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RESEARCH PAPER

Does the body adiposity index (BAI) apply to paediatric populations?

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Abstract

Objective: Validation of body adiposity index (BAI) in a paediatrics sample; and to develop, if necessary, a valid BAI for paediatrics (i.e. BAI_p).
Methods: A total of 1615 children (52% boys) aged 5–12 years underwent anthropometry. Their body composition was assessed using a foot-to-foot bioimpedance. The validity of BAI = (Hip circumference/Height$^{1.5}$) − 18 was tested by combining correlation and agreement statistics. Then, the sample was split into two sub-samples for the construction of BAI_p. A regression was used to compute the prediction equation for BAI_p-based percentage of body fat (%BF).
Results: The initial BAI over-estimated the %BF of children by 49% (29.6 ± 4.2% versus 19.8 ± 6.8%; $p < 0.0001$). The original methodology led to a BAI_p = (Hip circumference/Height$^{0.8}$) − 38 in children. When compared to BAI, BAI_p showed both better correlation ($r = 0.57$; $p < 0.01$ versus $r = 0.74$; $p < 0.0001$) and agreement (ICC = 0.34; [95% CI = −0.19–0.65] versus ICC = 0.83; [95% CI = 0.81–0.84]). However, there were some systematic biases between the two values of %BF as exemplified by the large 95% limit of agreement [−9.1%; 8.8%] obtained.
Conclusion: BAI over-estimates the %BF in children. In contrast, BAI_p appears as a new index for children's body fatness, with acceptable accuracy. In its current form, this index is valid only for large-scale studies.

Keywords

Bioelectrical impedance, body composition, childhood obesity

History

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Introduction

Over the last few decades the prevalence of childhood overweight and obesity has increased dramatically. About 170 million children (aged < 18 years) are estimated to be overweight worldwide (Lobstein et al., 2004) and in many countries, including Canada, France, Germany, Japan, the UK and the US, the number of overweight children has at least doubled since 1970 (Han et al., 2010). Aside from research that has shown that childhood obesity is likely to track into adulthood (Serdula et al., 1993; Whitaker et al., 1997), the health consequences of obesity are substantial, including long-lasting morbidities and an increased risk of premature mortality (WHO, 2009). Thus, despite cumulative data suggesting a levelling off in the prevalence of childhood obesity (Olds et al., 2011), public health endeavours should be continued in order to curb the current epidemic. In order to be effective, these prevention strategies need to be based on an accurate assessment of body fatness in young people.

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Basically, obesity is defined as an excessive accumulation of fat in the body (OMS, 2003). It is often assessed by body mass index (BMI), with internationally defined standards (Cole et al., 2000; de Onis et al., 2007) for the classification of young people. Nevertheless, the use of BMI as a surrogate of body fat or adiposity in children raises a number of issues (Hall & Cole, 2006). Importantly, BMI is unable to differentiate fat mass from fat free mass, especially in the growing body of a child (Neovius et al., 2004; McCarthy et al., 2006). On the other hand, laboratory-based methods such as dual energy X-ray absorptiometry (DEXA), computed tomography, underwater weighing or magnetic resonance imaging (MRI) provide a reproducible and accurate measurement of body composition. However, body fat is difficult and expensive to measure directly in large samples using these sophisticated techniques. Alternative less-expensive, simple and reproducible anthropometric measurements such as waist-to-hip ratio (WHR), waist circumference (WC) and waist-to-height ratio (WHtR) have been associated with cardio-metabolic comorbidities in young people, beyond BMI (Gillum, 1999; McCarthy, 2006; Browning et al., 2010; Taylor et al., 2011).

Because measures of body fat, even if they are indirect, may be better than BMI (Cole et al., 2000), there still remains

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a need to provide a cheap and easy-to-use tool for children in large-scale studies. In adults, Bergman et al. (2011) recently proposed the body adiposity index (BAI), which is an anthropometry-based (i.e. height and hip circumference) formula to estimate body fat. BAI is currently under investigation and debates regarding its superiority to BMI as well as its relationships with various health outcomes are ongoing (Elisha et al., 2013; Freedman et al., 2012; Godoy-Matos et al., 2012; Hung et al., 2012; López et al., 2012; Schulze et al., 2012; Snijder et al., 2012). However, unlike BMI, BAI has not been extended to, or tested in, paediatrics. If BAI is to be used to determine the percentage of fat in children, it should first provide similar results regarding any other measure of their body fat. Additionally, all assumptions underlying the development of BAI in adults should also apply to young people.

