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Original Article

Tracking and association of body weight and body fat in elementary school children

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Abstract

Background: Excess body fat is a major health risk to various chronic diseases. Given the ease of measurement and low cost of body weight and height, body mass index (BMI) has been widely used to estimate body fatness. The present study evaluates the accuracy of BMI as an indicator of body fatness, measured via bioelectric impedance (BIA) during the elementary school years in Austrian children.

Methods: Out of six schools in Innsbruck, Austria, anthropometric assessments and BIA measurements were performed in 199 children starting elementary school in fall 2013. Annual follow-up measurements were performed by the same measurement team until 4th grade.

Results: Cross-sectional analyses revealed a significant moderate correlation between BMI and percent body fat (%BF) (r=0.61) and an AUC of 0.88 indicated high accuracy of BMI as an indicator for body fatness. There was also high tracking of BMI and %BF over the 4-year observation period ($r \geq 0.84$). Follow-up measurements further showed that the association between BMI and %BF increased with age during the elementary school years ($r_{grade\ 4} = 0.78$; $AUC_{grade\ 4} = 0.96$).

Conclusions: Given the health problems associated with excess body fat an accessible and accurate assessment of body composition is warranted. The BMI provides a low-cost and easily administered surrogate measure of body fatness in elementary school children for initial screening. Children considered at risk, however, may require more elaborate assessments that directly measure fat mass and fat-free mass.

Keywords: body composition, obesity, overweight, youth

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Introduction

The prevalence of childhood overweight and obesity continues to increase or has stabilized at high levels, even though a considerable number of interventions have attempted to reverse this trend [1-6]. In the USA, for example, the prevalence of childhood obesity increased from 12.4% to 30% in only four years (2010-2014) [7]. As a complex condition childhood obesity increases the risk for various chronic diseases (e.g. diabetes, dyslipidemia, hypertension, obstructive sleep apnea), orthopedic and psychosocial problems as well as overall impaired quality of life [8,9]. Further, excess body weight during childhood and adolescence is associated with an increased risk to become an overweight/obese adult [10-12] and even in the absence of adult obesity, excess body weight during childhood is associated with an increased risk for chronic diseases later in life [13]. Accordingly, excess body weight puts a significant burden on the social system due to care costs and lost productivity [2,14]. Rather than excess body weight, increased body fat content, however, is the key risk factor of various chronic diseases due to the production of proinflammatory cytokines and hormones related to cardiometabolic problems by adipose tissue [15]. Detrimental effects of excess body fat, including atherosclerosis dyslipidemia and insulin resistance, therefore, may already be present during childhood [16,17]. As a result, the pediatric years have been recognized as a crucial period for the prevention, diagnosis and treatment of obesity [18].

In order to identify children and adolescents who are at risk, a reliable and accurate assessment of body fatness is of crucial importance [18]. An exact determination of body fat, however, requires elaborate and expensive methods. There are also indirect methods for the assessment of body fatness, such as skinfold measurements, waist circumference and various indices of weight to height ratios. Given the simplicity and affordability body weight and height measurements, the body mass index (BMI, kg/m²) is one of the most used measures to estimate body fatness. Height and body weight are also routinely measured in clinical settings and are commonly included in medical records. Accordingly, the BMI has been well established in everyday medical practice worldwide [14,19] and the International Obesity Task Force (IOTF) and the European Childhood Obesity Group have recommended the use of BMI to define overweight and obesity in children and adolescents [20]. Nevertheless, there remain some concerns regarding the accuracy of the BMI for the quantification of body fatness and the implications on fat metabolism at the individual pediatric patient due to ongoing growth of various tissues and body compartments (e.g. bone tissue, muscle, tissue, adipose tissue, body water) as well as the influence of sexual maturation on body composition [14,21,22].

