ISSN (electrónico): 1699-5198 - ISSN (papel): 0212-1611 - CODEN NUHOEQ S.V.R. 318

Nutrición Hospitalaria

Trabajo Original

Pediatría

# Triponderal mass index rather than body mass index in discriminating high adiposity in Brazilian children and adolescents

*Índice de masa triponderal en lugar de índice de masa corporal para discriminar la alta adiposidad en niños y adolescentes brasileños*

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## Abstract

**Introduction:** body mass index (BMI) is used worldwide to track excess weight; however, it has limitations in predicting body fat percentage (BF%). Triponderal mass index (TMI) has been studied as an alternative indicator to predict BF%.

**Objective:** to compare BMI and TMI as predictors of BF% and develop TMI cutoff points for screening high adiposity in Brazilian children and adolescentes.

**Methods:** a cross-sectional and multicenter study conducted with 226 individuals aged 5 to 17 years from two municipalities in the Southeast and South regions of Brazil. BF% was assessed by bioimpedancemetry. The association between BMI and TMI with BF% was assessed using generalized additive models. ROC curve analyzes were performed to verify the accuracy of BMI and TMI in detecting high adiposity. The areas under the curve (AUC) of BMI and TMI were compared using non-parametric analysis. The TMI cutoff points were obtained using Youden's J index.

**Results:** bioimpedancemetry detected high BF% in 54.1 % (95 % confidence interval [CI], 44.8-63.2) of boys and 63.5 % (95 % CI, 54.5-71.9) of girls. TMI was able to predict BF% better than BMI in males, presenting a higher R-square (0.737 versus 0.646, respectively). The TMI presented AUC significantly greater than BMI to indicate high adiposity in the entire population (p = 0.007) and in females (p = 0.014). TMI cutoff points for different age groups and sex were presented.

**Conclusion:** TMI proved to be a better predictor of excess body fat than BMI in Brazilian children and adolescents.

**Keywords**:

Adiposity. Adolescent. Child. Obesity. Mass screening.

Received: 18/07/2024 • Accepted: 26/09/2024

*Conflicts of interest: the authors declare no conflicts of interest.*

*Artificial intelligence: the authors declare not to have used artificial intelligence (AI) or any AI-assisted technologies in the elaboration of the article.*

Ued FV, Castro MJS, Bardi LR, Ciampo LA, Martinez EZ, Ferraz IS, Contini AA, EMello EZ, Nogueira-de-Almeida CA. Triponderal mass index rather than body mass index in discriminating high adiposity in Brazilian children and adolescents. Nutr Hosp 2025;42(1):40-47

DOI: http://dx.doi.org/10.20960/nh.05432

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## Resumen

**Introducción:** el índice de masa corporal (IMC) se utiliza en todo el mundo para rastrear el exceso de peso, pero tiene limitaciones para predecir el porcentaje de grasa corporal (%GC). El índice de masa triponderal (IMT) se ha estudiado como un indicador alternativo para predecir el %GC.

**Objetivo:** comparar el IMC y el IMT como predictores del %GC y desarrollar puntos de corte del IMT para detectar la alta adiposidad en niños y adolescentes brasileños.

**Métodos:** estudio transversal y multicéntrico realizado con 226 personas entre 5 y 17 años de dos municipios de las regiones Sudeste y Sur de Brasil. El %GC se evaluó mediante bioimpedanciametría. La asociación entre el IMC y el IMT con el %GC se evaluó mediante modelos aditivos generalizados. Se realizaron análisis de curvas ROC para verificar la precisión del IMC y el IMT en la detección de alta adiposidad. Las áreas bajo la curva (AUC) del IMC y el IMT se compararon mediante el análisis no paramétrico. Los puntos de corte del IMT se obtuvieron mediante el índice J de Youden.

