


# Anthropometry did not approach adequate predictive accuracies for detecting elevated fasting plasma glucose or hemoglobin A1c levels among Chinese children aged 7–9 years

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## Keywords

Anthropometric, Children, Hyperglycemia

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## ABSTRACT

**Aims/Introduction:** Elevated concentrations of fasting plasma glucose (FPG) or hemoglobin A1c (HbA1c) are well-established independent risk factors for progression to diabetes, cardiovascular comorbidities and mortality. Most previous studies on the relationships of anthropometric measures with hyperglycemia were carried out among adults and adolescents, but few data are available for the performance prediction of the predictors for diagnosing elevated FPG or HbA1c among young children.

**Materials and Methods:** Involving 5,556 students of aged 7–9 years, a school-based cross-sectional survey was carried out between March and June 2019 in Shenzhen, China. Receiver operating characteristic curve analysis was utilized.

**Results:** The median was 4.6 (interquartile range [IQR] 4.3–4.8) mmol/L for FPG and 5.3% (IQR 5.1–5.5%) for HbA1c levels for all participants. For detecting elevated FPG, weight (0.651, IQR 0.583–0.719) and waist circumference (0.650, IQR 0.584–0.717) showed the highest area under the curve and 95% confidence interval, followed by body mass index and the z-score of body mass index (both 0.635, IQR 0.567–0.703); other anthropometric measures showed poorer diagnostic efficiencies or no ability. For detecting elevated HbA1c, lower efficiencies for the Conicity Index (0.651, IQR 0.583–0.719), waist-to-height ratio, waist-to-hip ratio and waist-to-chest ratio were shown. The correlations of FPG and HbA1c levels with anthropometric indices were weak (Spearman's  $r \leq 0.179$ ).

**Conclusions:** None of the evaluated anthropometric indicators approached an adequate predictive accuracy for the detection of elevated FPG or HbA1c levels in Shenzhen children aged 7–9 years. The current study did not recommend anthropometry screening for prediabetes in young children.

## INTRODUCTION

Elevated concentrations of fasting plasma glucose (FPG) or hemoglobin A1c (HbA1c), also known as intermediate hyperglycemia, are well-established independent risk factors for progression to type 2 diabetes mellitus<sup>1–3</sup>, cardiovascular comorbidities<sup>4,5</sup> and mortality<sup>6,7</sup>, and significantly and independently related to future development of hypertension<sup>8,9</sup>. Screening for elevated blood glucose concentrations could assist in identifying individuals at risk for the above chronic conditions,

but blood collection is inherently invasive and cannot be widely used for a large-scale survey, especially for non-adults. In contrast, simple measurements of anthropometric parameters, such as height, weight, waist circumference (WC), hip circumference (HC) and chest circumference (CC), are relatively quick, inexpensive and non-invasive, and therefore can be applied for large crowds in a massive epidemiological investigation. If the discriminative accuracy of anthropometry to detect hyperglycemia is high and anthropometry is closely related to blood glucose concentrations, the anthropometric indices could be useful surrogate markers for blood glucose levels.

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Numerous studies on the association of anthropometric measures with hyperglycemia have been carried out in some countries and regions. For example, several epidemiological studies suggested that body mass index (BMI), WC, waist-to-hip ratio (WHpR) or waist-to-height ratio (WHtR) has an effective predictive power for diabetes or impaired fasting glucose<sup>10–15</sup>. On the contrary, a study from Durban of South African Asian Indians did not confirm these results, showing that anthropometric measures had a low predictive accuracy for the detection of diabetes in Asian Indians<sup>16</sup>. For adolescents, BMI and WC estimation are easy-to-use tools, and can be carried out for early detection of prediabetes for both boys and girls in India<sup>17</sup>. However, whether the potential indices of the *z*-score of BMI-for-age (BMI-*z*), waist-to-chest ratio (WCtR), chest-to-hip ratio (CHpR) and a novel body index of Conicity Index (C-Index) for predicting elevated FPG and HbA1c were comparable or superior to the above-mentioned parameters remained a controversial issue up to now. Furthermore, although most previous investigations on the relationships of anthropometric measures with hyperglycemia were carried out among adults and adolescents, few data are available for the performance prediction of the predictors for diagnosing elevated blood glucose among young children.

In response to the insufficiency of evidence, the present study was designed to examine the diagnostic performance of 14 anthropometric parameters and subsequent combinations of variables in discriminating elevated FPG and HbA1c among Shenzhen children aged 7–9 years. Early screening and diagnosis for hyperglycemia among children are vital in preventing or delaying progression to some chronic and metabolic diseases.

## METHODS

### Study design and data collection

The school-based cross-sectional survey was carried out between March and June 2019, involving grade 2 students from 19 schools, randomly selected for cluster sampling from 134 local primary schools, in the Bao'an District of Shenzhen, China. The new metropolis of Shenzhen is a major financial center, and the world's largest manufacturing base, with a gross domestic product of \$27,100 per capita in 2017, ranking number one in mainland China<sup>18,19</sup>. This study was approved by the institutional review board of Bao'an Central Hospital of Shenzhen (IRB-PJ-2018-002).

