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# Comparison of child adiposity indices in prediction of hypertension in early adulthood

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**Abstract**

We aimed to compare child body mass index (BMI) in prediction of hypertension in early adulthood with 4 other adiposity indices (waist circumference [WC], waist circumference-to-height ratio [WHtR], waist-to-hip ratio [WHR], and triceps skinfold [TSF]). The cohort from the China Health and Nutrition Survey 1993-2011 consisted of 1444 adults aged 18-36 years who were examined in childhood and early adulthood. Child adiposity indices and adult blood pressure (BP) were transformed into age-, sex-, and survey year-specific *Z*-scores. Adult hypertension was defined as BP ≥130/80 mm Hg as per the 2017 American College of Cardiology/American Heart Association guidelines. Adult hypertension prevalence was 32.9% during a mean follow-up of 10.1 years. Childhood BMI showed stronger correlation with adult BP than WHR and TSF ($P_S$ for difference <.05). Child BMI showed the better prediction of adult hypertension compared with WHtR, WHR, and TSF using area under the receiver operating characteristic curves ($P_S$ for difference <.05). Per SD change in the predictor, child BMI (relative risk [95% confidence interval], 1.11 [1.04-1.18]) and WC (1.12 [1.05-1.20]) were significantly associated with adult hypertension using covariate-adjusted Poisson models with robust standard errors. Child BMI performed equally or better compared with 4 other adiposity indices in predicting adult hypertension.

## 1 | INTRODUCTION

Adult hypertension is a major contributor of cardiovascular disease (CVD).[1] Prevention of adult hypertension is the most effective means for curbing the rising CVD epidemic.[2] Meta-analysis has demonstrated adult hypertension onset in childhood.[3] Therefore, the early identification of hypertension risk factors in childhood should be considered a top priority.

Childhood obesity prevalence has been increasing worldwide.[4] Previously the effect of pediatric obesity on adult hypertension has been well established.[5] The disturbances in autonomic function, insulin resistance, and abnormalities in vascular structure and function have been implicated in the pathogenesis of obesity-related hypertension.[6] Current guidelines recommend body mass index (BMI) as the practical estimate of childhood obesity.[7] However, BMI cannot differentiate between fat and fat-free mass. The use of BMI to measure adiposity remains controversial and not widely accepted. In contrast, other adiposity indices present advantages in assessing obesity. Waist circumference (WC) can provide more information about the distribution of fat. In adulthood, WC has been considered as the more accurate predictor of obesity-related CVD risk compared with BMI.[8] Waist circumference-to-height ratio (WHtR) was proposed for assessing abdominal obesity due to the impact of height on risk. Based on meta-analysis results, adult WHtR was superior to BMI for identifying future CVD risk.[9] In addition, waist-to-hip ratio (WHR) is an accurate measurement of visceral fat, and triceps skinfold (TSF) thicknesses remain important and valid measurements of subcutaneous fat.

Large cohorts in western populations reported a significant relationship between adiposity in childhood and future hypertension.[10-14]

  

Previous studies revealed that childhood BMI and other adiposity indices significantly predicted adult hypertension.[5,15] However, there are few such studies in the Chinese population, and it is known that association of obesity with health consequences may vary in different populations.[16] It is still an open question whether child BMI performs better or equally in predicting adult hypertension compared with other adiposity indices in the Chinese population. Consequently, this study aimed to compare child BMI and 4 other aforementioned adiposity indices in prediction of adult hypertension based on longitudinal data from the China Health and Nutrition Surveys (CHNS) 1993-2011.

## 2 | METHODS

### 2.1 | Study population

CHNS, previously introduced in detail,[17] is an ongoing nationwide longitudinal study to assess the health and nutritional status of Chinese population. It has been conducted in 1989, 1991, 1993, 1997, 2000, 2004, 2006, 2009, 2011, and 2015 by the University of North Carolina at Chapel Hill, and the National Institute for Nutrition and Health at the Chinese Center for Disease Control and Prevention. A multistage, random cluster process was used to select participants from 15 provinces and municipal cities in China. Institutional Review Board approvals from the University of North Carolina at Chapel Hill, and the China Center for Disease Control and Prevention for CHNS were obtained. All participants provided written informed consent.[17]

The cohort from CHNS consisted of 2180 participants who were examined in childhood and early adulthood. Only the first measurement with full record of key information in childhood and the last measurement with full record of key information in adulthood were obtained from those with more than one measurement during any period, ensuring a long enough follow-up. After excluding 736 participants with incomplete data about their demographic characteristics (sex, age, and living area), adult blood pressure (BP), smoking and drinking, and childhood measurements (BP, weight, height, WC, hip circumference, and TSF), 1444 participants from CHNS 1993-2011 were included in the current study.

