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Application of Body Mass Index to Schoolchildren of Mexico City

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Key Words
Arm muscle area · Body mass index · Elbow breadth · Height · Mexico · Obesity · Overweight · Schoolchildren · Waist circumference · Youden index

Abstract
Background: The validity of body mass index (BMI)-for-age for obesity diagnosis in Latin-American children may be limited due to observed cases of overweight without obesity (i.e. body fat excess), possibly due to certain physical characteristics. In the current study, we investigated whether the usefulness of BMI-for-age in the diagnosis of obesity among Mexican schoolchildren is modified by height, trunk length, muscle mass, body frame, or waist circumference. ***Methods:*** Our study cohort comprised 1,015 schoolchildren (aged 6–11 years) from Mexico City. Obesity diagnostics were derived from three classifications of BMI-for-age: percentiles of BMI according to the references of the Centers of Disease Control (CDC), the National Center for Health Statistics and the International Obesity Task Force. The area under the curve (AUC, through receiver-operating characteristic curves) and optimal cutoff points (by Youden index) of each classification were calculated. Body fat percentage, triceps skinfold thickness and blood pressure were used as standards. AUC and optimal cutoff point analysis were stratified according to height-for-age, sitting height, elbow breadth, arm muscle area (AMA) and waist circumference. ***Results:*** For the general population, the CDC reference had the highest values of AUC (0.94 for triceps skinfold thickness and 0.96 for body fat percentage), and the optimal cutoff point was the 85th percentile. Among schoolchildren with large body frames (measured through elbow breadth) or with high muscle mass (assessed by AMA), the optimal cutoff point was the 95th percentile of the CDC reference. ***Conclusions:*** Our results suggest that the percentile cutoff to define obesity in children with high muscle mass or a large body frame should be the 95th percentile, while the 85th percentile can still be used for the other children.

Introduction

Three reference sources for body mass indice (BMI)-for-age are widely used to diagnose childhood obesity: (1) estimated percentiles based on data of the US National Center for Health Statistics (NCHS) [1]; (2) data of the US Centers for Disease Control (CDC) 2000 Growth Charts developed from 1963 to 1980 using percentiles and Z scores (Zs) [2], and (3) the average percentile corresponding to the BMI of 25 and 30 at 18 years developed

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from data from six countries by the International Obesity Task Force (IOTF) [3]. The use of one internationally accepted reference would be preferable to facilitate comparisons between studies.

However, each of the aforementioned references has advantages and disadvantages. The American references (NCHS and CDC) include values to identify malnutrition (i.e. –2.00 Zs or 5th percentile); they cover other anthropometric indices (i.e. height-for-age, weight-for-height or triceps skinfold thickness) and the NCHS reference has been recommended for use by the World Health Organization [4]. Although the NCHS reference has been replaced by other references, it is still used because it includes values for skinfold thickness. The CDC reference provides reference values for each month of age, allows estimates of the exact percentiles or Zs, and includes more data than the NCHS reference. Additionally, improved methods were used to smooth the curves [5]. However, this reference only reflects the population of one country and therefore may not adequately represent racial and ethnic differences in body growth and composition. In this respect, the IOTF reference is advantageous because it includes the populations of different continents. However, it has been criticized for the decision to average percentiles of curves with different shapes to create cutoff points, setting an arbitrary age at which 'adulthood' begins (18 years) [6], and because some country samples were not representative [7].

The use of BMI as an indicator of adiposity has been criticized because it does not take into account racial and ethnic differences in body composition [8]. Considering the Latin-American population, two positions have been articulated. One holds that in the pediatric population of Latin America, it is necessary to use higher cutoff points[1] since Latin Americans commonly have a higher weight-to-height ratio than the above-mentioned reference populations. This is not always the result of body fat excess; they typically have higher levels of muscle mass [9], hydration of fat-free mass [10], trunk length [9, 11], body frame (i.e. bone breadth) [11], and thorax, abdomen and head circumferences [9, 11–14]. Some of these differences may be the result of chronic malnutrition, while others may reflect true racial and ethnic differences. The other position feels that the BMI obesity cutoff point should be lower in Latin Americans since they have more body fat than Caucasians at the same BMI because the former are often shorter [15]. This could help to explain why populations of lower height have a higher death risk associated with a certain level of BMI compared to populations of normal height [16, 17]. Unfortunately, studies addressing these two positions have not assessed the effects of variations in the relationship between BMI and adiposity derived from the physical characteristics of the Latin-American population regarding the accuracy of the obesity diagnosis.