Basic personal characteristics, such as name, sex and national identification number (used to calculate age), were recorded. Anthropometric parameters of standing height (to the nearest 0.5 cm), weight (0.1 kg), WC (1 cm), HC (1 cm) and CC (1 cm) for each student were respectively measured by trained physicians. By using a measuring tape, WC was measured midway between the lower margin of the rib cage and iliac crest, and HC was dimensioned around the widest portion of the buttocks in a standing position.

Blood samples were drawn into vacutainer tubes by trained nurses in the morning after children fasted for at least 10 h.

FPG was measured using the hexokinase method with the automatic analyzer (Model 7170s; Hitachi, Tokyo, Japan), and the concentrations of serum HbA1c were measured utilizing the ion high performance liquid chromatography with Bio-Rad VARIANT II (Hercules, CA, USA), which is standardized to the Diabetes Control and Complications Trial reference assay.

### Data preprocessing

To set up a database, BMI (calculated in weight divided by the square of height; kg/m<sup>2</sup>), WHtR, WHpR, WCtR and CHpR were calculated for each participant<sup>20</sup>. C-Index = WC / 0.109 / square root (weight / height), where WC is in meters, weight is in kg and height is in meters<sup>21</sup>. BMI-*z* was calculated using the R macro (<https://www.who.int/growthref/en/>), based on an international norm of the 2007 World Health Organization growth reference for school-aged children<sup>21</sup>.

A total of 6,192 students aged 7–9 years first agreed to participate in our survey, and written informed consent was obtained for each student and their parents before entering the study. We excluded 484 students due to missing data on any of the anthropometric measurements (i.e., identification number or age, height, weight, WC, HC and CC). Those with missing values on the concentrations of serum FPG or HbA1c (*n* = 148) were also excluded. Thus, effective statistical analyses were carried out in our investigation based on the remaining 5,556 participants.

### Definition of elevated FPG or HbA1c levels

For the main analysis, in the current study, an elevation of serum FPG level among children was defined as FPG  $\geq 5.6$  mmol/L, and elevated HbA1c was defined as HbA1c  $\geq 5.7\%$ , with reference to the diagnostic criteria of prediabetes or intermediate hyperglycemia for adults<sup>2,17</sup>. As there was no consensus on what levels constituted an elevated serum FPG or HbA1c concentration for children and adolescents, we also reported a secondary analysis for the sake of comparison and to check the stability of our main findings, by changing the definitions of elevated FPG levels as equal to or greater than the 75th percentile (4th quartile) of FPG distribution (i.e.,  $\geq 4.8$  mmol/L) and of elevated HbA1c levels as equal to or greater than the 75th percentile of HbA1c distribution (i.e.,  $\geq 5.5\%$ ) among all young participants.

### Statistical analysis

The normal distribution for each variable was determined through the Shapiro–Wilk test, and all of the anthropometric and laboratory indices were non-normal distribution (all *P* < 0.001). The non-normally distributed measurements were described as the median with the interquartile range (IQR; 25–75th percentile), and significance for differences was evaluated by the Mann–Whitney *U*-test. The receiver operating characteristic (ROC) curve analysis with area under the curve (AUC) was utilized to examine the diagnostic performance of each parameter as an indicator of FPG and HbA1c elevation<sup>22</sup>. The

proposed cut-off point for an anthropometric parameter was chosen by the highest Youden Index (sensitivity + specificity - 1)<sup>23</sup>. The Spearman's rank correlation analyses for anthropometric measures with the levels of FPG and HbA1c among the skewed parameters were also carried out. All statistical analyses were processed by SPSS for Windows 21.0 (SPSS Inc., Chicago, IL, USA) results, with two-tailed  $P < 0.05$  considered statistically significant.

## RESULTS

### Characteristics of participants

A total of 5,556 children aged 7–9 years were enrolled for analysis, of which 3,025 (54.4%) were boys. Table 1 shows the descriptive statistics for anthropometric and laboratory parameters. Each anthropometric index was significantly greater among boys than girls (all  $P < 0.05$ ). Overall, the median was 4.6 (IQR 4.3–4.8) mmol/L for FPG and 5.3% (IQR 5.1–5.5%) for HbA1c levels.

As shown in Table 2, children with an elevated FPG activity had greater anthropometric parameters than those with a normal FPG level (all  $P < 0.05$ ); children with elevated HbA1c had higher WHtR, WHpR, WCtR and C-Index values than those with normal HbA1c (all  $P < 0.05$ ).