### 2.2 | General examinations

Weight and height were measured. BMI was calculated as weight in kilograms divided by the square of height in meters. The measurement of WC was conducted at a point midway between the lowest rib and the iliac crest in a horizontal plane using non-elastic tape. The measurement of hip circumference was taken at the level of the maximum extension of the buttocks posteriorly in a horizontal plane. Waist circumference-to-height ratio and WHR were calculated by dividing WC in centimeters by height and hip in centimeters, respectively. TSF thickness was measured to the nearest 0.5 mm at the triceps on the right arms between the tip of the olecranon process of the ulna and the acromion process of the scapula.

BP was measured in the sitting position with the use of standard mercury sphygmomanometers. Trained health care workers chose appropriately sized cuffs. Systolic BP (SBP) and diastolic BP (DBP) were recorded by the first and fifth Korotkoff sounds, respectively. Three consecutive measurements were conducted, and the average of last two measurements was used for data analysis.

Information on sex, age, living area (urban/rural area), and adult risk factors (smoking and alcohol consumption) was collected through a self-reported questionnaire.

### 2.3 | Definitions

Childhood and adulthood were defined as age <18 years and ≥18 years, respectively. Childhood overweight (including obesity) was defined by the BMI cutoffs recommended by the International Obesity Task Force.[18] Adult overweight (including obesity) was defined as BMI ≥ 25 $kg/m^2$.[19] Child hypertension was defined as SBP/DBP ≥95th percentile for gender, age, and height according to BP reference for Chinese children, which performed equally or better compared with other standards in predicting adult hypertension.[20,21] Adult hypertension was defined as SBP/DBP ≥ 130/80 mm Hg using the 2017 American College of Cardiology (ACC)/American Heart Association (AHA) guideline.[22]

### 2.4 | Statistical analysis

Continuous and categorical variables were presented as means (SDs) and percentages, respectively. The child adiposity indices and adult BP were standardized with Z-transformation (mean = 0, SD = 1) using regression residual analysis with adjustment for sex, age, and survey year.[21] Pearson correlation analyses between child adiposity indices and BP in adulthood were conducted. The Fisher r-to-z transformation was used to evaluate the differences between two correlation coefficients. The ability of child adiposity indices to predict adult hypertension was evaluated by calculating the area under the receiver operating characteristic curve (AUC). The 95% confidence intervals (95% CIs) of AUC included 0.5, which indicates that the predictor is no better than mere chance for making a correct classification. Differences in AUC were determined using DeLong's algorithm. Covariate-adjusted Poisson models with robust standard errors were used to calculate relative risks (RRs) and 95% CIs to examine the associations between child adiposity indices and hypertension in adulthood.[23] Statistical analyses were conducted on SAS version 9.4. A 2-tailed *P* value <.05 was considered to be of statistical significance.

## 3 | RESULTS

The mean follow-up length was 10.1 years (median, 11.0 years; range, 2-18 years). The childhood (age range, 4-17 years) and adulthood (age range, 18-36 years) characteristics of all the participants are summarized in Table 1. A total of 1444 participants were included in the current study. The prevalence of overweight (including obesity) defined by BMI in childhood and adulthood were 5.7% and 13.4%, respectively. The prevalence of hypertension in childhood and adulthood were 12.7% and 32.9%, respectively.

Pearson correlation coefficients between child adiposity indices and BP in adulthood are shown in Table 2. Childhood BMI showed stronger correlations with adult SBP than WHtR, WHR, and TSF ($P_S$ for difference <.05), and stronger correlations with adult DBP than WHR and TSF ($P_S$ for difference <.05). Additionally, compared with child BMI, WC had equal ability to predict adult BP.

The AUCs between youth adiposity indices and adult hypertension are presented in Table 3. Except for WHtR, WHR, and TSF, BMI and WC in childhood were able to predict hypertension in adulthood ($P_S$ < .05). Moreover, BMI performed equally in predicting adult hypertension compared with WC (*P* for AUC difference >.05).

Table 4 describes the impact of child adiposity indices on hypertension in adulthood. With adjustment for sex and childhood age, child BMI and WC were significantly associated with adult hypertension. In contrast, child WHtR, WHR, and TSF were not associated with adult hypertension. Even after further adjustment for childhood hypertension, living area, the length of follow-up, and adult risk factors (smoking and drinking), those associations did not differ substantially. For child BMI and WC, the strengths of the significant associations were similar.

