Validity of body mass index compared with other body-composition screening indexes for the assessment of body fatness in children and adolescents[1,2]

Zuguo Mei, Laurence M Grummer-Strawn, Angelo Pietrobelli, Ailsa Goulding, Michael I Goran, and William H Dietz

ABSTRACT

Background: Validation studies of height- and weight-based indexes of body fatness in children and adolescents have examined only small samples of school-age children.

Objective: The objective was to validate the performance of age- and sex-specific body mass index (BMI) compared with the Rohrer index (RI) and weight-for-height in screening for both underweight and overweight in children aged 2–19 y.

Design: Data from the third National Health and Nutrition Examination Survey ($n = 11096$) and a pooled data set from 3 studies that used dual-energy X-ray absorptiometry ($n = 920$) were examined. The receiver operating characteristic curve was used to characterize the sensitivity and specificity of these 3 indexes in classifying both underweight and overweight. Percentage body fat and total fat mass were determined by dual-energy X-ray absorptiometry. Subcutaneous fat was assessed on the basis of the average of triceps and subscapular skinfold thicknesses.

Results: For children aged 2–19 y, BMI-for-age was significantly better than were weight-for-height and RI-for-age in detecting overweight when average skinfold thicknesses were used as the standard, but no differences were found in detecting underweight. When percentage body fat or total fat mass was used as the standard, BMI-for-age was significantly better than was RI-for-age in detecting overweight in children aged 3–19 y. No differences were found between BMI-for-age and weight-for-height in detecting overweight or underweight.

Conclusion: For children and adolescents aged 2–19 y, the performance of BMI-for-age is better than that of RI-for-age in predicting underweight and overweight but is similar to that of weight-for-height. *Am J Clin Nutr* 2002;75:978–85.

KEY WORDS Dual-energy X-ray absorptiometry, body mass index, Rohrer index, weight-for-height, skinfold, anthropometry, receiver operating characteristic curve, sensitivity, specificity, children

INTRODUCTION

Anthropometry is one of the most basic tools for assessing nutritional status, whether overnutrition or undernutrition. A variety of methods are available to measure body fatness and body thinness (1, 2). Commonly used techniques for the accurate estimation of body fatness include underwater weighing, dual-energy X-ray absorptiometry (DXA), total body water, total-body electrical conductivity, total body potassium, and computed tomography. However, the use of most of these methods is limited to research settings because of their complexity and cost (3–7). The most frequently used tools in public health evaluations and clinical screening are anthropometric-based measurements such as skinfold-thickness or circumference measurements or various height- and weight-based indexes such as weight-for-height, body mass index [BMI; wt (kg)/ht^2 (m)], and the Rohrer index [RI; wt (kg)/ht^3 (m)] (1, 2).

Traditionally, body fatness has been estimated from measurements of skinfold thicknesses, which correlate reasonably well with body fatness. Concerns have been expressed about the accuracy of this approach because skinfold thicknesses are poorly reproducible and only a few regional body sites are measured (1, 2, 8–10). A series of validation studies of DXA measurements in animal and human studies showed that DXA measurements accurately capture regional and total body composition and may constitute a new reference method (11–20).

Height- and weight-based measurements are the most practical tools for assessing nutritional status because of their simplicity and low cost. Of these methods, BMI is the one most commonly recommended and widely used for classifying overweight and obesity in adults (2, 21–23) and has also been recommended for screening overweight and obesity in adolescents (24–28). To date, however, the validity of BMI in accurately classifying underweight children has not been examined, and this index has not been used routinely for children aged <5 y. New growth charts from the Centers for Disease Control and Prevention (CDC) include an age- and sex-specific BMI reference for children aged 2–20 y in addition to a sex-specific

[1] From the Division of Nutrition and Physical Activity, Centers for Disease Control and Prevention, Atlanta (ZM, LMG-S, and WHD); the Institute of Pediatrics, University of Verona, Verona, Italy (AP); the Department of Medicine, Otago University, Dunedin, New Zealand (AG); and the Department of Nutrition Sciences, University of Alabama at Birmingham (MIG).

[2] Address reprint requests to Z Mei, Centers for Disease Control and Prevention, Mailstop K-25, 4770 Buford Highway, Atlanta, GA 30341-3724. E-mail: zam0@.cdc.gov.

Received August 4, 2000.

Accepted for publication June 22, 2001.