### Univariate ROC curve analyses

Table 3 shows the information about the ROC curves for discriminating abilities of various anthropometric indices for screening elevated FPG and HbA1c separately. The anthropometric measures of weight (AUC 0.651, confidence interval [95% CI] 0.583–0.719) and WC (AUC 0.650, 95% CI 0.584–0.717) showed the highest AUC and 95% 95% CI for

elevated FPG, followed by BMI and the z-score of BMI (both AUC 0.635, 95% CI 0.567–0.703), but the differences were small. In addition, sex, height, HC, CC and WHtR had a poorer diagnostic efficiency in detecting abnormal FPG. Age, CHpR, and C-Index had no ability to evaluate elevated FPG (all  $P > 0.05$ ). For detecting elevated HbA1c, a low diagnostic performance for C-Index (AUC 0.547, 95% CI 0.519–0.574) and lower efficiencies for WHtR, WHpR and WCtR were shown; the discriminatory power of other anthropometric indices in the prediction of elevated HbA1c was null (all  $P > 0.05$ ). In the stratification analyses by sex, most diagnostic associations were similar, with poorer or null efficiencies (AUC 0.456–0.660 for boys and 0.437–0.644 for girls).

Figure 1 shows the ROC curves of significant indicators for identifying elevated FPG and HbA1c among total Shenzhen children. Based on the largest Youden Index, Table 4 shows the optimal cut-points, and the probability of meaningful and significant indices in diagnosing abnormal FPG and HbA1c. The reasonable cut-off points were 26.2 kg for weight and 55 cm for WC to differentiate elevated FPG, and 1.134 for C-Index to recognize an elevation of HbA1c level.

### Spearman's rank correlation analyses

Table 5 presents the correlation coefficients of anthropometric parameters with FPG and HbA1c. Individual FPG levels were positively correlated with height, weight, WC, HC, CC, BMI and BMI-z indices ( $r = 0.140$ – $0.179$ , all  $P < 0.001$ ). In contrast, the correlations of HbA1c levels with anthropometric indices were very weak ( $r \leq 0.082$ ).

**Table 1** | Baseline descriptive statistics for anthropometric and laboratory parameters stratified by sex among children of Shenzhen aged 7–9 years in 2019

Parameters	Total children ( $n = 5,556$ )	Boys ( $n = 3,025$ )	Girls ( $n = 2,531$ )	$P$
Age (years)	8 (7–8)	8 (7–8)	8 (7–8)	0.051
Height (cm)	130.0 (126.5–134.0)	131.0 (127.0–134.5)	129.5 (126.0–133.0)	<b>&lt;0.001</b>
Weight (kg)	25.8 (23.2–29.5)	26.5 (24.0–30.8)	25.0 (22.7–28.2)	<b>&lt;0.001</b>
WC (cm)	54 (51–58)	55 (52–60)	53 (50–57)	<b>&lt;0.001</b>
HC (cm)	66 (63–70)	66 (63–71)	65 (62–69)	<b>&lt;0.001</b>
CC (cm)	59 (57–63)	60 (58–64)	58 (56–61)	<b>&lt;0.001</b>
BMI ( $\text{kg}/\text{m}^2$ )	15.27 (14.21–16.79)	15.51 (14.45–17.33)	14.94 (13.92–16.27)	<b>&lt;0.001</b>
BMI-z	-0.32 (-1.09 to 0.57)	-0.18 (-0.99 to 0.88)	-0.50 (-1.19 to 0.29)	<b>&lt;0.001</b>
WHtR	0.418 (0.395–0.445)	0.423 (0.400–0.454)	0.411 (0.390–0.436)	<b>&lt;0.001</b>
WHpR	0.826 (0.794–0.859)	0.838 (0.806–0.870)	0.815 (0.786–0.847)	<b>&lt;0.001</b>
WCtR	0.914 (0.879–0.952)	0.915 (0.879–0.955)	0.912 (0.878–0.949)	<b>0.033</b>
CHpR	0.905 (0.877–0.933)	0.913 (0.886–0.940)	0.892 (0.867–0.919)	<b>&lt;0.001</b>
C-Index	1.115 (1.075–1.158)	1.123 (1.082–1.167)	1.108 (1.068–1.148)	<b>&lt;0.001</b>
FPG (mmol/L)	4.6 (4.3–4.8)	4.6 (4.4–4.9)	4.5 (4.2–4.7)	<b>&lt;0.001</b>
HbA1c (%)	5.3 (5.1–5.5)	5.3 (5.2–5.5)	5.3 (5.1–5.5)	0.136

Data are expressed as the median (interquartile range); the bold indicates a statistically significant association. BMI, body mass index; BMI-z, z-score of BMI-for-age; CC, chest circumference; CHpR, chest-to-hip ratio; C-Index, Conicity index; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HC, hip circumference; WC, waist circumference; WCtR, waist-to-chest ratio; WHpR, waist-to-hip ratio; WHtR, waist-to-height ratio.

