Tri-ponderal mass index and body mass index in prediction of pediatric metabolic syndrome: the CASPIAN-V study

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ABSTRACT

Objective: Body mass index (BMI) and tri-ponderal mass index (TMI) are anthropometric measures to evaluate body adiposity in the various age groups. The present study aims to compare the predictive value of TMI and BMI for metabolic syndrome (Mets) in children and adolescents of both genders. **Subjects and methods:** A cross-sectional study conducted on 3731 Iranian children and adolescents aged 7-18 years obtained from the fifth survey of 'Childhood and Adolescence Surveillance and Prevention of Adult Non-communicable Disease' (CASPIAN-V) study. The predictive value of BMI and TMI for MetS were determined using Receiver-operator curves. Logistic regression analysis was used to assess the relationship between these indices with MetS. **Results:** 52.6% of participants were boys. The mean (standard deviations) age for boys and girls were 12.62 (3.02) and 12.25 (3.05) years, respectively. In boys, the area under the curve (AUC) of TMI was greater than BMI for all age groups. AUC of TMI was also greater than BMI for age group of 11-14 years (AUC = 0.74; 95% CI (0.67, 0.81)) in girls. Furthermore, our findings showed that odds ratio of Mets for TMI was greater than BMI in age groups of 11-14 years (OR = 1.33 vs 1.22) and 15-18 years (1.16 vs 1.15) in girls and boys, respectively. **Conclusion:** TMI and BMI had moderate predictive value for identifying MetS. However, TMI was a better predictor of MetS than BMI in both genders, especially in age groups of 11-14 and 15-19 years for girls and boys. Arch Endocrinol Metab. 2020;64(2):171-8

Keywords
Metabolic syndrome; body mass index; tri-ponderal mass index; pediatric

INTRODUCTION

Metabolic syndrome (MetS) is defined as a cluster of cardio metabolic risk factors, including central obesity, glucose intolerance, dyslipidemia and raised blood pressure (1). MetS can occur from early life (2). During last decades, MetS has become a major health problem in children and adolescents; because of various factors including epidemiologic transition, double burden of nutritional disorders, and lifestyle changes. MetS is not limited to developed countries (3).

A systematic review determined the worldwide prevalence rates of MetS ranged between 0 and 19.2% among children and adolescents in 2012 (4). Previous studies indicated that MetS is a common metabolic disorder among Iranian children (5-8). A systematic review reported prevalence rates of MetS in the range of 1-22% in Iran (9).

Obesity and overweight in childhood and adolescence have emerged as one of the most important public health concerns in the 21st century (10). It is important to determine the optimal weight-height indices, which are closely correlated with weight but uncorrelated with height across the growing period (11). Several studies determined that the body mass index (BMI: body weight (kg)/height^2 (m^2)) is a preferable index in preschool children and adult (12-14). Furthermore, tri-ponderal mass index (TMI: body weight (kg)/height^3 (m^3)) may be applicable for newborns (15). Traditionally, the ponderal index was devised in 1921 by Rohrer and cols. (16). It was originally suggested as a corpulence index and has been used as an indicator of fetal nutrition. Several studies showed that the accuracy of TMI is higher than BMI to determine adiposity in infants (17,18).

The general trend of Power (p) in Weight/Height p by age and gender was specified. However, trends of p are still not clear due to population differences in the studies (14). Recently, Peterson et al showed that TMI estimated body fat percentage more accurately than BMI in adolescents aged 8 to 17 years (19). Another study reported reference values of BMI and TMI for age for healthy non-underweight, non-obese millennial children in the Barcelona longitudinal growth study (1995-2017) (20).

The anthropometric measures are reliable, low cost, non-invasive and can be performed without highly technologic equipment by staff with minimal training (21). Many studies have indicated association between anthropometric measures with MetS and its components in children and adolescents (22-25). However, to our knowledge, there is only one study that explored thresholds of gender-specific TMI and FMI ((fat mass)/height^3) for the prediction of MetS in population of Colombian children and youth (26). The purposes of this study were (a) to compare predictive ability of TMI and BMI for the prediction of Mets among a large population of Iranian children and adolescents and (b) to determine the optimal cutoff values for BMI and TMI by gender and age groups.

