J Pediatr (Rio J). 2015;91(3):248–255

Jornal de Pediatria
www.jped.com.br

ORIGINAL ARTICLE

Reference curves of the body fat index in adolescents and their association with anthropometric variables☆

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Received 26 March 2014; accepted 15 July 2014
Available online 2 December 2014

KEYWORDS
Adolescents;
Sexual maturation;
Fat;
Skin folds

Abstract
Objectives: To develop reference curves for the body fat index (BFI) in the pediatric population, in adolescents from the city of São Paulo, Brazil, and verify their association with body mass index and body fat percentage.
Methods: The study is part of the research project ''Nutritional Profile of Adolescents from Public and Private Schools of São Paulo'' that was performed in 2004-2005. A total of 4,686 adolescents (2,130 boys and 2,556 girls) aged 10-15 years were divided into two groups: 10-12 and 13-15 years of age. Body mass, height, body mass index, hip circumference, body fat percentage, body fat index, and sexual maturation performed by the self-assessment method (prepubertal, pubertal, and postpubertal) were analyzed. ANOVA was performed, as well as percentile distribution, Pearson's correlation, and Bland-Altman plot.
Results: In boys, there was an increase in body mass, height, body mass index, and hip circumference with advancing age and Tanner stage. In girls, there was an increase in body fat index and body fat percentage with advancing age and stage of sexual maturation. An association was found between body fat index and body mass index ($r = 0.67$ in boys and 0.80 in girls, $p < 0.001$) and body fat percentage ($r = 0.71$ in boys and 0.68 in girls, $p < 0.001$).
Conclusion: The body fat index seems to reflect well the phenomena of sexual dimorphism in adolescence, is easy to perform, and represents a method that should be used in population samples.

☆ Please cite this article as: Frignani RR, Passos MA, Ferrari GL, Niskier SR, Fisberg M, de Pádua Cintra I. Reference curves of the body fat index in adolescents and their association with anthropometric variables. J Pediatr (Rio J). 2015;91:248–55.

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http://dx.doi.org/10.1016/j.jped.2014.07.009

PALAVRAS-CHAVE
Adolescentes;
Maturação sexual;
Adiposidade;
Pregas cutâneas

Curvas de referência do índice de adiposidade corporal de adolescentes e sua relação com variáveis antropométricas

Resumo

Objetivos: Desenvolver curvas de referência do índice de adiposidade corporal para população pediátrica, em adolescentes da cidade de São Paulo, Brasil, e verificar a sua relação com o índice de massa corporal e percentual de gordura corporal.

Métodos: O estudo faz parte do projeto de pesquisa ''Perfil Nutricional de Adolescentes de escolas Públicas e Privadas de São Paulo'' realizado em 2004/2005. 4.686 adolescentes (2.130 meninos e 2.556 meninas) de 10-15 anos foram divididos em dois grupos: 10-12 e 13-15 anos. Massa corporal, estatura, índice de massa corporal, circunferência de quadril, porcentagem de gordura corporal, índice de adiposidade corporal e maturação sexual realizada pelo método de autoavaliação (pré-púbere, púbere e pós-púbere) foram analisadas. Foi feito ANOVA, distribuição percentilar, correlação de Pearson e o gráfico de Bland-Altman.

Resultados: Nos meninos, ocorreu aumento da massa corporal, estatura, índice de massa corporal e circunferência do quadril com o avanço da idade e estágio de Tanner. Nas meninas, ocorreu aumento do índice de adiposidade corporal e do percentual de gordura corporal com o avanço da idade e estágio de maturação. Foi encontrada uma associação entre o índice de adiposidade corporal com o índice de massa corporal ($r = 0,67$ nos meninos e 0,80 nas meninas; $p < 0,001$) e com o percentual de gordura ($r = 0,71$ nos meninos e 0,68 nas meninas; $p < 0,001$).

Conclusão: O índice de adiposidade corporal parece refletir bem os fenômenos do dismorfismo sexual na adolescência, sendo um método de fácil realização que deveria ser mais utilizado em amostras populacionais.