**Table 2** | Baseline descriptive statistics for anthropometric parameters stratified by fasting plasma glucose (elevated fasting plasma glucose  $\geq 5.6$  mmol/L) and hemoglobin A1c (elevated hemoglobin A1c  $\geq 5.7\%$ ) levels among children of Shenzhen aged 7–9 years in 2019

Parameters	FPG			HbA1c		
	Normal FPG (n = 5,495)	Elevated FPG (n = 61)	P	Normal HbA1c (n = 5,065)	Elevated HbA1c (n = 491)	P
Age (years)	8 (7–8)	8 (8–8)	0.414	8 (7–8)	8 (7–8)	0.787
Height (cm)	130.0 (126.5–134.0)	133.0 (130.0–136.5)	<b>&lt;0.001</b>	130.5 (126.5–134.0)	130.0 (126.0–134.0)	0.071
Weight (kg)	25.8 (23.2–29.4)	29.4 (25.7–34)	<b>&lt;0.001</b>	25.8 (23.3–29.5)	25.5 (23.0–29.75)	0.347
WC (cm)	54 (51–58)	57 (54–63)	<b>&lt;0.001</b>	54 (51–58)	55 (51–59)	0.186
HC (cm)	66 (63–70)	68 (65–74)	<b>&lt;0.001</b>	66 (63–70)	66 (63–70)	0.625
CC (cm)	59 (57–63)	62 (59–65)	<b>0.001</b>	59 (57–63)	60 (57–63)	0.504
BMI (kg/m <sup>2</sup> )	15.26 (14.2–16.76)	16.13 (15.20–18.11)	<b>&lt;0.001</b>	15.27 (14.21–16.76)	15.26 (14.15–17.05)	0.796
BMI-z	-0.33 (-1.09 to 0.57)	0.16 (-0.41 to 1.24)	<b>&lt;0.001</b>	-0.32 (-1.08 to 0.56)	-0.34 (-1.13 to 0.72)	0.767
WHtR	0.418 (0.395–0.444)	0.432 (0.406–0.467)	<b>0.003</b>	0.418 (0.395–0.444)	0.421 (0.395–0.457)	<b>0.012</b>
WHpR	0.826 (0.794–0.859)	0.836 (0.806–0.879)	<b>0.021</b>	0.825 (0.794–0.859)	0.831 (0.799–0.871)	<b>0.029</b>
WCtR	0.914 (0.879–0.952)	0.919 (0.897–0.966)	<b>0.035</b>	0.914 (0.879–0.951)	0.919 (0.881–0.958)	<b>0.044</b>
CHpR	0.905 (0.877–0.933)	0.896 (0.879–0.925)	0.592	0.905 (0.877–0.933)	0.908 (0.875–0.933)	0.691
C-Index	1.115 (1.075–1.158)	1.130 (1.097–1.169)	0.056	1.114 (1.075–1.157)	1.128 (1.078–1.171)	<b>0.001</b>

Data are expressed as the median (interquartile range); the bold indicates a statistically significant association. BMI, body mass index; BMI-z, z-score of BMI-for-age; CC, chest circumference; CHpR, chest-to-hip ratio; C-Index, Conicity index; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HC, hip circumference; WC, waist circumference; WCtR, waist-to-chest ratio; WHpR, waist-to-hip ratio; WHtR, waist-to-height ratio.

### Sensitivity analyses

Sensitivity analyses were carried out by altering the definitions of elevated FPG levels as  $\geq 4.8$  mmol/L and of elevated HbA1c levels as  $\geq 5.5\%$ . All associations were similar, but with poorer diagnostic efficiencies or null ability in detecting abnormal FPG or HbA1c (Tables S1–S2). The AUCs of all anthropometric parameters and individual characteristics as predictive factors were  $\leq 0.590$  for discerning elevated FPG and  $\leq 0.541$  for elevated HbA1c.

### DISCUSSION

The present large-scale, school-based, cross-sectional survey provided detailed evidence for the diagnostic performance of anthropometric parameters in diagnosing elevated serum FPG and HbA1c concentrations among 5,556 young children of Shenzhen. Boys and individuals with elevated blood glucose had greater anthropometric parameters than girls and those with blood glucose, respectively. The results of the present data also disclosed that most anthropometric indices had poor diagnostic efficiencies or null ability in detecting elevated FPG and HbA1c for children aged 7–9 years.

A large body of evidence suggested that the excess risks of mortality, diabetes, cardiovascular and cerebrovascular morbidity were associated with increased HbA1c or FPG concentrations<sup>5,24–26</sup>. For instance, 10,232 Norfolk residents aged 45–79 years were followed up for 8 years, and the population-based prospective cohort study showed that per 1-percentage point increase of HbA1c was linked to a 24% (14–34%) increase in men and 28% (6–32%) in women for total mortality, 21% (13–29%) in men and 21% (11–31%) in women for cardiovascular disease, and 25% (16–34%) in men and 20% (7–

34%) in women for the occurrence of coronary heart disease events<sup>6</sup>. Including 103 prospective cohort studies, a review on assessing the overall prognosis of individuals with intermediate hyperglycaemia for developing type 2 diabetes from the Cochrane database of systematic reviews also showed that the pooled hazard rate was 4.32 (95% CI 2.61–7.12) for elevated FPG (5.6–6.9 mmol/L), and 5.55 (95% CI 2.77–11.12) for elevated HbA1c (5.7–6.4%), as compared with normoglycaemia<sup>2</sup>. A previous survey from Shenzhen<sup>27</sup> pointed out that the crude prevalence was 1.57% (95% CI 1.21–1.94%) for elevated FPG of 5.6–6.9 mmol/L, and 8.89% (95% CI 8.08–9.70%) for elevated HbA1c of 5.7–6.4% among Shenzhen children aged 6–10 years. Taking into consideration the available evidence, we strongly suggest that practitioners and policymakers should be careful about the potential implications of any active intervention for individuals with elevated blood glucose concentrations, not only for adults, but also for children and adolescents.

