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Triponderal mass index rather than body mass index: An indicator of high adiposity in Italian children and adolescents

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ABSTRACT

Objective: The aims of this study were to compare body mass index (BMI) and triponderal mass index (TMI) as predictors of fat mass percentage (FM%) and to develop TMI cutoffs for screening high adiposity. Therefore, TMI- and BMI-based references against FM% criterion for indicating adiposity in Italian children and adolescents were compared.

Methods: This was a cross-sectional study conducted at the University of Rome Tor Vergata, Human Nutrition Unit, from 2008 to 2015. The sample included 485 children and adolescents from 8 to 17 y of age from central-southern Italy. Body weight (kg) and height (m) were assessed to calculate BMI and TMI. FM% was assessed by dual-energy x-ray absorptiometry. The prevalence of high adiposity was based on the 75th percentile of FM%, according to Ogden et al. curves. Statistical tests such as Mann–Whitney, Kruskal–Wallis, polynomial regression, receiver operating characteristics curve, and Cohen's κ, were performed using SPSS version 24 and MedCalc version 18.

Results: Prevalence of high adiposity according to FM% was 50.2% (95% confidence interval [CI], 43.2–57.2) in boys and 43.2% (95% CI, 37.3–49.2) in girls. TMI rather than BMI could better predict FM% for both sexes (boys $R^2 = 0.67$ and girls $R^2 = 0.79$ versus boys $R^2 = 0.44$ and girls $R^2 = 0.74$, respectively). TMI was found to present a significantly higher area under the curve than BMI for indicating high adiposity in children and adolescents. TMI sex- and age-specific cutoffs were responsible by better classification of adiposity, followed by the International Obesity Task Force, World Health Organization, and Cacciari reference curves.

Conclusion: TMI is a useful screening tool in pediatric clinical practice and epidemiologic studies concerning childhood obesity.

Introduction

Childhood obesity rates have reached high levels in recent decades, and it is now considered a global public health issue [1,2]. Overweight, including obesity, is defined as an excess of body fat mass, which is highly associated with chronic diseases [3]. To properly evaluate children and adolescent body composition (BC), direct methods of assessment should be employed for understanding health status and risk [4]. In the absence of accurate techniques to directly measure adiposity, alternative estimations as skinfold thickness, bioelectrical impedance analysis (BIA), and anthropometric indexes can be used [5,6].

One of the most practical, affordable, and agile alternatives is the body mass index (BMI), which has been used as a worldwide surrogate for screening overweight and obesity in children and adolescents [7,8]. Although useful mainly for epidemiologic purposes, BMI presents several weak points in assessing the fat mass percentage (FM%), even if used as age- and sex-specific percentiles [8–10].

In 1986 [11], Cole diagnosed overweight in preschool children using BMI and demonstrated how to improve diagnostic accuracy by increasing the height exponent to 3 at age 11 and then reducing it back to 2 after puberty. Thus, he affirmed the presence of a precise power of height as a function of the child's age. In 2010, Flegal

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et al. demonstrated the need for BMI-based, race-, sex-, and age-specific curves for the assessment of childhood obesity [12]. Ogden et al. highlighted the presence of a cardiometabolic alteration related to an increase in blood lipid levels associated with adiposity, rather than an obesity based on BMI, in childhood [13].

Even in adults, "new BMIs" have been proposed to better reflect BC through weight and height than Quetelet's BMI, as that suggested by the mathematician Nick Trefethen [14,15]. The same has been observed in the pediatric population, where the scaling power of height should be around 3 rather than 2, whereas weight is more influenced by height in this developmental phase [11,16,17].

As an alternative to better estimate FM%, still applying simple methods, Peterson et al. [18] tested BMI through the use of different exponential numbers in the denominator (height). They verified that the triponderal mass index (TMI) was more accurate than weight-to-height indexes of the form M/H^n *z* score for indicating adiposity in non-Hispanic white children and adolescents.

The aim of the present study was to compare BMI and TMI as predictors of FM%; to develop sex- and age-specific TMI cutoffs for screening high adiposity; and to compare TMI- and BMI-based references with FM% criterion for indicating adiposity in Italian children and adolescents.

