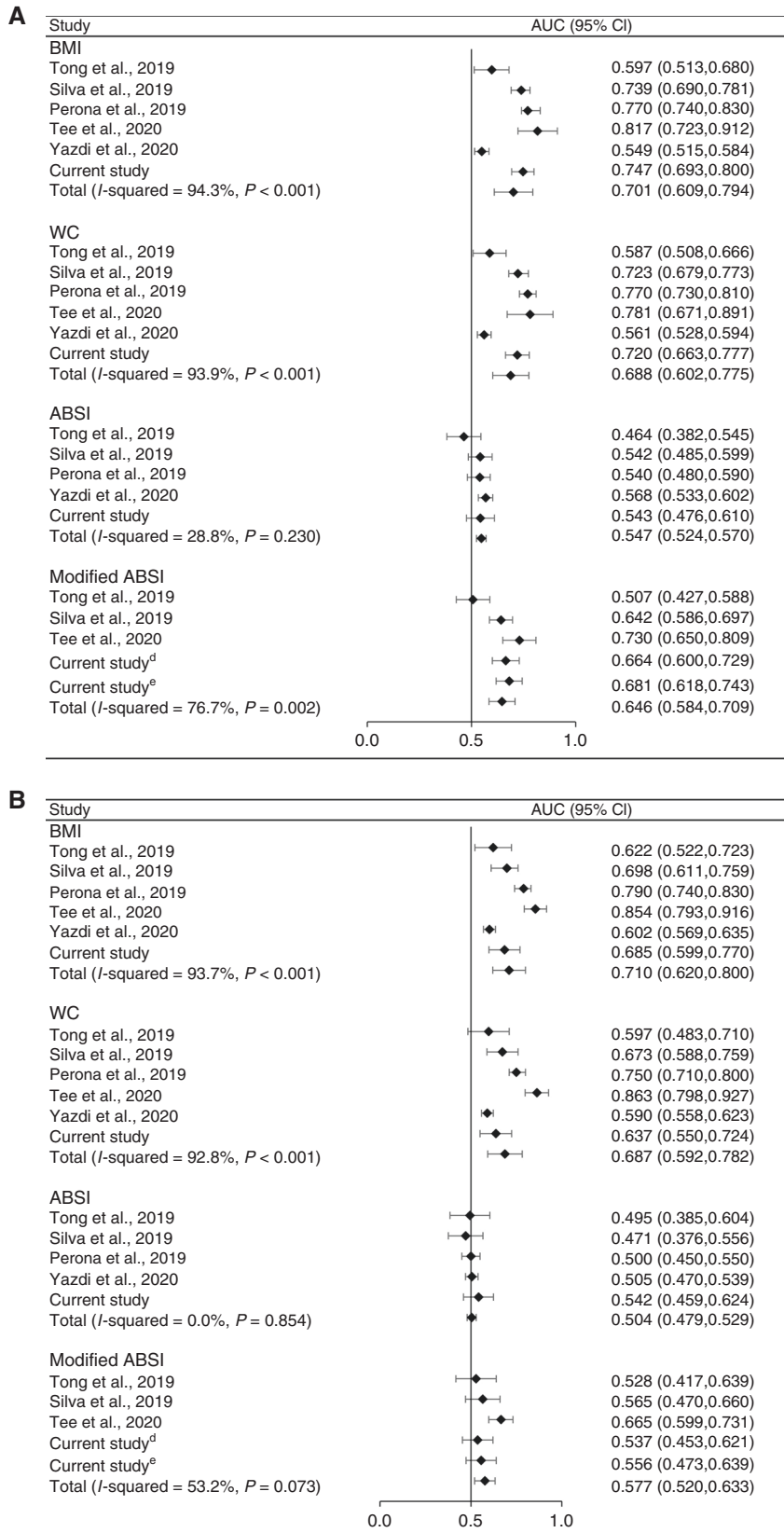


Fig. 3 The pooled area under the curve of anthropometric indicators for screening high blood pressure in adolescents. Panel **A**: boys and panel **B**: girls. ^dUsed the modified ABSI equation for Chinese adolescents by Tong et al.²³; ^eused the modified ABSI equation for Chinese adolescents by Xu et al.¹¹).

pooled AUC value in girls was 0.577 (95% CI: 0.520, 0.633). In children, BMI offered superior performance in predicting pediatric HBP than both original ABSI and ABSI-ch (Table S2). In adolescents, BMI remained to be the best indicator (Table S3).