Clearly, it is more convenient to collect anthropometric indices than biochemical indices to screen for junior grade school children in some investigations or clinical diagnoses, due to the low cost, simplicity, speed and convenience of the non-invasive anthropometry. It is not clear which indices are the highest related to elevated blood glucose among children. Involving 526 Indian students aged 17–19 years, a previous cross-sectional study<sup>17</sup> confirmed that the ROC analysis for BMI showed a good predictive power for an FPG of 5.6–6.9 mmol/L for both boys (AUC 0.828) and girls (AUC 0.838). The approximate efficiency for WC was also shown for both boys (AUC 0.804) and girls (AUC 0.795); the best cut-offs were 22.8 kg/m<sup>2</sup> for boys and 20.5 kg/m<sup>2</sup> for girls for BMI, and 82.5 cm for boys and 80.3 cm for girls for WC. On the

**Table 3** | Area under the and 95% confidence interval of the receiver operating characteristic curve to judge the discrimination ability of various anthropometric parameters for detecting elevated fasting plasma glucose ( $\geq 5.6$  mmol/L) and hemoglobin A1c ( $\geq 5.7\%$ ) separately

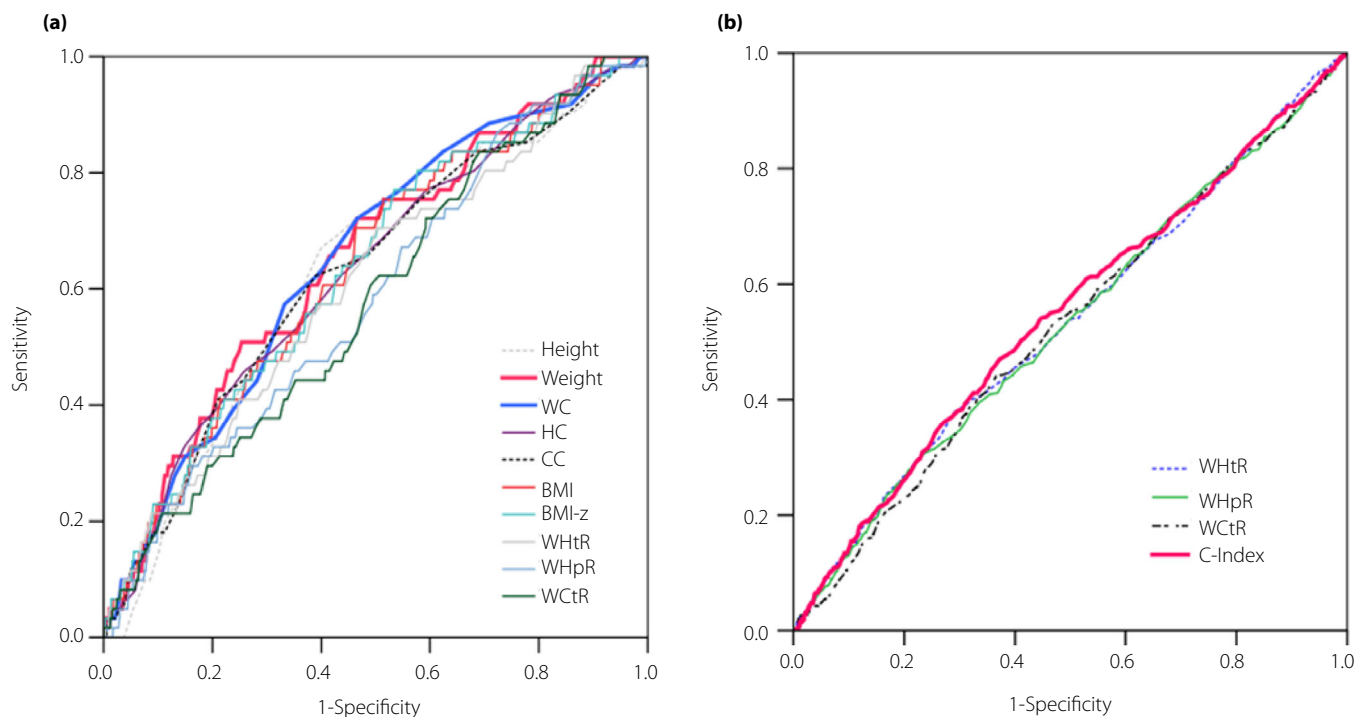
Parameters	Total children (n = 5,556)			Boys (n = 3,025)			Girls (n = 2,531)		
	AUC	95% CI	P	AUC	95% CI	P	AUC	95% CI	P
Elevated FPG ( $\geq 5.6$ mmol/L)									
Age	0.524	0.452–0.597	0.511	0.546	0.396–0.697	0.550	0.514	0.432–0.597	0.737
Sex	0.614	0.549–0.680	<b>0.002</b>	–	–	–	–	–	–
Height	0.629	0.561–0.698	<b>0.001</b>	0.660	0.517–0.803	<b>0.039</b>	0.598	0.518–0.677	<b>0.021</b>
Weight	0.651	0.583–0.719	<b>&lt;0.001</b>	0.603	0.469–0.737	0.182	0.638	0.559–0.718	<b>0.001</b>
WC	0.650	0.584–0.717	<b>&lt;0.001</b>	0.572	0.431–0.713	0.354	0.644	0.569–0.718	<b>0.001</b>
HC	0.632	0.562–0.702	<b>&lt;0.001</b>	0.550	0.408–0.693	0.517	0.638	0.560–0.715	<b>0.001</b>
CC	0.627	0.556–0.699	<b>0.001</b>	0.545	0.405–0.684	0.563	0.619	0.538–0.700	<b>0.005</b>
BMI	0.635	0.567–0.703	<b>&lt;0.001</b>	0.532	0.403–0.660	0.684	0.641	0.564–0.719	<b>0.001</b>
BMI-z	0.635	0.566–0.703	<b>&lt;0.001</b>	0.528	0.405–0.650	0.721	0.642	0.565–0.718	<b>0.001</b>