Material and methods

Study design and participants

This cross-sectional study was conducted at the University of Rome Tor Vergata, Human Nutrition Unit, from 2008 to 2015, with white children and adolescents from central-southern of Italy. The sample included 485 healthy children and adolescents from 8 to 17 y of age who were divided as the following age range groups: 8 to 9, 10 to 11, 12 to 13, 14 to 15 and 16 to 17 y. The study protocol conformed with the ethical guidelines of the Declaration of Helsinki and Tor Vergata University Medical Ethical Committee in Rome, Italy. Before starting the assessments, a written informed consent was signed by participants' parents.

Anthropometric and body composition measurements

Body weight (kg) was measured to the nearest 0.1 kg with the balance scale (Invernizzi, Rome, Italy). Height (m) was measured to the nearest 0.1 cm with stadiometer (Invernizzi, Rome, Italy) [19]. BMI was calculated as weight in kilograms divided by height in meters squared. Triponderal TMI was calculated as weight in kilograms divided by height in meters cubic as proposed by Peterson et al in a pediatric population [18], not only sex-specific, but also age-specific, to develop age-specific clustering based on growth and puberty sexual dimorphism. Children and adolescent adiposity was based on total FM% assessed by dual-energy x-ray absorptiometry (DXA; iDXA, G.E. Medical Systems, Madison, WI, USA) using a dedicated pediatric system software package (EnCORE Software GE Healthcare) to measure absolute and percentage values of total BC, as previously described [10,11,20]. Before each testing session, standard DXA quality control and calibration measures were carried out.

Adiposity classification

We consider high adiposity for FM% to be equal to or greater than the age- and sex-specific 75th percentile according to Ogden et al. curves [13], as previously suggested [12,21]. To compare the classification based on FM% and on age- and sex-specific BMI-based curves, we defined all participants with high adiposity overweight (OW), according to BMI. We considered OW as follows: BMI-for-age ≥OW extracentile according to Cacciari reference curves [22]; BMI-for-age ≥85th percentile, according to the growth curves from the Centers for Disease Control and Prevention [23]; BMI-for-age ≥85th percentile according to the growth curves from the World Health Organization [24]; and BMI-for-age ≥25 kg/m^2 according to the International Obesity Task Force cutoffs [25]. Finally, the herein developed TMI cutoffs also were used for classifying children and adolescents as having high adiposity.

Statistical analysis

BC parameters and indexes were compared between sexes for each age group using Mann–Whitney test and among age groups for each sex using Kruskal–Wallis test followed by Dann–Bonferroni post hoc. Association of BMI and TMI with FM% was assessed by quadratic polynomial regression because there was no linearity between variables. Receiver operating characteristic (ROC) analyses were carried out to verify the accuracy of BMI and TMI for detecting high adiposity in children and adolescents. The curves were constructed considering FM% as the criterion and the indexes as diagnostic tests. To compare BMI and TMI ROC curves, a non-parametric statistical analysis of differences between areas under correlated curves was performed, according to DeLong et al. [26]. The area under the curve (AUC) was obtained from TMI ROC analyses for each sex and age group. The AUC values ranged from 0.5 to 1, where 1 represents a perfect screening test that is able to discriminate children and adolescents with and without high adiposity. The TMI cutoffs were developed based on the higher nonlinear function of sensitivity and specificity for identifying high adiposity according to the criterion value. These represent the probability of correctly indicating children and adolescents for having high adiposity (true-positive) and for not having high adiposity (true-negative), respectively. Cohen's κ for binary outcome was used to measure the agreement between adiposity classification according to the criterion (FM%) and each reference classification, including TMI-based classification based on the novel cutoffs. According to Landis and Koch [27], Cohen's κ values can indicate an agreement as poor (<0.00), slight (≤0.00 to ≤0.20), fair (≤0.21 to ≤0.40), moderate (≤0.41 to ≤0.60), substantial (≤0.61 to ≤0.80), or almost perfect (>0.80). Moreover, false-positive rate (FPR) and false-negative rate (FNR) were calculated for the different classification methods. Analyses were performed using SPSS version 24 (IBM, Armonk, NY, USA) and MedCalc version 18 (MedCalc Software bvba, Ostend, Belgium; https://www.medcalc.org; 2016). Categorical data were presented as median (minimum–maximum) and qualitative data were presented as percentage. The null hypotheses were rejected at the 0.05 level of probability.