Therefore, the aim of the present study is 2-fold: (1) to test the validity of BAI in a paediatric population; and (2) to develop, if necessary, a valid BAI for children.

Materials and methods

Subjects

Children were recruited from public primary schools and kindergarten of two Education Authority Areas in the Northern France (School districts of Lille and Avesnes-Val de Sambre). A total of 1615 children aged 5–12 years were involved in a series of cross-sectional studies implemented during several periods located between September 2005 and May 2009. The sample encompasses pre-school- and school-aged children from 30 schools out of a possible total of 54 schools (i.e. recruitment rate of 56% at the school level). A participation rate of 35% with an equal distribution between genders was obtained at children level. Schools engaged in this protocol were only those whose head of school were willing to participate. In these schools, all children was invited to participate and only those whose parents provided written informed consent were included. The study received the approval of the local advisory board of Lille. All participants underwent anthropometric and body composition assessments, which were performed by the same trained examiners.

Anthropometric and body fat measurement

Height was measured to the nearest 0.1 cm with a stadiometer (Seca 214, Hamburg, Germany). The complete stature was defined as the maximal distance from the floor to the vertex of the head. For measurements, children were standing without shoes with their body stretched upward and their head in the Frankfurt plane (Lohmann et al., 1988). Body mass was measured and recorded to the nearest 0.1 kg with an in-built bioelectrical impedance analysis (BIA) used as a weight scale and body mass index (BMI) was calculated as body mass in kilograms divided by the square of height in metres (kg/m^2). Hip circumference (HC) was recorded at the maximum circumference over the buttocks to the nearest 1 mm.

The percentage of body fat (%BF) of each child was recorded to the nearest 0.1% using a single frequency (50 kHz, 90 μA) foot-to-foot Tanita body composition analyser BC-420 MA (Tanita Corp., Tokyo, Japan) (Lloret Linares et al., 2011). An in-built equation by the manufacturer allowed the calculation of body composition on the basis of the body resistance index. Furthermore, the %BF of each child was also independently estimated through BAI provided by Bergman et al. (2011) using the following equation:

$$\begin{aligned} &\%\text{Adiposity}\ \left(\%\,\text{BF}_{\text{predicted}}\right) = \text{BAI} - 18; \\ &\text{with BAI} = \frac{\text{HC(cm)}}{\text{Height(m)}^{1.5}} \end{aligned} \qquad (1)$$

Statistical analysis and construction of BAI for paediatrics (BAI$_p$)

Descriptive data are expressed as mean ± standard deviation. Gender differences were examined using unpaired Student's *t*-tests. To determine whether the original BAI (Bergman et al., 2011) could be applied to paediatrics, the predicted %BF was compared to the actual %BF using Student's *t*-tests for matched pairs, Pearson's product moment coefficients of correlation and the intra-class coefficient of correlation (ICC) for absolute agreement. The agreement between the two values of %BF was then checked using a Bland & Altman (1999) plot.

For the construction of BAI$_p$, the initial sample was split into two sub-groups (A and B) using a random sampling technique. In this instance, a target of 50% was set to determine whether a given child should be placed in sub-group A or B. Bergman et al.'s (2011) procedure, for the development of the initial BAI in adults, was applied to sub-group A *in extenso*, beginning with the acceptance of the formalism as follows:

$$\text{BAI}_\text{p} = \frac{\text{HC(cm)}}{\text{Height(m)}^{x}} \qquad (2)$$

In this equation, x denotes a unitless power term, defined as the value exhibiting the highest coefficient of correlation between BAI$_p$ and the actual %BF. Once determined, BAI$_p$ was regressed onto the actual %BF in order to obtain the intercept and slope for the new prediction equation of %BF, valid for children. Rounding off and other formal adjustments, for example combining Lin's (1989) concordance coefficient of correlation (CCC) with Bland & Altman (1999) pairwise comparison, were performed as appropriate to obtain the final equation. The intercept was obtained by regressing BAI$_p$ onto the actual %BF. Then, the possible different values of the intercept were compared for their CCC, by keeping constant both the correlation coefficient and slope of the first equation. The intercept that provided the highest CCC was used for the final equation.