TABLE 1
Comparison of the subject sample and the method of measurements used for the pooled data set

	Goran et al (16)	Pietrobelli et al (26)[1]	Goulding et al (27, 28)
Country	United States	Italy	New Zealand
Dates conducted	1994–1997	1996–1997	1994–1995
Number of subjects	200	317	403
Age range (y)	4–9	5–19	3–19
Race or ethnicity			
Non-Hispanic white	121	317	403
Non-Hispanic black	79	0	0
Percentage male (%)	50.5	50.2	28.6
DXA measurement[2]	Pediatric medium scan mode, version 1.5d	Pediatric medium scan mode (5–16 y), adult software (>16 y)	Pediatric medium scan mode (3–16 y), adult software (>16 y)
Height measurement	Fixed wall-mounted metric ruler to the nearest 0.5 cm	Standard laboratory stadiometer to the nearest 0.5 cm	Stadiometer to the nearest 0.5 cm
Weight measurement	Subjects wore light clothing and no shoes; beam scale to the nearest 0.01 kg	Subjects wore minimal clothing; balance-beam scale to the nearest 0.2 kg	Subjects wore light clothing and no shoes; scale to the nearest 0.5 kg

[1] Includes unpublished observations (A Pietrobelli, 1997).
[2] Lunar DPX-L scanner (Lunar Radiation Co, Madison, WI). DXA, dual-energy X-ray absorptiometry.

weight-for-height reference for children aged 2–6 y (29). Weight-for-height is already used routinely in preschool children in clinical settings to screen for underweight and overweight (1, 2, 30). Some evidence has shown that the RI predicts body fatness during puberty better than does BMI (1). In the current study, we validated the CDC's new age- and sex-specific BMI-for-age reference and compared its performance (ie, its sensitivity and specificity) with that of RI-for-age and weight-for-height in screening both underweight and overweight in children aged 2–19 y.

SUBJECTS AND METHODS

Two data sets were used for this study. To compare skinfold thicknesses with measures of height-adjusted weight, we used data collected as part of the third National Health and Nutrition Examination Survey (NHANES III), which was conducted by the CDC (National Center for Health Statistics, Atlanta) to provide representative data from samples of the civilian, noninstitutionalized US population aged 2 mo to 74 y (31). Conducted from 1988 to 1994, NHANES III included standardized measurements of height, weight, and skinfold thicknesses. Detailed descriptions of the sample selected were published elsewhere (31, 32). For this analysis, we included all 11 096 records for children aged 2–19 y and incorporated their original sample weights. We used the average of the triceps and subscapular skinfold thicknesses in this data set as a measure of body fatness.

To compare DXA measurements of fatness with height-adjusted weight measures, we pooled 3 data sets containing height, weight, and DXA measurements (pooled data set). The data sets were collected from 3 studies conducted separately in the United States, Italy, and New Zealand (16, 26–28; A Pietrobelli, unpublished observations, 1997). The Lunar DPX-L scanner (Lunar Radiation Co, Madison, WI) with pediatric medium or adult software was used in all 3 studies. Each study used a standardized protocol for the height, weight, and DXA measurements, as summarized in **Table 1**. Measurements for a total of 920 children aged 3–19 y from the pooled data sets were compared. Both percentage body fat (%BF) and total fat mass (TFM) were used as references to predict both body fatness and body thinness, and total fat-free mass (TFFM) was used as a reference to predict body thinness.

The age- and sex-specific BMI reference, which was developed recently by the CDC (29), was used in this study to assign BMI percentiles (z scores) to the NHANES III and the pooled data sets. We developed weight-for-height, RI-for-age, and average triceps and subscapular skinfold thickness references for children aged 2–19 y by using the same CDC growth reference data set and smoothing techniques. To create an internal DXA reference, we first grouped the children in the pooled data set into 3 age groups (3–5, 6–11, and 12–19 y) by sex and then calculated each single empirical centile from the 3rd to the 97th centiles by sex and age group. We included all children aged 2–19 y in the NHANES III study who had height, weight, triceps, and subscapular skinfold-thickness measurements and assigned each child a BMI-for-age, RI-for-age, weight-for-height, and skinfold-for-age percentile. For the pooled data set, we included all children who had height, weight, and DXA measurements and assigned each child a BMI-for-age, RI-for-age, weight-for-height, %BF, TFM, and TFFM percentile. We defined underweight as being below the 15th percentile on the basis of both the DXA (%BF, TFM, and TFFM) and average skinfold-thickness measurements, and we defined overweight as being above the 85th percentile for %BF, TFM, and average skinfold-thickness measurements in the study population. The cutoffs for %BF, TFM, and TFFM from the DXA measurements are summarized in **Table 2**.