Table 1
Body composition parameters and indexes for each sex and age group

		Median (min–max)				
Age group (y)	n	Weight (kg)	Height (cm)	BMI (kg/m^2)	TMI (kg/m^3)	Fat mass (%)
Boys						
8–9	35	40 (22.5–58.3)[*,†,‡]	135 (125–145)[*,†,‡]	20.7 (14.1–28.9)[*,‡]	15.4 (10.9–21.8)	36.23 (14.45–50.73)[‡]
10–11	33	50.3 (19–120.4)[†,‡]	150.5 (120.5–163)[†,‡]	22.1 (13.1–50.8)	14.7 (9.9–33)	40.11 (12.50–52.04)[†,‡]
12–13	40	58.9 (30.9–120)[†,§]	159 (141–178)[†,‡]	24.7 (14.8–45.9)[§]	16 (9.8–28.5)[§]	41.34 (13.61–53.29)[†,‡]
14–15	37	69 (42.20–111)[§]	170 (150.5–187.5)[§]	23.6 (16.7–34.8)	14 (9.7–20.7)	25.06 (11.08–46.51)[§]
16–17	62	74.7 (52.1–136.1)[§]	175.7 (158–188.5)[§]	23.5 (16–41.7)[§]	13.6 (8.8–23.8)	20.81 (10.57–52.65)[§]
Girls	n					
8–9	34	32.4 (20.8–66.6)[*,†,‡]	136.2 (121–156.5)[‖]	17.8 (13.5–34.5)[†,‡]	13.7 (9.6–24.8)	34.89 (14.00–55.28)
10–11	32	47.6 (24.1–73.3)[†,‡]	148.5 (130–169)[‖]	21.2 (11.9–30.4)	13.9 (8.2–21.5)	35.06 (14.00–48.80)
12–13	45	52 (34.5–87.5)	159 (145.8–167.5)[‡]	21 (14–31.7)	13.3 (8.9–20)	35.48 (13.05–52.08)
14–15	81	61.6 (37–99.2)	161.5 (137–178)	23.5 (16–39.4)	14.3 (9.5–24.9)	37.78 (12.12–55.07)
16–17	86	59.5 (38–108.4)	162 (152–175.5)	22.7 (15.5–37.5)	14 (9.5–22.3)	35.52 (17.30–52.75)

[*]Significantly different from the 12–13 y age group within sex, $P < 0.05$.
[†]Significantly different from the 14–15 y age group within sex, $P < 0.05$.
[‡]Significantly different from the 16–17 y age group within sex, $P < 0.05$.
[§]Significantly different from the same age group across sexes, $P < 0.05$.
[‖]Significantly different across age groups within sex, $P < 0.05$.