METHODS AND MATERIALS

Study design and sample

The data of this nationwide cross-sectional study were collected as a part of the "National survey of school student high risk behaviors" (2014-2015), as the fifth survey of the school-based surveillance system entitled **C**hildhood and **A**dolescence **S**urveillance and **P**reventI**o**n of **A**dult **N**on-communicable Disease (CASPIAN-V) study. This school-based nationwide health survey was conducted in 30 provinces in Iran. Details on the study protocol have been explained before (27) and here we report it in brief.

The study population consisted of students aged 7-18 years in primary and secondary schools in urban and rural areas across the country. They were selected using multistage stratified cluster sampling method. Sampling within each province was conducted according to the student's place of residence (urban or rural) and level of education (primary and secondary) using the proportional to size method and with equal sex ratio. 4200 students were randomly selected for blood sampling.

Physical measurements

A team of trained health care experts recorded information based on approved check lists; they performed the examinations under standard protocols by using calibrated instruments. Weight was measured on a scale placed on a flat ground to the nearest 0.1 kg while subjects wearing a light cloth, and height were measured without shoes to the nearest 0.1 cm (28). BMI was calculated by dividing weight (kg) to height squared (m^2) and TMI was calculated dividing weight (kg) to height cubed (m^3). Waist circumference (WC) was measured using a non-elastic tape at a point midway between the lower border of the rib cage and the iliac crest at the end of normal expiration to the nearest 0.1 cm (29).

Blood pressure was measured in the sitting position on the right arm using a mercury sphygmomanometer with an appropriate cuff size. It was measured 2 times at 5-min intervals; systolic and diastolic pressures were recorded and the average was registered (30).

Blood sampling

Fasting blood samples were obtained from students after 12–14 h of overnight fast. Fasting blood glucose (FBG), triglycerides (TG), total cholesterol (TC), low-density lipoprotein-cholesterol (LDL-C) and high-density lipoprotein-cholesterol (HDL-C) were measured enzymatically by Hitachi auto148 analyzer (Tokyo, Japan) (31,32).

MetS components

Subject were classified as having MetS, if they had at least three of the following criteria according to the Adult Treatment Panel III (ATP III) criteria modified for the pediatric age group (33).

1) Abdominal obesity was defined as waist-to-height ratio equal to or more than 0.5 (34).

2) Elevated FBG ≥ 100 mg/dL.
3) High serum TG ≥ 100 mg/dL.
4) Low serum HDL-C < 40 mg/dL (except in boy 15-18 y in whom the cut-off was < 45 mg/dL) (35).
5) Elevated blood pressure was defined as either high systolic blood pressure (SBP) (≥ 90th percentile for age, sex and height) or high diastolic blood pressure (DBP) (≥ 90th percentile for age, sex and height) (30).

Statistical analysis

The results are represented as mean ± standard deviation (SD). Comparisons between means of anthropometric measures in boys and girls were performed using independent Student t test.

Pearson correlation coefficients were used to determine associations between BMI and TMI with weight and height and also MetS components.

The discriminatory power of BMI, TMI and their z-scores for MetS was calculated by areas under the receiver operating characteristic (ROC) curve. Area under the ROC (AUC) value equal to 1 means perfect accuracy. Furthermore, the optimal cutoff values for BMI, TMI and their z-score were obtained using the Youden index (sensitivity+specificity−1) by gender. The association between TMI, BMI and their z-score with risk of MetS was evaluated using logistic regression model by gender and age. The results of logistic regression are presented as odds ratio (OR) and 95% confidence interval (CI).

The analyses data were performed using statistical software STATA 12.0 (STATA Corp, College Station, Texas, USA). All statistical analysis was performed using survey analysis method. P-valuesless than 0.05 were considered as statistically significant.

RESULTS

The participation rate was 91.5%. In total, 52.4% of them were boys. The mean (standard deviation) age was 12.62 (3.02) and 12.25 (3.05) years for boys and girls, respectively. Table 1 shows the weight, height, BMI and TMI of participants by age and gender. Mean of weight, height and BMI in boys were more than girls in the age group of 7-10 years ($p < 0.05$). However, in the age group of 11-14 years, girls had significantly greater mean of weight and height than boys ($p < 0.05$). In the age group of 15-18 years, mean of weight and height were significantly greater in boys than girls ($p < 0.05$) whereas mean of BMI and TMI in girls was significantly greater than boys ($p < 0.05$).

