Original Article

Diagnostic Accuracy of Anthropometric Indices for Obesity Screening Among Asian Adolescents

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Abstract

Introduction: Weight-and-height-based anthropometric indices have long been used for obesity screening among adolescents. However, the ability of their age-and-sex-specific reference values in classifying adolescent as "obese" in different populations was not fully established. Our study aimed to validate the existing international (BMI-for-age charts from WHO, CDC, IOTF) and local cut-offs [percent weight for height (PWH)] for obesity against body fat percentage, as assessed by 4 skinfolds measurement. Materials and Methods: A cross-sectional sample of 6991 adolescents aged 12 to 18 years was measured. All anthropometric measurements were compliant with the internationally accepted protocol. Obesity was defined as percentage body fat greater than or equal to 95 percentile, specific to age and sex. The validity of the existing classification criteria in detecting obesity was evaluated by comparing their respective diagnostic accuracy. Results: Both prevalence of obesity and diagnostic accuracy indices varied by the classification criteria. While all criteria generated very high specificity rates with the lowest being 95%, their sensitivity rates were low ranging from 43% to 71%. Youden's index suggested that CDC and WHO criteria had optimal sensitivity and specificity. ROC analysis showed that overall performance could be improved by refining the existing cut-offs. Conclusions: Clinical validity of weight-and-height-based classification systems for obesity screening in Asian adolescents is poorer than expected, and this could be improved by refining the existing cut-offs.

Ann Acad Med Singapore 2009;38:3-8

Key words: BMI-for-age references, Percentage body fat, Singapore, Validity, Weight-for-height

Introduction

Obesity or excess body fat is strongly associated with enhanced risks of morbidity and mortality, and its prevalence is rapidly escalating worldwide.[1,2] Despite these concerns, no standard definition of obesity for screening, diagnosis and subsequent intervention has been agreed upon internationally.[3,4] The current definitions are mostly defined statistically, and hence they are arguably arbitrary. For practical reasons, weight-and-height-based anthropometric indices including body mass index (BMI, in kg/m^2) have long been used as a surrogate measure for adiposity,[5] and are increasingly recommended for preventive obesity screening among adolescents.[6]

International organisations and experts have published age-and-sex-specific BMI reference values and proposed them for international use.[7-10] These are based on population data either from a single country or a limited number of countries. Country-specific references are appropriate for their respective populations, corresponding to increases in body fat and also immediate and future health risks.[7,11] However, the validity of these reference values for adolescent obesity screening in different populations is not fully established.[12,13]

The BMI cut-offs for obesity in Asian adults have been found to be lower than the internationally recommended ones,[14-16] due to the presence of higher levels of body fat and risk factors at lower BMI levels among different Asian populations. Among children, various studies have shown that international cut-offs may not be appropriate for all populations.[17-20] In Singapore, only 1 local study, which was limited to 623 Chinese children aged below 12 years, has assessed the applicability of BMI cut-offs for obesity

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screening.[21] The aim of this study was to validate the existing international and local cut-offs for obesity, among Singaporean Chinese, Malay and Indian adolescents aged 12 to 18 years, against body fat percentage.

Materials and Methods

This cross-sectional analysis was based on anthropometric data of 6,991 Singaporean multiethnic adolescents aged 12 to 18 years old comprising 56% Chinese, 27% Malays and 17% Indians. It was based on the sampling frame provided by the Ministry of Education (MOE), where 10 schools were selected from all geographical zones, to ensure that the students are representative of the Singapore student population in terms of ethnic composition, gender breakdown and housing type (as surrogate of socio-economic status). MOE then sampled classes where all students in those selected classes were enrolled in the study. Written informed consent was obtained from all subjects' parents or guardians before participating in the study, which was approved by the local institutional review board. The field teams comprised trained nurses, who underwent rigorous training sessions to ensure that they achieve high levels of intra- and inter-observer consistency (acceptable variation ±5%) for all the anthropometric measures. The nurses were then assigned to the anthropometric measurement that they were most competent in. Refresher sessions for the fieldworkers were also conducted mid-way through the fieldwork. Close daily supervision were provided by the PI and co-investigators at the schools to ensure strict adherence to protocols.

