Chapter

Sexual Dimorphism of the Fat Mass Index and the Fat-Free Mass Index in Healthy Adolescents

Teodoro Durá-Travé and Fidel Gallinas-Victoriano

Abstract

Body mass index (BMI) does not allow to discriminate the composition of the different body compartments. This study points to the formulation of reference values of fat mass index (FMI) and fat-free mass index (FFMI) in healthy adolescents by means of anthropometric techniques, and the subsequent availability in clinical practice as reference charts. The following is a cross-sectional study in a group of 1040 healthy Caucasian adolescents (470 boys and 570 girls), aged 10.1 to 14.9 years. Weight, height and skinfold thickness were registered, and BMI, percentage of total body fat, FMI and FFMI, and FMI and FFMI percentiles were calculated. Boys show a significant increase in FFMI and a decline in body fat and FMI. By contrast, girls show an increase in body fat, FMI and FFMI. Except for the 10 years, FMI was higher ($p < 0.05$) in girls in all ages and FFMI was higher ($p < 0.05$) in boys in all ages. There were no significant differences in the values of BMI between sexes in all ages. The availability of reference values for FMI and FFMI in daily clinical practice would be helpful in the diagnosis and assessment of changes in body composition during the treatment of childhood obesity.

Keywords: adolescents, anthropometric measurements, body composition, body mass index, fat mass index, fat-free mass index, skinfold thickness

1. Introduction

The percentage of children categorized as overweight and obesity in children has increased firmly, to the extent that it has become the most relevant nutritional disorder in present-day developed society [1]. In this way, this percentage of excess body weight in otherwise healthy adolescents in our community (Navarra, Spain) hits 22.5% [2]. This figure is comparable to the values in other regions of our country (Spain), the European countries, and the USA, and it even exceeds the eastern European countries [1, 3].

Obesity implies an excess of body fat, and the most adequate and usual anthropometric measure for the initial nutritional assessment in clinical practice is the body mass index (BMI) [4]. Despite this potential in the diagnosis of obesity, this parameter does not define the percent distribution of the body compartments (fat mass and fat-free mass). As a matter of fact, different studies promote FMI before the BMI in the diagnosis and assessment of childhood obesity, claiming a higher sensibility in the detection of changes in body fat [5–8].

Notwithstanding the above, FMI is not satisfactorily extended in the diagnosis and assessment of childhood obesity and, consequently, few referent charts for pediatricians are available at the present day [9, 10]. The evaluation by means of anthropometric measures, as a consequence of the relative simplicity and low cost, is regarded as an important stage in the evaluation of body composition at the pediatric age and should have a primary role in the assessment process [6, 10–14]. In fact, the accessibility to FMI and FFMI reference charts based on the measures of body skin folds would largely help in the evaluation.

The aim of the present work is to compile standard values charts for FMI and FFMI in healthy adolescents (both sexes), from the measurement of skin folds in order to be available as benchmarks in daily clinical practice.

2. Methods

2.1 Participants

The design of the study was cross-sectional and the sample consisted of 1040 individuals (470 boys and 570 girls). All of them were Caucasian adolescents, aged 10.1 to 14.9 years, students of the different corresponding grades of four public schools located in Pamplona (Navarre, Spain) and enrolled specifically for this survey. The period of study was January–June 2018.

Pamplona is a city located in the north region of Spain, with a population of 203 382 inhabitants (2018 census, Instituto de Estadística de Navarra). The population corresponding to the range 10.1 to 14.9 years is 9772 (4.8% of the total population) in the year 2018, distributed as 5042 boys and 4680 girls. The calculation of the sample size was made assuming the worst-case estimate (0.50), with a 95% confidence level and a precision of 0.04, thereby resulting in a number of 600 participants as the minimum required.

All legal guardians/parents had plenty information of about the survey and written consent available in order to participate in this study.

A normal nutrition study was a mandatory condition in order to be included in this study: BMI value should be in the range +1/ −1 SD. Other causes of exclusion were non-Caucasian origin and previous chronic pathologies that may influence growth, body composition, food ingestion, or physical activity.