WHtR	0.609	0.539–0.680	<b>0.003</b>	0.482	0.347–0.618	0.818	0.622	0.543–0.700	<b>0.004</b>
WHpR	0.586	0.517–0.655	<b>0.021</b>	0.536	0.424–0.648	0.640	0.570	0.487–0.653	0.099
WCtR	0.579	0.509–0.648	<b>0.035</b>	0.561	0.427–0.695	0.429	0.581	0.500–0.661	0.058
CHpR	0.480	0.411–0.549	0.592	0.491	0.362–0.619	0.904	0.437	0.355–0.519	0.139
C-Index	0.571	0.503–0.640	0.056	0.535	0.395–0.674	0.655	0.560	0.482–0.638	0.155
Elevated HbA1c ( $\geq 5.7\%$ )									
Age	0.503	0.475–0.531	0.828	0.502	0.461–0.542	0.940	0.504	0.466–0.542	0.820
Sex	0.502	0.475–0.529	0.891	–	–	–	–	–	–
Height	0.475	0.449–0.502	0.071	0.460	0.423–0.498	<b>0.050</b>	0.490	0.453–0.528	0.603
Weight	0.487	0.459–0.515	0.347	0.456	0.416–0.496	<b>0.031</b>	0.513	0.475–0.551	0.469
WC	0.518	0.490–0.546	0.187	0.485	0.445–0.526	0.470	0.547	0.509–0.584	<b>0.012</b>
HC	0.507	0.479–0.534	0.626	0.479	0.439–0.520	0.310	0.529	0.491–0.566	0.120
CC	0.509	0.481–0.537	0.505	0.468	0.428–0.509	0.120	0.544	0.507–0.581	<b>0.017</b>
BMI	0.504	0.476–0.531	0.796	0.466	0.425–0.506	0.089	0.534	0.497–0.571	0.065
BMI-z	0.504	0.476–0.532	0.767	0.466	0.425–0.507	0.094	0.533	0.496–0.570	0.074
WHtR	<b>0.534</b>	0.507–0.562	<b>0.012</b>	0.501	0.461–0.541	0.958	0.564	0.527–0.601	<b>0.001</b>
WHpR	<b>0.530</b>	0.502–0.557	<b>0.029</b>	0.503	0.464–0.543	0.867	0.556	0.518–0.594	<b>0.002</b>
WCtR	<b>0.528</b>	0.500–0.555	<b>0.044</b>	0.512	0.472–0.552	0.561	0.539	0.502–0.577	<b>0.033</b>
CHpR	0.505	0.478–0.533	0.691	0.486	0.444–0.527	0.477	0.519	0.482–0.556	0.301
C-Index	<b>0.547</b>	0.519–0.574	<b>0.001</b>	0.519	0.479–0.560	0.347	0.570	0.533–0.607	<b>&lt;0.001</b>

The bold indicates a statistically significant association. Null hypothesis: true area = 0.5. AUC, area under curve; BMI, body mass index; BMI-z, z-score of BMI-for-age; CC, chest circumference; CHpR, chest-to-hip ratio; CI, confidence interval; C-Index, Conicity index; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HC, hip circumference; WC, waist circumference; WCtR, waist-to-chest ratio; WHpR, waist-to-hip ratio; WHtR, waist-to-height ratio.