Introduction

In recent decades, the prevalence of overweight and obesity has increased alarmingly worldwide, which is considered a public health problem.[1,2] The period of greatest risk for the incidence of obesity is the transition between adolescence and the early stages of adulthood in both genders and several ethnic groups,[3] in addition to also representing a major risk factor for cardiovascular disease.[4] Although the clinical manifestations of these diseases occur in adulthood, studies have shown that comorbidities such as dyslipidemia, hypertension, and insulin resistance may be present as early as in childhood and adolescence,[4] and are responsible for the increased risk of morbidity and mortality in adult life.[5]

In addition to increasing the chances of obesity in adulthood,[3,4] the strong association of excess weight in childhood with metabolic alterations (lipid profile and blood pressure) has resulted in the development of several techniques (hydrostatic weighing and dual-energy X-ray absorptiometry) to accurately determine body fat; however, most methods are complex, time consuming, and expensive to be routinely applied.[6,7] Thus, anthropometric assessment constitutes an important diagnostic method, as it is easy to perform, inexpensive, noninvasive, universally applicable, has good acceptance by the population, and is universally accepted and proposed by the World Health Organization.[8,9] In addition to the measurement of body weight and body fat percentage (BF%), the body mass index (BMI) is the most commonly used approach to characterize obesity in individual subjects.[7–9]

Although the BMI is used to characterize body growth of children, this measure is routinely applied, not only in epidemiological studies, but also in clinical practice.[1,9,10] When used indiscriminately, it can lead to false results, as it is a still controversial measure, in addition to the fact that it is particularly difficult to determine body fat in children.[10,11]

Bergman et al. proposed the Body Fat Index (BFI) for adults, a new parameter to assess body composition based on two anthropometric measures, both easily reproducible - height, in meters, and hip circumference (HC), in cm.[7] The BFI has been developed and applied in adults from different countries,[6,7] but this index is still scarcely applied in Brazilian adolescents.

Thus, the aim of this study was to develop BFI reference curves for the pediatric population, using adolescents living in the city of São Paulo, Brazil as models, as well as verify their association with BMI and BF%.

Methods

Study population and school sampling

The present study is part of a research on the life habits and nutritional status of adolescents, entitled ''Nutritional Profile for Adolescents from Public and Private schools in São Paulo.'' The project was coordinated by researchers at the Centro de Atendimento e Apoio ao Adolescente of the Discipline of Pediatric Specialties of the Department of Pediatrics, Universidade Federal de São Paulo (UNIFESP).

The study evaluated adolescents who were enrolled between the fifth and eighth grades from 43 randomly selected public and private schools. Randomization considered the number of public and private schools in each region, containing at least 200 students from the fifth to eighth grade attending the morning and/or afternoon shifts, and a 2:1 relation of proportionality was verified between them. Due the difficulty in agreeing to apply the Tanner stages by the private schools and as this information was important for the research, the final proportion was 4:1 public to private schools, representing a loss of 28%. These were randomly selected in 31 schools (25 public and 6 private) from the four regions (north, south, east, and west) of the city of São Paulo, Brazil.

This study sample was constituted by analyzing a database consisting of more than 8,020 students of both genders who had to meet the following inclusion criteria: (a) have complete demographic and clinical data available for the study (b) age between 10 and 15 years; (c) be regularly enrolled in a public or private school in the city of São Paulo; (d) and have an informed consent signed by a parent or guardian. The study protocol was approved by the Ethics Committee of UNIFESP, protocol No. 0977/03. Pregnant adolescents were excluded from the study.

This study included 4,686 adolescents, of whom 45.5% (n = 2,130) were males and 54.5% (n = 2,556) were females, aged from 10 years and one day to 15 years, 11 months and 29 days, representing a sampling fraction of 1.3% of the 360,000 students enrolled in public and private schools in São Paulo. No formula was used to estimate the sample size, as a probabilistic approach was used. Data were collected between September of 2004 and June of 2005.

The age distribution among the female and male students was respectively, as follows: 646 and 554 aged between 10 and 11 years; 1,308 and 1,053 aged between 12 and 13 years; and 602 and 523 aged between 14 and 15 years.

Anthropometric measurements

A team of four trained researchers coordinated the performance of all measurements; the team was trained regarding the techniques and the standardization of the methods used, in order to achieve greater accuracy of the collected data.