An informed consent was provided to 1451 legal guardians (763 boys and 740 girls). From the initial 763 boys, 62 individuals did not add the consent in time or had some failure in the completion, 136 individuals suffered from excess weight (overweight/obesity, BMI> 1SD), 78 individuals were excluded because of ethnic reasons (non-Caucasian family origin), and 17 individuals did not meet the preconditions (chronic pathologies, etc.). Subsequently, the number of remaining participants was 470. Of the initial 740 girls, 49 did not complete adequately the consent, 53 presented with excess weight (overweight/obesity BMI>1 SD), 57 because of ethnic origin (non-Caucasian), and 11 because of other preconditions (chronic pathologies, etc.). Therefore, the total of recruited girls was 570. In this way, the response rate after the appropriate disposal was 92.1%, and the total response rate in both sexes was 90.4.

This study meets with the terms and conditions of the local Ethics Committee for Human investigation (Navarre University Hospital) in accordance with the ethical standards established by the 1964 Declaration of Helsinki and posterior amendments.

2.2 Anthropometric measurements

Different anthropometric measures were recorded during clinical evaluation at the consultation: height, weight, body mass index, (BMI), and skinfold thickness (in the different localizations: biceps, triceps, subscapular, and suprailiac regions).

A clinical examination with the patient in underclothes and barefoot was completed. The measurement of weight required an Año-Savol scale (reading interval 0 to 120 kg and precision of 100 g) and the measurement of height was made with a Holtain wall stadiometer (reading interval 60 to 120 cm, precision 0.1 cm). These measures allowed subsequent calculation of BMI by means of the corresponding formula: weight (kg)/height^2 (m).

Three consecutive skinfold-thickness measurements were recorded in the corresponding anatomical locations: the biceps (front side middle upper arm), the triceps (back side middle upper arm), subscapular (right beneath the lowest point of the scapula), and suprailiac (right above the iliac crest of the hip bone). All of them were performed by the same-trained person and the average of the three measures was the figure to be used in the estimate. The skinfold values were taken with a precision of 0.1 mm on the left side of the body with the Holtain skinfold caliper (CMS Weighing Equipment, Crymych, United Kingdom). The calculation of the percentage of total body fat, fat mass (kg) and fat-free mass (kg) required the use of the formulas delivered by Slaughter et al. [15], adjusted for sex and age. Additionally, the FMI and the FFMI were estimated with the formulas: fat mass (kg)/height^2 (m), and free fat mass (kg)/height^2 (m), respectively.

Secondarily, the z-score values for the BMI were calculated with the Aplicación Nutricional, from the Spanish Society of pediatric gastroenterology, hepatology, and nutrition (available at http://www.gastroinf.es/nutritional/). The graphics from Ferrández et al. (Centro Andrea Prader, Zaragoza 2002) were used as reference charts [16].

2.3 Statistical analysis

The program Statistical Packages for the Social Sciences version 20.0 (SPSS, Chicago, IL, USA) was used to perform the statistical analysis (descriptive statistics, percentiles calculation, Student's t test, and analysis of variance), and the results are shown as means (M) and standard deviations (SD). The condition for statistical significance was a p-value <0.05.

3. Results

Table 1 illustrates the values and the comparison of the different anthropometric measurements and the estimation of body composition according to age in adolescent boys. As can be noted, a significant increase in the mean values of weight, height, BMI, fat mass, fat-free mass, and FFMI is discernible ($p < 0.05$). On the contrary, the comparison of the mean values of body fat, skinfold thickness (triceps), and FMI reveal a significant decrease ($p < 0.05$). No significant differences were found