The objectives of the present study were: (1) to apply three BMI-for-age classification systems (NCHS, CDC, and IOTF) to diagnose obesity in Mexican schoolchildren, and (2) to determine if the results were modified by height, ratio of upper-to-lower body segments (i.e. sitting height), muscle mass, body frame, and waist circumference.

Materials and Methods

In September and October 2005, 1,015 schoolchildren aged 6–11 years were assessed at two primary schools in Mexico City. Students whose measurements could not be obtained (e.g. those with a casted limb) and those who refused to participate in the study were excluded. Verbal consent was obtained. The technical and ethical aspects of the study were approved by the Research Committee of the Division of Biological and Health Sciences of the Metropolitan Autonomous University, Xochimilco Campus.

The measurements of height (stadiometer BM 208; SECA, Hamburg, Germany), weight, sitting height (Harpenden anthropometer; Holtain Crymych, UK), arm circumference, triceps skinfold thickness (Harpenden caliper, Holtain) and elbow breadth (using a caliper; Scala, México City, México) were done in accordance with standardized techniques [18]. Skinfold thickness was determined thrice for each child and the average was calculated. Waist circumference was measured with the method reported by Fernandez et al. [19]. All circumferences were assessed with a non-elastic glass fiber tape (Gulick, Gays Mills, Wisc., USA). Body fat percentage was calculated with a bioelectric impedance analyzer (TBF-310 model; Tanita, Tokyo, Japan), following the recommendations of the manufacturer. This percentage could not be obtained for 171 subjects since the analyzer was not able to estimate these data for subjects aged ≤6 years. Body composition was measured by the bioelectric impedance analyzer. The anthropometric measurements were carried out by three observers who were trained according to the standardization procedures of Habicht [20], and in all cases the accuracy and precision were within acceptable limits. Blood pressure was measured with a sphygmomanometer (model 1050; Baum, New York, N.Y., USA) using standardized procedures [21].

Obesity was diagnosed using the three BMI-for-age criteria. The percentiles of BMI-for-age according to the CDC reference were estimated using EpiInfo software (CDC, Atlanta, Ga., USA). An ordinal variable was created for the NCHS reference (0, ≤5th percentile; 1, >5th and ≤15th percentile; 2, >15th and ≤50th percentile; 3, >50th and ≤85th percentile; 4, >85th and ≤95th per-

[1] High cutoff points: 95th percentile, ≥2.00 Zs, or the percentile corresponding to BMI 30 of IOTF. Low cutoff points: 85th percentile, ≥1.00 Zs, or the percentile corresponding to BMI 25 of IOTF.

centile, and 5, >95th percentile). The two IOTF cutoff points were the percentiles corresponding to BMIs of 25 and 30 in adulthood.

To evaluate the validity of the diagnoses derived from BMI-for-age classifications, the body fat percentage estimated through bioelectric impedance, percentiles of triceps skinfold thickness and blood pressure were used as standards. These methods were used because the body fat percentage by bioelectric impedance [22] and skinfold thickness [23] has been found to be closer correlated with direct measurements of adiposity than BMI. Girls were considered obese at body fat percentages ≥30.0%, whereas the cutoff point for boys was ≥25.0% [24]. On the basis of the NCHS reference [1], children were diagnosed as obese when the triceps skinfold thickness was ≥95th percentile.

Blood pressure was classified in terms of the percentiles published for the American population [20]. This reference has specific blood pressure values for groups of age, gender and the height-for-age index. In this case, the height-for-age index was expressed in percentiles according to the NCHS reference [25], as these values were used to elaborate the blood pressure reference. With the systolic and diastolic blood pressures, three groups were formed: normal pressure (<90th percentile), normal-high pressure (90th–95th percentile) and high pressure (≥95th percentile) [20].