Bioelectric impedance (BIA) provides a portable alternative to assess body fatness in large-scale studies. Specifically, BIA relies on the different bioelectric properties of different body tissues, with cell and water content influencing the resistance to an electric current. It evaluates the conductivity of various body tissues using a weak alternating current. As fat-free mass in the human body generally has higher water content, compared to fat tissue, it provides lower resistance and the total fat-free mass and fat mass can be estimated. The present study uses BIA as a criterion measure for body fatness and examines its association with BMI in a sample of Tyrolean primary school children. In addition, this study examined the sensitivity and specificity of BMI as an indicator of overweight and obesity in relation to the reference method BIA in 6- to 10-year-old children.

Methods

Out of 21 public elementary schools in the city of Innsbruck, Austria, six schools were randomly selected for participation. Children that started elementary school in the fall of 2013 were eligible for participation. The study protocol was approved by the Institutional Review Board of the University of Innsbruck, the school board of the Federal State of Tyrol and the participating schools. Parents provided written informed consent and children provided oral assent at the time of data collection. The study was conducted in accordance with the ethical standards of the declaration of Helsinki (2008).

Participants were followed over a period of four academic years (2013/14 to 2016/17) with annual anthropometric measurements, including body weight, height and percent body fat (%BF) conducted during the fall semester (October/November). All measurements were taken by the same measurement team throughout the entire observation period. Body weight (kg) and height (cm) were measured with children wearing gym clothes and being barefoot. Specifically, body weight was measured with an electronic scale (SECA® 803, Hamburg, Germany) to the nearest 0.1 kg and height was measured with a portable stadiometer (SECA® 217, Hamburg, Germany) to the nearest 0.1 cm. BMI was calculated (kg/m²) and converted to BMI percentiles (BMIPCT) based on German reference values [20]. Children with a BMI percentile above the 90th percentile were classified as overweight/obese.

Body fat content was measured via tetrapolar BIA, which has shown a high correlation for percent body fat with dual-energy absorptiometry (DXA) [23]. Specifically, a multifrequency bioelectrical impedance analyzer (BIA 2000-M, Data Input GmbH, Pöcking, Germany) was used that operates at three fixed frequencies (5, 50, 100 kHz) and passes an 800 µA alternating current through the body. The measurements were performed according to the manufacturer guidelines on the right side of the body with subjects in a supine position with their arms and legs slightly abducted. Detector electrodes were placed on a line between the radial and ulnar styloid processes on the dorsum of the wrist and a line between the medial and lateral malleoli on the dorsum of the ipsilateral foot [Figure 1]. Source electrodes were placed on the same side as the detector electrodes, overlying the head of the third metacarpal on the dorsum of the hand and the third metatarsal on the dorsum of the foot. It was ensured that their thighs were not in contact with each other and their arms were not touching the sides of their bodies. In order to ensure optimal distribution of body water, participants rested for five minutes in a comfortable supine position with slightly separated legs and arms positioned next to the torso before the measurement.

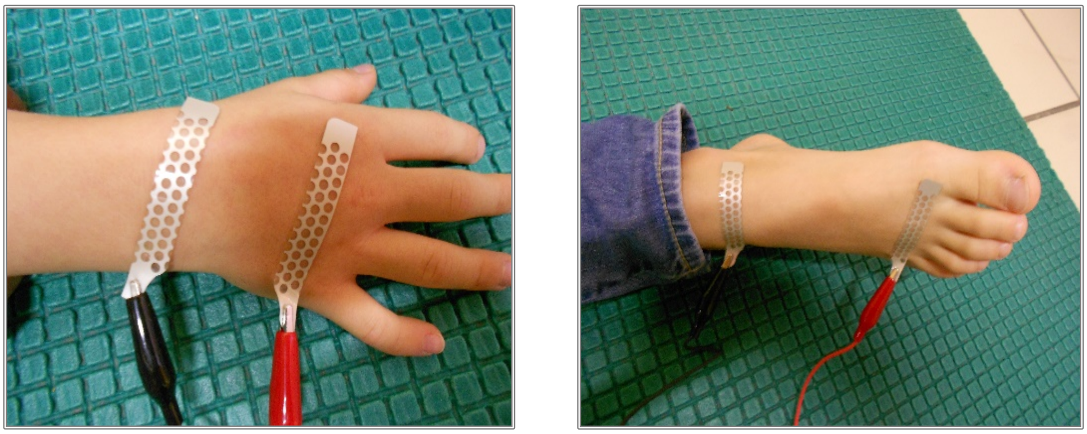

Figure 1. Placement of the detector electrodes.