contrary, an ongoing cohort study followed up from 2003 to 2013 in central Iran suggested that neither the value of BMI (AUC 0.541) nor WC (AUC = 0.552) was a significant risk factor for prediabetes among Isfahan adults<sup>14</sup>. The previous study based on children and adolescents of Shenzhen also showed that the association of BMI and prediabetes was non-linear, and followed a U-shaped curve, indicating higher rates of prediabetes for underweight and obese people<sup>27</sup>. Overweight and obesity are highly related to type 2 diabetes in youth, and Asian people might have weaker insulin secretion compared with Western people<sup>28,29</sup>. In addition, the occurrence of diabetes in children and adolescents might relate to gestational diabetes risk of mothers, and is sometimes observed at the beginning of puberty; the occurrence of diabetes in girls might 1–2 years earlier than that in boys<sup>30</sup>. During puberty, glucose

intolerance might be apparent as a result of the secretion of sex hormones, and the impact of puberty on glucose tolerance should be different between boys and girls, as some girls, but only few boys, start puberty at the age of 7–9 years. Thus, we highly recommended that several larger-scale surveys involved with some factors (e.g., menstrual onset and Tanner classification of stages G1–G5 for young girls) related to blood glucose levels or anthropometric indices should be investigated among children and adolescents.

With the advantage of not being dependent on sex- or age-specific percentiles relative to a reference population, indices, such as WHtR, BMI-z and C-Index, could be used in adolescents and children, and might represent more practical tools to evaluate abdominal obesity or hyperglycemia, which might have relevant public health implications. However, the findings based



**Figure 1** | Receiver operating characteristic curve of significant anthropometric parameters for predicting elevated (a) fasting plasma glucose and (b) hemoglobin A1c among children of Shenzhen aged 7–9 years. BMI, body mass index; BMI-z, z-score of BMI-for-age; CC, chest circumference; CHpR, chest-to-hip ratio; C-Index, Conicity Index; HC, hip circumference; WC, waist circumference; WCtR, waist-to-chest ratio; WHpR, waist-to-hip ratio; WHtR, waist-to-height ratio.

**Table 4** | Optimal cut-off points and the probability of significant anthropometric parameters for predicting elevated fasting plasma glucose ( $\geq 5.6$  mmol/L) and hemoglobin A1c ( $\geq 5.7\%$ ) separately among children of Shenzhen aged 7–9 years in 2019

Parameters	Cutoff	Sensitivity (%)	Specificity (%)	Youden index (%)
Prediction of elevated FPG				
Height	132 cm	67.2	60.0	27.2
Weight	26.2 kg	72.1	53.4	25.6
WC	55 cm	72.1	53.4	25.5
HC	69 cm	45.9	74.1	20.0
CC	61 cm	62.3	61.0	23.3
BMI	15.15 kg/m <sup>2</sup>	75.4	47.5	22.9
BMI-z	-0.45	77.0	46.0	23.1
WHtR	0.417	70.5	49.8	20.2
WHpR	0.800	86.9	27.7	14.6
WCtR	0.889	83.6	30.8	14.4
Prediction of elevated HbA1c				
WHtR	0.438	38.1	70.6	8.7
WHpR	0.865	29.9	77.2	7.1
WCtR	0.932	44.0	63.4	7.4
C-Index	1.134	47.0	62.7	9.7

BMI, body mass index; BMI-z, z-score of BMI-for-age; CC, chest circumference; CHpR, chest-to-hip ratio; C-Index, Conicity index; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HC, hip circumference; WC, waist circumference; WCtR, waist-to-chest ratio; WHpR, waist-to-hip ratio; WHtR, waist-to-height ratio.

**Table 5** | Spearman's rank correlation coefficients of anthropometric parameters with FPG and HbA1c among children of Shenzhen aged 7–9 years in 2019

Parameters	FPG		HbA1c	
	<i>r</i>	<i>P</i>	<i>r</i>	<i>P</i>
Age	0.028	<b>0.040</b>	−0.003	0.832
Sex	0.199	<b>&lt;0.001</b>	0.020	0.136
Height	0.140	<b>&lt;0.001</b>	−0.002	0.869
Weight	0.179	<b>&lt;0.001</b>	0.017	0.197
WC	0.156	<b>&lt;0.001</b>	0.058	<b>&lt;0.001</b>
HC	0.152	<b>&lt;0.001</b>	0.029	0.031
CC	0.154	<b>&lt;0.001</b>	0.045	0.001
BMI	0.153	<b>&lt;0.001</b>	0.027	0.048
BMI-z	0.146	<b>&lt;0.001</b>	0.028	0.038
WHtR	0.106	<b>&lt;0.001</b>	0.068	<b>&lt;0.001</b>
WHpR	0.067	<b>&lt;0.001</b>	0.069	<b>&lt;0.001</b>
WCtR	0.069	<b>&lt;0.001</b>	0.046	0.001
CHpR	−0.006	0.657	0.030	0.023
C-Index	0.059	<b>&lt;0.001</b>	0.082	<b>&lt;0.001</b>

The bold indicates a statistically significant association. BMI, body mass index; BMI-z, z-score of BMI-for-age; CC, chest circumference; CHpR, chest-to-hip ratio; C-Index, Conicity index; FPG, fasting plasma glucose; HbA1c, hemoglobin A1c; HC, hip circumference; WC, waist circumference; WCtR, waist-to-chest ratio; WHpR, waist-to-hip ratio; WHtR, waist-to-height ratio.

on the young children of Shenzhen did not confirm the implication – the highest AUC to detect elevated FPG was just 0.651 (0.583–0.719) for weight, followed by WC, BMI and BMI-z, and lower diagnostic efficiencies for C-Index, WHtR, WHpR and WCtR to identify elevated HbA1c. For young children, especially for students aged 7–9 years in China, we do not recommend anthropometric indicators to screen for elevated FPG or HbA1c level, because of the poor diagnostic performance.