The physical characteristics studied were muscle mass, body frame, ratio of upper-to-lower body segments, linear growth, and distribution of body fat. Muscle mass was estimated with the Zs of the arm muscle area (AMA): $AMA = [(\text{arm circumference} - \pi \text{ triceps skinfold thickness})^2]/4\pi$. Children were classified using AMA standards as having high (≥1.0 Zs) or normal (<1.0 Zs) muscle mass. The body frame was estimated by means of elbow breadth Zs, and two groups were formed: large (≥1.0 Zs) and regular (<1.0 Zs) body frames. The ratio of upper-to-lower body segments was evaluated using the Zs of the sitting height index (sitting height/height × 100) and two categories were formed: longer (≥1.0 Zs) and regular (<1.0 Zs) trunks. To estimate the Zs of AMA, elbow breadth and sitting height index, the values published by Frisancho [26] were used. The following equation was used: $Zs = X - M/DE$, where X = subject's value; M = reference's median, and DE = standard deviation of the reference. To evaluate linear growth, the Zs of the height-for-age index according to the CDC reference [2] were estimated using EpiInfo software. We created two categories for the height-for-age index: low (<–1.00 Zs) and normal (≥–1 Zs) height. Distribution of body fat was assessed by waist circumference, and participants were grouped as with (≥75th percentile) or without (<75th percentile) centralized body fat distribution using the reference for the American population [19].

We estimated descriptive statistics of the anthropometric characteristics of schoolchildren and calculated the prevalence of obesity using the different diagnostic criteria. To identify sex differences, Student's t test and χ^2 tests were performed. To determine the contribution of the different anthropometric characteristics to BMI, multivariate linear regression models were estimated in which the three BMI-for-age classification systems (NCHS, CDC, and IOTF) were considered dependent variables, while independent variables comprised body fat percentage, percentile of waist circumference, and Zs of height-for-age, sitting height, elbow breadth, and AMA. The diagnostic accuracy of the three BMI-for-age classification systems was estimated using the receiver-operating characteristic (ROC) curve method [27], which is generated by plotting sensitivity (true positive/total positive) of all possible cutoff points for the classification on the y axis as a function of 1 – specificity (true negative/total negative) on the x axis. The sensitivity and specificity of the different BMI-for-age diagnostic criteria were estimated considering the body fat percentage by bioelectric impedance, the percentile of the triceps skinfold thickness and levels of blood pressure as standard methods. A summary statistic of the ROC is the area under the curve (AUC), with higher values indicating higher discriminative ability of the classification across the cutoff points. An accurate classification corresponds to an AUC of 1.00 (differentiates perfectly between cases and no cases), and an inadequate classification to an AUC of 0.50 (is unable to distinguish between cases and no cases). Values of AUC ≥0.90 are considered highly accurate; 0.70–0.90 moderately accurate, and 0.50–0.70 minimally accurate. To determine the optimal cutoff point (i.e. maximal specificity and sensitivity), the Youden index [maximum (sensitivity + specificity – 1)] was calculated. The cutoff point on the ROC curve that corresponds to the Youden index was considered optimal. The AUC and optimal cutoff point analysis were stratified by the following variables: height-for-age index (two were established: <–1.0 Zs and ≥–1 Zs), sitting height strata (<1 Zs and ≥1.0 Zs), elbow breadth (<1 Zs and ≥1.0 Zs), AMA (<1 Zs and ≥1.0 Zs) and waist circumference (≥75th and <75th percentile). Differences between AUC values were assessed using χ^2 tests. Statistical analyses were conducted using SPSS and STATA software.

Results

The population studied comprised 1,015 children: 52% boys and 48% girls. Two thirds of the population were either 7.0–8.9 (35.8%) or 9.0–10.9 years old (30.4%). Table 1 shows their anthropometric characteristics. In contrast to the reference population, the Mexican schoolchildren had higher values of sitting height (0.30 Zs), similar AMA (0.0 Zs) and lower height-for-age (–0.1 Zs) and elbow breadth values (–1.1 Zs). In absolute measurements of BMI, elbow breadth and waist circumference, the boys had greater dimensions than girls, but the differences disappear in comparisons using the Zs. Nearly half (48.6%) of the children had a waist circumference above the 75th percentile.

High systolic blood pressure was detected in 13.2% of the children, while 16.7% of them had high diastolic blood pressure. The obesity rate differed according to the measurement applied: using triceps skinfold thickness, the obesity rate was 22.8%, while it was 35.0% with body fat. With the low cutoff points (85th percentile or percentile corresponding to a BMI of 25), the prevalence of obesity was 36.0 and 41.1%, respectively. With the high cutoff points (95th percentile or percentile corresponding to a BMI of 30), the prevalence of obesity was 13.1 and 21.6%, respectively. Boys had higher obesity rates than girls using skinfold thickness and body fat.