**Resultados:** la bioimpedanciametría detectó un %GC elevado en el 54,1 % (IC 95 %, 44,8-63,2) de los niños y en el 63,5 % (IC 95 %, 54,5-71,9) de las niñas. El IMT fue capaz de predecir el %GC mejor que el IMC en los niños, presentando un R-cuadrado mayor (0,737 versus 0,646, respectivamente). El IMT presentó AUC significativamente mayor que el IMC para indicar adiposidad alta en toda la población (p = 0,007) y en las niñas (p = 0,014). Se presentaron los puntos de corte del IMT para diferentes grupos de edad y sexo.

**Conclusión:** el IMT demostró ser un mejor predictor del exceso de grasa corporal que el IMC en niños y adolescentes brasileños.


**Palabras clave:**

Adiposidad. Adolescente. Niño. Obesidad. Tamizaje masivo.

## INTRODUCTION

Childhood obesity is a global epidemic. Changes in human habits, including urbanization, social inequality, consumption of foods with an inadequate nutritional profile, and reduced physical activity, among other factors, have promoted a disproportionate increase in adiposity in children (1,2). In Brazil, in 2022, the notifications of the Sistema de Vigilância Alimentar e Nutricional (SISVAN), which uses body mass index (BMI) as an indicator, showed that among children aged 5 to 9 years, 15.4 % were overweight, 9.5 % were obese, and 6.3 % were severely obese. Among adolescents aged 10 to 19 years, 18.8 % were overweight, 9.7 % had obesity, and 2.6 % had severe obesity (3).

The consequences of this situation involve pathophysiological, biopsychosocial, and socioeconomic aspects. Regarding individual aspects, childhood obesity is responsible for several consequences for the child's health and their future adult life, which may include psychological damage, hypertension, cardiovascular diseases, dyslipidemias and diabetes (4). On the other hand, there are also widespread effects that involve the entire society, as the increase in childhood obesity influences the decrease in the population's quality of life and puts pressure on public health spending (5).

Obesity is a chronic disease characterized by the accumulation of fat caused by the association of genetic, environmental, and behavioral factors (2). One of the possible ways to diagnose obesity is by measuring body fat percentage (BF%), which can be done by different methods, such as skinfold measurement, bioimpedanciometry and even more sophisticated methods, as dual-emission X-ray absorptiometry (DEXA) and computed tomography.

However, the use of gold standard methods in clinical practice can be time-consuming and costly. Thus, over the last few decades, anthropometric indicators have been considered simple and inexpensive alternatives for estimating adiposity and overweight. The most widely used, so far, is BMI, which is obtained by dividing weight by the square of height. This index, used together with reference curves, allows the classification of individuals as underweight, normal, overweight or obese. However, BMI has been shown to be a poor predictor of BF% in children and adolescents (6).

To facilitate the screening of excess adiposity by means of simple tools, recent studies have indicated the use of the triponderal mass index (TMI), which, unlike BMI, uses height increased to factor 3 (7). This change in the height factor favors a better constancy of values throughout childhood and adolescence and seems to be better correlated with BF% measurements (7). Based on this finding, several studies were initiated to investigate the use of TMI in the evaluation of metabolic syndrome (4), insulin resistance (8) and adiposity (9).

The present study aims to compare BMI and TMI as predictors of BF% among Brazilian children and adolescents; and to develop TMI cutoff points, according to sex and age group, for screening for high adiposity.

## METHODS

### STUDY DESIGN

This is a cross-sectional and multicenter study with data obtained from electronic medical records of individuals treated in two health services, located in the Southeast and South regions of Brazil and with different socioeconomic profiles. Location 1: private clinic specialized in nutritional diseases and cares for patients with health insurance in the city of Ribeirão Preto, São Paulo, Brazil. Location 2: Child Nutrology Outpatient Clinic of the Porto Alegre Clinical Hospital, intended for the care of patients from the public health system in the city of Porto Alegre, Rio Grande do Sul, Brazil.

### ETHICAL ASPECTS

This study was conducted in accordance with the Declaration of Helsinki and was approved by the Research Ethics Committee (REC) of the University of Ribeirão Preto, number 538.137, and by the REC of the Porto Alegre Clinical Hospital, number 07/258.