Body mass was measured on a portable digital scale (Seca®, CA, USA) with capacity of 150 kg. Adolescents were weighed on the center of the platform, in the standing position, facing the front, with lateral spacing between the feet and the body weight evenly distributed between the feet, barefoot, wearing light clothing, and steady with the arms alongside the body.[12]

Height was determined using a digital wall stadiometer (Seca®, CA, USA), with the adolescent barefoot or wearing thin socks and light clothes, so that the body positioning could be seen by the examiner. The adolescent stood on a flat surface with the weight distributed evenly on both feet, with the eyes perpendicular to the body. The arms were positioned alongside the body, and the head, back, and buttocks were in contact with the vertical plate. The measurement was made during a deep inspiration with the body fully erect.[12]

BMI was calculated by dividing weight in kilograms by height in square meters (kg/m^2), according to the curves proposed by the World Health Organization (WHO) for age and gender.[9] This classification has been used to identify the risk or the actual condition of obesity in populations.[7–9]

An inelastic measuring tape (Seca®, CA, USA) was used to measure the HC, while the adolescent maintained the feet together and with the weight distributed evenly on both feet. The measurement was performed on the area of greatest gluteal circumference.[13] Both HC and height were measured three times, consecutively, and the arithmetic mean was considered as the final value. Based on these two measurements mentioned above, the BFI was obtained by dividing the HC by height multiplied by the square root of height, minus 18:[7]

$$\text{BFI} = \frac{\text{HC}}{\text{height}\sqrt{\text{height}}} - 18$$

To calculate BF%, measurements of the triceps skinfold thickness (TST), at the point that comprises half the distance between the superolateral border of the acromion and the olecranon, and of the subscapular skinfold thickness (SST), performed obliquely in relation to the longitudinal axis and located 2 cm below the inferior angle of the scapula, were obtained, using the equations of Slaughter et al.[14] When interpreting the results, body fat values proposed by Lohman et al. were considered acceptable.[15]

Sexual maturation was determined based on Tanner pubertal staging,[16] using the previously validated[17] self-rating technique for breast development (B1, B2, B3, B4, and B5) for girls and genitalia (G1, G2, G3, G4, and G5) for boys, with results grouped into prepubertal (M1 and G1), pubertal (M2 to M4 and G2 to G4), and postpubertal (M5 and G5).

For calculation purposes, the adolescents were divided according to the biological age as: early adolescence: 10-12 years, middle adolescence 13-15 years.[18]

Statistical analysis

Mean descriptive analysis and standard deviation were used. Normality of continuous data was evaluated using the Kolmogorov-Smirnov test. To compare the genders with the dependent variables (body mass, height, BMI, HC, BFI, and BF%), analysis of variance with two factors (gender with chronological and biological age) was applied, followed by the Bonferroni multiple comparison method.[19]

To develop BFI reference curves, the age of the adolescents was used in centesimal form and the LMS method was used to define the distribution and cutoffs of BFI according to gender, with the following percentile values: 3, 5, 10, 15, 25, 50, 75, 85, 90, 95, and 97.[20]

The Bland-Altman scatter-plot was used to verify the absolute agreement between BFI and BMI and BF%.[21] This procedure allows visualizing the mean differences and the extreme limits of agreement, in case of two standard deviations of difference. Thus, the Bland-Altman scatter plot can provide useful information regarding the ranges of values for which the two methods are more concordant/discordant.[21] Pearson's correlation was used to determine the association

Table 1 Sample size, mean, and standard deviation for body mass, height, BMI, HC, BFI, and BF% of adolescents in São Paulo according to age and Tanner stage.