The prediction equation obtained from sub-group A was then used to predict the %BF of children in sub-group B. The %BF predicted in this way was further compared to the actual %BF using a matched pairs Student's *t*-test. The final BAI$_p$-based formula to predict %BF was developed using the pooled data from sub-groups A and B. This equation was cross-validated in each sub-group by taking into account a potential gender effect. A residual analysis was further carried out to check for the assumptions of normality and homoscedasticity.

Table 1. General characteristics of children (values are expressed in mean ± SD).

	Age (years)	Body mass (Kg)	Height (cm)	BMI (kg/m^2)	HC (cm)	BF (%)
Group A						
Boys ($n = 434$)	8.7 ± 1.8	31.3 ± 8.9	132.9 ± 10.3	17.4 ± 3.0	72.4 ± 8.6	18.2 ± 6.2
Girls ($n = 404$)	8.6 ± 1.7	31.9 ± 9.6	132.8 ± 11.2	17.7 ± 3.1	73.4 ± 9.0	21.9 ± 7.1*
Sample A ($n = 838$)	8.6 ± 1.7	31.6 ± 9.3	132.8 ± 10.7	17.6 ± 3.1	72.8 ± 8.8	20.0 ± 6.9
Group B						
Boys ($n = 407$)	8.6 ± 1.7	31.3 ± 9.4	132.8 ± 10.8	17.4 ± 3.1	72.6 ± 8.9	18.0 ± 6.3
Girls ($n = 370$)	8.7 ± 1.6	31.7 ± 9.0	133.3 ± 11.0	17.5 ± 2.9	73.0 ± 8.3	21.4 ± 6.7*
Sample B ($n = 777$)	8.6 ± 1.7	31.5 ± 9.2	133.0 ± 10.9	17.4 ± 3.0	72.8 ± 8.6	19.6 ± 6.7
Total sample						
Boys ($n = 841$)	8.6 ± 1.7	31.3 ± 9.2	132.8 ± 10.5	17.4 ± 3.0	72.5 ± 8.7	18.1 ± 6.2
Girls ($n = 774$)	8.6 ± 1.7	31.8 ± 9.3	133.0 ± 11.1	17.6 ± 3.0	73.2 ± 8.7	21.7 ± 6.9*
Total ($n = 1615$)	8.6 ± 1.7	31.5 ± 9.2	132.9 ± 10.8	17.5 ± 3.0	72.8 ± 8.7	19.8 ± 6.8

BMI, body mass index; HC, hip circumference; BF, body fat.
*Denotes a significant difference between boys and girls, $p < 0.0001$.

Durbin–Watson's statistic was used to test the autocorrelation of the residuals.

Results

General characteristics of the sample

As shown in Table 1, the sample included 841 boys and 774 girls, aged 8.6 ± 1.7 years. Their mean body mass, height, BMI, HC and %BF were 31.5 ± 9.2 kg, 132.9 ± 10.8 cm, 17.5 ± 3.0 kg/m^2, 62.6 ± 8.7 cm and 19.8 ± 6.8%, respectively. Apart from %BF, where a significant difference was found between boys (18.1 ± 6.3%) and girls (21.7 ± 6.9%) in the whole sample, as well as in sub-groups A (18.2 ± 6.2% versus 21.9 ± 7.1%, respectively) and B (18.0 ± 6.3% versus 19.6 ± 6.7%, respectively) ($p < 0.0001$ in each case), no further gender differences were obtained between or within sub-groups (Table 1).

Application of the original BAI to children

When the initial BAI was used to predict the %BF of children in the current sample, it translated into a mean %BF of 29.6 ± 4.2%. This value was ~49% higher than the actual %BF of 19.8 ± 6.8% ($p < 0.0001$). Furthermore, a moderate coefficient of correlation ($r = 0.57$, $p < 0.01$) and a poor agreement (ICC = 0.34; 95% confidence interval [CI]: −0.19; 0.65) were obtained between the two values of %BF. Moreover, as displayed in Figure 1, the mean bias between the two values of %BF was −10%, with a 95% limit of agreement of [−21.0%; 1.0%], which denote a substantial lack of agreement between the two values and an over-estimation of %BF as predicted using BAI.