Table 1. Anthropometric characteristics of schoolchildren from Mexico City

	Total n	Total mean	SD	Boys mean	Girls mean	p value
Weight, kg	1,015	33.1	11.8	33.7	32.5	0.086
BMI	1,015	18.5	3.9	18.7	18.2	0.020
Triceps skinfold thickness, mm	1,015	15.1	6.3	14.8	15.5	0.079
Height, cm	1,015	132.0	12.2	132.2	131.7	0.480
Sitting height, cm	1,013	70.4	5.6	70.6	70.3	0.521
Elbow breadth, mm	1,015	50.0	5.4	51.1	48.7	0.000
Waist circumference, cm	1,015	67.3	12.0	68.1	66.5	0.029
Height-for-age Zs	1,015	–0.1	1.0	–0.2	–0.1	0.082
Sitting height Zs	1,013	0.3	1.1	0.3	0.3	0.508
Elbow breadth Zs	1,015	–1.1	1.0	–1.1	–1.1	0.786
AMA Zs	1,015	0.0	1.0	–0.1	0.0	0.754
		n	%	%	%	p
Waist circumference >75th per.	1,015	493	48.6	48.6	48.6	0.994
Systolic blood pressure						
Normal high (90th to <95th per.)	1,015	11	10.9	12.5	9.3	0.100
High (≥95th per.)	1,015	134	13.2	14.4	11.9	
Diastolic blood pressure						
Normal high (90th to <95th per.)	1,015	124	12.2	12.7	11.7	0.474
High (≥95 per.)	1,015	169	16.7	15.3	18.1	
Triceps skinfold thickness, n						
Obesity (≥95 per.)	1,015	231	22.8	27.0	18.1	0.001
Body fat percentage by BI, n[1]						
Obesity	844	295	35.0	38.7	30.7	0.015
NCHS reference, n						
≥85 per.	1,015	417	41.1	42.7	39.3	0.268
≥95 per.	1,015	219	21.6	23.6	19.3	0.097
CDC reference, n						
≥85 per.	1,015	378	37.2	40.6	33.5	0.019
≥95 per.	1,015	188	18.5	22.7	14.0	0.000
IOTF reference, n						
Per. of BMI 25	1,015	365	36.0	37.6	34.2	0.251
Per. of BMI 30	1,015	133	13.1	14.9	11.1	0.071

BI = Bioelectric impedance; per. = percentiles; n = subjects that have the event of interest.
[1] For 171 subjects, data were not available. The cutoff points were 30% in girls and 25% in boys.

This pattern persisted with the CDC reference, but using the NCHS and IOTF references sex differences were smaller.

Table 2 presents the results of multivariate linear regression models, in which the three criteria based on the BMI-for-age were considered as dependent variables. Body fat, sitting height, waist circumference, and elbow breadth were positively and independently associated with the percentile of BMI-for-age according to the CDC and NCHS references; conversely, the correlations with the height-for-age index were negative. The IOTF reference model rendered similar correlations, except for the waist circumference, which lacked a statistically significant association (p = 0.115).

The AUC and optimal cutoff points for the general sample and for each sex are shown in table 3. Overall, and for girls and boys separately, the CDC reference had the highest AUC values using the triceps skinfold thickness and body fat as standards. The AUC values of the NCHS reference were lower, but still higher than those from the IOTF reference. In the overall sample and for boys, the CDC reference had the highest AUC values using systolic

Table 2. Multivariate linear regression models with BMI-for-age indices as dependent variables and anthropometric characteristics as independent variables

	BMI with CDC reference (per.)		BMI with IOTF reference (groups)[1]		BMI with NCHS reference (per.)[2]	
	β	p	β	p	β	p
Constant	–5.515	0.004	–0.623	0.000	0.657	0.000
Body fat percentage by BI	0.805	0.000	0.047	0.000	0.045	0.000
Height-for-age Zs	–5.232	0.000	–0.069	0.000	–0.208	0.000
Sitting height Zs	1.830	0.000	0.028	0.026	0.083	0.000
Elbow breadth Zs	1.568	0.007	0.091	0.000	0.133	0.000
AMA Zs	3.872	0.000	0.127	0.000	0.211	0.000
Waist circumference (per.)[3]	14.739	0.000	0.029	0.115	0.462	0.000
r^2	0.92		0.71		0.82	

BI = Bioelectric impedance.
[1] Codification for analysis was: 0, normal; 1, equal or greater to the percentile (per.) corresponding to a BMI of 25, but lower than the per. corresponding to a BMI of 30; 2, equal to or greater to the per. corresponding to a BMI of 30.
[2] Codification: 0, ≤5th per.; 1, >5th to ≤15th per.; 2, >15th to ≤50th per.; 3, >50th to ≤85th per.; 4, >85th to ≤95th per.; 5, >95th per.
[3] Codification: 0, <10th per.; 1, ≥10th to <25th per.; 2, ≥25th to <50th per.; 3, ≥50th to <75th per.; 4, ≥75th to <90th per.; 5, ≥90th per.