Table 1. Characteristics of participants by age and gender: the CASPIAN-V Study

Gender	Age group (yr)	Boys		Girls		P
		N	Mean ± SD	N	Mean ± SD	
Weight (kg)	7-10	565	28.53 ± 8.25	582	26.85 ± 7.59	< 0.001
	11-14	845	41.07 ± 11.89	809	42.49 ± 12.33	0.019
	15-18	602	56.85 ± 17.85	440	54.93 ± 13.42	0.063
	Total	2012	42.27 ± 17.05	1831	40.45 ± 15.46	0.757
Height (cm)	7-10	565	130.78 ± 10.62	582	128.85 ± 9.82	0.002
	11-14	845	148.56 ± 12.13	809	149.86 ± 11.37	0.029
	15-18	602	164.80 ± 16.74	440	159.86 ± 10.41	< 0.001
	Total	2012	148.44 ± 18.56	1831	145.52 ± 16.12	0.096
BMI (kg/m^2)	7-10	565	16.54 ± 3.74	582	16.01 ± 3.51	0.015
	11-14	845	18.33 ± 3.64	809	18.62 ± 3.82	0.117
	15-18	602	20.45 ± 4.40	440	21.27 ± 4.15	0.003
	Total	2012	18.46 ± 4.18	1831	18.42 ± 4.28	0.001
TMI (kg/m^3)	7-10	565	12.74 ± 3.46	582	12.48 ± 3.13	0.189
	11-14	845	12.37 ± 2.57	809	12.43 ± 2.41	0.665
	15-18	602	12.46 ± 2.75	440	13.31 ± 2.49	< 0.001
	Total	2012	12.50 ± 2.90	1831	12.66 ± 2.70	< 0.001

BMI: body mass index; TMI: tri-ponderal mass index.

The correlation coefficients between the indices of BMI and TMI with the weight, height and MetS components are showed in Table 2. For both girls and boys in all age groups, BMI had the greatest correlation with weight. Furthermore, WC and systolic and diastolic pressures had significant correlation with BMI and TMI, with the greatest correlation coefficients for BMI. The correlation between BMI and TMI with TG and LDL were also significant in boys aged 15-18 years.

Table 3 shows the optimal cutoffs, corresponding sensitivity and specificity, AUC for BMI and AUC for TMI. Table 4 shows optimal cutoffs, corresponding sensitivity, specificity and AUC of BMI z- score and TMI z-score. In all age groups for boys, TMI and TMI

Table 2. Correlation between indices of BMI and TMI with weight, height and components of metabolic syndrome: the CASPIAN-V Study

		Age group (yr)	Weight	Height	WC	SBP	DBP	FBG	TG	TC	HDL	LDL
Boys	BMI	7-10	0.74*	0.02	0.44*	0.21*	0.22*	-0.04	0.03	0.005	0.01	0.02
		11-14	0.82*	0.26*	0.67*	0.26*	0.22*	0.014	-0.02	-0.003	-0.02	-0.01
		15-18	0.84*	0.34*	0.73*	0.28*	0.23*	-0.06	0.10*	0.06	0.01	0.10*
	TMI	7-10	0.41*	-0.36*	0.19*	0.15*	0.16*	-0.04	0.04	0.02	-0.01	0.04
		11-14	0.47*	-0.20*	0.43*	0.16*	0.16*	-0.001	-0.02	0.03	-0.01	0.01
		15-18	0.44*	-0.17*	0.44*	0.12*	0.09*	-0.01	0.12*	0.05	0.02	0.10*
Girls	BMI	7-10	0.77*	0.10*	0.44*	0.27*	0.22*	-0.01	0.02	-0.02	-0.05	0.01
		11-14	0.88*	0.34*	0.65*	0.24*	0.15*	-0.01	0.03	-0.03	-0.08*	0.02
		15-18	0.90*	0.27*	0.74*	0.31*	0.23*	0.003	0.02	0.003	-0.06	0.03
	TMI	7-10	0.47*	-0.26*	0.20*	0.16*	0.15*	-0.01	0.01	-0.03	-0.06	-0.0003
		11-14	0.64*	-0.03	0.47*	0.13*	0.08*	-0.02	0.02	-0.06	-0.06	-0.003
		15-18	0.72*	-0.05	0.64*	0.23*	0.18*	-0.02	-0.0001	0.003	-0.04	0.01

WC: waist circumference; SBP: systolic blood pressure; DBP: diastolic blood pressure; FBG: fasting blood glucose; TG: triglycerides; TC: total cholesterol; HDL: high density lipoprotein; LDL: low density lipoprotein; BMI: body mass index; TMI: tri-ponderal mass index.