Gender	Age (years)	Body mass (kg)	Height (cm)	BMI (kg/m^2)	HC (cm)	BFI	BF%
Boys	10-12 (n = 1,087)	43.11[a,b] ± 10.61	149.60[a,b] ± 8.17	19.09[b] ± 3.59	79.44[a,b] ± 8.76	25.42[a,b] ± 3.94	20.22[b] ± 8.89
	13-15 (n = 1,043)	54.75[a] ± 12.65	163.77[a] ± 9.20	20.26[a] ± 3.68	86.66[a] ± 8.88	23.40[a] ± 3.85	18.88[a] ± 8.06
Girls	10-12 (n = 1,311)	45.08[b] ± 10.90	151.58[b] ± 7.79	19.46[b] ± 3.75	83.18[b] ± 9.34	26.55[b] ± 3.97	20.95[b] ± 7.55
	13-15 (n = 1,245)	52.84 ± 10.10	159.08 ± 6.34	20.84 ± 3.56	90.28 ± 8.02	27.04 ± 3.95	23.06 ± 6.85
	Tanner stage	Body mass (kg)	Height (cm)	BMI (kg/m^2)	HC (cm)	BFI	BF%
Boys	Prepubertal (n = 115)	44.01[a,c,d] ± 12.26	149.47[c,d] ± 8.75	19.43[a] ± 3.87	80.72[a] ± 9.81	26.13[c,d] ± 3.92	21.04 ± 9.34
	Pubertal (n = 1,998)	49.01[e] ± 12.98	156.84[a,e] ± 11.13	19.67[a] ± 3.68	83.07[a] ± 9.49	24.36[a] ± 4.00	19.50[a] ± 8.48
	Postpubertal (n = 17)	57.56 ± 14.29	169.17[a] ± 13.30	19.88 ± 3.15	87.37 ± 9.34	21.83[a] ± 3.54	16.84[a] ± 6.15
Girls	Prepubertal (n = 115)	38.31[c,d] ± 10.38	146.12[c,d] ± 8.87	17.74[c,d] ± 3.56	76.77[c,d] ± 8.53	25.47[c,d] ± 3.72	18.56[c,d] ± 7.55
	Pubertal (n = 2,365)	49.11[e] ± 10.94	155.57 ± 7.75	20.17[e] ± 3.68	86.89[e] ± 9.16	26.79[e] ± 3.95	22.01[e] ± 7.22
	Postpubertal (n = 76)	57.21 ± 10.12	158.62 ± 6.97	22.68 ± 3.33	93.72 ± 7.96	28.96 ± 3.88	26.28 ± 6.63

BMI, body mass index; HC, hip circumference; BFI, body fat index; BF%, body fat percentage.
[a] $p < 0.05$ differences between the genders.
[b] $p < 0.05$ differences between age.
[c] $p < 0.05$ differences between prepubertal and pubertal.
[d] $p < 0.05$ differences between prepubertal and postpubertal.
[e] $p < 0.05$ differences between pubertal and postpubertal.

between BFI with BMI and BF%. The calculations were performed using the SPSS, release 20.0 (IBM Corp, 2011. IBM SPSS Statistics for Windows, NY, USA) and the level of significance was set at $p < 0.01$.[19]

Results

Sample characterization is shown in Table 1, according to the analyzed variables. It is possible to verify that boys showed an increase in body mass, height, BMI, and HC with advancing age and Tanner stage. As for the girls, the same occurred for all variables analyzed in the present study.

Regarding gender (Table 1), it can be observed that the younger boys (10-12 years) had significantly lower mean body mass, height, HC, and BFI than girls of the same age ($p < 0.001$). Among the older adolescents (13-15 years), this occured for all variables ($p < 0.001$). In both genders, the younger adolescents had significantly different mean values when compared to older ones ($p < 0.001$), for all analyzed variables.

Table 1 results showed that, in the comparative analysis between the genders, the prepubertal adolescents showed a significant difference in body mass, BMI, and HC ($p < 0.001$). In pubertal adolescents, only body mass did not differ between genders ($p = 0.06$). As for the postpubertal, only height, BFI, and BF% values were statistically different ($p < 0.001$).

When comparing Tanner stages, prepubertal boys had significantly lower mean values than pubertal and postpubertal boys for body mass, height, and BFI. When comparing pubertal with postpubertal boys, mean values in boys were significantly lower regarding body mass and height ($p < 0.001$).

Prepubertal girls had significantly lower mean values than pubertal and postpubertal girls for all variables ($p < 0.001$). When comparing mean values of pubertal with postpubertal girls, only height showed no significant difference ($p = 0.08$).

Table 2 establishes the percentiles of BFI classification according to age and Tanner stage of the adolescents. It was observed that between genders, the difference in values in adolescents aged 10-12 years is lower than in those aged 13-15 years.

It can be observed that, in the comparison between genders, from the 3rd percentile to the 75th percentile, there was an increase in the difference of values as the sexual development stage advanced. From the 85th percentile, prepubescent boys had higher values than girls of the same classification.

It can be demonstrated that BFI behavior is different according to gender and age, as the mean values in boys

Table 2 BFI according to the percentile, gender, age, and Tanner stage of adolescents in São Paulo, aged 10-15 years.