Table 3. AUC by ROC and optimal cutoff points of diagnostic criteria for obesity

	Total		Boys		Girls	
	AUC	CoP	AUC	CoP	AUC	CoP
Standard: triceps skinfold thickness[1]						
NCHS reference	0.92[a, b]	85	0.92[a, b]	85	0.91[a]	85
CDC reference	0.94[a, c]	88	0.94[a, c]	89	0.94[a, c]	88
IOTF reference	0.90[b, c]	25	0.89[b, c]	25	0.91[c]	25
Standard: body fat percentage by BI[2]						
NCHS reference	0.94[a, b]	85	0.96[a, b, d]	85	0.92[a, b, d]	85
CDC reference	0.96[a, c]	85	0.98[a, c, d]	85	0.95[a, c, d]	85
IOTF reference	0.92[b, c]	25	0.94[b–d]	25	0.89[b–d]	25
Standard: systolic blood pressure[3]						
NCHS reference	0.72[a]	85	0.73[a]	85	0.70	85
CDC reference	0.73[a, c]	89	0.75[a, c]	90	0.71	80
IOTF reference	0.71[c]	25	0.71[c]	25	0.70	25
Standard: diastolic blood pressure[3]						
NCHS reference	0.69	85	0.70	85	0.68	85
CDC reference	0.70	87	0.71	88	0.69	80
IOTF reference	0.70	25	0.71	25	0.68	25

CoP = The optimal cutoff point according to the Youden index (percentiles); BI = bioelectric impedance.
[a] $p \leq 0.05$, NCHS vs. CDC; [b] $p \leq 0.05$, NCHS vs. IOTF; [c] $p \leq 0.05$, CDC vs. IOTF; [d] $p \leq 0.05$, boys vs. girls.
[1] Obesity case: ≥95th percentile.
[2] Cutoff points: 30% in girls and 25% in boys.
[3] Case: high blood pressure (≥95th percentile).

Table 4. AUC by ROC and optimal cutoff points of diagnostic criteria for obesity by height-for-age, sitting height, and elbow breadth

	Height-for-age Zs				Sitting height Zs				Elbow breadth Zs			
	low height (<–1.0)		normal height (≥–1)		regular trunk (<1.0)		longer trunk (≥1.0)		regular frame (<1.0)		large frame (≥1.0)	
	AUC	CoP	AUC	CoP	AUC	CoP	AUC	CoP	AUC	CoP	AUC	CoP
Standard: triceps skinfold thickness[1]												
NCHS reference	0.87[a]	85	0.92[a, b]	85	0.93[a, b]	85	0.89[a]	95	0.92[a, b, d]	85	0.74[d]	95
CDC reference	0.91[a, c]	80	0.94[a, c]	90	0.94[a, c]	88	0.94[a, c]	91	0.94[a, c]	88	0.86	97
IOTF reference	0.82[c]	25	0.90[b, c]	25	0.90[b, c]	25	0.91[c]	25	0.89[b, c]	25	0.81	30
Standard: body fat percentage by BI[2]												
NCHS reference	0.92[a]	85	0.94[a, b]	85	0.94[a, b]	85	0.94[a]	85	0.94[a, b]	85	0.82	85
CDC reference	0.96[a, c]	80	0.97[a, c]	85	0.97[a, c]	83	0.97[a, c]	90	0.97[a, c]	85	0.99	95
IOTF reference	0.88[c]	25	0.92[b, c]	25	0.91[b, c]	25	0.94[c]	25	0.91[b–d]	25	0.97[d]	30
Standard: systolic blood pressure[3]												
NCHS reference	0.66	85	0.72[a]	95	0.72	85	0.71[a]	85	0.71	85	0.64	95
CDC reference	0.62	75	0.75[a, c]	90	0.73[c]	88	0.75[a]	88	0.72[c]	85	0.74	98
IOTF reference	0.60	25	0.72[c]	25	0.70[c]	25	0.72	25	0.69[c]	25	0.67	30
Standard: diastolic blood pressure[3]												
NCHS reference	0.61	85	0.69	85	0.68	85	0.72[a, b]	95	0.67	85	0.66	95
CDC reference	0.62	74	0.70	87	0.68	80	0.75[a]	87	0.68	87	0.69	98
IOTF reference	0.64	25	0.70	25	0.68	25	0.76[b]	25	0.68	25	0.71	30