Percentage body fat (PBF). Body fat was estimated from the sum of skinfold thickness (SFT) of 4 regional body sites-triceps, biceps, subscapular and supra-iliac. The measurement is done in triplicate using a Holtain skinfold caliper (Holtain Ltd, Crymych, UK) over the left side of the body according to Durnin and Womersley.[22] Measurements were accepted only if the difference between measurements was 2 mm or less. The mean measurement obtained was used in the computation of percentage body fat using the previously validated sex-specific skinfold prediction equations for local adolescents based on deuterium oxide dilution methodology,[23] as below:

$$\%BF = \{562 - 4.2\,[age(y) - 2]\}/\text{Body density (BD)} - \{525 - 4.7\,[age(y) - 2]\}, \text{ where}$$

BD (g/mL) = 1.1690 – 0.0788 x log(sum of 4 skinfold thicknesses) (for boys)

BD (g/mL) = 1.2063 – 0.0999 x log(sum of 4 skinfold thicknesses) (for girls)

Anthropometric measurements. Weight was measured, with subjects wearing light indoor clothing and without shoes, using Seca 762 mechanical scale to the nearest 0.5 kg. A correction of 0.5 kg was made for the weight of the clothes. A wall-mounted Seca 206 stadiometer was used to measure the standing height without shoes against a Frankfurt plane horizontal, and read to the nearest 0.1 cm. The weighing scales were calibrated daily by the investigators before the start of each measurement session. BMI was expressed as weight in kilograms divided by height in metres squared, while percentage weight-for-height (PWH) measured an individual's weight as a percentage of the mean weight for height, according to the 1993 sex-specific normative values of local children aged 6 to 18 years.[24] Weight, height and skinfold thickness measurements were compliant with the internationally accepted protocol, as described in the Anthropometric Standardization Reference Manual.[25]

Obesity classification. Currently, no PBF cut-offs for obesity in adolescents were internationally accepted.[26] Several previous studies have defined adolescent obesity using cut-offs of ≥25% for boys and ≥30% for girls.[27,28] In this study, the arbitrary cut-off of percentage body fat greater than or equal to 95 percentile, by gender and age group, has been adopted as the definition for obesity, similar to that used in studies elsewhere.[29-30]

Anthropometric measures. Reference values used for obesity screening were based on the existing BMI-based classification systems by the International Obesity Taskforce (IOTF);[8] the USA Center for Disease Control and Prevention (CDC)[9], and the World Health Organization (WHO).[10] In addition, we also used the percentage mean weight-for-height values currently used for local school children (PWH).[24] The classification systems for adolescent obesity screening and their reference populations are summarised in Table 1.

Statistical analysis. The validity of the existing criteria (IOTF, WHO, CDC and PWH) in detecting PBF-based obesity was evaluated by comparing their respective diagnostic accuracy indices, namely sensitivity, specificity, positive predictive value, positive likelihood ratio and Youden's index. Sensitivity (true positive rate) is the probability of classifying a subject as obese when the subject is truly obese; specificity (true negative rate) is the probability of classifying a subject as non-obese when the subject is truly non-obese; positive predictive value is the probability of being truly obese when a subject is classified as obese by screening method; positive likelihood ratio is the ratio of true positive rate (sensitivity) to false positive rate (1-specificity); and Youden's index is an overall measure to summarise the sensitivity and specificity, ranging from zero to a perfect value of 100.[31] The index is calculated using the formula as below:

$$YI = (\text{Sensitivity} + \text{Specificity}) - 1$$

Table 1. Classification Systems for Adolescent Obesity Screening and Their Reference Populations

	IOTF, 2000[7]	CDC, 2000[8]	WHO, 2007[9]	PWH, 1996[21]
Reference population	Large survey data from the US, Brazil, Britain, Hong Kong, Singapore and the Netherlands	US NHANES I data	US NHANES I data	1993 survey data of Singaporean children
Cut-offs used in our study	BMI-for-age cut-offs derived from BMI-age curves passed BMI of 30 at age 18	BMI-for-age ≥95th percentile	BMI-for-age z score >2.0	% mean weight-for-height ≥140