Gender	Age (years)	3%	5%	10%	15%	25%	50%	75%	85%	90%	95%	97%
Boys	10-12 (n = 1,087)	19.50	19.98	21.02	21.71	22.67	24.75	27.60	29.28	30.87	32.92	34.20
	13-15 (n = 1,043)	17.39	18.00	19.13	19.67	20.70	22.88	25.50	27.47	28.64	30.81	32.41
Girls	10-12 (n = 1,311)	20.46	21.20	22.08	22.75	23.95	26.01	28.58	30.63	31.89	33.97	35.48
	13-15 (n = 1,245)	20.55	21.31	22.49	23.28	24.41	26.72	29.16	30.57	31.89	34.26	36.06
Gender	Tanner stage	3%	5%	10%	15%	25%	50%	75%	85%	90%	95%	97%
Boys	Pre (n = 115)	19.62	20.28	21.85	22.34	23.22	25.73	29.09	30.31	32.01	33.48	34.76
	Pubertal (n = 1,998)	18.09	18.88	19.78	20.51	21.60	23.77	26.69	28.36	29.74	32.10	33.04
	Post (n = 17)	15.58	15.58	17.05	17.70	19.13	22.50	24.85	26.35	26.93	-	-
Girls	Pre (n = 115)	20.56	20.94	21.51	22.10	22.94	25.09	27.26	28.87	29.84	32.23	33.36
	Pubertal (n = 2,365)	20.49	21.23	22.27	23.02	24.21	26.35	28.91	30.52	31.87	34.22	35.62
	Post (n = 76)	23.75	24.28	24.84	25.19	26.48	28.15	31.07	32.94	33.26	36.63	40.02

BFI, body fat index; Pre, prepubertal; Post, postpubertal.

decrease with advancing age and the mean values in girls showed a slight increase with advancing age (Fig. 1).

Regarding the association between variables, Fig. 2 shows a significant association of BFI with BMI and BF% of adolescents of both genders in the city of São Paulo ($p < 0.001$). Furthermore, Fig. 2 shows the Bland-Altman plot with high agreement of BFI with BMI and BF% in both genders. In males, the mean difference (BFI-BMI) was equal to 4.73 ± 3.21, with limits of agreement ranging from 11.03 (+2 SD) to -1.57 (-2 SD). As for BF%-BFI, the mean difference was equal to -4.83 ± 6.37, with limits of agreement ranging from 7.66 (+ 2 SD) to -17.31 (-2 SD) (Fig. 2: A, B).

For the female gender, the mean difference (BFI-BMI) was equal to 6.65 ± 2.43, with limits of agreement ranging from 11.40 (+ 2 SD) to 1.90 (-2 SD). As for BF%-BFI, the mean difference was equal to -4.81 ± 5.43, with limits of agreement ranging from 5.84 (+ 2 SD) to -15.46 (-2 SD) (Fig. 2: C, D).

Discussion

This study presented data and percentile curves for the BFI of adolescents aged 10-15 years, with height and hip circumference used for this evaluation. Although this technique has been validated and found to be extremely useful in epidemiological studies of adults due to its ease of use and low cost, Bergman et al. [7] highlight a prediction error of 3%. BFI is a direct estimate of BF%, and unlike BMI, BFI provides

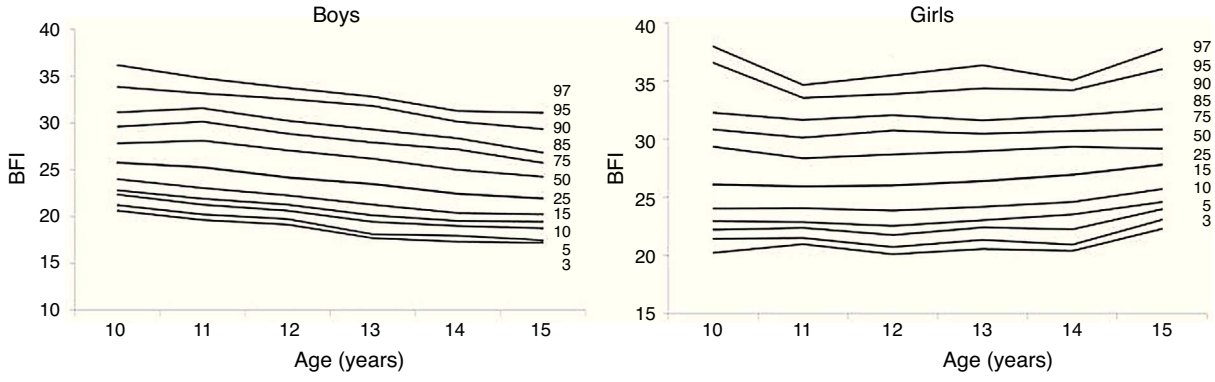

Figure 1 BAI percentile curves according to age and gender of adolescents from Sao Paulo.
BFI, body fat index.