To test the stability of our findings, the sensitivity analysis was performed. First, considering the difference between childhood hypertension classified as BP distribution and adult hypertension defined as absolute BP levels, we did not exclude participants with childhood hypertension.[20-22] However, we repeated the analyses after excluding subjects with childhood hypertension (n = 183) with similar results (Table S1). Second, we repeated the analyses after excluding subjects with follow-up duration less than 10.1 years (n = 676) and obtained similar results (Table S2). Finally, we used the 2018 European Society of Cardiology (ESC)/European Society of Hypertension (ESH) guideline (BP ≥ 140/90 mm Hg and/or taking antihypertensive agents) to define adult hypertension.[24] The

**TABLE 1** Characteristics of 1444 participants (60.7% Males; 32.6% Urban area) in childhood and adulthood with a mean follow-up of 10.1 years

| | Childhood | Adulthood |
|---|---|---|
| Age (y) | 12.8 (3.1) | 22.9 (4.2) |
| BMI (kg/m$^2$) | 18.0 (2.7) | 21.5 (3.5) |
| Overweight and obesity by BMI (%) | 5.7 | 13.4 |
| WC (cm) | 63.2 (8.5) | 76.1 (10.3) |
| WHtR | 0.43 (0.04) | 0.46 (0.06) |
| WHR | 0.83 (0.07) | 0.84 (0.08) |
| TSF (mm) | 9.7 (5.7) | 14.6 (7.3) |
| SBP (mm Hg) | 99.4 (12.9) | 112.1 (11.6) |
| DBP (mm Hg) | 65.3 (9.8) | 73.7 (8.6) |
| Hypertension (%) | 12.7 | 32.9 |
| Smoking (%) | | |
| Never | | 72.3 |
| Former | | 1.4 |
| Current | | 26.3 |
| Drinking (%) | | |
| Never | | 66.2 |
| Almost every day | | 2.7 |
| 3-4 times/wk | | 4.1 |
| 1-2 times/wk | | 9.0 |
| 1-2 times/mo | | 11.6 |
| <1 time/mo | | 6.4 |

*Note:* Data are presented as means (SDs) or frequencies (%) as appropriate.
Abbreviations: BMI, body mass index; DBP, diastolic blood pressure; SBP, systolic blood pressure; TSF, triceps skinfold; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist circumference-to-height ratio.

**TABLE 2** Correlations between child adiposity surrogates and BP in adulthood

| | SBP in adulthood | | DBP in adulthood | |
|---|---|---|---|---|
| | $r$[a] | *P* for difference[b] | $r$[a] | *P* for difference[b] |
| BMI | .172*** | Ref | .147*** | Ref |
| WC | .118*** | .139 | .147*** | .992 |
| WHtR | .072** | .006 | .076** | .055 |
| WHR | −.004 | <.001 | −0.010 | <.001 |
| TSF | .048 | <.001 | .030 | .002 |

*Note:* All BP values and child adiposity indices were transformed into age-, sex-, and survey year-specific *Z*-scores.
Abbreviations: BMI, body mass index; BP, blood pressure; DBP, diastolic blood pressure; SBP, systolic blood pressure; TSF, triceps skinfold; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist circumference-to-height ratio.
[a]Pearson correlation coefficient.
[b]The Fisher r-to-z transformation was used to assess the difference between 2 correlation coefficients.
***P* < .01.
****P* < .001.

**TABLE 3** Performance of child adiposity indices in prediction of hypertension in adulthood

| | AUC analysis | | |
|---|---|---|---|
| | AUC (95% CI) | *P* | *P* for AUC difference |
| BMI | 0.564 (0.532-0.595) | <.001 | Ref |
| WC | 0.543 (0.511-0.575) | .008 | .188 |
| WHtR | 0.517 (0.485-0.549) | .298 | .004 |
| WHR | 0.505 (0.473-0.537) | .749 | .006 |
| TSF | 0.495 (0.463-0.527) | .778 | .023 |

*Note:* Child adiposity indices were transformed into age-, sex-, and survey year-specific *Z*-scores.
Abbreviations: AUC, area under the curve; BMI, body mass index; CI, confidence interval; TSF, triceps skinfold; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist circumference-to-height ratio.