CoP = The optimal cutoff point according to the Youden index (percentiles); BI = bioelectric impedance.
[a] $p \leq 0.05$, NCHS vs. CDC; [b] $p \leq 0.05$, NCHS vs. IOTF; [c] $p \leq 0.05$, CDC vs. IOTF; [d] $p \leq 0.05$, regular frame vs. large frame.
[1] Obesity case: ≥95th percentile.
[2] Cutoff points: 30% in girls and 25% in boys.
[3] Case: high blood pressure (≥95th percentile).

blood pressure as standard. Using body fat as standard, boys had higher AUC values than girls in all three classifications. Considering triceps skinfold thickness and body fat, the optimal cutoff point for the total sample varied from the 85th to 88th percentile of the CDC reference, the 85th percentile of the NCHS reference, and the percentile corresponding to a BMI of 25 for the IOTF classification.

The AUC and optimal cutoff point analysis, stratified by the height-for-age index, sitting height, elbow breadth, AMA, and waist circumference, are presented in tables 4 and 5. Where differences existed between the references, the CDC reference had AUC values higher than NCHS and IOTF references. For example, using triceps skinfold thickness as a standard, in normal height children, the CDC had the highest value (AUC = 0.94), followed by NCHS (AUC = 0.92), and IOTF references (AUC = 0.90; table 4); using body fat as standard, the AUC values in children with normal muscle mass were 0.96, 0.93, and 0.88, respectively (table 5).

With respect to the differences in physical characteristics, taking the triceps skinfold thickness as standard, in the children with large frame the AUC values of the NCHS reference were lower in comparison to those with regular frame (0.74 vs. 0.92, respectively); but taking body fat as standard, with the IOTF reference the opposite occurred (0.97 vs. 0.91, respectively). The AUC values of the three classification systems were lower in children with high muscle mass than in those with normal muscle mass; the AUC values were 0.90 and 0.95, respectively, for the CDC reference considering triceps skinfold thickness as standard. In comparison to the children with central body fat distribution, those without had lower AUC values; the values for the IOTF reference using body fat as standard were 0.84 and 0.50, respectively.

The optimal cutoff point analysis is based on the CDC reference because it had the highest AUC values. The optimal cutoff points were between the 80th and 89th percentile for the following groups of children: low height, regular trunk, regular frame, and normal muscle mass. Optimal cutoff points for children with normal height or longer trunk were between the 85th and 91st percentiles.

Table 5. AUC and optimal cutoff points of diagnostic criteria for obesity by AMA and waist circumference

	AMA Zs				Waist circumference			
	normal (<1.0)		high (≥1.0)		without central (<75th per.)		with central (≥75th per.)	
	AUC	CoP	AUC	CoP	AUC	CoP	AUC	CoP
Standard: triceps skinfold thickness[1]								
NCHS reference	0.93[a, b, d]	85	0.75[a, d]	95	0.82[b]	50	0.81[a]	95
CDC reference	0.95[a, c, d]	84	0.90[a, c, d]	97	0.87[c]	66	0.86[a, c]	95
IOTF reference	0.89[b, c, d]	25	0.78[c,d]	30	0.56[b, c, e]	25	0.80[c, e]	30
Standard: body fat percentage by BI[2]								
NCHS reference	0.93[a, b]	85	0.89	95	0.85[b]	50	0.85[a]	95
CDC reference	0.96[a, c]	80	0.95[c]	93	0.91[c]	58	0.90[a, c]	90
IOTF reference	0.88[b, c]	25	0.90[c]	30	0.50[b, c, e]	[f]	0.84[c, e]	30
Standard: systolic blood pressure[3]								
NCHS reference	0.65	85	0.63[a]	95	0.57	50	0.67[a, b]	95
CDC reference	0.66	77	0.71[a, c]	97	0.54[e]	41	0.72[a, c, e]	96
IOTF reference	0.62	25	0.66[c]	30	0.49[e]	[f]	0.70[b, c, e]	30
Standard: diastolic blood pressure[3]								
NCHS reference	0.60	85	0.61	95	0.47[e]	50	0.66[a, e]	95
CDC reference	0.60	80	0.67	96	0.45[e]	40	0.69[a, e]	94
IOTF reference	0.61	25	0.64	30	0.51[e]	[f]	0.68[e]	30

CoP = The optimal cutoff point according to the Youden index (percentiles); BI = bioelectric impedance; per. = percentiles.