BMI: body mass index; CDC: Center for Disease Control and Prevention; IOTF: International Obesity Taskforce; NHANES: National Health and Nutrition Examination Survey; PWH: percentage weight-for-height; WHO: World Health Organization

Table 2. Descriptive Characteristics of Study Population

	Boys (N = 3652)	Girls (N = 3339)	Mean Diff* (95% CI)
Mean (95% CI)			
Age (y)	15.0 (14.9-15.1)	15.2 (15.1-15.3)	-0.2 (-0.3, -0.1)
Weight (kg)	55.9 (55.5-56.3)	50.5 (50.2-50.8)	5.3 (4.8, 5.9)
Height (cm)	164.0 (163.7-164.3)	156.9 (156.7-157.1)	7.1 (6.7, 7.5)
BMI (kg/m^2)	20.6 (20.5-20.7)	20.5 (20.4-20.6)	0.1 (-0.05, 0.3)
Body fat (%)	19.7 (19.5-19.9)	32.4 (32.2-32.6)	-12.7 (-13.0, -12.4)

95% CI: 95% confidence interval; BMI: body mass index; SD: standard deviation
* Diff: difference (i.e. boys' value minus girls' value);

The receiver operating characteristic (ROC) analysis[32] was performed to determine the percentages of area under the curve (AUC) for *BMI-for age* and *percentage weight-for-height*, and their respective cut-offs for an expected sensitivity of at least 80% specific for boys and girls. All statistical analyses were conducted using SPSS version 15.0.

Results

Our study population consisted of 6991 adolescents aged 12 to 18 years old with 52% girls [mean age (SD) =15.0 (1.8) years] and 48% boys [mean age (SD) =15.2 (1.9) years]. As shown in Table 2, boys were significantly heavier (56 kg vs 51 kg) and taller (164 cm vs 157 cm) than girls. No significant difference in the mean age and BMI was seen between the sexes. However, girls had a significantly higher percentage of body fat than boys (32% versus 20%).

The prevalence of obesity varied by gender and the classification criteria used (Table 3). There was a significantly higher proportion of girls in the obese category using the local PWH criteria, while the reverse was observed when BMI-based criteria (CDC, WHO, IOTF) were applied, where more boys were classified as obese compared to girls. The overall prevalence of obesity based on CDC (6.4%) was the same as the one based on WHO criteria (6.4%), and they were higher than the figures based on IOTF (4.3%) or PWH criteria (4.9%).

Table 3. Obesity Prevalence (%) Based on Different Classification Systems

	Overall	Boys (N = 3652)	Girls (N = 3339)	*P*
CDC	6.4	8.4	4.3	<0.001
WHO	6.4	8.4	4.4	<0.001
IOTF	4.3	5.0	3.5	0.002
PWH	4.9	4.4	5.5	0.04

CDC: Center for Disease Control and Prevention; IOTF: International Obesity Taskforce; PWH: percentage weight-for-height; WHO: World Health Organization

Table 4 compares the diagnostic accuracy indices between BMI-based criteria (CDC, WHO, IOTF) and PWH criteria. The BMI-based criteria, particularly of CDC and WHO, had better sensitivity in boys and better specificity in girls, while the PWH criteria showed the reverse. Overall, the sensitivity rates varied from 43% (IOTF cut-off for girls) to 71% (CDC cut-off for boys), and were lower in girls. This means that up to 57% of obese female adolescents would be mis-labelled as non-obese ("false negative" cases) according to IOTF classification.

All classification systems (CDC, WHO, IOTF and PWH) examined in this study had very high specificity rates in both sexes with the lowest being 95% (WHO cut-off for boys). However, none of them performed well with regard to other diagnostic accuracy indices including positive predictive value (range, 42% to 61%) and positive likelihood ratio (range, 14 to 31). Based on Youden's index, a

Table 4. Diagnostic Accuracy Indices of BMI-based Criteria using their Existing Cut-offs to Screen PBF-defined Obesity