	10 y (n = 82)	11 y (n = 84)	12 y (n = 112)	13 y (n = 108)	14 y (n = 84)	p-value*
Age (y)	10.4 ± 0.3	11.5 ± 0.2	12.4 ± 0.2	13.4 ± 0.2	14.2 ± .1	0.001
Weight (kg)	37.9 ± 6.1	39.8 ± 5.5	43.2 ± 7.6	49.3 ± 7.8	54.1 ± 9.1	0.001
Height (cm)	142.0 ± 9.7	146.5 ± 8.2	153.4 ± 9.5	158.7 ± 9.6	164.8 ± 9.4	0.001
BMI (kg/m^2)	18.7 ± 1.5	18.9 ± 1.5	19.2 ± 1.5	19.6 ± 1.6	20.3 ± 1.7	0.001
BMI z-score	0.08 ± 0.61	0.02 ± 0.56	0.01 ± 0.54	0.05 ± 0.57	0.05 ± 0.05	0.072
Skinfold thickness						
Biceps (mm)	9.1 ± 3.5	8.9 ± 2.9	9.1 ± 3.8	8.3 ± 4.2	8.9 ± 4.1	0.508
Triceps (mm)	14.2 ± 3.7	14.5 ± 4.1	13.9 ± 5.1	13.4 ± 5.2	13.5 ± 4.9	0.028
Subscapular (mm)	9.9 ± 4.1	9.8 ± 4.3	10.3 ± 5.1	10.2 ± 5.3	10.2 ± 3.9	0.222
Suprailiac (mm)	12.3 ± 6.3	12.4 ± 6.5	12.2 ± 6.1	12.6 ± 6.8	12.4 ± 6.4	0.328
Body fat (%)	25.4 ± 5.8	24.4 ± 4.5	23.1 ± 5.9	21.5 ± 5.9	22.4 ± 5.9	0.001
Fat mass (kg)	9.7 ± 3.1	9.7 ± 2.9	10.1 ± 3.8	10.2 ± 3.7	11.9 ± 4.1	0.001
Fat-free mass (kg)	28.2 ± 4.3	28.7 ± 4.1	32.7 ± 5.6	37.1 ± 5.8	39.8 ± 6.1	0.001
FMI (kg/m^2)	4.8 ± 1.4	4.6 ± 1.2	4.4 ± 1.4	4.2 ± 1.4	4.3 ± 1.5	0.003
FFMI (kg/m^2)	13.8 ± 0.7	14.2 ± 0.9	14.7 ± 0.9	15.3 ± 0.9	15.6 ± 0.7	0.001

**ANOVA. BMI, body mass index; FMI, fat mass index; FFMI, fat-free mass index.*

Table 1.
Anthropometric measurements and body composition in adolescent boys (M ± SD).

Age	p3	p10	p25	p50	p75	p90	p97
Fat mass index (kg/m^2)							
10 y	2.78	2.85	3.79	4.29	6.25	7.32	7.45
11 y	2.47	2.86	3.58	4.22	5.91	6.93	7.45
12 y	2.17	2.90	3.38	4.15	5.57	6.54	7.46
13 y	2.15	2.48	3.09	4.10	5.56	6.52	6.81
14 y	2.21	2.38	3.07	4.61	5.82	6.76	6.95
Fat-free mass index (kg/m^2)							
10 y	12.25	12.90	13.45	13.93	14.28	14.8	15.12
11 y	12.75	13.10	13.74	14.39	14.86	15.57	15.85
12 y	13.28	13.33	13.96	14.84	15.41	16.35	16.61
13 y	13.38	14.27	14.61	15.32	15.81	17.11	17.85
14 y	14.35	14.81	15.31	15.51	16.17	16.91	17.44

p, percentile.

Table 2.
Percentiles values for fat mass index and fat-free mass index in adolescent boys in different ages.

in the comparison of the mean values of BMI z-score and skinfold thickness (biceps, subscapular, and suprailiac).

Table 2 displays the percentile distribution corresponding to FFMI and FMI in adolescent boys according to age.

Table 3 shows the mean values and the comparison of the anthropometric measurements and the estimation of body composition according to age in adolescent girls. A significant increase ($p < 0.05$) in the mean values of weight, height, BMI, skinfold thickness (subscapular and suprailiac), body fat, fat mass, fat-free mass, FMI, and FFMI can be appreciated. The comparison of the mean values of BMI z-score and skinfold thickness (biceps and triceps) showed no significant differences.

Table 4 lists the percentile distribution of FFMI and FMI in adolescent girls according to age.

Figure 1 presents the comparison of the mean values of FMI in both sexes for the different ages. Excluding the period 10–11 years, a significant increase ($p < 0.05$) in the values of FMI is detected in girls with respect to boys in the different age groups.

Figure 2 displays the values of FFMI in both sexes in the different ages and compares them. Significantly higher ($p < 0.05$) values are recorded in boys of all ages.

There were no significant differences in the values of BMI between sexes in all ages (**Figure 3**).