The application of Informed Consent was waived because it was a research to analyze electronic medical records.

## POPULATION

Individuals aged 5 to 17 years old were included, who had anthropometric data measured at the first consultation during the years 1998 and 2020, constituting a convenience sample. Individuals with incomplete data on weight, height and BF% recorded in the electronic medical record, and with a diagnosis of hormonal disorders or genetic diseases, were excluded. Initially, 845 children were eligible for the study; 224 individuals were excluded due to the lack of BF% recorded in the medical records, 317 due to a diagnosis of hormonal disorders and 78 due to a diagnosis of genetic diseases. After applying the exclusion criteria, 226 individuals participated in the study.

## DATA COLLECTION

The following data were collected in the electronic medical record: age, sex, weight, height, BF% and diagnosis of endocrine or genetic diseases. Weight and height measurements and BMI/age index classification were carried out as recommended by the World Health Organization (WHO) (10). BF% was assessed by tetrapolar bioimpedance (Biodynamics 310e®) in both health services, following previously validated methodology (11). The information was extracted from electronic medical records and digitized into a database by the medical team responsible for care at the private clinic in Ribeirão Preto/SP and the public hospital in Porto Alegre/RS and made available to the team that conducted the current research. The researchers from both health services and the researchers of the current project are members of the research group CINuS (Center for Research in Nutrology and Health), registered in the Directory of Research Groups of the National Council for Scientific and Technological Development (CNPq) (dgp.cnpq.br/dgp/espelhogrupo/2700061712047513).

From the data, the BMI and TMI of each individual were calculated. BMI was calculated as weight in kilograms divided by height in meters squared ($kg/m^2$). TMI was calculated as weight in kilograms divided by height in cubic meters ($kg/m^3$), as proposed by Peterson et al. (7) in a pediatric population. Individuals with BF% above the 85th percentile for sex and age were considered to have excess body fat, according to McCarthy et al. (12) and as suggested by the Brazilian Society of Pediatrics (13). Furthermore, the individuals were also divided into three age groups: 5 to 8, 9 to 12 and 13 to 17 years, to create the TMI cutoff points.

## STATISTICAL ANALYSIS

Generalized additive models (GAM) based on a smooth function were used to assess the association between the fat mass (dependent variable) and the variables BMI and TMI. GAM allows more flexibility in the shape of the relationships between the variables than traditional models (14). For each fitted model, the proportion of the null deviance explained by the model, the effective degrees of freedom (EDF) of the smooth term, the adjusted R-squared, and the Akaike information criteria (AIC) were obtained. The EDF of the smooth term is a measure such that more EDF implies more complex and wiggly splines. When a smooth term has an EDF value that is close to 1, it is close to being a linear term. The adjusted R-squared is defined as the proportion of variance explained by the model, where both the original variance and residual variance are both estimated using unbiased estimators. The convergence of the smoothness selection optimization, the assumptions on the residuals distribution, and the appropriateness of the basis dimensions used for the smooth terms were verified for all model fits.

Receiver Operating Characteristic (ROC) curve analyzes were performed to verify the accuracy of BMI and TMI in detecting high adiposity in children and adolescents. The curves were constructed considering BF% as a criterion and the indices (BMI and TMI) as diagnostic tests. To compare the ROC curves of BMI and TMI, non-parametric statistical analysis of the differences between the correlated areas under the curves (AUC) was performed, according to DeLong et al. (15). AUC was obtained for each sex and age group. AUC values range from 0.5 to 1, where 1 represents a perfect screening test, capable of discriminating between children and adolescents with and without high adiposity.

ROC curve analyzes with Youden's J index (16) were used to suggest the optimal TMI cutoff points capable of identifying high adiposity, for each sex and age group. The Youden index is defined as J = maxc [sensitivity (c) + specificity (c) - 1] for a given cutoff point c on a ROC curve, corresponding to the maximum distance from the diagonal line from (0, 0) to (1, 1).