Pearson correlation coefficients were used to examine the relations between either subcutaneous fat based on average skinfold thicknesses or %BF and TFM determined by DXA and the height- and weight-based measures (BMI-for-age, RI-for-age, and weight-for-height). We also examined the correlation between BMI-for-age and weight-for-height because the new CDC growth charts have both references available for children aged 2–5 y (29). We used receiver operating characteristic (ROC) curves (33) to assess the performance of the indexes in detecting both underweight and overweight. The ROC curve is constructed by first calculating the sensitivity and specificity generated by using a series of percentile cutoffs from the 3rd to the 97th percentile of the screening indexes. Then, the series of sensitivities were plot-

TABLE 2
The 15th and 85th percentile cutoffs of percentage body fat, total fat mass, and total fat-free mass for the pooled data set

Age	Percentage body fat		Total fat mass		Total fat-free mass	
	Boys	Girls	Boys	Girls	Boys	Girls
	%		kg		kg	
15th Percentile						
3–5 y	10.2	13.6	1.83	2.19	15.09	13.90
6–11 y	11.3	16.0	2.66	4.21	19.82	18.95
12–19 y	12.5	20.9	5.98	10.00	32.37	31.78
85th Percentile						
3–5 y	29.9	28.2	7.47	6.76	—	—
6–11 y	40.3	44.7	17.53	23.49	—	—
12–19 y	46.0	47.8	37.58	38.34	—	—

ted on the *y* axis against the corresponding values of 1 − specificity on the *x* axis. In general, the farther the curve is away from the diagonal chance line, which extends at 45° from the origin ($x = 0$, $y = 0$), the better the indicator's performance. MEDCALC software (34) was used to test significance for the areas under the ROC curves (AUC), and a Bonferroni adjustment (35) was used to correct the *P* values from the AUC tests.

RESULTS

Body-composition characteristics of the pooled data set are shown separately for boys and girls in **Table 3**. For the NHANES III data, the correlation coefficients of BMI-for-age, RI-for-age, and weight-for-height with average skinfold thicknesses are summarized in **Table 4**. The correlation coefficients of all 3 indexes with average skinfold thicknesses were significantly lower for preschoolers than for school-age children and adolescents (≈0.6–0.7 for children aged 2–5 y compared with 0.7–0.8 for children aged 6–11 and 12–19 y). In all 3 age groups, correlation coefficients were higher for girls than for boys. For the pooled data, the correlation coefficients for the relations between BMI-for-age, RI-for-age, and weight-for-height with DXA measurements of %BF and TFM (**Table 5**) were not significant but were consistently higher than the corresponding correlation coefficients in Table 4.

Both BMI-for-age and RI-for-age were strongly correlated with weight-for-height (r = 0.99, 0.97, and 0.95 for BMI and 0.92, 0.98, and 0.98 for RI, respectively, for children aged 2–5, 6–11, and 12–19 y). BMI-for-age and weight-for-height assigned similar percentiles to preschool children. The assigned percentile was within 5 percentile points 75% of the time and within 10 percentile points 95% of the time for children aged 2–5 y.

TABLE 3
Comparison of body-composition characteristics of the pooled data by age group and sex