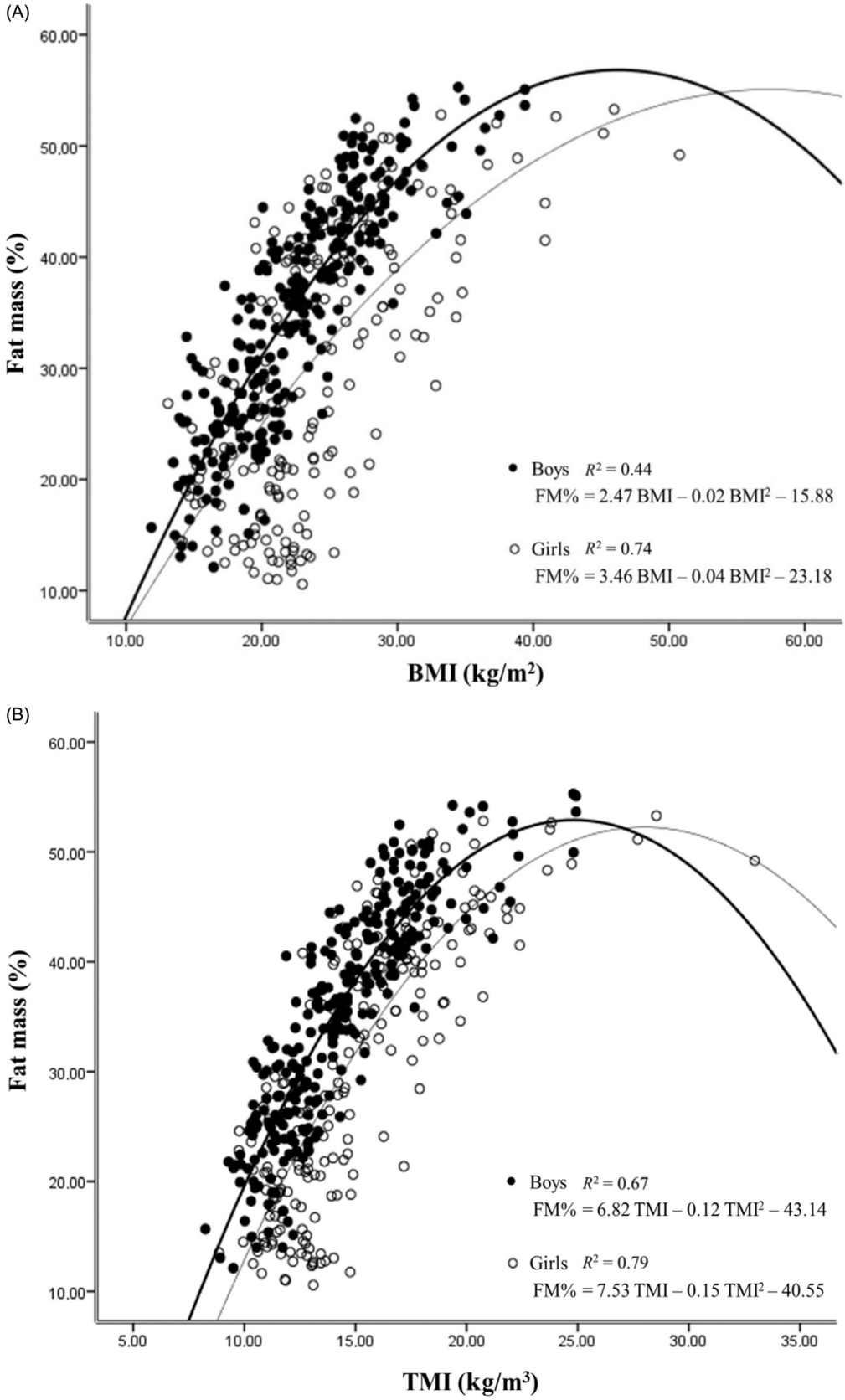

Fig. 1. Quadratic polynomial regressions for (**A**) BMI and (**B**) TMI as predictors of FM%. ROC curves for TMI and BMI were performed in the overall sample, as shown in Figure 2. BMI, body mass index; FM%, fat mass percentage; ROC, receiver operating characteristics; TMI, triponderal mass index.