Bioelectric impedance measures resistance, reactance and phase angle and provides estimates for fat-free mass (FFM), fat mass (FM), total body water (TBW) extra-cellular water (ECW) and mass (ECM), intracellular water (ICW), body cell mass (BCM) and phase angle [24]. Percent body fat (%BF) was calculated and participants were classified as overweight/obese based on the reference data of the BIA Compendium [25].

Statistical analysis

Descriptive statistics were calculated with prevalence being reported for categorical variables and means with standard deviation for interval scaled variables. ANOVA was used to examine differences in anthropometric characteristics between boys and girls and linear mixed models were used to calculate the change in anthropometric characteristics over the 4-year observation period. Associations between BMIPCT and %BF were examined via Pearson correlation at baseline and follow-up. Also, the tracking of BMIPCT and %BF was determined by examining the association of baseline values with follow-up measurements. The strength of the correlations was defined as high/strong ($r > 0.7$), moderate ($0.7 \geq r \geq 0.5$), low/weak ($0.5 > r \geq 0.3$), or negligible ($r < 0.3$) [26]. In addition, ROC analyses were used to determine the accuracy of BMIPCT as a measure of body fatness and the discriminatory ability of the 90th percentile as the cutoff for overweight/obese. All statistical analyses were performed for the total sample and separately for boys and girls using SPSS 26.0 (Armonk, NY, USA).

Results

Baseline data were provided by 199 (52.2% male) first-grade elementary school students. Of the total sample, 35.2% reported migration background with no significant difference between boys and girls (31.7% vs. 38.9%, respectively). Boys were slightly older and taller than girls [Table 1]. There were no significant sex differences in body weight or BMIPCT. Boys, however, had a significantly higher fat-free mass compared to girls, which resulted in a lower %BF ($p<0.01$). Nevertheless, there were no sex differences in the prevalence of overweight/obesity irrespective of using BMIPCT or %BF as a determinant (12.8% and 11.3%, respectively).

Correlation analyses revealed a significant ($p<0.01$) moderate association between BMIPCT and %BF in the total sample ($r=0.610$) and in sex-specific analyses ($r_{boys}=0.625$, $r_{girls}=0.653$). ROC analyses using %BF as a determinant for overweight/obesity showed a high accuracy of BMIPCT as an indicator for body fatness (AUC = 0.883, $p<0.01$). The specificity of 92.3% and sensitivity of 54.5% further indicated the good discriminatory ability of the 90th percentile, which is currently used as the cutoff for overweight/obesity in children and adolescents [Figure 2a]. Results were comparable when analyzing boys and girls separately with a specificity of 95.2% and 89.4% and sensitivity of 53.8% and 55.6% for boys and girls, respectively [Figure 2b,c].

Table 1. Descriptive characteristics at baseline (Mean±SD)

	Total sample (N=199)	Boys (N=104)	Girls (N=95)
Age (years)**	6.6 ± 0.5	6.7 ± 0.5	6.5 ± 0.5
Height (cm)*	122.6 ± 6.6	123.7 ± 6.7	121.4 ± 6.2
Weight (kg)	24.3 ± 5.0	24.9 ± 5.7	23.7 ± 4.1
Fat-free mass (kg)**	20.0 ± 3.2	20.8 ± 3.6	19.1 ± 2.6
Fat mass (kg)	4.3 ± 2.4	4.0 ± 2.7	4.6 ± 2.0
BMI percentile	52.5 ± 27.8	52.1 ± 27.8	52.9 ± 27.9
% Body fat**	17.1 ± 5.9	15.3 ± 6.0	18.9 ± 5.2

*p<0.05, ** p<0.01.