The statistical analysis was performed in the SPSS program version 20.0 (IBM, New York, NY, USA) and in the R software environment using the "mgcv" and "pROC" packages. The significance level was set at 0.05.

## RESULTS

Two hundred and twenty-six children and adolescents participated in the study, 115 (50.9 %) of whom were female. Ninety-three children (41.1 %) lived in Porto Alegre/RS and 133 (58.9 %) in Ribeirão Preto/SP. The BMI/age index classification showed that 14 (6.2 %) individuals were underweight, 80 (35.4 %) normal, 68 (30.1 %) overweight and 64 (28.3 %) obese. The prevalence of high adiposity according to BF% was 54.1 % (95 % confidence interval [CI], 44.8-63.2) in boys and 63.5 % (95 % CI, 54.5 -71.9) in girls.

Figure 1 shows smoothed plots of body fat for each sex against the values of BMI and TMI. In all model fits, we have a significant association between the variables ($p < 0.01$). The smooth terms are greater than 1 in all panels of figure 1, indicating a non-linear association between the variables (EDF > 1), except for the relationship between TMI and body fat for the girls (panel D, EDF = 1).

For boys, the adjusted R-squared for the model including the BMI as an independent variable was lower than that for the model including the TMI (0.646 and 0.737, respectively). This suggests that the TMI can explain the variability in body fat better than the BMI. This difference was not observed in girls (the adjusted R-squared was 0.620 and 0.629 for the models including BMI and TMI, respectively).

When comparing the ROC curves for the indices, TMI showed a significantly higher AUC to indicate high adiposity in the group of children and adolescents. The AUC for BMI and TMI were, respectively, 0.862 (95 % CI, 0.813-0.911) and 0.904 (95 % CI, 0.862-0.946). The paired comparison between the ROC curves of BMI and TMI was $p = 0.007$ (Fig. 2).

In boys, the AUC for BMI and TMI were, respectively, 0.925 (95 % CI, 0.874-0.977) and 0.950 (95 % CI, 0.911-0.989). Comparison between the ROC curves did not provide evidence of difference ($p = 0.154$) (Fig. 3A). In girls, the AUC for BMI and TMI were, respectively, 0.770 (95 % CI, 0.679-0.861) and 0.843 (95 % CI, 0.763-0.922). The comparison between the ROC curves of BMI and TMI was significant ($p = 0.014$) (Fig. 3B).

Table I shows that when stratified by sex and age group, all the AUC values were significantly different from the diagonal line (corresponding to an AUC of 0.5), except for girls aged 5 to 8 years. Table I also shows the optimal cutoff point and the corresponding sensitivity and specificity values for TMI for each sex and age group.