	10 y (*n* = **148**)	**11 y** (*n* = **108**)	**12 y** (*n* = **110**)	**13 y** (*n* = **104**)	**14 y** (*n* = **100**)	*p*-**value***
Age (y)	10.4 ± 0.2	11.5 ± 0.3	12.4 ± 0.3	13.4 ± .2	14.3 ± 0.2	0.001
Weight (kg)	38.1 ± 5.3	42.8 ± 6.4	46.0 ± 6.7	49 ± 6.9	52.2 ± 8.1	0.001
Height (cm)	143.0 ± 7.3	149 ± 8.6	154.1 ± 8.5	157.7 ± 8.2	159.8 ± 7.1	0.001
BMI (kg/m^2)	18.6 ± 1.4	19.3 ± 1.6	19.7 ± 1.9	20.1 ± 1.7	20.8 ± 1.9	0.001
BMI z-score	0.09 ± 0.5	0.09 ± 0.53	0.04 ± 0.64	0.05 ± 0.57	0.02 ± 0.67	0.086
Skinfold thickness						
Biceps (mm)	10.3 ± 3.4	10.3 ± 3.9	10.1 ± 2.8	10.4 ± 3.3	10.9 ± 3.2	0.709
Triceps (mm)	16.1 ± 3.9	15.8 ± 4.4	15.9 ± 4.4	16.3 ± 4.5	16.9 ± 3.7	0.738
Subscapular (mm)	10.9 ± 4.2	11.4 ± 4.8	11.1 ± 4.1	12.2 ± 5.2	13.1 ± 5.1	0.002
Suprailiac (mm)	14.4 ± 6.1	15.7 ± 6.5	15.9 ± 6.5	17.7 ± 7.1	18.2 ± 6.4	0.001
Body fat (%)	27.4 ± 5.9	28.3 ± 4.3	28.6 ± 3.7	29.2 ± 4.2	29.3 ± 3.5	0.005
Fat mass (kg)	10.7+3.3	12.5 ± 3.0	13.0 ± 3.1	14.3 ± 2.8	15.6 ± 3.8	0.001
Fat-free mass (kg)	27.7 ± 3.2	31.3 ± 4.4	33.7 ± 4.4	34.7 ± 4.3	37.0 ± 4.4	0.001
FMI (kg/m^2)	5.1 ± 1.4	5.5 ± 1.2	5.7 ± 1.1	5.9 ± 1.2	6.2 ± 1.2	0.001
FFMI (kg/m^2)	13.4 ± 0.8	13.8 ± 0.8	14.2 ± 0.9	14.3 ± 0.9	14.7 ± 0.9	0.001

**ANOVA. BMI, body mass index; FMI, fat mass index; FFMI, fat-free mass index.*

Table 3.
Anthropometric measurements and body composition in adolescent girls (M ± SD).

Age	p 3	p 10	p 25	p 50	p 75	p 90	p 97
Fat mass index (kg/m^2)							
10 y	2.79	3.46	3.92	5.33	6.24	7.31	7.74
11 y	3.57	3.77	4.68	5.49	6.30	7.21	7.89
12 y	3.75	4.12	4.68	5.18	6.40	7.33	7.88
13 y	3.89	3.99	4.83	5.91	7.07	7.79	7.90
14 y	4.08	4.80	5.02	6.46	6.99	8.28	8.60
Fat-free mass index (kg/m^2)							
10 y	12.05	12.31	12.84	13.54	14.04	14.53	14.91
11 y	12.48	12.79	13.17	13.87	14.39	14.86	15.52
12 y	12.86	13.04	13.54	14.29	15.07	15.76	16.31
13 y	12.77	12.78	13.62	14.21	14.45	16.12	16.35
14 y	12.84	13.00	13.87	14.88	15.61	16.00	16.55

p, percentile.

Table 4.
Percentiles values for fat mass index and fat-free mass index in adolescent girls in different ages.

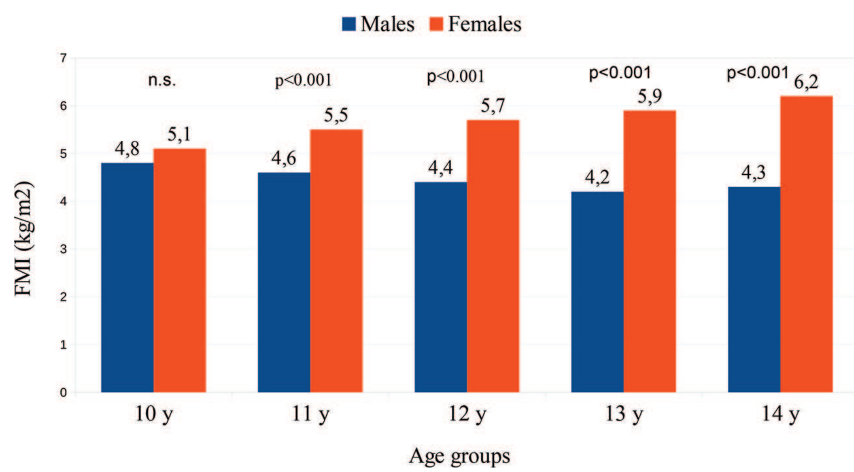

Figure 1.
Gender differences for FMI in each of the ages.