Characteristic and age	Goran et al (16)		Pietrobelli et al (26)[1]		Goulding et al (27, 28)	
	Boys	Girls	Boys	Girls	Boys	Girls
3–5 y						
n	25	28	8	7	21	73
Age (y)	5.3 ± 0.5[2]	5.2 ± 0.5	5.0 ± 0.0	5.0 ± 0.0	4.3 ± 0.8	4.5 ± 0.7
Height (cm)	113.0 ± 6.5	113.0 ± 6.2	113.0 ± 4.0	114.1 ± 3.2	110.6 ± 7.4	111.0 ± 7.8
Weight (kg)	22.0 ± 4.8	22.4 ± 5.4	24.4 ± 9.1	25.4 ± 4.7	20.8 ± 4.9	19.6 ± 3.8
BMI (kg/m^2)	17.1 ± 2.2	17.3 ± 2.7	18.8 ± 6.0	19.5 ± 3.6	16.8 ± 2.2	15.7 ± 1.5
Percentage body fat (%)	19.1 ± 9.3	23.3 ± 8.4	26.1 ± 13.9	38.3 ± 6.8	16.3 ± 10.3	17.4 ± 5.5
Total fat mass (kg)	4.5 ± 3.1	5.6 ± 3.7	7.4 ± 6.6	9.9 ± 3.1	3.7 ± 3.8	3.4 ± 2.0
6–11 y						
n	76	71	66	71	51	131
Age (y)	7.6 ± 1.2	8.0 ± 1.1	8.8 ± 1.4	8.7 ± 1.5	8.5 ± 1.8	9.1 ± 1.6
Height (cm)	128.6 ± 9.8	128.8 ± 10.2	136.2 ± 9.6	136.4 ± 11.9	134.5 ± 11.8	136.9 ± 11.1
Weight (kg)	30.7 ± 10.7	34.0 ± 12.1	40.7 ± 15.0	45.8 ± 15.3	32.0 ± 9.0	34.9 ± 11.1
BMI (kg/m^2)	18.1 ± 3.9	20.0 ± 5.4	21.5 ± 6.3	24.0 ± 5.4	17.3 ± 2.5	18.2 ± 3.7
Percentage body fat (%)	21.8 ± 10.9	29.9 ± 10.5	29.9 ± 14.8	40.3 ± 10.1	16.5 ± 7.4	24.4 ± 9.8
Total fat mass (kg)	7.7 ± 6.7	11.2 ± 7.5	14.1 ± 11.0	19.6 ± 9.6	5.6 ± 4.2	9.1 ± 6.7
12–19 y						
n	—	—	85	80	51	76
Age (y)	—	—	14.0 ± 2.1	13.8 ± 2.0	15.0 ± 2.5	14.6 ± 2.6
Height (cm)	—	—	160.5 ± 13.5	156.2 ± 7.3	167.7 ± 13.3	158.6 ± 9.6
Weight (kg)	—	—	63.7 ± 21.7	64.9 ± 19.5	59.8 ± 15.1	53.2 ± 10.6
BMI (kg/m^2)	—	—	24.1 ± 5.9	26.4 ± 7.1	20.9 ± 3.3	21.1 ± 3.4
Percentage body fat (%)	—	—	30.1 ± 15.1	39.1 ± 12.4	18.0 ± 8.5	28.2 ± 7.9
Total fat mass (kg)	—	—	21.1 ± 14.8	27.3 ± 15.1	10.9 ± 6.5	15.5 ± 7.0

[1] Includes unpublished observations (A Pietrobelli, 1997).
[2] $\bar{x}$ ± SD.

TABLE 4
Correlation coefficients (and 95% CIs) between selected anthropometric variables and the average of the triceps and subscapular skinfold thicknesses in children aged 2–19 y with the use of data from the third National Health and Nutrition Examination Survey (31)[1]

	Average skinfold thickness	
Age and index	Boys	Girls
2–5 y		
BMI-for-age	0.68 (0.66, 0.70)	0.71 (0.69, 0.73)
RI-for-age	0.61 (0.58, 0.64)	0.66 (0.64, 0.68)
Weight-for-height	0.67 (0.65, 0.69)	0.73 (0.71, 0.75)
6–11 y		
BMI-for-age	0.81 (0.79, 0.83)	0.85 (0.84, 0.86)
RI-for-age	0.77 (0.75, 0.79)	0.82 (0.80, 0.84)
Weight-for-height	0.79 (0.77, 0.81)	0.82 (0.80, 0.84)
12–19 y		
BMI-for-age	0.81 (0.79, 0.83)	0.85 (0.84, 0.86)
RI-for-age	0.79 (0.77, 0.81)	0.84 (0.83, 0.85)
Weight-for-height	0.79 (0.77, 0.81)	0.83 (0.81, 0.84)
2–19 y		
BMI-for-age	0.76 (0.75, 0.77)	0.80 (0.79, 0.81)
RI-for-age	0.72 (0.71, 0.73)	0.77 (0.76, 0.78)
Weight-for-height	0.74 (0.73, 0.75)	0.79 (0.78, 0.80)

[1] RI, Rohrer index.

A comparison of the sensitivities and specificities of the ROC curves of BMI-for-age, RI-for-age, and weight-for-height in detecting underweight or overweight in children aged 2–19 y with average skinfold thicknesses as the reference is shown in **Figure 1**. The AUC test results of these 3 indexes are shown in **Table 6**. Among preschool children (2–5 y), the sensitivity and specificity of BMI-for-age and weight-for-height in detecting both underweight (<15th percentile) and overweight (>85th percentile) were not significantly different and were consistently better than was RI-for-age. For example, at cutoffs giving an 80% specificity (1 − specificity of 20%), the sensitivities for detecting underweight were 61% for BMI-for-age, 61% for weight-for-height, and 56% for RI-for-age, and those for detecting overweight were 87%, 87%, and 78%, respectively. For school-age children (6–11 and 12–19 y), the ROC performance of BMI-for-age was better than that of weight-for-height and RI-for-age in predicting overweight on the basis of average skinfold thicknesses. For example, at cutoffs giving an 80% specificity, the sensitivities for detecting overweight were 96%, 94%, and 94% for children aged 6–11 y and were 92%, 89%, and 88% for children aged 12–19 y. However, no differences were found in detecting underweight among these 3 indexes for children aged 6–11 y. Both BMI-for-age and RI-for-age were better than was weight-for-height in detecting underweight for children aged 12–19 y. The patterns of ROC performances were similar with the use of %BF and TFM to define underweight and overweight for children and adolescents aged 3–19 y (**Figure 2**, **Table 7**). However, the sensitivities and specificities defined on the basis of TFM were consistently lower than those defined on the basis of %BF (data not shown for TFM). With the use of age- and sex-specific TFFM values below the 15th percentile as the standard of underweight, we found that BMI-for-age and weight-for-height performed similarly (both were better than RI-for-age) for children aged 3–5 y but the performance of BMI-for-age was clearly superior for children and adolescents aged 6–11 y. The ROC performances were also similar when different cutoffs (5th and 10th percentiles for underweight and 75th, 90th, and 95th percentiles for overweight) from both data sets were used. However, the ROC curves were more stable when the 15th and 85th percentiles were used.

