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Review Paper

Comparison of methods to measure body fat in 7-to-10-year-old children: a systematic review

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ABSTRACT

Objective: To investigate methodological aspects in body fat (BF) measurements in 7-to-10-year-old children.

Study design: Systematic review of the literature.

Methods: The studies were chosen from the PubMed and Scielo databases according to a protocol that defined: inclusion criteria; a search and quality-assessment strategy; and information extraction.

Results: 27 studies published from 2004 to 2014 were included. The literature describes skinfold measurements and dual energy X-ray absorptiometry (DEXA) as being the reference methods most widely used in the assessment of the ability of methods to identify BF. The most commonly-used statistical analyses were the Pearson correlation coefficient, and sensitivity and specificity performance analyses. The comparison between the tested methods and the references showed that body mass index (BMI) and waist circumference (WC) are strongly correlated to BF as calculated by bioelectrical impedance or skinfolds, and that there is a moderate positive correlation with percent body fat as calculated by DEXA, air-displacement plethysmography (ADP) or isotope dilution. There was a moderate positive correlation between weight-to-height ratio (WtHR) and BF, as estimated by ADP and skinfolds. Performance studies suggest that BMI and WC are very specific but less sensitive methods.

Conclusions: The results of this systematic review show favourable evidence for the use of anthropometric indicators – above all BMI and WC– in the measurement of BF, when more accurate techniques such as DEXA and ADP are not feasible. They also demonstrate features that make them advantageous for epidemiological studies in a child population, since they are easy and safe to obtain and well tolerated by the children.

Introduction

Obesity is an important risk factor for cardiovascular diseases, type-2 diabetes, hypertension and cancer,[1] and when it occurs in infancy it increases the likelihood of these diseases in adult life.[2,3] Early evaluation of nutritional status therefore becomes important, since it enables interventions that can prevent and control obesity and overweight-associated diseases.[4]

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Evaluation of body fat (BF) in children may be performed by techniques that provide valid estimates of body composition, such as dual X-ray absorptiometry (DEXA), isotope dilution and air-displacement plethysmography (ADP).[5] However, other measurement methods are more feasible in epidemiological studies, including skinfolds and bioelectrical impedance (BIA).[6]

Anthropometric measurements and indicators are also present in epidemiological studies, such as waist circumference (WC) and body mass index (BMI), defined as the body mass (kg) divided by the square of the height (m^2).[7] The measurement method for BF must not only be valid and reliable, but also be easily-obtained and easy to interpret. However, for children, there are difficulties in identifying the method to be used, given the profusion of studies on the topic, involving different measurements and statistical analyses. Therefore, this study aims to investigate methodological aspects in body fat (BF) measurements in 7-to-10-year-old children.

Methods

The studies were chosen according to a protocol that defined: inclusion criteria; a search and quality-assessment strategy; and information extraction. For a study to be included, it needed to have addressed the comparison of BF evaluation methods in 7-to-10-year-old children, as shown in Fig. 1. Bibliographical data were searched for in the PubMed/Medline and Scielo databases using a specific strategy defined in sentences made up of keywords based on the features of interest. An example is presented in PubMed (Fig. 2) of the search results.

The parameters of the search were defined as the period (January 2003 to August 2014) and the languages (English, Spanish and Portuguese). Despite the use of Boolean operators to extend or restrict the number of studies identified, it was impossible only to include studies that presented the features of interest. For the first listing obtained ($N_0 = 1770$ articles) a further selection had to be carried out on the basis of a reading of the titles. This led to the identification of $N_1 = 107$ studies as eligible, after an analysis of the abstracts carried out independently by two evaluators. They decided upon the eligibility of the studies based on the features of interest (Fig. 1). The decision was made by consensus whenever there was a dissenting opinion about the inclusion of a study.

We followed PRISMA guidelines to conduct this review. The methodological quality and risk of bias of eligible studies ($N_2 = 54$) were assessed by reading them in their entirety and constructing a score according to Downs and Black (1998).[8] Since the aim of the study was to compare methods, we opted to use 11 questions out of a total of 27 in the original instrument. In this systematic review, we decided arbitrarily that we would include articles with a final score equal to or above eight points, corresponding to the 3rd quartile (Q3) of the score, as an indication of methodological quality.

For articles presenting methodological quality ($N_3 = 27$), two researchers extracted the data concerning the purpose of the study; population studied; sample size; and study design. Other variables related to BF-measuring methodology were extracted, such as type of method and the device manufacturer, body sites for the skinfold and waist circumference measurements, methods taken as reference; methods used for statistical analysis and outcomes of interest. Fig. 3 shows the flow chart of the study selection.

Results

The methodological characteristics and main results of the studies are given in Table 1. The articles were published between 2004 and 2014 and the participants' ages ranged from 5 to 19 years. The sample sizes ranged from 30 to 8269 participants. In all, eight studies (29.6%) were conducted in Europe, seven (25.9%) in Asia, four in North America (14.8%), four in South America (14.8%), two in Africa (7.4%) and two in Oceania (7.4%).

It was found that BMI was used in 78% of the studies ($n = 21$), and its performance was tested against methods such as ADP, DEXA, BIA and skinfolds. The performance of WC was investigated in nine studies, followed by weight-to-height ratio (WtHR) ($n = 5$), BIA ($n = 5$), skinfolds ($n = 3$), waist to hip ratio ($n = 3$), hip circumference ($n = 1$), neck circumference ($n = 1$), Rohrer's index[a] ($n = 1$), conicity index[b] ($n = 1$) and arm fat area ($n = 1$).