Construction of BAI_p and validity of the predicted %BF

Let us remember that the first step in the determination of BAI_p is based on the knowledge of the x term that maximizes the correlation between the ratio HC/Height^x and the actual bioimpedance-based %BF. As shown in Figure 2, the suitable x term for children was equal to 0.8 for a correlation coefficient of 0.74. This value was consistent throughout the sub-groups as well as the whole sample (Figure 2). It is noteworthy that, in this figure, for a power term x of 1.5, a weaker correlation coefficient of 0.56 was obtained. Thus, BAI_p should be written:

$$BAI_p = \frac{HC(cm)}{Height(m)^{0.8}}. \quad (3)$$

The linear regression of BAI_p onto the actual %BF led to the following raw formulae in the two sub-groups (Table 2).

$$\text{Group A}: \ \%BF_{predicted} = 1.055 \times BAI_p - 41.159; \quad R^2 = 0.55, \quad SEE = 4.64. \quad (4)$$

$$\text{Group B}: \ \%BF_{predicted} = 1.036 \times BAI_p - 40.336; \quad R^2 = 0.56, \quad SEE = 4.47. \quad (5)$$

Because of roughly similar prediction equations in the two sub-groups, data from these sub-groups were pooled to express the final prediction equation as follows:

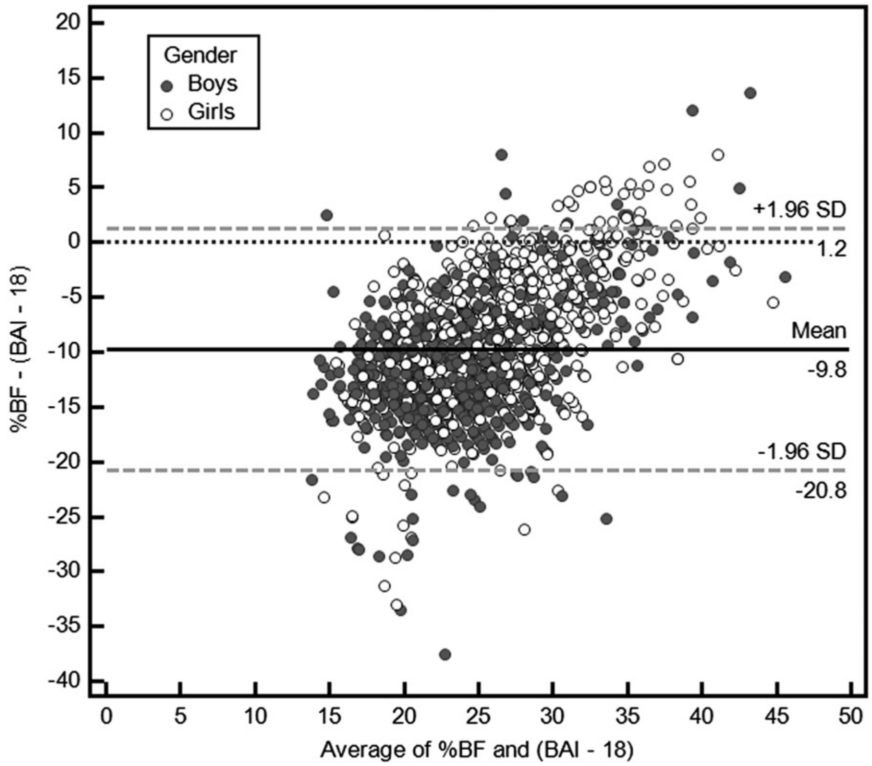
$$\%BF_{predicted} = 1.046 \times BAI_p - 40.779; \quad R^2 = 0.55, \quad SEE = 4.56. \quad (6)$$

Since the slope of this equation was close to 1, it was set at exactly 1. Then, on the basis of the best adjustment combining the bias correction factor (C_b) and CCC, an intercept of −38 was obtained (for $C_b = 0.94$ and CCC = 0.70). Thus, Equation (6) became:

$$\%BF_{predicted} = BAI_p - 38; \quad R^2 = 0.55, \quad SEE = 4.56. \quad (7)$$

The different formulae showed a similar level of adequacy when cross-validated on each sub-group and on the whole sample (Table 2). The use of BAI_p on the current sample translated into a mean %BF of 19.9 ± 4.8% (Boys = 19.7 ± 4.9% versus Girls = 20.2 ± 4.7%, $p = 0.03$). This predicted mean %BF was only marginally different from the actual %BF (−0.1 ± 4.6%; Δ = 0.5%, $p = 0.28$). A high coefficient of correlation ($r = 0.74$, $p < 0.0001$) and an excellent agreement (ICC = 0.83; 95% CI = 0.81; 0.84) were found between the predicted %BF using BAI_p and the actual %BF. The Bland and Altman plot in Figure 3 displays a better agreement between the actual %BF and the predicted %BF

Figure 1. Bland and Altman pairwise comparison between the actual and the estimated percentage of body fat using the original body adiposity index (BAI).