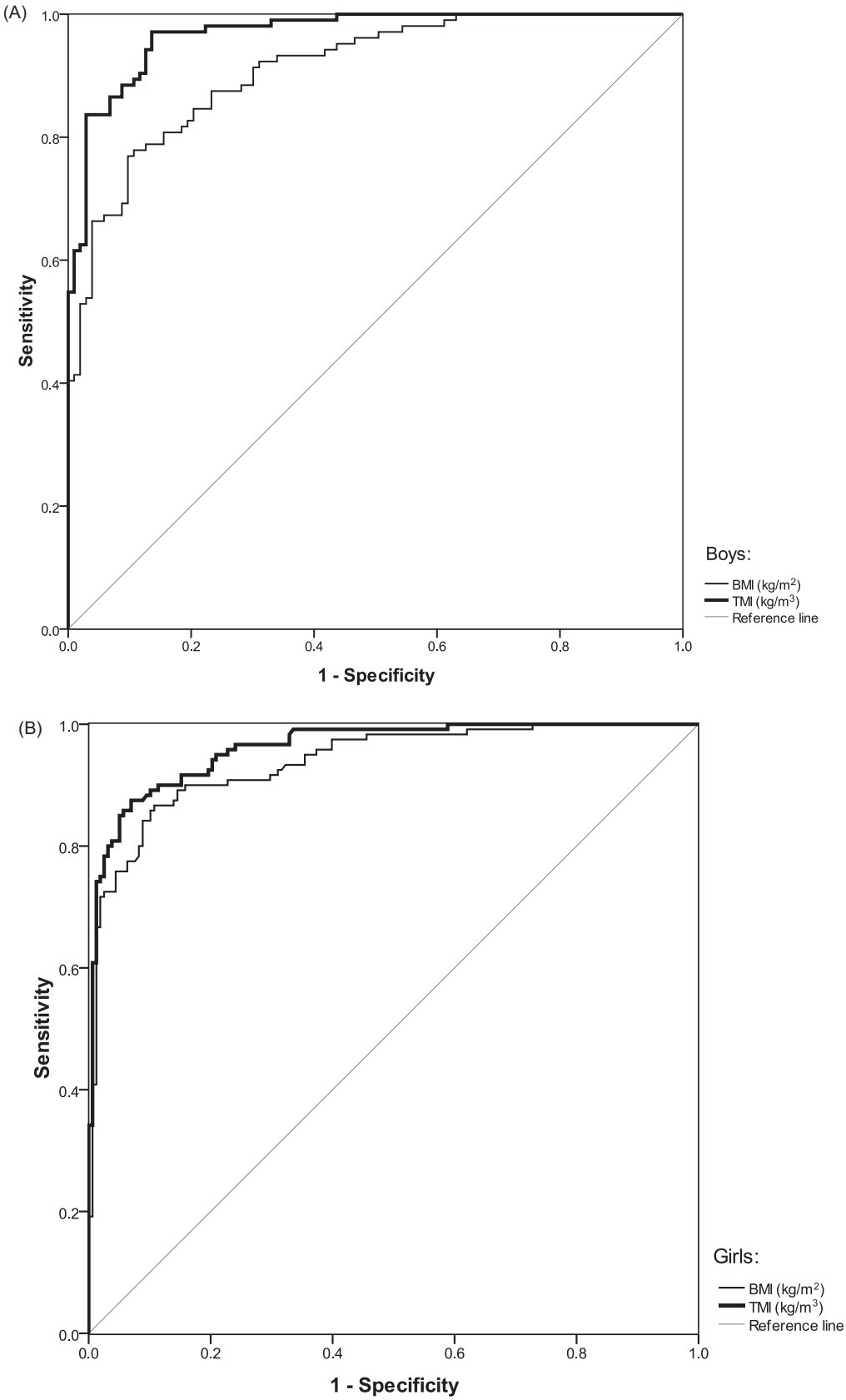

Fig. 2. ROC curves for (**A**) BMI and (**B**) TMI indicating high adiposity in Italian boys (n = 207) and girls (n = 278). BMI, body mass index; ROC, receiver operating characteristics; TMI, triponderal mass index.

Results

The studied sample consisted of 57.3% girls. BC parameters, BMI, and TMI are described by sex and age groups in Table 1.

From weight and height, BMI was significantly higher only for boys 12 to 13 y of age (probably owing to the onset of the growth spurt in boys) and 16 to 17 y of age when compared between sexes. Boys and girls 8 to 9 y of age had lower BMI compared with their older pairs.

TMI presented no differences between sexes nor among age groups, except for boys 12 to 13 y of age who had higher TMI than girls in the same age group.

There was no significant difference in FM% of girls among age groups. Up through ages 12 to 13, girls had similar FM% as boys; after ages 14 to 15, girls had higher FM% than boys. Boys 14 to 15 y and 16 to 17 y of age had lower FM% than the other age groups.

Prevalence of high adiposity according to FM% criterion was 50.2% (95% confidence interval [CI], 43.2−-57.2) in boys and 43.2% (95% CI, 37.3−49.2) in girls.

From quadratic regression analyses, TMI could better predict FM% than BMI for both sexes, presenting higher R^2 (0.67 and 0.79 versus 0.44 and 0.74 for boys and girls, respectively) as illustrated in Figure 1.

In the comparison between the ROC curves for the indexes, TMI was found to present a significantly higher AUC for indicating high adiposity in children and adolescents. In particular, the AUC for BMI was 0.93 (95% CI, 0.90−0.95; SE, 0.01; $P < 0.001$) and AUC for TMI was 0.96 (95% CI, 0.95−0.98; SE, 0.01; $P < 0.001$). Pairwise comparison between BMI and TMI ROC curves was $P < 0.001$.