A comparison of the sensitivities and specificities of the ROC curves for detecting overweight at the 85th percentiles of BMI-for-age, RI-for-age, and weight-for-height is shown in **Table 8**. In general, BMI-for-age had a relatively higher sensitivity than did RI-for-age and weight-for-height across the 3 age groups.

DISCUSSION

The validation of simple, low-cost height- and weight-based indexes to assess both body fatness and thinness is of practical importance for routine clinical evaluation of body composition.

TABLE 5
Correlation coefficients (and 95% CIs) between selected anthropometric variables and either percentage body fat or total fat mass in children aged 3–19 y with the use of the pooled data set[1]

	Percentage body fat		Total fat mass	
Age and index	Boys	Girls	Boys	Girls
3–5 y				
BMI-for-age	0.80 (0.68, 0.88)	0.78 (0.69, 0.84)	0.87 (0.79, 0.92)	0.75 (0.65, 0.82)
RI-for-age	0.71 (0.55, 0.82)	0.71 (0.60, 0.79)	0.79 (0.66, 0.87)	0.69 (0.58, 0.78)
Weight-for-height	0.80 (0.68, 0.88)	0.81 (0.73, 0.87)	0.87 (0.79, 0.92)	0.79 (0.71, 0.85)
6–11 y				
BMI-for-age	0.81 (0.76, 0.85)	0.88 (0.85, 0.90)	0.77 (0.71, 0.82)	0.82 (0.78, 0.86)
RI-for-age	0.81 (0.76, 0.85)	0.87 (0.84, 0.90)	0.79 (0.73, 0.84)	0.81 (0.76, 0.85)
Weight-for-height	0.81 (0.76, 0.85)	0.85 (0.81, 0.89)	0.77 (0.71, 0.82)	0.74 (0.68, 0.79)
12–19 y				
BMI-for-age	0.82 (0.76, 0.87)	0.85 (0.80, 0.89)	0.87 (0.82, 0.91)	0.83 (0.77, 0.87)
RI-for-age	0.85 (0.80, 0.89)	0.84 (0.79, 0.88)	0.85 (0.80, 0.89)	0.81 (0.75, 0.86)
Weight-for-height	0.81 (0.74, 0.86)	0.83 (0.77, 0.87)	0.84 (0.78, 0.88)	0.82 (0.76, 0.87)
3–19 y				
BMI-for-age	0.78 (0.74, 0.82)	0.81 (0.78, 0.84)	0.68 (0.62, 0.73)	0.67 (0.62, 0.71)
RI-for-age	0.80 (0.76, 0.83)	0.83 (0.80, 0.85)	0.72 (0.67, 0.77)	0.69 (0.64, 0.73)
Weight-for-height	0.79 (0.75, 0.82)	0.80 (0.77, 0.83)	0.69 (0.63, 0.74)	0.65 (0.60, 0.70)

[1] RI, Rohrer index.