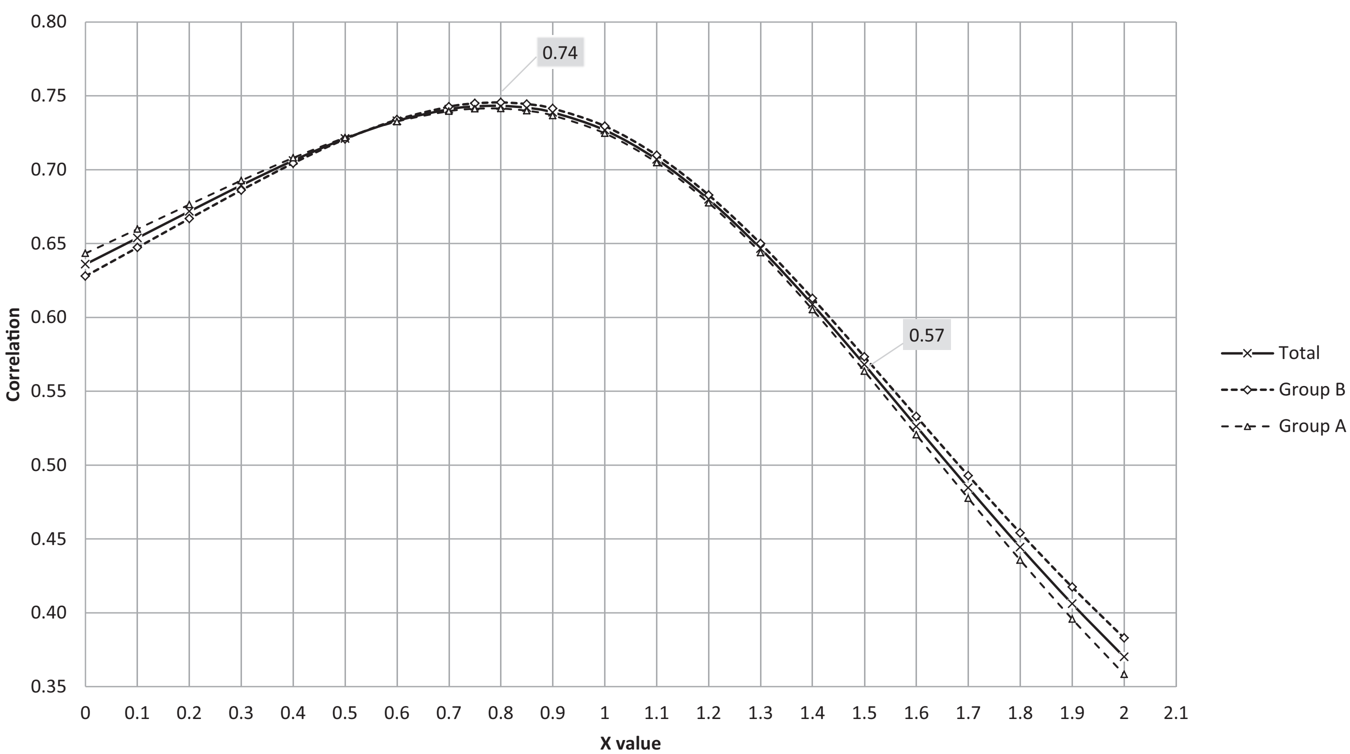


Figure 2. Calculated suggested body adiposity index for paediatrics (BAI_p) with varying x power term (abscissa).

using BAI_p (mean bias of -0.1%; see Figure 3) compared to that provided with the original BAI (mean bias of -10%; see Figure 1). However, when genders were considered separately, the newly predicted %BF over-estimated the %BF in boys and under-estimated the %BF in girls ($p < 0.0001$ in each case). Furthermore, the limit of agreement between the predicted and the actual %BF was quite wide [-9.1%; 8.8%].