Regarding TMI ROC curves for each sex and age group, all AUC were significant and close to ideal values. In addition to the AUC, sex- and age-specific cutoffs of TMI are shown in Table 2. Single sex-specific cutoffs for TMI were also developed: cutoffs for girls' TMI was 14.6 kg/m^3 (AUC 0.96) and boys was 14. kg/m^3 (AUC 0.97).

Diagnoses of OW based on BMI or TMI were compared with the true adiposity status as defined by FM%, through κ agreement test, and the prevalence of OW for each classification was reported (Table 3). Among all reference classifications, high adiposity was better indicated by TMI cutoffs (Table 2) because it presented the highest Cohen's κ value, representing an almost perfect agreement for both sexes. The lowest FPR (9.7%) among boys was seen with TMI-based sex- and age-specific classifications, whereas for girls it was seen in Cacciari classification followed by TMI-based sex- and age-specific classification. Among girls, Cacciari classification presented the lowest FPR (4.4%) and the highest FNR (20.8%) when compared with the other reference classifications. The lowest and absent FNR (0.0%) in boys was observed with the WHO classification. Among girls, the lowest FNR (4.2%) was seen with the TMI-based classification. TMI single sex-specific cutoffs were inferior, indicating higher adiposity than the TMI sex- and age-specific cutoffs.

Table 2
AUC and cutoffs of BMI and TMI for indicating high adiposity in Italian children and adolescents, according sex and age group.

	BMI			
	Boys		Girls	
Age group (y)	AUC*	Cutoff (kg/m^3)	AUC*	Cutoff (kg/m^3)
8–9	1.00	18.4	0.99	18.2
10–11	0.98	19.9	0.97	21.7
12–13	0.98	21.3	1.00	22.6
14–15	0.97	22.2	0.97	23.2
16–17	0.97	23.8	0.93	24.4
	TMI			
	Boys		Girls	
Age group (y)	AUC*	Cutoff (kg/m^3)	AUC*	Cutoff (kg/m^3)
8–9	1.00	13.9	0.99	12.7
10–11	0.96	14.4	0.98	12.8
12–13	0.97	12.9	1.00	13.5
14–15	0.97	14.4	0.96	14.1
16–17	0.96	14	0.94	15.5

BMI, body mass index; ROC, receiver operating characteristics; TMI, triponderal mass index.
*All AUC *P*-values were <0.001. There was no significant difference in pairwise comparisons between BMI and TMI ROC curves.

Discussion

In this study, we discussed the reliability of BMI as an adiposity screening for Italian children and adolescents and developed the cutoffs for a resurgent index, the TMI [18,28]. The main findings of the present study pinpointed TMI rather than BMI to present greater association with FM%. Moreover, the developed TMI cutoffs were found to better indicate high adiposity then the usual BMI-based references. Regarding differences among age groups and sex, TMI was found to be more stable than BMI in children and adolescents, as previously evidenced [18].

The results corroborated Peterson et al.'s findings [18] because TMI presented higher coefficient of determination than BMI when associated with FM%, better explaining its variance. Both indicies were more associated with FM% in girls than in boys. However, in boys, TMI demonstrated a notably greater association with FM% than BMI, as previously observed [18]. Furthermore, from the AUC comparison, TMI was also shown to be more accurate than BMI in detecting high adiposity in children and adolescents.

Until now, there has been no standard FM% cutoff for diagnosing excess of adiposity in children and adolescents, which is different than for adults [29]. As such, we developed TMI cutoffs based on the 75th percentile of FM%, which was previously observed to represent a health risk with the manifestation of adverse levels of serum lipids [12,21]. Regarding TMI-established cutoffs, the AUC achieved high values, which suggests a good accuracy of this screening test, independent of sex and age groups.