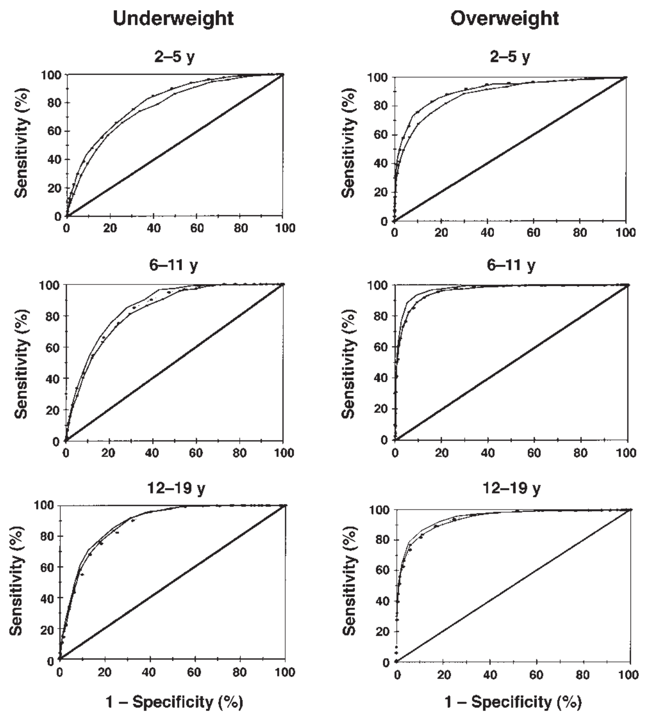

FIGURE 1. Comparison of the performance of the receiver operating characteristic curves of BMI-for-age (———), RI (Rohrer index)-for-age (—■—), and weight-for-height (- -●- -) in predicting underweight (<15th percentile) and overweight (>85th percentile) with the use of average skinfold thicknesses as the reference in children and adolescents aged 2–5 y (n = 4285), 6–11 y (n = 3279), and 12–19 y (n = 3189). Data from the third National Health and Nutrition Examination Survey (31) were used.

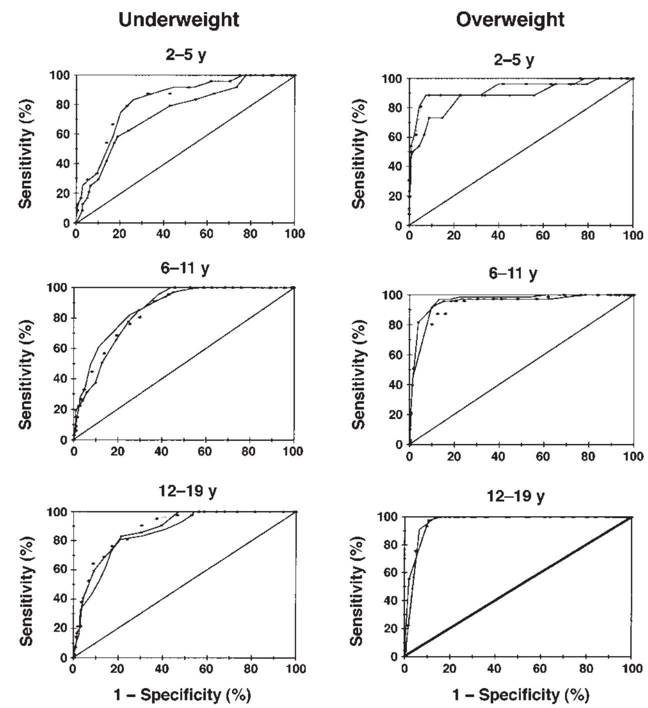

FIGURE 2. Comparison of the performance of the receiver operating characteristic curves of BMI-for-age (———), RI (Rohrer index)-for-age (—■—), and weight-for-height (- -●- -) in predicting underweight (<15th percentile) and overweight (>85th percentile) in children and adolescents aged 3–5 y (n = 162), 6–11 y (n = 465), and 12–19 y (n = 293). Pooled data on percentage body fat derived with dual-energy X-ray absorptiometry.

TABLE 6
Comparison of the performance of the areas under the receiver operating characteristic curves of BMI-for-age, weight-for-height, and RI (Rohrer index)-for-age as defined by the average of the triceps and subscapular skinfold thicknesses at the cutoffs for overweight (>85th percentile) and underweight (<15th percentile) in children aged 2–19 y with the use of data from the third National Health and Nutrition Examination Survey (31)[1]

Age and index	Underweight	Overweight
2–5 y (n = 4285)		
BMI-for-age	0.808 ± 0.009[a]	0.910 ± 0.009[a]
RI-for-age	0.770 ± 0.010[b]	0.880 ± 0.010[b]
Weight-for-height	0.805 ± 0.009[a]	0.908 ± 0.009[a]
6–11 y (n = 3279)		
BMI-for-age	0.864 ± 0.008	0.973 ± 0.004[a]
RI-for-age	0.832 ± 0.009	0.960 ± 0.005[b]
Weight-for-height	0.846 ± 0.009	0.958 ± 0.005[b]
12–19 y (n = 3189)		
BMI-for-age	0.891 ± 0.007[a]	0.951 ± 0.006[a]
RI-for-age	0.884 ± 0.007[a]	0.939 ± 0.006[b]
Weight-for-height	0.873 ± 0.008[b]	0.939 ± 0.006[b]
2–19 y (n = 10753)		
BMI-for-age	0.850 ± 0.005	0.946 ± 0.004[a]
RI-for-age	0.823 ± 0.005	0.930 ± 0.004[b]
Weight-for-height	0.838 ± 0.005	0.937 ± 0.004[b]

[1] $\bar{x}$ ± SE. Values within columns (by age group) with different superscript letters are significantly different, $P < 0.05$.