DISCUSSION

Based on a cross-sectional survey in Suzhou city and a subsequent meta-analysis, we compared the predictive power for HBP of BMI, WC, original ABSI, and modified ABSI in children and adolescents. We found that ABSI was inferior to BMI in screening pediatric HBP, which was consistent with a similar meta-analysis on adults²². Although the predictive powers of modified ABSI for HBP were improved after modifying the scale exponents in children and adolescents, they were still weaker than BMI. The current study suggested that BMI was still the optimal choice for evaluating the effect of obesity on HBP in children and adolescents.

The cardiovascular risks contributed by overweight and obesity in children and adolescents were well documented¹⁰. As we know, the risk of disease associated with obesity involves increased amounts and the distribution of fat tissue. In adults, the indicator of abdominal obesity (i.e., WC) has been suggested to be more tightly associated with the development and progression of CVD than BMI³⁶. Our meta-analysis further supported the most excellent BMI effect on HBP than WC regardless of age and sex. The results were consistent with a recent meta-analysis that compared obesity indicators for predicting pediatric HBP³⁶. The above evidence supports the view that in the pediatric population, BMI may provide sufficient information on visceral fat³⁷. A reasonable biological explanation could be that subcutaneous fat accounts for nearly 90% of abdominal obesity in the pediatric population, while visceral fat accounts for a relatively small percentage³⁸. Simultaneously, BMI was better associated with subcutaneous fat than visceral fat³⁹. Therefore, BMI remains the optimal indicator in pediatric HBP screening.

ABSI, a novel supplement to the abdominal obesity indicator, was highly expected to predict chronic diseases¹⁷. Previous studies had found a high correlation between ABSI and age¹⁷. However, in the current study, it was found that original ABSI had insufficient predictive power in predicting pediatric HBP than BMI and WC, even in subgroups stratified for age. Notably, the predictive power of modified ABSI (i.e., ABSI-ch, ABSI-ad1, and ABSI-ad2) for HBP was unsatisfactory. It was reported that the curve of ABSI had a high peak but a small standard deviation²², making it challenging to define an optimal cut-off value for clinical practice. It should also be kept in mind that Chung et al.¹⁸ proposed a log-transformed ABSI with z-score (LBSIZ), which was revealed to be significantly associated with hypertension in adults. However, it remained unclear whether LBSIZ was appropriate for children and adolescents. Overall, the complexity in calculation and the inferior performance in prediction hamper the usage of ABSI in screening pediatric HBP.

To the best of our knowledge, the current study is the first to evaluate whether original ABSI or modified ABSI is comparable to BMI and WC for screening HBP in children and adolescents, through new original data from a cross-sectional study in Suzhou and meta-analysis. The large sample size and racial variety of similar studies largely increase the generalizability and robustness of our findings. However, we should admit that there were some shortcomings in our study. First, all the included studies had a cross-sectional design that could not reveal the causal relationship between ABSI and HBP. Therefore, future longitudinal studies on the current topic are warranted. Second, the included papers are mainly from Asia, making it difficult to conduct an ethnically stratified meta-analysis. Finally, the incomplete concordance of the diagnostic criteria for HBP in children and adolescents may potentially impact our results.

In summary, the current study found that ABSI may not be a favorable indicator for predicting HBP in children and adolescents. In comparison, BMI remains a crucial anthropometric indicator for detecting HBP at present. Further studies are required to verify the current results' accuracy and whether the results are consistent across race and sex.

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AUTHOR CONTRIBUTIONS

J.Y.Y. and J.H. contributed to the design and concept of the manuscript. W.X.G., C.Q.X., and L.P.Y. were responsible for the analysis, interpretation of data, and manuscript drafting. Y.X., J.Y.L., and F.L. were responsible for the critical revision of the manuscript for intellectual content. All authors were involved in writing the paper and had final approval of the submitted and published versions.

COMPETING INTERESTS

The authors declare no competing interests.

CONSENT STATEMENT

For the recruited participants, informed consent forms in writing duly signed by their guardians were collected before their examination. The project was reviewed by the ethics committees of the Suzhou Center for Disease Prevention and Control.

ADDITIONAL INFORMATION

Supplementary information The online version contains supplementary material available at <https://doi.org/10.1038/s41390-021-01844-5>.

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