Cohen's κ results reiterated that adiposity classification based on BMI-for-age references were less accurate than those based on TMI-for-age, as the former had a substantial agreement with FM% criterion and the latter had an agreement almost perfect with FM% criterion. Consequently, the new TMI cutoffs presented the lower total misclassification in screening adiposity. The second lower misclassification was found for IOTF, followed by WHO and Cacciari, which demonstrated prominent FPR and FNR, respectively. In fact, these references present weakness points that go beyond the intrinsic error of BMI in screening adiposity in children and adolescents [7–10]. The current BMI references used to screen OW and obesity are outdated and do not reflect FM% percentile curves, which often induce a low sensitivity and a high specificity [30–32].

By using Cacciari reference rates, Italian children and adolescents, mainly girls, were not screened as OW and obese when they actually had high adiposity by FM%. This underestimation of high adiposity in OW and obese children and adolescents could be explained by the fact that Cacciari growth curves were constructed with data collected from 1990 to 2004, when childhood OW was not prevalent, and children were shorter in Italy [22,33,34]. High misclassifications also were suggested when Cacciari was directly compared with international references for screening OW [35,36].

Table 3
κ coefficient, false-positive and false-negative rates of usual and novel classification for high adiposity (overweight, including obesity), based on FM% as a criterion

	Boys (n = 207)				Girls (n = 278)			
Reference classifications	OW (%) (95% CI)	FPR (%)	FNR (%)	κ*	OW (%) (95% CI)	FPR (%)	FNR (%)	κ*
			BMI-based					
Cacciari	50.7 (43.7–57.7)	10.7	9.6	0.80	36.7 (31–42.7)	4.4	20.8	0.76
CDC	56.5 (49.5–63.4)	17.5	4.8	0.78	44.6 (38.7–50.7)	8.9	8.3	0.82
WHO	61.4 (54.4–68)	22.3	0	0.78	47.8 (41.8–53.9)	13.9	7.5	0.78
IOTF	56.5 (49.5–63.4)	16.5	3.8	0.80	46 (40.1–52.1)	11.4	8.3	0.80
Sex- and age-specific cutoffs	57.5 (50.4–64.3)	15.5	1	0.83	44.6 (38.7–50.7)	7	5.8	0.87
			TMI-based					
Sex- and age-specific cutoffs	53.1 (46.1–60.1)	9.7	3.8	0.86	46.8 (40.8–52.8)	9.5	4.2	0.85
Sex-specific cutoffs	55.6 (48.5–62.4)	13.6	2.9	0.84	41.7 (35.9–47.8)	7	12.5	0.81

BMI, body mass index; FNR, false-negative rate; FPR, false-positive rate; IOTF, International Obesity Task Force; OW, overweight; TMI, triponderal mass index; WHO, World Health Organization.
*All κ *P*-values were <0.001.

The total misclassification found using TMI cutoffs herein developed, especially for FNR, was lower with respect to Peterson et al. [18]. This might be explained by their development of only one threshold for each sex, disregarding the influence of age on TMI because of its high stability across different age groups. Despite the high consistency of TMI, a longitudinal growth study revealed a small, but still significant difference in children's TMI over the years [28]. Hence, this fact sustains our choice for developing cutoffs that are sex and age specific.

Most of the similar studies have developed ROC curves using the McCarthy cutoffs [37] as the criterion for classifying adiposity, even if these cutoffs were generated based on BIA [38,39]. In the present study, we used Ogden et al. cutoffs for FM%, which were generated based on DXA analysis, as well as our data. Although the prevalence of high adiposity in this study population has been substantially elevated, most of the age groups divided by sex presented a uniform distribution regarding the percentage of normal and high adiposity. This has allowed us to avoid typical sampling biases of this type of study, which could have affected the positive or negative predictive values. However, this study was limited by the lack of FM% curves for the Italian pediatric population, constricting us to use the US curves because US standards were previously confirmed as safe to be adopted in Italian pediatric population [40]. Another limitation was the small sample size, leading us to merge single ages in age groups. Moreover, maturity status was not assessed as neither BMI nor TMI take it into account.

Conclusion

To our knowledge, this was the first study to confirm TMI rather than BMI as a predictor of FM% in an Italian pediatric population and to develop sex- and age-specific TMI cutoffs, which indicate high adiposity more accurately than other BMI-based references. Therefore, TMI is a useful and practical screening tool for clinical practice and epidemiologic studies concerning childhood OW and obesity.

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