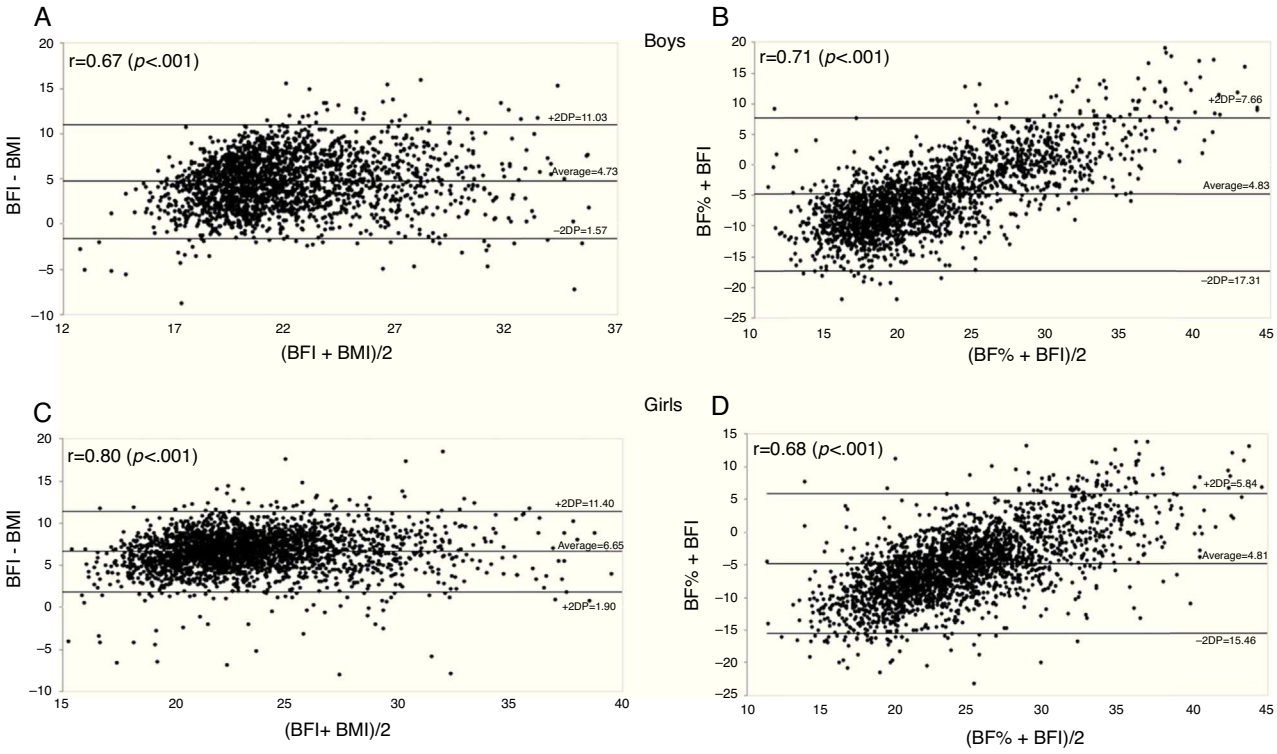

Figure 2 Bland-Altman plot to assess the degree of agreement of BAI with BMI and BF% of adolescents (Boys: A, B; Girls: C, D) from São Paulo, aged 10-15 years.

BF% data without statistical correction and does not require body mass measurement.[7]

BFI values can be used in obesity prevention as a tool for specific evaluation, whereas BMI only represents a gross value for body fat without gender and pubertal stage differentiation, which could easily lead to misclassification.[22]

The present study showed that in adolescence (10-12 years and 13-15 years), statistical differences were observed between gender and age group concerning BMI, BFI, and BF%. However, in mid-adolescence (13-15 years), although boys are taller and have greater body mass, they have lower BMI, HC, BFI, and BF% values than girls of the same age group.