In this study we validated 3 height- and weight-based indexes as predictors of underweight and overweight with the use of skinfold thicknesses and DXA measurements as the gold standard. We used skinfold-thickness data from a nationally representative survey with >10000 standardized measurements for children aged 2–19 y, the largest available set of values in the United States from which to compare the body composition of children and adolescents. We also used pooled data from 3 different studies conducted in the past 5 y in 3 developed countries, which include a large set of DXA measurements to compare the body composition of children and adolescents.

Of the many validation studies of height- and weight-based indexes as predictors of body fatness in children and adolescents (8–20, 26–28, 36, 37; A De Lorenzo, et al, unpublished observations, 1995), some used skinfold thicknesses (8–10) and others used DXA measurements as the gold standard (11–20, 26–28, 36, 37; A Pietrobelli, unpublished observations, 1997). However, most of the studies examined only small samples of school-age children. One study by Ellis et al (36) involved children and adolescents aged 3–18 y but examined only the association between %BF and BMI. In addition, these validation studies focused only on the prediction of body fatness in overweight children rather than on the prediction of body fatness across children with body fat values ranging from low to high (8–20, 26–28, 36, 37).

We defined underweight as reduced fat (<15th percentile) in the pooled data and as a low triceps and subcutaneous fat layer

TABLE 7
Comparison of the performance of the areas under the receiver operating characteristic curves of BMI-for-age, weight-for-height, and RI (Rohrer index)-for-age as defined by percentage body fat measured with dual-energy X-ray absorptiometry at the cutoffs for overweight (>85th percentile) and underweight (<15th percentile) in children aged 3–19 y with the use of a pooled data set[1]

	Underweight	Overweight
3–5 y (*n* = 162)		
BMI-for-age	0.829 ± 0.037[a]	0.927 ± 0.036
RI-for-age	0.748 ± 0.046[b]	0.880 ± 0.036
Weight-for-height	0.833 ± 0.036[a]	0.929 ± 0.035
6–11 y (*n* = 465)		
BMI-for-age	0.871 ± 0.018[a]	0.958 ± 0.017
RI-for-age	0.838 ± 0.021[b]	0.951 ± 0.018
Weight-for-height	0.850 ± 0.020[b]	0.933 ± 0.021
12–19 y (*n* = 293)		
BMI-for-age	0.846 ± 0.025	0.974 ± 0.017
RI-for-age	0.847 ± 0.025	0.966 ± 0.019
Weight-for-height	0.853 ± 0.024	0.967 ± 0.019
3–19 y (*n* = 920)		
BMI-for-age	0.857 ± 0.013[a]	0.952 ± 0.013[a]
RI-for-age	0.826 ± 0.015[b]	0.930 ± 0.015[b]
Weight-for-height	0.849 ± 0.014[a]	0.937 ± 0.014[a,b]

[1] $\bar{x}$ ± SE. Values within columns (by age group) with different superscript letters are significantly different, $P < 0.05$.

in the NHANES III data. This does not mean to imply that the rate of change in body fat and body lean was constant, only that the patterns of change in each tended to be similar (38–42), eg, as TFM decreased or increased, TFFM tended to decrease or increase as well. A reduction in %BF mathematically implies an increase in %FFM. However, changes are unlikely to be symmetrical at the 2 ends of the BMI distribution.

The recent release of CDC growth charts with age- and sex-specific BMI reference values for children aged 2–19 y should help researchers and practitioners to track overweight or underweight consistently from early childhood through adolescence and adulthood. Substantial evidence suggests that overweight or obese children are more likely to be overweight or obese as adults (43–49). Thus, prudent interventions during childhood and adolescence may yield long-term benefits (50–53). However, the tracking cannot be started before age 2 y in the United States because no BMI reference data are available for that age period. The new CDC growth charts did not extend BMI to infancy because the rapid changes that take place at that stage make it difficult to capture the actual shape of the BMI distribution.