**TABLE 4** Associations of child adiposity indices with hypertension in adulthood

| | Model 1 | | Model 2 | |
|---|---|---|---|---|
| | RR (95%CI) | P | RR (95%CI) | P |
| BMI | 1.13 (1.06-1.21) | <.001 | 1.11 (1.04-1.18) | .002 |
| WC | 1.13 (1.06-1.21) | <.001 | 1.12 (1.05-1.20) | .001 |
| WHtR | 1.05 (0.97-1.12) | .218 | 1.04 (0.96-1.11) | .336 |
| WHR | 1.01 (0.94-1.09) | .738 | 1.01 (0.94-1.09) | .779 |
| TSF | 0.99 (0.92-1.06) | .720 | 0.99 (0.92-1.07) | .801 |

*Note:* Child adiposity indices were transformed into age-, sex-, and survey year-specific Z-scores.
Model 1: adjusted for sex and childhood age; Model 2: additionally adjusted for childhood hypertension, living area, the length of follow-up, and adult risk factors (smoking and drinking).
Abbreviations: BMI, body mass index; CI, confidence interval; RR, relative risk; TSF, triceps skinfold; WC, waist circumference; WHR, waist-to-hip ratio; WHtR, waist circumference-to-height ratio.

prevalence of adult hypertension was 4.9%. Sensitivity analyses exhibited similar results (Table S3).

## 4 | DISCUSSION

In the present study with a mean 10-year follow-up, we demonstrated that child BMI had equal or better ability in prediction of hypertension in early adulthood when compared with 4 other adiposity indices in the Chinese population. Our results did not vary substantially in the sensitivity analysis.

There were two further noteworthy observations in our study. First, the prevalence of overweight and obesity in childhood was 5.7%, which was lower than the prevalence estimated in the previous study.[25] The difference can be attributed to childhood measurements obtained at the very young age, different overweight and obesity definitions, and variation in survey year. Second, the trend in the prevalence of hypertension from childhood (prevalence, 12.7%, as defined in BP ≥ 95th percentile for gender, age, and height) to adulthood (prevalence, 32.9% and 4.9%, as defined in 2017 ACC/ AHA and 2018 ESC/ ESH guidelines, respectively) varied widely depending on the different definitions.[20,22,24]

Cohort studies indicated that child BMI as a continuous scale was positively associated with BP in adulthood.[10-13] Meta-analyses showed that pediatric BMI can significantly predict hypertension and CVD in adulthood.[5,15] Along with previous studies, our study also agreed and confirmed that BMI in childhood can be a significant predictor of adult hypertension in the Chinese population.

Some studies showed that adult WC or WHtR was superior to BMI in predicting future hypertension.[8,9] However, data are presently limited to compare childhood BMI with other adiposity indices in predicting adult hypertension in the Chinese population. Our findings suggested that child BMI had equal or better ability to predict adult hypertension in contrast with 4 other adiposity indices. Similarly, cross-sectional studies support the use of BMI in identifying childhood hypertension.[25-27] Our results were also partly supported by several meta-analyses showing the equal or better screening power of child BMI for detecting concurrent hypertension and cardiometabolic risks in comparison with other adiposity indices.[28,29] Additionally, our results were consistent with the findings from several longitudinal studies in Western populations, which revealed BMI and other adiposity indices in childhood had the similar magnitudes of associations with future hypertension.[10-14]

Taken together, most existing evidence supported the use of BMI as childhood adiposity surrogate in predicting adult hypertension. There is probably one reason which can explain those findings. Child abdominal adipose tissue is mainly composed of subcutaneous rather than intra-abdominal adipose tissue.[30,31] BMI as a general obesity indicator seemed to be suited to assess obesity-related health risks in childhood and early adulthood.

The present study had some limitations. First, 736 (33.8%) participants were not included due to missing data. There was the significant difference in age and BMI in childhood between eligible and non-eligible participants (Table S4), which may bias the results. Second, we cannot identify participants with white-coat hypertension in adulthood, although results from a recent meta-analysis indicated white-coat hypertension was not a benign condition.[32] Third, due to data unavailability, we cannot compare the ability of direct measures of child body adiposity (eg, fat mass measured by dual-energy X-ray absorptiometry) in prediction of hypertension in adulthood compared with BMI. To fill this gap, further cohort studies are needed.

In summary, our study showed that child BMI performed equally or better compared with 4 other adiposity indices in predicting adult hypertension in the Chinese population. Considering accessibility and reliability, our findings supported the use of BMI in childhood in predicting adult hypertension.

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## CONFLICT OF INTEREST

The authors have no conflict of interest to declare.

## AUTHOR CONTRIBUTIONS

Dr Fan conceptualized and designed the study, carried out the initial analyses, drafted the initial manuscript, and reviewed and revised the manuscript; Ms Zhu, Dr Medrano-Gracia, and Dr Zhang critically reviewed and revised the manuscript; and all authors approved the final manuscript for submission.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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