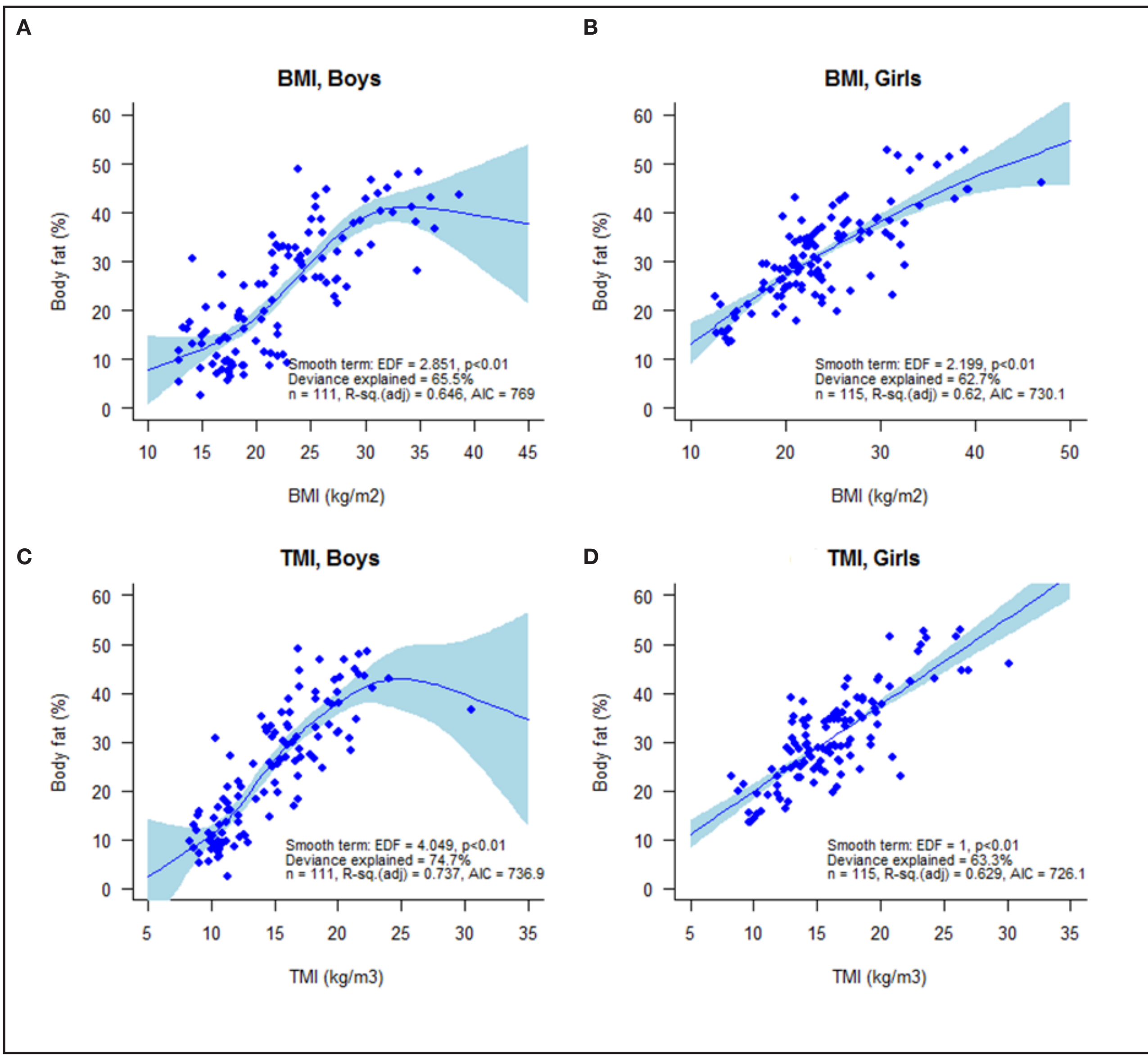


**Figure 1.**

Generalized additive model (GAM) analysis of the body fat as a function of the BMI (panel A: boys, B: girls) and TMI (panel C: boys, D: girls). The shaded areas are error bands.

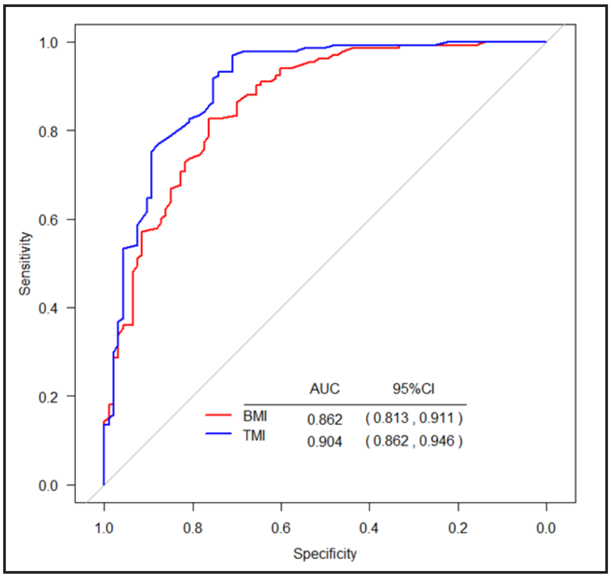


**Figure 2.**

ROC curves for BMI and TMI indicating high adiposity in Brazilian children and adolescents ($n$ = 226).