BFI has been previously used and validated in different age ranges and ethnic groups.[7,23] Due to the increasing prevalence of childhood obesity and the fact that the obese pediatric population has high odds of becoming obese adults,[24] with high risk of cardiovascular disease, type 2 diabetes, and hypertension,[25] the authors consider BFI data and curves to be very relevant for pediatric patients according to age and sexual maturation. For Bergman et al., it is critical to assess BFI behavior in prepubertal and postpubertal schoolchildren of both genders and different ethnicities.[7] The same authors make it clear that it is important to assess the association of BFI with body fat, which was performed in the present study.

One of the surprising results was the strong association of BFI with BF%, so there was no need to use a specific and/or electronic tool for the measurement of BF%. Thus, even in environments where only the simplest and least expensive tools are available (a measuring tape), a reliable estimate of adiposity can be obtained.

Regarding the stages of sexual maturation, both BFI and BF% values showed similar behavior in both genders. In boys, the mean of these two variables showed a significant decrease, and in girls, the means were higher with advancing Tanner stages. Similar results related to BF% have been demonstrated by other authors,[11,26,27] and it is important to emphasize that during puberty, girls gain more body fat, while boys gain more muscle mass.[18]

It should be emphasized that puberty is characterized by the appearance of drastic hormonal changes that induce significant changes in growth, bone mass, and body composition. These changes are associated with variations in certain biochemical parameters, which are true markers that regulate bone turnover and leptin levels, reflecting changes in bone growth and fat mass, respectively.[28]

When analyzing the percentiles of BFI in schoolchildren according to age group and Tanner stage, it is observed that in boys the mean values decreased with advancing Tanner stage, while girls showed the opposite pattern.

The association between BF% and cardiovascular disease risk is well-documented.[3,4] However, there is convincing evidence that visceral fat content[29] may be a stronger predictor of cardiovascular risk than general adiposity, even though this study measured only overall BF%. At this time, it is not possible to determine if BFI can be more harmful in the visceral fat or in the liver fat, but in the future, it will be of interest to compare BFI with selected fat deposits.

Although there is no consensus regarding the diagnosis of obesity through BF% and BFI in adolescents, some authors have defined the 85th and 95th percentiles as excess body fat and obesity, respectively.[11,27]

When the 85th and 95th percentiles of the BFI were evaluated according to sexual maturation, it was observed that there was an increase in prepubertal and pubertal boys, of approximately 10% and 17%, respectively. As for girls, the greatest increase was observed among those classified as postpubertal.

These data demonstrate the importance of assessing sexual maturation and its influence on body composition of adolescents. When the groups aged 10-12 years and 13-15 years were compared, boys had a greater increase in the age group 10-12 years; in girls, the greatest increase occurred in the age group of 13-15 years. As boys had higher prevalence of excess weight in the studied population and the same trend has been observed in the authors' clinical experience, it is considered important to use these data to evaluate adolescents of São Paulo.

Many population studies have focused on BFI in foreign populations and other ethnicities.[23] To date, no Brazilian study had shown the values of BFI according to gender, age, and sexual maturation, which is essential during adolescence, as there is a wide variation of pubertal events in individuals of the same gender and of the same age. Moreover, an increase in BMI has been shown at each stage of sexual maturation[30] and, consequently, this study offers an additional contribution to body composition assessment in adolescents, making the assessment of this parameter in this age group more reliable.

A limitation of the study is that by separating adolescents aged 10-15 years according to sexual maturation, most were classified as pubertal and there were few prepubertal (predominantly males) and postpubertal (predominantly females) adolescents.

Sample size may also affect the results. In future studies, it will be necessary to include a larger sample size in all stages of sexual maturation.

This is the first study to provide data on BFI for adolescents according to gender, age, and sexual maturation, allowing a more appropriate assessment for pubertal stage, as the chronological age at this stage shows great variability, thereby providing an important tool for the assessment of adiposity in adolescence.

BFI appears to reflect well the phenomena of sexual dimorphism in adolescence, representing an easy-to-perform method that should be used more often in population samples; further studies may, along with the present work, result in a normality curve, which would be of great use in clinical practice.

Conflicts of interest

The authors declare no conflicts of interest.

Acknowledgments

The authors acknowledge the support of the Adolescent Division, Pediatric Department, Universidade Federal de São Paulo (Federal University of São Paulo) and the International Life Sciences Institute (ILSI). They also thank the participants, their parents and guardians, the teachers and coordinators at each school, and the Municipal Government of São Paulo, Brazil.

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