The new CDC growth charts also include sex-specific weight-for-length references from birth to <3 y of age and weight-for-height references for children aged 2–5 y. The advantages of having both weight-for-length and weight-for-height references are that preschool children can be tracked consistently by a single index. Furthermore, practitioners have more experience with this index and do not need to perform any calculations before plotting the growth indexes. Therefore, 2 references (BMI and weight-for-height) are available for screening body fatness and body thinness in children aged 2–5 y. Researchers or practitioners have a choice of which reference to use, depending on their purpose: for tracking or monitoring children aged 0–5 y, weight-for-length and weight-for-height can be used consistently; for tracking or monitoring children aged >2 y, BMI-for-age can be used consistently. The drawback of having 2 indexes for use at this overlapping age range (2–5 y old) is that confusion can occur if the percentiles assigned by both indexes are different. In the current study, the use of BMI-for-age and weight-for-height as references resulted in assignment of similar percentiles to children and similar predictions of overweight and underweight for children aged 2–5 y; therefore, such confusion should have been minimal.

We used both correlation coefficients and ROC curves to examine the associations between the gold standards and the 3 height- and weight-based indexes and the sensitivities and specificities of the 3 indexes in classifying underweight and overweight. Correlation coefficients can estimate the degree of closeness of a linear relation between 2 variables. However, correlation coefficients should be interpreted with caution. For example, one indicator could consistently over- or underestimate from the true values for the predictor variable but could have the same correlation coefficient. The ROC curve can summarize all the sensitivities and specificities of the 3 indexes in detecting underweight or overweight into one chart.

TABLE 8
Comparison of the sensitivities and specificities (and 95% CIs) for detecting overweight at the 85th percentiles of BMI-for-age, RI (Rohrer index)-for-age, and weight-for-height in children aged 2–19 y with the use of the pooled data set and data from the third National Health and Nutrition Examination Survey (NHANES III; 31)

	NHANES III		Pooled data set	
Age and index	Sensitivity	Specificity	Sensitivity	Specificity
	%		%	
2–5 y[1]				
BMI-for-age	78.3 (74.6, 81.8)	88.3 (87.2, 89.4)	88.5 (69.8, 97.4)	79.4 (71.6, 85.9)
RI-for-age	65.7 (61.4, 69.7)	90.8 (89.8, 91.7)	73.1 (52.2, 88.4)	91.9 (86.0, 95.5)
Weight-for-height	74.6 (70.7, 78.3)	90.9 (89.9, 91.8)	88.5 (69.8, 97.4)	88.2 (81.6, 93.1)
6–11 y				
BMI-for-age	92.7 (90.5, 94.6)	91.5 (90.4, 92.6)	98.6 (92.4, 99.8)	67.7 (62.8, 72.3)
RI-for-age	87.9 (85.1, 90.2)	91.1 (90.0, 92.2)	97.2 (90.2, 99.6)	68.4 (63.6, 73.0)
Weight-for-height	83.9 (80.9, 86.5)	92.6 (91.5, 93.6)	95.8 (88.1, 99.1)	70.8 (66.1, 75.3)
12–19 y				
BMI-for-age	84.7 (81.8, 87.3)	90.5 (89.2, 91.7)	100 (100, 100)	72.2 (66.2, 77.7)
RI-for-age	82.3 (79.2, 85.0)	89.7 (88.4, 90.9)	100 (100, 100)	71.4 (65.3, 76.9)
Weight-for-height	79.6 (76.4, 82.5)	90.3 (89.0, 91.5)	100 (100, 100)	74.4 (68.5, 79.7)

[1] Only 3–5 y from the pooled data set.

We could not examine the racial- or ethnic-specific ROC performance in the pooled data because most of the children were white. A potential bias exists in the pooled data set because the data were drawn from different studies and different populations. However, the bias is irrelevant to this study because all the assigned height- and weight-based percentiles and the percentiles assigned from the DXA measurements were from the same children. The results of the classification of both underweight and overweight from the pooled data are generally consistent with the results from the NHANES III data (Figures 1 and 2).

Our data provide additional support for the use of BMI-for-age in assessing underweight and overweight in children and adolescents aged 2–19 y. However, we only examined the validity of BMI-for-age as an indicator of body fatness. Our data do not address the clinical utility of the 15th and 85th percentiles of BMI. However, other data showed that the 85th percentile of BMI predicts children at risk of developing obesity (49) and identified children with additional risk factors for cardiovascular disease (54). As recommended by an expert committee (55), the use of BMI to predict overweight in individual patients requires the use of ancillary criteria. The recommendations provide practical guidance to pediatric clinicians who evaluate and treat overweight children.

In conclusion, this study cross-validated 3 height- and weight-based indexes for predicting both overweight and underweight in children and adolescents. In general, the performance of BMI-for-age is better than that of RI-for-age in predicting both underweight and overweight but is similar to that of weight-for-height in children and adolescents aged 2–19 y.

We thank Kelley Scanlon, Bettylou Sherry, and Ibrahim Parvanta for reviewing preliminary drafts of this manuscript.

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