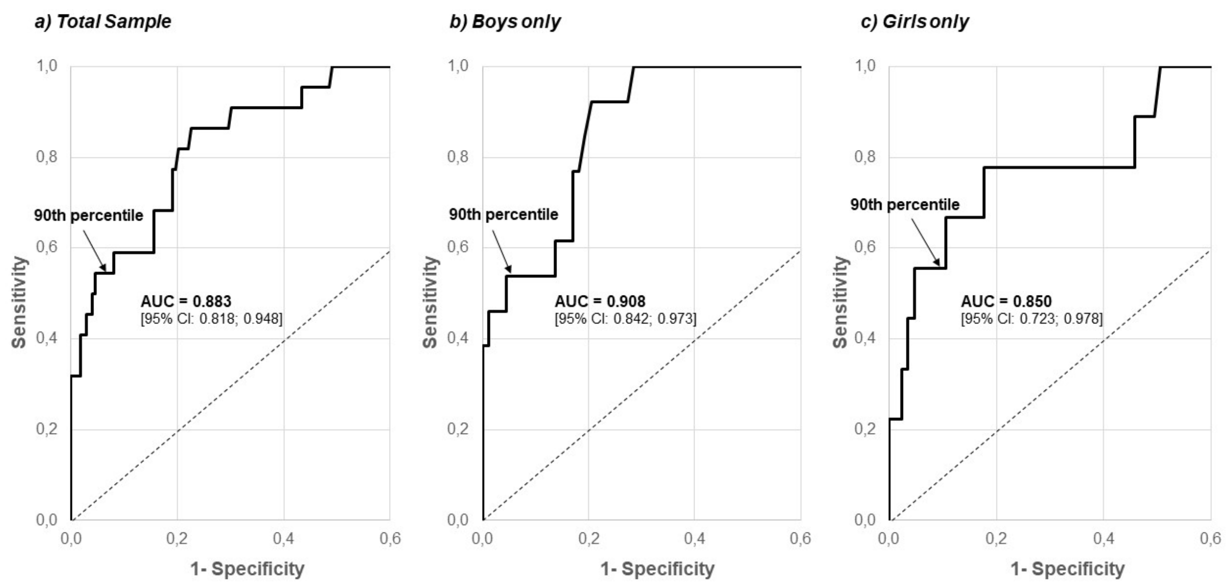

Figure 2. ROC curves for BMI percentile to determine overweight/obesity in first-graders based on body fat percentage in the total sample (a) and separately for boys (b) and girls (c).

Longitudinal analysis

Participants experienced a significant weight gain across the 4-year observation period of 3.6±1.7 kg/year ($p<0.01$). Even though no significant change was observed in BMIPCT the prevalence of overweight/obesity increased to 18.5% in 2016 (4th grade). %BF also increased significantly ($p<0.01$) to 21.0±7.3% in boys and 24.7±6.5% in 4th grade. There were no significant differences in change in anthropometric characteristics between boys and girls.

Table 2. Tracking of BMI percentile and percent body fat over the 4-year observation period.

	Total Sample			Boys Only			Girls Only		
	2014	2015	2016	2014	2015	2016	2014	2015	2016
BMIPCT	.925	.851	.844	.943	.841	.828	.906	.862	.863
% Fat	.906	.842	.838	.903	.829	.843	.890	.815	.804

Pearson correlation coefficients between baseline and follow-up measurements.

Tracking, indicated by the correlation between baseline measures and subsequent BMIPCT as well as %BF, was high across the 4-year observation period [Table 2]. Change in BMIPCT was also moderately correlated with change in %BF ($r=0.64$, $p<0.01$), with a slightly stronger association in boys ($r=0.688$) compared to girls ($r=0.576$). Correlation analyses between BMIPCT and %BF at each grade further show an increase in strength of the association between BMIPCT and %BF with increasing age [Table 3].