[a] $p \leq 0.05$, NCHS vs. CDC. [b] $p \leq 0.05$, NCHS vs. IOTF. [c] $p \leq 0.05$, CDC vs. IOTF. [d] $p \leq 0.050$, normal vs. high muscle mass. [e] $p \leq 0.05$, without vs. with centralized body fat. [f] Significance was not calculated because the sensitivities for all cutoff points were zero.

1 Obesity case: ≥95th per.

[2] Cutoff points: 30% in girls and 25% in boys.

[3] Case: high blood pressure (≥95th per.).

For children with large frames, high muscle mass or centralized body fat distribution, the optimal cutoff points were at the 90th percentile or above.

Discussion

Physical Characteristics of Mexican Children

Studies on Mexican schoolchildren revealed that the Latin-American youth population was shorter [11, 28], and had larger waist circumference [19] and a proportionally longer trunk [9], but a similar amount of muscle mass [9, 11] compared with the reference American population. However, these differences in the body structure of the population have not been consistently reported [11, 14]. Similar to other populations [14], the Mexican schoolchildren had lower average elbow breadth compared to the reference population, which would indicate that they have smaller body frames.

Accuracy of BMI in the Overall Sample

It is customary to select a cutoff point depending on its particular use. If the diagnostic tool will be used in a clinical context, it is advisable to select a point with high specificity because children may be negatively affected by receiving an erroneous diagnosis (i.e. stigma, excessive concern about body weight and nutrition, and pressure from parents) [29, 30]. Also, low sensitivity values should be avoided since they can lead to an increase in false-negative results, i.e. non-detection of obese individuals that require treatment [31]. On the other hand, when a diagnostic criterion is used in population studies to estimate prevalence, a balance should be reached to avoid under- or overestimation [32]. Using AUC values (obtained by ROC analysis) and the optimal cutoff point (identified by the Youden index), both sensitivity and specificity can be taken into account.

In Mexican schoolchildren, the CDC reference had the highest AUC values, followed by the NCHS and IOTF references. Applying the CDC reference, the optimal cutoff points varied from the 85th to the 88th percentiles. A similar pattern (i.e. a better balance between sensitivity and specificity at the 85th percentile) has been observed in other populations [32–38]. Only one study reported a high sensitivity at the 95th percentile [39]. In a study with Swiss children, the CDC reference was also superior to the IOTF [40], although another study found no difference [36].

An indirect obesity indicator must not only be associated with direct adiposity measurements, but should also predict risks related to excessive body fat [7, 41, 42]. Therefore, we compared BMI-for-age diagnoses with blood pressure levels of Mexican schoolchildren. In the whole sample, boys, and some groups formed according to physical characteristics (i.e. children with normal height, regular trunk, longer trunk, regular frame, high muscle mass, or centralized body fat), AUC values were higher using the CDC reference than the other two references when systolic blood pressure was used as the standard. In addition, these results were consistent with those of the adiposity indicators (i.e. skinfold thickness and body fat). Similar findings were reported from the Bogalusa Heart Study [36].

Effects of Physical Characteristics on the Accuracy of Obesity Diagnosis

It has been suggested that the physical characteristics of the Latin-American population may limit the use of BMI as an indicator of obesity since overweight is not always accompanied by excess body fat. In such situations, the BMI-for-age might have reduced the specificity to diagnose obesity, making the use of high cutoff points necessary. Ideally, weight-for-height indices should have an independent distribution of height, but in Caucasian schoolchildren, BMI is positively correlated with height [31, 43, 44], i.e. a tall child could have high BMI values because of his/her height but not due to adiposity. Among Mexican adults with the same BMI, those with short height had more body fat than those of normal height [15]. On the contrary, in Mexican schoolchildren, the association of the height-for-age index with the BMI-for-age was negative, which means that with the same amount of body fat, children with low height tend to have a higher BMI than those with normal height. This is consistent with a prior observation that the high prevalence of low height in Latin America might limit the use of the weight-height indices [28]. Although the optimal cutoff points in low-height children (80th percentile using the triceps skinfold thickness and body fat as standards) were lower than those observed for normal-height children (85th and 90th percentiles), there were no differences in AUC values. It is reasonable to conclude that the same cutoff point can be used for both groups.