The current study first investigated the utility of the C-Index as a predictive index of intermediate hyperglycemia for children, showing a low diagnostic performance of C-Index for detecting an elevated HbA1c activity and a null discriminative power for elevated FPG. With the ability to provide estimates of centripetal concentration of body fat, the C-Index had been proposed to assess cardiometabolic risk in a pediatric population, although its use was still limited to research purposes without a widespread use in the clinical and population settings. Among adolescents aged 12–15 years attending school in Jacarezinho, Brazil, the C-Index showed a significant low capacity to predict metabolic syndrome (e.g., high FPG, altered blood pressure), with an AUC of 0.64 (95% CI 0.60–0.69) for boys and 0.68 (95% CI 0.64–0.72) for girls<sup>31</sup>.

A population-based study carried out in a southwest rural region of China by Zhao *et al.*<sup>11</sup> in 2010 showed that only WHpR ( $r = 0.151$ ,  $P < 0.001$ ) and WHtR ( $r = 0.153$ ,

$P < 0.001$ ), but not BMI ( $r = 0.015$ ,  $P = 0.622$ ), had significant correlations with the concentrations of FPG, controlling for WC in the partial correlation analysis; WHpR and WHtR are common indices of central obesity, which is closely linked to insulin resistance and diabetes. However, the levels of FPG in the present study were positively correlated with BMI ( $r = 0.153$ ), whereas weakly linked to WHtR ( $r = 0.106$ ) and WHpR ( $r = 0.067$ ), all  $P < 0.001$ . In terms of HbA1c, the correlation coefficients of all anthropometric indices became weaker.

The present study was the first, as far as we know, to examine the diagnostic performance of 14 anthropometric parameters for the detection of an elevated FPG or HbA1c activity, carried out with 5,556 Shenzhen children aged 7–9 years. Several shortcomings of the present study should be considered. First, sampling based on schools might weaken the representativeness of the population or children, but the school attendance rate in the prosperous city of Shenzhen appears to be nearly 100%. Second, the age range of 7–9 years was narrow, and the results based on a cross-sectional design from a single city of China should be carefully generalized to other regions and other age groups of children. Among children aged 7–9 years in Shenzhen, the median was 130.0 cm (IQR 126.5–134.0 cm) for height, 25.8 kg (23.2–29.5 kg) for weight and 15.27 kg/m<sup>2</sup> (14.21–16.79 kg/m<sup>2</sup>) for BMI. In an international norm from the 2007 World Health Organization growth reference for school-aged children, the median (−1 standard deviation to standard deviation) of BMI-for-age of 8-year-olds (96 months) was 15.7 kg/m<sup>2</sup> (14.4–17.4 kg/m<sup>2</sup>) for boys, and 15.7 kg/m<sup>2</sup> (14.1–17.7 kg/m<sup>2</sup>) for girls<sup>21</sup>. BMI values of our Shenzhen students were similar to those of the World Health Organization, and our sample might show representativeness of these age groups in the world population. Third, the present study did not take into account some potential confounders of hyperglycemia for school children (e.g., leisure time physical activity, sedentary behavior, dietary, and family socioeconomic position and living settings). Another limitation was our inability to consider the 2-h postprandial oral glucose tolerance test among a large sample of children for the definition of hyperglycemia, which might lead to a bias in assessing an elevated blood sugar activity.

In conclusion, the present study showed that all of the checked anthropometric indices did not approach adequate predictive accuracies for the detection of elevated FPG or HbA1c levels in a group of Shenzhen children aged 7–9 years. We do not recommend anthropometric indicators to screen for prediabetes in young children, because of the poor diagnostic performance.

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**DISCLOSURE**

The authors declare no conflict of interest.

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## SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

**Table S1** | Baseline descriptive statistics for anthropometric parameters stratified by fasting plasma glucose (elevated fasting plasma glucose  $\geq 4.8$  mmol/L) and hemoglobin A1c (elevated hemoglobin A1c  $\geq 5.5\%$ ) levels among children aged 7–9 years of Shenzhen, 2019.

**Table S2** | Area under the curve and 95% confidence interval of the receiver operating characteristic curve to judge the discrimination ability of various anthropometric parameters for detecting elevated fasting plasma glucose ( $\geq 4.8$  mmol/L) and hemoglobin A1c ( $\geq 5.5\%$ ) separately.