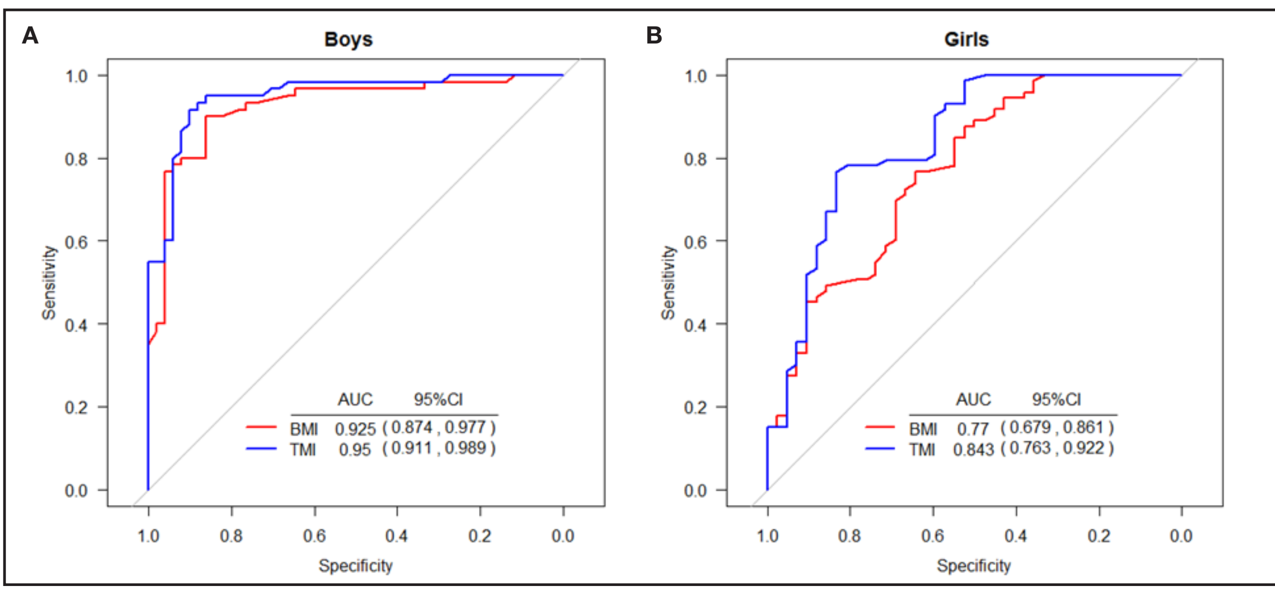


**Figure 3.**

ROC curves for BMI and TMI indicating high adiposity in Brazilian (A) boys ($n$ = 111) and (B) girls ($n$ = 115).

**Table I.** AUC and TMI cutoff points to indicate high adiposity in Brazilian children and adolescents, according to sex and age group

| | | Boys | | | | | | Girls | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age group | *n* | AUC (95 % CI) | *p*-value | Cutoff (kg/m³) | SE | SP | *n* | AUC (95 % CI) | *p*-value | Cutoff (kg/m³) | SE | SP |
| 5-8 | 18 | 0.903 (0.756-1.000) | 0.007 | 14.6 | 1.000 | 0.667 | 34 | 0.697 (0.480-0.914) | 0.075 | 15.3 | 0.807 | 0.625 |
| 9-12 | 48 | 0.930 (0.849-1.000) | 0.000 | 14.2 | 0.885 | 0.923 | 44 | 0.914 (0.803-1.000) | 0.000 | 12.1 | 1.000 | 0.733 |
| 13-17 | 45 | 0.976 (0.937-1.000) | 0.000 | 12.9 | 0.923 | 0.968 | 37 | 0.816 (0.678-0.954) | 0.001 | 15.6 | 0.722 | 0.842 |

*AUC: area under the curve; SE: sensitivity; SP: specificity.*

## DISCUSSION

In this study, the capabilities of BMI and TMI were compared as predictors of obesity in its most correct sense, that is, a condition characterized by excess adiposity. The main findings suggest that TMI, and not BMI, can better explain body fat variability in Brazilian children and adolescents, in both sexes, as previously demonstrated in other studies (7,9). Furthermore, from the comparison of AUC across the entire study population, TMI also proved to be more accurate than BMI in detecting high adiposity. Recognizing the TMI as superior for this purpose, cutoff points were proposed for Brazilian children.