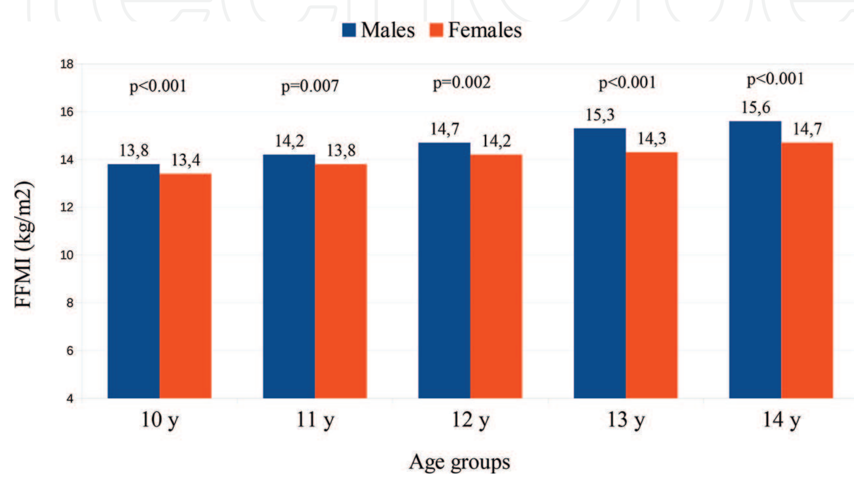

Figure 2.
Gender differences for FFMI in each of the ages.

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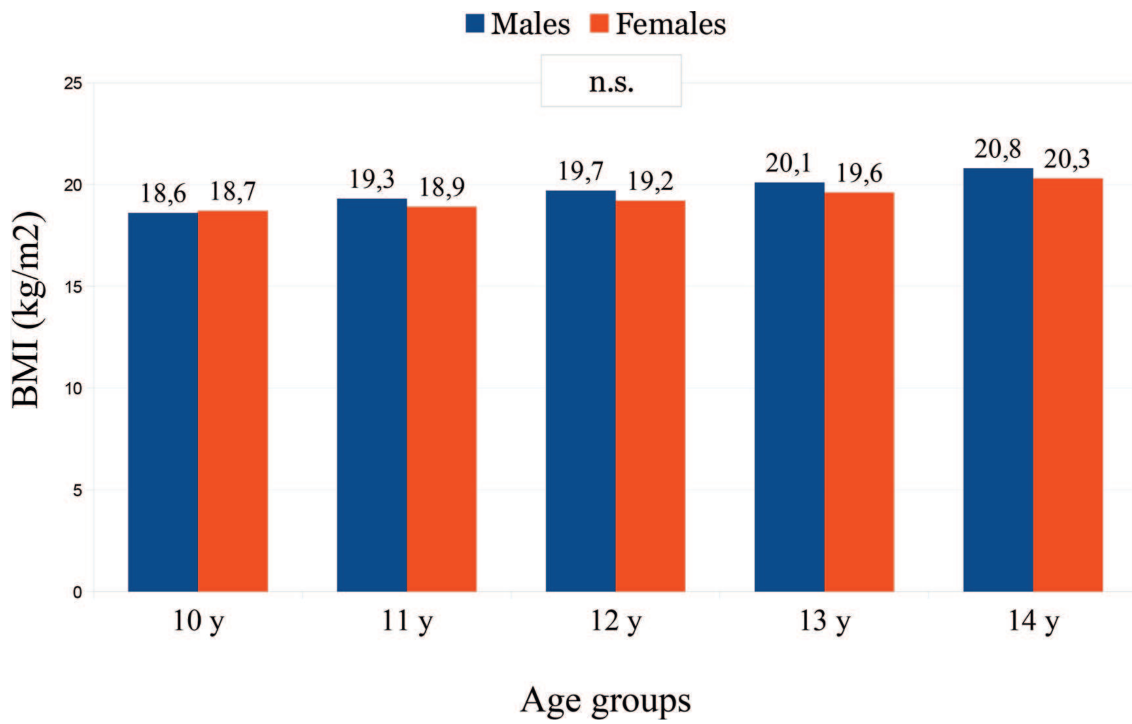

Figure 3.
Gender differences for BMI in each of the ages.