* P-value < 0.05.

Table 3. ROC curve analysis for indices of BMI and TMI as predictors of metabolic syndrome by gender and age: the CASPIAN-V Study

Gender/Indices	Age groups (yr)	cutoffs	Sensitivity	Specificity	AUC	95% CI
Boys						
BMI	7-10	17.71	59.26%	75.67%	0.69	(0.58, 0.80)
	11-14	20.7	60.00%	81.54%	0.74	(0.66, 0.81)
	15-18	23.05	61.76%	81.31%	0.67	(0.55, 0.79)
	Total	19.65	63.21%	69.72%	0.69	(0.63, 0.75)
TMI	7-10	13.26	66.67%	72.99%	0.73	(0.63, 0.83)
	11-14	12.19	84.44%	58.33%	0.74	(0.67, 0.81)
	15-18	13.26	64.71%	71.69%	0.70	(0.59, 0.80)
	Total	13.17	63.21%	72.75%	0.72	(0.67, 0.78)
Girls						
BMI	7-10	18.09	55.56%	84.14%	0.71	(0.60, 0.81)
	11-14	19.73	69.23%	68.68%	0.74	(0.66, 0.81)
	15-18	20.95	76.92%	54.19%	0.64	(0.48, 0.81)
	Total	19.61	60.76%	68.27%	0.67	(0.61, 0.73)
TMI	7-10	14.34	44.44%	87.69%	0.67	(0.56, 0.79)
	11-14	15.35	51.28%	89.92%	0.74	(0.67, 0.81)
	15-18	13.43	76.92%	57.88%	0.64	(0.47, 0.81)
	Total	14.8	45.57%	86.18%	0.68	(0.61, 0.74)

AUC: area under the receiver operating curve; BMI: body mass index; TMI: tri-ponderal mass index.

z-score had greater AUC than BMI and BMI z-score for the prediction of Mets. However, the AUC of BMI was greater than TMI for age group of 7-10 years and the AUC of BMI z-score was also greater for groups of 7-10 and 11-15 years in girls. The optimal cutoffs for BMI and TMI in different age groups were obtained using the same method. Figure 1 represents ROC curves of anthropometric indexes for prediction of MetS in the total data.

Table 5 presents the ORs and 95% CI for the association between BMI, TMI and their z-scores with MetS by age and gender. The significant associations were found between BMI and TMI and MetS in girls and boys for all age groups except in girls with age group of 15-18 years. The values of OR for TMI and TMI z-score were greater than BMI and BMI z-score for age groups of 11-14 and 15-18 years in girls and age group of 15-18 years in boys.

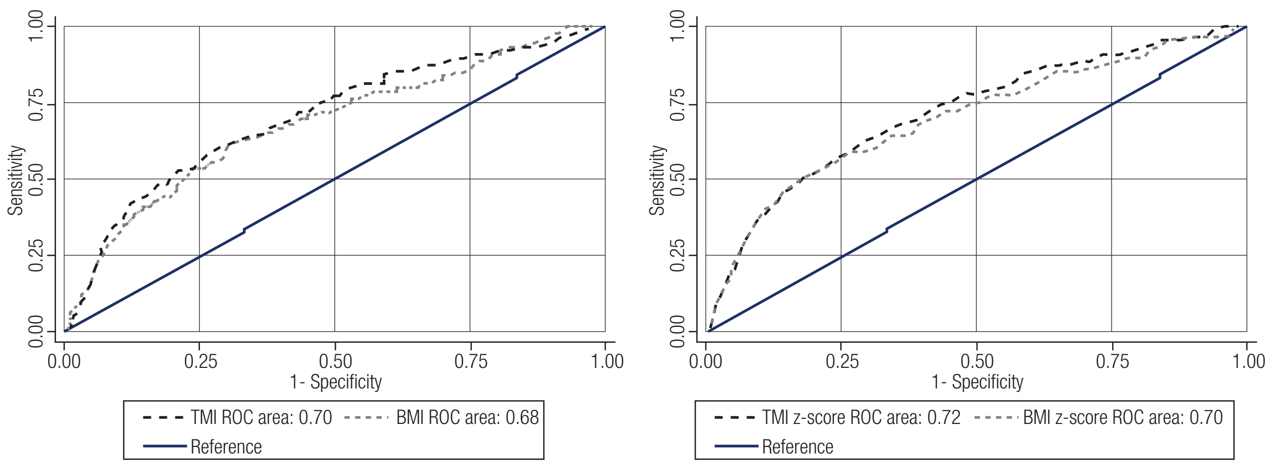

Figure 1. Roc curve of anthropometric indices for predicting metabolic syndrome in children and adolescents: The CASPIAN-V study.
BMI: body mass index; TMI: tri-ponderal mass index.