Discussion

To our knowledge, this is the first study that aims to test the validity of body adiposity index (BAI) in children and to develop, if necessary, an appropriate BAI for paediatrics (i.e. BAI_p). Results of the current study indicate that the initial BAI, which was developed using an adult sample, is not valid

Table 2. Summary of the models and cross-validation.

	Characteristics of the model			Cross-validity of the model		
	Equation	R^2	SEE	Group A	Group B	Whole group
Group A ($n=838$)	$Y=1.055X-41.159$	0.550	4.641	–	-0.267 ± 4.479 $r=0.745$***	0.123 ± 4.567 $r=0.743$***
Group B ($n=777$)	$Y=1.036X-40.336$	0.556	4.478	-0.111 ± 4.646 $r=0.741$***	–	0.123 ± 4.567 $r=0.743$***
Whole sample ($n=1615$)	$Y=X-38$	0.552	4.563	-0.111 ± 4.646 $r=0.741$***	-0.267 ± 4.479 $r=0.745$***	–

X, BAIp: body adiposity index for paediatrics; *Y*, %BF: percentage of body fat; SEE, Standard Error of Estimate.
***Denotes a significant relationship, $p<0.0001$

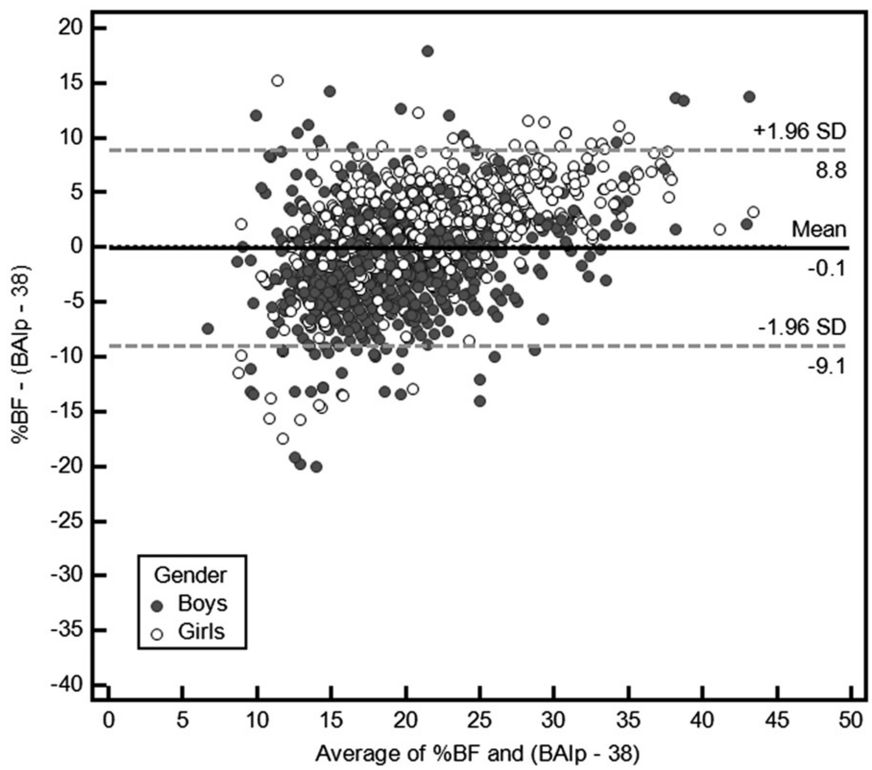


Figure 3. Bland and Altman pairwise comparison between the actual and the estimated percentage of body fat using the constructed body adiposity index for paediatrics (BAI_p).