	Sensitivity (%)		Specificity (%)		PPV (%)		LR+		YI* (%)	
	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls
CDC	70.6	53.0	94.9	98.2	41.6	60.0	13.8	29.0	65.4	51.2
WHO	69.4	53.0	95.0	98.1	41.7	59.6	13.8	28.5	64.4	51.2
IOTF	51.7	43.3	97.4	98.6	50.8	61.2	19.9	30.5	49.1	41.9
PWH	50.0	61.6	98.0	97.4	56.3	55.5	24.8	24.1	48.0	59.0

BMI: body mass index; CDC: Center for Disease Control and Prevention; IOTF: International Obesity Taskforce; LR+ is positive likelihood ratio; PBF: percentage body fat (obese: greater than or equal to age-and-sex specific 95th percentile); PPV: positive predictive value; PWH: percentage weight-for-height; WHO: World Health Organization

* Youden's index (YI) equals to (Sensitivity+ Specificity) -1

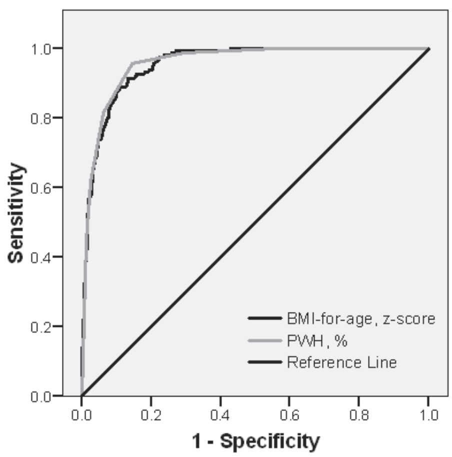
composite measure of accuracy indices indicating optimal sensitivity and specificity rates, CDC and WHO classification systems performed better than others in boys (YI~65%), while PWH system did so in girls (YI = 59%). Details of diagnostic accuracy indices are depicted in Table 4.

The overall accuracy of BMI-for-age and percentage weight-for-height measures in screening for adolescent obesity is generally indicated by the percentage of area under the ROC curve (or AUC). No significant difference was found in the percentage of AUC between the measures, and between sexes (Table 5 and Fig. 1). To achieve a sensitivity of at least 80%, the cut-offs of the PWH-based classification system would need to be set at ≥120% of mean weight for height (for both sexes) instead of ≥140% (current). Likewise, the existing z-score cut-off of >2.0 for the WHO classification system has to be lowered down up to 1.86 for boys and 1.38 for girls (Table 5).

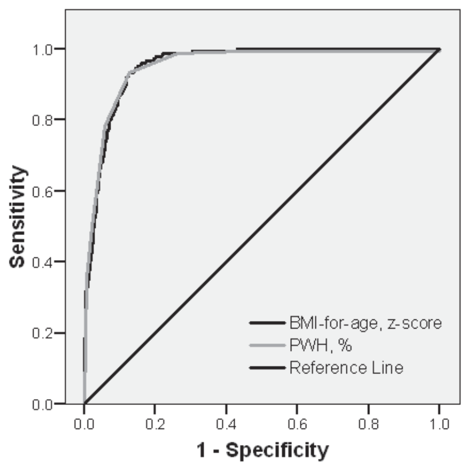
Discussion

The main finding of this study was that diagnostic accuracy indices against percentage body fat differed between different classification criteria and between sexes. While the percentage of false positive cases is expected to be 5% or below, up to 57% of screened adolescents would be misclassified as false negative. For obesity screening, it may be desirable to set a higher sensitivity by varying the cut-offs, to reduce the false negative rates. Screened positive adolescents should be further assessed by skinfold thickness for actual PBF, and risk factors such as hypertension, hyperlipidaemia and impaired glucose tolerance. If there are increased levels of body fat and/or risk factors, early intervention could be instituted, thus preventing long-term obesity-associated psychosocial and medical consequences. On the other hand, a higher specificity (and lower sensitivity) would minimise the number of adolescents being labelled falsely as obese and avoiding possible subsequent impact

In Girls



In Boys



BMI-for-age (z-score) : Area under ROC, 95% CI=95.5, 94.4 to 96.6
PWH (%) : Area under ROC, 95% CI=95.8, 94.8 to 96.9

BMI-for-age (z-score) : Area under ROC, 95% CI=95.6, 94.6 to 96.5
PWH (%) : Area under ROC, 95% CI=95.4, 94.0 to 96.8

Fig. 1. Receiver operating characteristic curves for z-score of BMI-for-age (WHO) and % mean weight for height (PWH), by gender.