Table 4. ROC curve analysis for indices of BMI z-score and TMI z-score as predictors of metabolic syndrome by gender and age: the CASPIAN-V Study

Gender/Indices	Age groups (yr)	cutoffs	Sensitivity	Specificity	AUC	95% CI
Boys						
BMI z- score	7-10	0.88	48.45%	83.46%	0.69	(0.57, 0.80)
	11-14	0.21	70.45%	67.01%	0.73	(0.65, 0.81)
	15-18	0.78	59.38%	83.40%	0.68	(0.56, 0.80)
	Total	0.56	57.43%	78.65%	0.70	(0.65, 0.76)
TMI z- score	7-10	0.42	64.00%	77.82%	0.72	(0.61, 0.83)
	11-14	0.16	70.45%	68.71%	0.74	(0.67, 0.82)
	15-18	0.82	56.25%	82.099%	0.70	(0.60, 0.81)
	Total	0.33	62.38%	72.32%	0.72	(0.67, 0.78)
Girls						
BMI z- score	7-10	0.75	55.56%	82.95%	0.71	(0.60, 0.82)
	11-14	0.36	68.42%	70.56%	0.73	(0.64, 0.82)
	15-18	0.16	69.23%	61.39%	0.65	(0.48, 0.81)
	Total	0.68	53.13%	79. 81%	0.71	(0.65, 0.77)
TMI z- score	7-10	0.88	48.15%	84.66%	0.69	(0.58, 0.80)
	11-14	0.61	57.89%	76.80%	0.71	(0.62, 0.80)
	15-18	0.25	69.23%	62.87%	0.65	(0.47, 0.82)
	Total	0.91	46.15%	85.26%	0.69	(0.63, 0.76)

AUC: area under the receiver operating curve; BMI: body mass index; TMI: tri-ponderal mass index.

Table 5. Odds ratio (95% CI) for the association between anthropometric indices with risk of metabolic syndrome by age and gender: The CASPIAN-V study

Age groups (yr)		Boys		Girls	
		OR (95% CI)	P	OR (95% CI)	P
7-10	BMI	1.16 (1.08, 1.24)	< 0.001	1.11 (1.04, 1.19)	0.003
	BMI z-score	1.84 (1.40, 2. 41)	< 0.001	1.41 (1.13, 1.76)	0.002
11-14	BMI	1.21 (1.13, 1.29)	< 0.001	1.22 (1.14, 1.32)	< 0.001
	BMI z-score	1.94 (1.51, 2.47)	< 0.001	1.62 (1.36, 1.93)	< 0.001
15-18	BMI	1.15 (1.07, 1.22)	< 0.001	1.11 (0.99, 1.25)	0.071
	BMI z-score	1.89 (1.42, 2.53)	< 0.001	1.32 (0.98, 1.77)	0.065
Total	BMI	1.16 (1.11, 1.20)	< 0.001	1.12 (1.07, 1.17)	0.024
	BMI z-score	1.89 (1.62, 2.20)	< 0.001	1.34 (1.20, 1.50)	0.024
7-10	TMI	1.14 (1.06, 1.21)	< 0.001	1.08 (1.01, 1.16)	0.033
	TMI z-score	1.70 (1.33, 2.19)	< 0.001	1.36 (1.08, 1.71)	0.009
11-14	TMI	1.19 (1.09, 1.29)	< 0.001	1.33 (1.19, 1.49)	< 0.001
	TMI z-score	1.65 (1.32, 2.06)	< 0.001	2.00 (1.52, 2.62)	< 0.001
15-18	TMI	1.16 (1.06, 1.28)	0.002	1.18 (0.97, 1.43)	0.102
	TMI z-score	1.54 (1.19, 2.00)	0.001	1.53 (0.94, 2.49)	0.102
Total	TMI	1.15 (1.10, 1.21)	< 0.001	1.14 (1.08, 1.21)	< 0.001
	TMI z-score	1.63 (1.42, 1.88)	< 0.001	1.58 (1.34, 1.87)	< 0.001

OR: odds ratio; CI: confidence interval; BMI: body mass index; TMI: tri-ponderal mass index.