In Mexican schoolchildren, the Zs of sitting height was positively related to the three BMI-for-age indexes. These findings partially support the hypothesis that the longer trunk of Latin children may lead them to be classified as obese in the absence of excess body fat [9, 12]. For this reason, it would be necessary to use high cutoff points. What we found, however, was that in Mexican children the AUC values did not differ between children with regular versus longer trunk. Also, the optimal cutoff points were similar in children with regular and longer trunk (88th and 91st percentiles using skinfold thickness as standard). Consistent with our interpretation, Trowbridge et al. [9] disregarded the contribution of a longer thorax to the weight-for-height index.

In Mexican children, elbow breadth was positively associated with the three BMI-for-age indicators suggesting that, regardless of body fat, children with large body frame have higher BMI-for-age. There were differences in AUC values among children with regular versus large frame; in addition, the optimal cutoff points were higher for the latter (88th vs. 97th percentiles and 85th vs. 95th percentiles, using skinfold thickness and body fat standards).

It is accepted that BMI does not allow for differentiation of overweight caused by increased muscle mass versus excess body fat [32, 33, 42]. The positive associations between the Zs of AMA and the three BMI-for-age classification systems observed in Mexican schoolchildren show that the latter is not only an indicator of adiposity but also of lean tissue. Positive associations between BMI and fat-free mass indicators in schoolchildren and adolescents have been reported [31, 44, 45]. However, there are no studies on the modifications affecting BMI-for-age cutoff points required to overcome this limitation. The AUC values of the children with high muscle mass were different from those with normal muscle mass. In addition, the optimal cutoff points were higher in the first group (84th vs. 97th percentiles for triceps skinfold thickness, and 80th vs. 95th percentiles for body fat).

After adjusting for body fat and other anthropometric variables, the waist circumference of Mexican schoolchildren was positively associated with two of the three classification systems. Therefore, both body fat and its distribution are correlated with and independently contribute to BMI. In low-income preschool children of Brazil, abdominal circumference was positively related to the weight-for-height index [12]. However, a comparison of our waist circumference results with other findings is difficult since some authors [19] considered a high value of waist circumference as an indicator of centralized body fat distribution, while other researchers [14] believe that a large abdomen in a child may be the result of an intestinal parasitosis or visceral protrusion due to abdominal muscle weakening, or that the abdominal circumference may reflect the bone structure [12]. The problem is that the measurement sites of these dimensions are similar (waist: at the level of the iliac crests, and abdomen: the broadest circumference between the ribs and iliac crests). Additionally, the AUC values were decreased in Mexican children without centralized body fat distribution using the IOTF classification, and optimal cutoff points were also low (58th and 66th percentiles of the CDC reference). Some AUC could not be estimated due to a sensitivity of zero. For children with centralized body fat distribution, the optimal cutoff points were high (90th and 95th percentiles). Further studies are required.

Limitations

We are aware that better methods than triceps skinfold thickness and bioelectric impedance exist to determine adiposity. However, in Mexico there is limited availability of specialized equipment for laboratory tests (e.g. densitometry or dual-energy X-ray absorptiometry), thus rendering examination using these techniques too expensive. Additionally, clinicians and field workers are more likely to have access to the methods we used, and therefore would be readily able to act upon the conclusions of this study. Nonetheless, more studies in larger cohorts using more sophisticated laboratory techniques to determine the gold standards of body fat are required.

To examine the accuracy of a diagnostic method, the standard must be independent of the evaluated indicator; in our study, to assess the BMI-for-age and triceps skinfold thickness, we used the same reference, therefore both could be correlated. However, skinfold thickness is a better indicator of body fat than BMI [22, 23].

Conclusions

In summary, our data indicate that for population studies, an adequate cutoff point to identify obesity in Mexican schoolchildren is the 85th percentile of the CDC reference. Even though height and trunk lengths in Mexican schoolchildren affect BMI-for-age, they have no significant effect on cutoff points used in the general population. Clinically, it would be useful to measure the AMA and the elbow breadth in addition to the BMI, thus the 95th percentile of the CDC reference could be used for children with high muscle mass or large body frame, while the 85th percentile of the CDC reference can be used for all other children.

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