Accordingly, ROC analyses indicate an increase in the accuracy of BMIPCT as an indicator of body fatness as children get older. AUC changed from 0.883 in 2013 (grade 1) to 0.963 in 2016 (grade 4) with sensitivity increasing from 54.5% in first grade students to 85.7% in 4th grade students while specificity remained high (Specificity Grade 1: 92.3%; Specificity Grade 4: 93.1%) [Figure 3a]. Sex-specific analyses also revealed good accuracy of BMIPCT as indicator for body fatness throughout elementary school with a tendency towards increased discriminatory ability of the 90th BMIPCT for overweight/obesity based on %BF as children get older (Grade 4 - Boys: Sensitivity = 90.0%, Specificity = 91.2%; Girls: Sensitivity = 81.8%, Specificity = 95.8%) [Figure 3b,c].

Table 3. Association between BMI percentile and % body fat across the elementary school years.

	2013 (Grade 1)	2014 (Grade 2)	2015 (Grade 3)	2016 (Grade 4)
Total sample	0.610	0.696	0.762	0.778
Boys only	0.625	0.706	0.754	0.799
Girls only	0.653	0.737	0.827	0.799

Pearson correlation coefficients from 1st grade (2013) to 4th grade (2016).

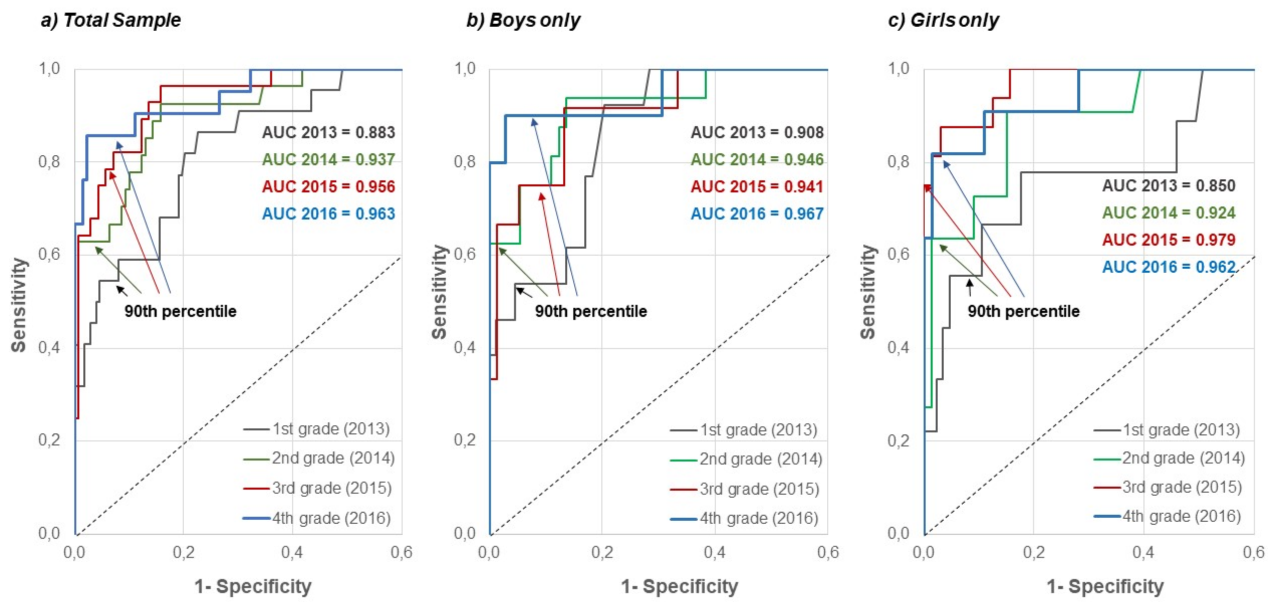

Figure 3. ROC curves for BMI percentile to determine overweight/obesity across elementary school-years based on body fat percentage in the total sample (a) and separately for boys (b) and girls (c).