TMI has recently gained prominence in scientific research (17,18). Studies have demonstrated that TMI is a better indicator for tracking adiposity in the pediatric age group, when compared to BMI (7,9,19-23). Peterson et al. (7), studying 2285 white, non-Hispanic North American participants, aged between 8 and 29 years, concluded that the TMI is capable of estimate BF% more accurately than BMI in adolescents, in the range of 8 to 17 years of age. Still in relation to Peterson's study, the authors also demonstrated that TMI misclassifies overweight status less frequently than BMI z-scores (8.4 % vs 19.4 %); and that the first index remains approximately constant during adolescence, while the second increases drastically, necessitating the use of age-specific percentiles (7). From Lorenzo et al. (9), with a sample of 485 Italian children and adolescents aged 8 to 17 years, demonstrated that TMI is a better predictor of BF% in both sexes when compared to BMI. In the study by Moselakgomo et al. (19), TMI revealed a higher incidence of overweight and obesity when compared to BMI after evaluating 1361 South African children. Malavazos et al. (20), in a cross-sectional study that included 3749 non-Hispanic white Italian adolescents aged between 12 and 13 years, concluded that TMI can discriminate body fat distribution more accurately than BMI.

De Oliveira et al. (21) evaluated 147 Brazilian children aged 6 to 8 years and found that although BMI is the anthropometric parameter most used in clinical practice, TMI is more specific in correlating with central adiposity and risk of developing metabolic syndrome. Nascimento et al. (22) also concluded that TMI proved to be a useful tool, superior to BMI, in screening central fat accumulation in preschoolers, after evaluating 1284 Brazilian children aged 2 to 5 years. Park et al. (23), in a cross-sectional study with Korean children and adolescents aged 10 to 20 years, determined that the TMI standard deviation score may be more advantageous than BMI in defining overweight and obesity in children and adolescents. Finally, the cross-sectional study carried out by Siraz et al. (18), with a sample of 4300 Turkish children aged 6 to 17 years, considered that TMI is as effective as BMI in association with the waist/height ratio, waist circumference, arm fat area and BF% in determining of overweight and obesity in children.

In addition to the correlation with BF%, studies have shown an association between TMI and other clinical conditions such as arterial hypertension (4,20), insulin resistance (8,18,24,25), cardiometabolic risk (4,19,20,22,23,25-27), and metabolic syndrome (4,18,20,21,26,27). Akcan et al. (24) concluded that TMI can be used as an auxiliary parameter to track the visceral effects of adiposity. Results from another study suggest that sex- and age-specific TMI may be applicable in the clinical setting as a useful screening tool for metabolic syndrome (4). The study by Neves et al. (8) concluded that TMI and BMI were similar when screening children and adolescents with insulin resistance, with TMI being more advantageous because it is calculated without adjustments for age. In the study population by Malavazos et al. (20), overweight adolescents, compared to normal weight according to TMI, had a higher risk of central obesity and hypertension, both factors involved in metabolic syndrome, supporting the use of TMI in association with the waist/height ratio to characterize overweight adolescents with high cardiometabolic risk. Yeste et al. (25) observed that the diagnostic accuracy of TMI to identify children and adolescents at metabolic risk is similar BMI; however, it simplifies the categorization of the degree of obesity in both sexes. The results of Ramírez-Vélez et al. (26) showed that the TMI had a moderate discriminatory power to detect metabolic syndrome in Colombian children, adolescents and adults. Khoshhali et al. (27) concluded that TMI was a better predictor of metabolic syndrome than BMI in both sexes, especially in the age groups of 11 to 14 and 15 to 19 years.