4. Discussion

The analysis of the different measurements and the changes in the estimation of the body compartments (fat mass and fat-free mass) in adolescents (range 10–14 years) with normal BMI values adjusted for age and sex shows a different pattern depending on sex. The FFMI shows a progressive and significant increase in both sexes related to age, but boys present with significantly higher values than girls do. Additionally, FMI decreases progressively and significantly in boys in relation to age, in comparison with the progressive and significant increase observed in girls. It should be noted that these changes occur concurrently with a continuous increase in BMI in both sexes in these life stages in the absence of significant differences in BMI values in both sexes.

The nutrition status classification of the participants in this study was established on the basis of the results the BMI. This index has proved to be useful in the definition of overweight and obesity [4, 6, 17, 18], but it provides limited information because it implies excessive weight in relation to height rather than excess body fat. In other words, the relative composition of the body compartments (fat mass and fat-free mass) is not adequately determined [19–23]. Furthermore, this limitation is even more marked during adolescence, a period of life in which several physical and physiological changes take place [24, 25], and weight gain does not necessarily imply excessive fat accumulation [26, 27]. In this way, the availability of a list of FMI and FFMI standardized values for healthy adolescents enables to differentiate between individuals that show high BMI values and, simultaneously, present with low FFMI and high FMI values (a condition that matches the criteria of overweight or obesity), and those that also show high BMI values and, simultaneously, present with high FFMI and low FMI (a condition that corresponds rather to muscle hypertrophy, and is reasonably frequent in adolescent boys).

The availability of reference charts for FMI and FFMI in the pediatric age is limited, and they require sophisticated methodologies, what makes them difficult to access in clinical practice, such as dual-energy X-ray absorptiometry or isotope dilution [9, 10, 28]; that is, the reason why they are used primarily in the investigation. Nonetheless, it has been corroborated that the values delivered with anthropometric measurements are in close correlation with those obtained with these high-cost and sophisticated techniques [6, 10–14, 29, 30]; even the easier models that divide the body in FM and FFM are as applicable as the more complex models that separate FFM in its different components (water, minerals, and proteins)[28].

The selection of the participants in the study is the main limitation we encountered. They were selected from the most crowded centers (public schools) of the city of Pamplona, and therefore the marginal zones of the city were not included. Moreover, students from private schools did not enter the study, and variables that could condition the results, like socioeconomic level or parental schooling and education were not included either. Even so, the participant eligibility criteria that were proposed for this study (BMI between +1 and −1 SD) allowed passing over these potential differences. All participants were healthy and showed BMI values in range, and so a typical and progressive pubertal development was assumed, being this condition a potential limitation. This assumption is reasonable and, in point of fact, basically every chart of anthropometric variables (height, weight, BMI, etc.), either cross-sectional of longitudinal, that is used in clinical practice refers entirely to the chronological age of the individuals [16, 31–35].

The precision of the measurements of skinfold thickness has been contested because of the hypothetical operator dependency. According to our experience, and in line with other authors, the FMI (evaluated by skin folds) can be used as a valid predictor of the changes in body fat composition in childhood obesity [6, 17, 36]. Bioelectrical impedance analysis (BIA) is an alternative approach in the evaluation of body composition through the measurement of impedance or resistance and reactance values of a small electric current as it spreads through the body water. BIA is a low-cost and noninvasive technique with high reproducibility, easy usage of the equipment, and low operator dependency. The majority of studies based on BIA have been undertaken in the adult population, they demand methodological or standardization rules in order to perform measurements in children, especially concerning fasting, hydration, voiding, clothing, skin preparation, and body position [37]. Furthermore, BIA might underestimate fat mass and overestimate fat-free mass in healthy as well as obese children [38–40], perhaps in relation to these methodological issues. In other words, BIA can be considered a valuable method, but we need additional studies focused on methodological issues to provide definitive guidelines for the standardization of these measurements in the child population.

5. Conclusion

The availability of valid charts (based on the measurements of skin thickness) for the application as reference patterns in healthy adolescents of both sexes in clinical practice would be very helpful for the diagnosis and, particularly, the analysis of the changes in body composition that occur during the treatment of childhood obesity. In fact, more studies are required to provide support the conclusions of the analysis of these data, as well as to evaluate its usefulness in clinical practice.

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Conflict of interest

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