for children, as it may over-estimate the percentage of body fat (%BF) of young people. On the other hand, the replication of the methodological approach used by Bergman et al. (2011) showed its feasibility on a sample of children, since BAI_p closely predicted the %BF obtained with a foot-to-foot bioimpedance technique. Even if the bioelectrical impedance analysis may be less accurate than traditional, sophisticated laboratory techniques such as DEXA or MRI, studies comparing bioelectrical impedance methods with these well-established methods commonly report high R^2 values (0.91–0.97) (Mueller et al., 2004). Mueller et al. (2004) hypothesized that impedance may exhibit higher validity and usefulness in children in comparison to adults. With a former model of the Tanita body composition analyser, the TBF-300 M, correlations with DEXA of 0.92–0.95 have been reported in children (Hosking et al., 2006). However, because of a between-method systematic bias (i.e. under-estimation of fat mass with the Tanita foot-to-foot bioimpedance compared to DEXA), the authors have recommended the use of this method only in large scale epidemiological studies (Hosking et al., 2006). Also, the device used in the present study was found in adults to be sufficiently valid for epidemiological studies rather than individual use (Lloret Linares et al., 2011). Unfortunately, to the best of our knowledge no such validation attempt has actually been made in children and youth with the Tanita BC-420 balance. To the contrary, data obtained with an earlier model, the BC-418, which was the last to be validated in the paediatric population, seems to converge in most weight categories with the %BF obtained with BC-420 in the present study. Further studies are, however, required for the validation of the BC-420 Tanita balance. Thus, although the bio-electrical impedance analysis has the advantage over sophisticated techniques to be a rapid, inexpensive, portable, simple and non-invasive method of assessing the body composition of children, interpretation of the current results should be performed whilst bearing in mind this limitation.

The %BF obtained in the current study with the foot-to-foot bioelectrical impedance was very close to values reported by earlier studies in a similar age group, using either