Table 5. Proposed Cut-offs of BMI-based Criteria to Screen PBF-based Obesity for an Expected Sensitivity of *at least* 80%

	Boys			**Girls**		
	Cut-off	**Sensitivity (%)**	**Specificity (%)**	**Cut-off**	**Sensitivity (%)**	**Specificity (%)**
WHO, BMI-for-age z-score	1.86	80.0	92.9	1.38	81.7	92.2
PWH, %	≥120	93.3	87.3	≥120	95.7	85.4

BMI: body mass index; PBF: percentage body fat (obese: greater than or equal to age-and-sex specific 95th percentile); PWH: percentage weight-for-height; WHO: World Health Organization

on psychosocial well-being and unnecessary follow-up treatments. Determining the appropriate cut-offs for obesity in a population is thus a delicate balancing act requiring the consideration of multiple factors besides physical health.

Despite giving different estimates of obesity prevalence (Table 3), where the prevalence rates derived using the CDC and WHO classification criteria were higher than those of other criteria (i.e. IOTF and PWH), none of these published age-and-sex-specific BMI reference values achieved optimal rates of sensitivity. Similar findings were reported by other studies[21,30,33,34] which can be explained by the choice of reference data, smoothing methods, and approaches to obesity indices and cut-off values adopted by different classification systems.

Thus, while our ROC analyses showed a relatively high validity of BMI-for-age and percentage weight-for-height in detecting obesity (indicated by the AUC), this finding itself is inadequate without determining the most suitable reference standard for identifying obesity in a particular population, based on both increase in body fat percentage and adverse effect on health. The use of different study populations, from whom the published reference values (i.e. by CDC, IOTF, WHO and PWH) were derived, could partly explain the observed variations in sensitivity and specificity of the anthropometric indices used in this study. For example, the percentage weight-for-height is derived from the 1993 reference data of local children aged 6 to 18 years.[24] A revision is necessary as studies on the secular trend of growth among local children showed that our children have not yet reached full growth potential.[35] The CDC cut-offs are based on the BMI distribution of representative samples of US children[9], participating in the 1970 National Health and Nutrition Examination Survey, as are the WHO references.[10] Finally, the IOTF cut-offs[8] are based on the 1993 data from 6 international countries, including Singapore, whose data validity is perhaps affected by some outliers (i.e. data points that are falling outside 2 standard deviations of the mean value of the sample population). As opposed to the other cut-offs, the IOTF cut-offs are not related to population distribution, but they are extrapolated from the cut-offs for BMI in adults passing through a point of 30 kg/m^2 for obesity at age 18 years.

Limitation of the study. The use of skinfold thickness measurement as an indirect measure of percentage body fat could be affected by differences in subcutaneous fat pattern, and the method of reference used to develop the prediction equation. These were addressed by the development of prediction equations among the local population, validated against the deuterium oxide dilution methodology. Skinfold measurement is the most feasible assessment for percent body fat in a large field study, where mobility and ease of measurement need to be taken into consideration. Another limitation of this study is a lack of data on the subjects' health and its cross-sectional nature. It is also important that the gold standard ("true obesity") should be first defined before comparing clinical validity (i.e diagnostic accuracy indices) of different classification criteria. The arbitrary choice of PBF cut-off to define obesity may be considered as another limitation of this study. The purpose of using this cut-off in this paper is for comparison between different BMI-based classification criteria. Ideally, obesity should not be merely defined as excessive body fatness but its associated detrimental impact on health needs to be taken into account too.[3,4] Therefore, further prospective validation studies using the gold standard based on excess body fat anchored with combined biological, chemical and metabolic endpoints are strongly recommended.

This study concludes that clinical validity of weight-and-height-based classification systems for obesity screening in Asian adolescents are comparable to each other. However their overall performance is poorer than expected, and this could be improved by refining the existing cut-offs. Further prospective validation studies incorporating both percentage body fat and risk factors measurements as a new gold standard are recommended.

Acknowledgements

We thank to all adolescents and their parents or guardians for their full participation in the study.

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