Discussion

Excess body fat in children is a major risk factor for non-communicable diseases, including cardio-metabolic problems, orthopedic problems and low self-esteem [10,27-29]. The present study along with previous research [30] also indicates high tracking of BMI and body fatness during childhood, which emphasizes the need for an accessible and accurate assessment of body fatness at young ages. The results of this study show that BMI provides a simple and low-cost surrogate measure of body fatness in elementary school children, irrespective of sex. Longitudinal results further indicate an increase in strength of the association between BMI and %BF with increasing age during childhood. In addition, it has been shown that BMI is an acceptable tool for diagnosing children with excess body fat based on BIA, indicated by an AUC > 0.88 in 7-year-old children that increased to an AUC > 0.96 in 10-year-old children. ROC analyses further showed high specificity and, depending on age, moderate to high sensitivity of BMI for identifying overweight/obese children. Specificity values showed that less than 10% of normal-weight children were misclassified as overweight/obese across the entire age range and sensitivity values showed an increase in the accuracy of correctly classifying overweight/obese children from 55% in 7-year-old children to 85% in 10-year-old children.

These results are in line with previous research that reported high specificity and moderate sensitivity of BMI as a determinant of body fatness in children and adolescents [22]. Previous studies also showed high correlations between BMI and direct measures of body fatness [31-37]. Correlation coefficients ranged from 0.61 to 0.92 when BIA was used to determine %BF [31,32,34,37] and from 0.75 to

0.94 when DXA was used [31,33-36]. Boeke et al. further reported that 78% of the variance in DXA measured body fat was explained by BMI [31]. In addition, available research indicates that the association between BMI and direct measures of body fatness is even stronger in children with overweight or obesity even though there is high agreement across all levels of adiposity [31,33,38]. Accordingly, it has been argued that BMI is a suitable surrogate measure for body fat in pre-pubertal children [32,33].

Lower correlations, however, were observed between BMI and body fat distribution, which appears to be even more important regarding cardio-metabolic disease risk [33]. Nevertheless, there is evidence of an association between anthropometric measures and various chronic disease risk factors, including dyslipidemia, hyperglycemia and hypertension in young people [39-41]. Even though the discriminatory ability of BMI for individual risk factors has been limited in children and adolescents, it seems to be an efficient measure when screening for clustered cardio-metabolic disease risk [18,42,43]. Quadros et al., for example, showed a significantly higher BMI in 6- to 18-year-old youth with two or more cardiometabolic risk factors compared to their peers with only one risk factor [18]. Further, alterations in BMI have been associated with changes in combined cardio-metabolic risk score [44] and a recent review showed a good predictive ability of BMI regarding clustered cardio-metabolic risk in children and adolescents [42]. As the onset of cardiometabolic disease already occurs during childhood [28], BMI appears to be a low-cost and easily obtained measure to identify children and adolescents that warrant additional screening for cardio-metabolic risk factors.

The present study, however, did not measure cardio-metabolic biomarkers, which can serve as an additional criterion for adiposity. It should also be considered that body composition was determined via BIA rather than the gold standard DXA. Previous research, however, showed good agreement between %BF determined via BIA and DXA [34,45]. It should also be considered that the generalizability of these findings may be limited due to the small sample size and regional proximity of the study population. The longitudinal nature of the study throughout the entire elementary school years with annual data collection conducted by the same measurement team, on the other hand, is a considerable strength of this study as it allowed for an examination of tracking of BMI and %BF along with an exploration of potential changes in the association between BMI and body fat.

Conclusion

Despite the high correlation of BMI with direct measures of body fatness, there remain concerns about its use in pediatric studies due to the lack of distinction between fat mass and fat-free mass. The low cost along with an easy and quick assessment, however, makes BMI a useful surrogate measure of adiposity in epidemiological studies of school-aged children when more elaborate measures are not feasible or available. Accordingly, BMI appears to be a reasonable tool when evaluating intervention strategies on a population scale. A more cautious approach, however, may be warranted at the individual level. Nevertheless, the results of the present study along with previous research indicate that BMI can be used as an initial screening tool for excess body fat in children and adolescents. In fact, it has been argued that BMI should be used more as an initial obesity screening tool rather than for identifying body composition [32]. Additional assessments, that directly measure body fat along with the assessment of cardiometabolic risk factors, however, may be warranted when young people are considered at risk for excess body fat.

Conflict of interest

There is no conflict of interest.

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