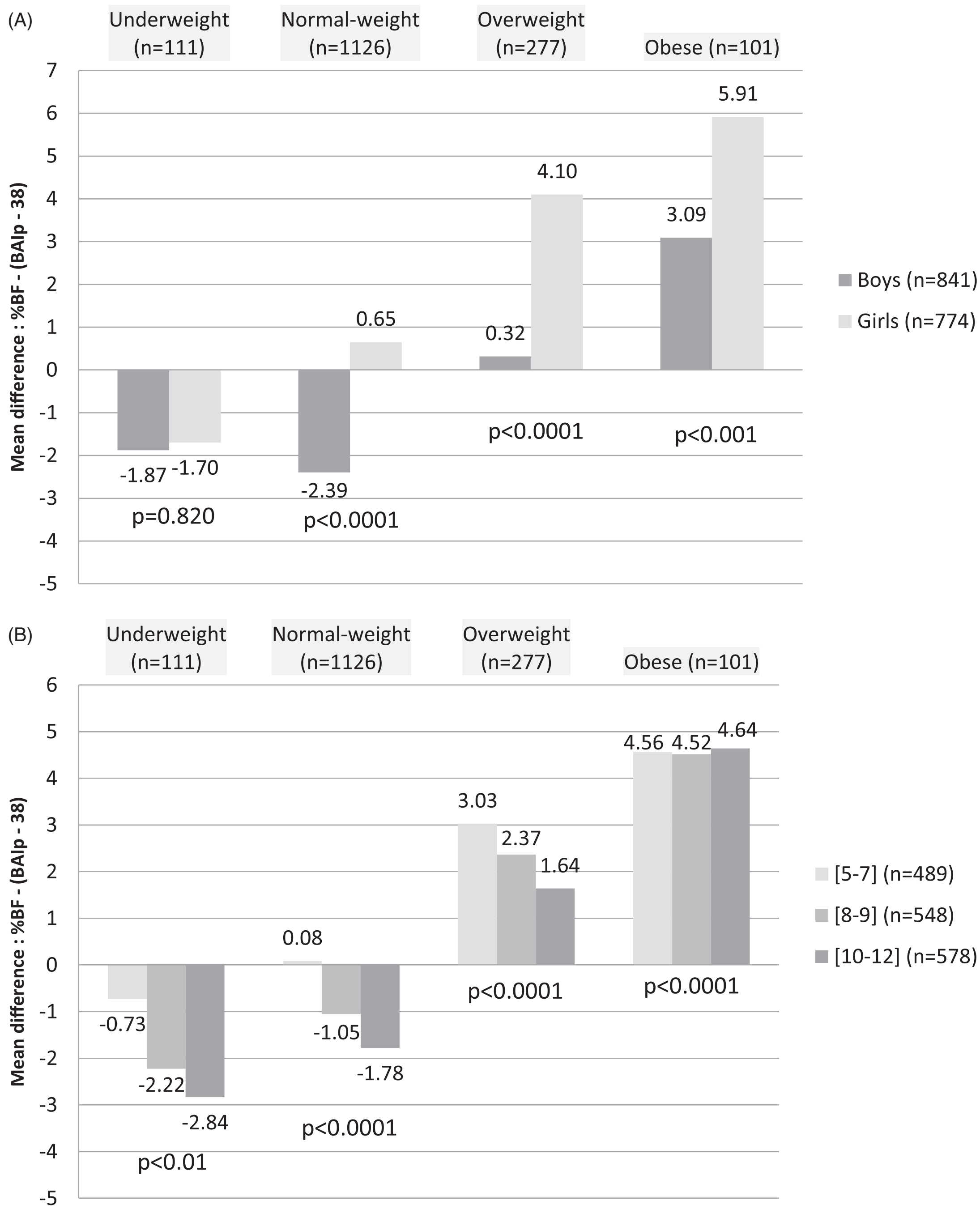


Figure 4. Mean difference in body fat percentage from bioimpedance and BAI_p according to gender, age group and weight status by the IOTF classification.

another model of foot-to foot device or DEXA in children (Eisenmann et al., 2004; Hosking et al., 2006). For example, with bioimpedance, mean values of %BF of 17.7% and 25.7% were found in boys and girls, respectively (Hosking et al., 2006), while the corresponding values in the current sample were 18.1% and 21.7%. The mean %BF for boys and girls in the present sample were even closer to those obtained by Hosking et al. (2006) with DEXA (i.e. 18.6% and 22.4% for boys and girls, respectively). Likewise, the estimated %BF using BAI_p (i.e. 19.7% and 20.2% for boys and girls, respectively), which slightly over-estimated the %BF in boys and under-estimated the %BF in girls, are in agreement with data obtained using DEXA in the literature (Eisenmann et al., 2004; Hosking et al., 2006). As the difference between the %BF obtained with bioimpedance and that predicted with BAI_p was neither statistically significant nor clinically meaningful, one might assume that the use of BAI_p may be an easier and valid way to obtain the %BF in paediatrics. However, it should be acknowledged that, for the screening of adiposity at an individual level, the use of BAI_p may be of limited value. Indeed, as displayed in Figure 4, BAI_p may both over- and under-estimate the %BF when the weight status, gender and age category of children are taken into account. For instance, the BAI_p-based %BF under-estimated the %BF of underweight and normal weight children, but over-estimated that of overweight and obese children, with differences reaching statistical significance according to gender or age category of children. Such differences could result from the lack of agreement between a BMI-based classification system and the value of %BF. It may also reflect the inaccuracy of the bioimpedance for estimating fat mass in children, especially at the extreme values of adiposity (i.e. very low and high adiposity) and this may have an effect upon BAI_p. In any case, BAI_p appears not to be appropriate for the estimation of the %BF at an individual level due to large errors in individual estimates as depicted by the wide limits of agreement in the Bland and Altman plot. In contrast, this BAI_p may be helpful for large-scale epidemiological studies. Nevertheless, the gender-related difference in the estimation of %BF using BAIp, which was apparent in all weight categories based on IOTF classification, should be considered as an indicator that BAI equation is a sex-specific one, at least in the paediatric population. This correcting factor that may improve the predictive value of BAI_p (unshown data) may, however, weaken its attractiveness when compared to the unique and easy to use formulae of BMI. Thus, caution should be exercised in the use of the current BAIp due to this intentional simplification, which may result in an under-estimation of %BF in girls and an over-estimation in boys.

There are other limitations to the current study. The first is related to the *a priori* acceptance of the formalism by Bergman et al. (2011) without testing its underlying postulates among children, including (i) the use of anthropometric parameters that exhibited the strongest correlation with % adiposity and (ii) the independence between the selected parameters. Because of important physiological differences between an adult and the growing body of a child, it may be pertinent to thoroughly consider these postulates. However, this may translate into the development of a different index, which cannot be named BAI, if the anthropometric characteristics associated with % adiposity were found to be different in children. Therefore, further studies are required to test this alternative. The second limitation relates to the use of the foot-to-foot bioimpedance technique as a validation method. Because this technique is not considered as the gold standard for body fatness, additional studies using DEXA or MRI are needed to substantiate the current findings.

Body adiposity index (BAI) is not able to predict %BF in children and indeed over-estimates %BF. In contrast, its equivalence in paediatric populations (i.e. BAI_p) represents a new index for estimating the body fatness of children, with acceptable accuracy compared with a bioimpedance measure. In its current form, this index may be valid for large-scale epidemiological studies, but it may not be pertinent for screening at an individual level. Further studies are required to improve its predictive ability at both group and individual levels and to compare its diagnostic performance to that of BMI.

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Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

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