In relation to the cutoff points established by the TMI, it was observed that the AUC reached high values, which suggests good accuracy of this screening test, regardless of sex and age group, a fact also observed by other authors (9). The only exception was observed in the AUC of girls between 5 and 8 years of age, whose low accuracy can be explained by the small sample size ($n$ = 34). Furthermore, De Lorenzo et al. (9) observed that the TMI specific cutoff points for sex and age were responsible for the better classification of adiposity compared to the BMI cutoff points available in the International Obesity Task Force, WHO and Cacciari reference curves.

It is worth noting that the TMI cutoff points presented are exclusive to the population studied and differ from other international studies due to the characteristics of the populations evaluated, as well as different criteria for diagnosing excess adiposity and different age groups. The present study was carried out with Brazilian children and adolescents divided into three age groups: 5 to 8 years old, 9 to 12 years old and 13 to 17 years old. Furthermore, bioimpedancemetry was used to assess the body composition of this population. In the study by De Lorenzo et al. (9), the sample population was of Italian origin, the technique used for body composition was DEXA and the cutoff points were divided into five age groups: 8 to 9 years, 10 to 11 years, 12 to 13 years, 14 to 15 years, and 16 to 17 years. In the study by Peterson et al. (7), participants were white North Americans of non-Hispanic origin, DEXA was used too and participants were divided into eight age groups: 8 to 9 years old, 10 to 11 years old, 12 to 13 years old, 14 to 15 years, 16 to 17 years, 18 to 19 years, 20 to 24 years and 25 to 29 years. Given this information, there is a need to develop multicenter studies including populations from different countries and with a larger sample size, to establish universal cutoff points.

In the present study, the prevalence of high adiposity according to BF% was high in both sexes, being 54.1 % in boys and 63.5 % in girls. Other brazilian studies with children and adolescents observed variation in BF% between 14 % and 28 % in the Southern region (28,29), 16 % to 28.2 % in the Southeast region (30,31) and 22 % to 64 % in the North of the country (32,33). Recent national data estimate that 29.3 % to 30.3 % of Brazilian children and adolescents between 5 and 19 years of age are overweight (34,35). The high adiposity found in this study can be explained by the high prevalence of overweight individuals according to BMI/age (58.4 %) in the sample. These individuals were recruited from clinics that provided nutritional care and, therefore, it can be assumed that the majority were seeking weight loss. Such information can influence the achievement of optimal TMI cutoff points for the Brazilian population. Although the results of the current study are a starting point for the adoption of a new anthropometric index in clinical practice in Brazil, a nationwide study is necessary to validate the TMI cutoff points in the Brazilian pediatric population.

Among the strengths of the current study, the following can be highlighted: I) multicenter data collection, with the participation of children from the Southern and Southeastern regions of Brazil; II) data collection with populations with different socioeconomic conditions, served in private and public services; III) and its unprecedented nature, being the first study that identified the greater capacity of TMI, compared to BMI, in detecting excess body adiposity (and not just central adiposity) in Brazilian children and adolescents, and which proposed cutoff points stratified by sex and age group, capable of tracking high BF%. Limitations of this study include: I) the low sample size, which led to the mixing of isolated ages into age groups; II) the lack of data collection in the Central-West, Northeast and North regions of Brazil; III) the high number of overweight individuals according to BMI/age, representing 58.4 % of the sample; IV) the absence of a cutoff point for high body adiposity in Brazilian children, so it was necessary to use the reference by McCarthy et al. (12), North American reference; V) and the non-assessment of pubertal staging.

## CONCLUSION

TMI has been shown to be a better predictor of excess body fat than BMI in Brazilian children and adolescents. The TMI cutoff points to detect excess adiposity were defined and stratified by sex and age group. It is concluded that the TMI is a useful and simple screening tool, requiring more multicenter studies with a larger sample size so that this index can be incorporated into clinical practice and in epidemiological studies related to overweight and obesity in children and adolescents in Brazil.

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