DISCUSSION

Previous studies assessed and compared BMI and TMI on adiposity (13) and body fat (19). To the best of our knowledge, this is the first study comparing the accuracy of TMI and BMI indices for Mets in pediatric population. This study indicated that the predictive power of TMI was higher than BMI in the prediction of Mets in boys for all age groups and in the age group of 11-14 years for girls. The optimal cutoffs for BMI (BMI z-score) and TMI (TMI z-score) for predicting MetS were 19.65 (0.56) and 13.17 (0.33) in boys and 19.61 (0.68) and 14.8 (0.91) in girls, respectively. Furthermore, our findings showed that in the age group of 7-10 years, the risk of Mets for BMI (BMI z-score) was higher than TMI (TMI z-score) in both girls and boys; in the age group of 11-14 years, TMI (TMI z-score) was greater than BMI (BMI z-score) in girls; and in age group of 15-18 years, TMI was greater than BMI in both girls and boys but in girls was not statistically significant.

According to findings, weight spurt during puberty spurts is more than twice the height spurt in percentage terms (13). The findings of previous studies showed that TMI is a better adiposity index than BMI during puberty (36), which was similar to the findings of the present study.

Recently, Peterson and cols. showed that TMI estimated body fat levels more accurately than BMI in non-Hispanic white adolescents aged 8 to 17 years. Furthermore, they indicated that TMI could diagnose overweight adolescents more accurately than BMI *z* scores (19). Several studies have found the associations between fat distribution (BF% and /or FMI) and MetS components (37,38). Our findings were concordant with results of these studies.

There are differences between the predictive values of BMI and TMI for MetS in various populations. A cross-sectional study on Brazilian children from public and private schools showed that BMI had AUC at 0.754 in 5th-grade girl students (25). Another cross-sectional study reported that BMI had high predictive value (AUC = 0.98) for MetS among Spanish adolescents of both genders (24). In study on Colombian children and adolescents, the ROC analysis showed that TMI had a moderate discriminatory power to detect MetS (all AUCs for age groups of 9-12 and 13-17 years in both girls and boys were less than 0.755) (26). In the present study, TMI and BMI had moderate diagnostic accuracy for identifying MetS among Iranian children and adolescents. This discrepancy in results could be described by the heterogeneity of the sample populations and or different definitions of pediatric Mets (35).

Previous studies have identified strong effects of puberty on distributions of adiposity (39) and the Mets (40). The present study also showed relationship between BMI and TMI with risk of Mets in puberty age particularly for TMI.

Findings of the present study provide optimal cutoffs for BMI and TMI by age and gender. More studies are suggested in different population (41). The optimal BMI cutoff values to predict MetS in our study were 19.65 kg/m² for boys and 19.61 kg/m² for girls, which differs from values in Spanish adolescents (cutoff = 27 for both gender) (24). Moreover, the optimal TMI cutoff values to predict MetS in Colombian children and adolescents for age groups of 9-12 and 13-17 years were 12.10 and 11.9 years for boys and 12.13 and 12.48 for girls, respectively. However, TMI cutoff values in the present study were greater than values in previous studies for all age groups in both boys and girls. The differences in these values could be due to differences in lifestyle between various population (41). In the current study, the optimal cutoff values for BMI z-score and TMI z-score to predict MetS were less than the values to predict overweight or obesity. This finding maybe because of the high prevalence of high TG and low HDL cholesterol levels among normal-weight children in Iran (42). Moreover, several studies reported CVD risk factors and metabolic syndrome among Asian adults, children and adolescents with normal weight (42-44).

The main limitation of the present study is cross-sectional nature, therefore the cause–effect relationships cannot be inferred from these findings. Another limitation is the lack of information on puberty age in adolescents. The main strengths of our study are its novelty in the pediatric age group and considering a large population-based sample.

In conclusion, the results of present study showed that both BMI and TMI had moderate diagnostic accuracy for identifying MetS in children and adolescents. However, generally TMI was a better predictor of MetS than BMI in both genders. TMI can be considered as an appropriate anthropometric index for large population-based studies in the pediatric age group.

Ethics approval and consent to participate: study protocols were reviewed and approved by ethical committees and other relevant national regulatory organizations. The Research and Ethics council of Isfahan University of Medical Sciences approved the study (Project number: 194049). After complete explanation of the study objectives and protocols, written informed consent and verbal consent were obtained from the parents and students, respectively.

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