The most commonly used techniques for estimating BF in children were skinfolds ($n = 10$) and DEXA ($n = 8$). BIA ($n = 6$), isotope dilution ($n = 3$), BMI ($n = 3$) and ADP ($n = 2$) were also taken as reference methods.

The most commonly used reference system for the classification of obesity based on BMI was that of the *International Obesity Task Force* – IOTF-2000[9] ($n = 10$; 37.0%), followed by the CDC-2000[10] curves in eight articles (29.6%). Four (14.8%) used the OMS-2007[11] curves, while the others (18.5%) took into consideration the reference curves of the countries where they were carried out: in two cases,[12,13] Conde and Monteiro-2006 curves were used.[14]

The most commonly used skinfold sites were the triceps ($n = 14$ studies) and subscapular ($n = 13$), followed by the iliac crest ($n = 5$), biceps ($n = 3$), thigh ($n = 2$) and calf ($n = 2$). One study used the abdominal skinfold. Researchers mostly worked by inserting skinfold values into predictive equations, particularly that of Slaughter et al. (1988)[15] ($n = 9$).

Repeated measurements were described in 11 articles: in six articles they were obtained in duplicate, in four they were obtained in triplicate, and in one study they were obtained four times. In three of the studies that used duplicate measurements, a third measurement was carried out whenever the values differed by more than 1 mm[13] or 2 mm.[16,17] Another study mentions this procedure but does not explicitly state the criterion of proximity between values measured.[18]

The most commonly used skinfold calliper was the Harpenden® ($n = 7$), followed by the Holtain® ($n = 3$), Lange® ($n = 3$) and Cescorf® ($n = 1$). Eleven studies stated which side of the child's body the measurements were taken from: six on the right and five on the left.

[a] Rohrer's index = weight (kg)/stature $(m)^3$.
[b] Conicity index = waist circumference (cm)/ $0.109 \times \sqrt{weight(kg)/stature(m)}$.

Eligibility criteria	
Population of interest	Children aged 7-10 years or age group including 7-10-year old children, healthy, not undernourished
Methods used to assess body fat	Body Mass Index (BMI), waist circumference (WC), waist-to-height ratio (WHtR), skinfold thicknesses, bioelectrical impedance (BIA), dual X-ray absorptiometry (DXA), air-displacement plethysmography (ADP), densitometry, isotope dilution
Statistical analysis	Comparison of methods (correlation, agreement, test performance, validity)

Fig. 1 – Inclusion criteria for studies in the initial survey.

Search	Query	Items found
#1	(child OR children OR schoolchildren OR childhood OR adolescents) Filters: published in the last 10 years; Humans; English; Portuguese; Spanish; Child: 6-12 years.	359269
#2	(body fat OR body fatness OR adiposity OR obesity OR overweight OR body composition) Filters: published in the last 10 years; Humans; English; Portuguese; Spanish; Child: 6-12 years.	18516
#3	(body mass index OR skinfold thickness OR bioimpedance OR waist circumference OR waist-to-height ratio OR dual x ray absorptiometry OR air displacement plethysmography OR isotope dilution) Filters: published in the last 10 years; Humans; English; Portuguese; Spanish; Child: 6-12 years.	13868
#4	(correlation OR agreement OR performance OR validity OR cut off values OR comparison) Filters: published in the last 10 years; Humans; English; Portuguese; Spanish; Child: 6-12 years.	52148
#1 AND #2 AND #3 AND #4 AND	(child OR children OR schoolchildren OR childhood OR adolescents AND body fat OR body fatness OR adiposity OR obesity OR overweight OR body composition AND body mass index OR skinfold thickness OR bioimpedance OR waist circumference OR waist-to-height ratio OR dual x ray absorptiometry OR air displacement plethysmography OR isotope dilution AND correlation OR agreement OR performance OR validity OR cut off values OR comparison) Filters: published in the last 10 years; Humans; English; Portuguese; Spanish; Child: 6-12 years.	1739

Fig. 2 – Search strategy based on keywords and Boolean operators for the PubMed/Medline database.

Eleven studies (40.7%) reported use of BIA; in six of them this method was used as the reference for BF. Five studies were carried out using tetrapolar BIA devices (Akern®, $n = 2$; Bodystat®, $n = 1$; Holtain®, $n = 1$; Bizmedic®, $n = 1$). The others carried out vertical BIA (leg to leg), with Tanita® electronic platforms.

Of those studies using BIA, five described specific protocols for the examination: in the case of tetrapolar BIA they addressed the placement of the electrodes, the removal of metal jewellery and accessories, the need for prior fasting and bladder voiding, and the need to take the measurement after the participant had remained for 5–10 min in supine position.[6,16,19] In those studies describing leg-to-leg bioimpedance, the measurement was taken in the morning, preceded by bladder voiding, with the child standing upright, wearing light clothing[20] 2 h after a light breakfast.[21]

Pearson's moment–product correlation coefficient was used in 55.6% of statistical analyses in validity studies ($n = 15$), followed by performance analyses by sensitivity, specificity and the construction of *Receiver Operating Characteristic* (ROC) curves ($n = 12$) and agreement by the BLAND and ALTMAN strategy (1986)[22] ($n = 7$). Other statistical techniques used in order to compare methods were linear regression ($n = 5$), the kappa agreement index ($n = 3$) and Spearman's correlation coefficient ($n = 3$).

Taking into consideration the most commonly anthropometric indicators used, the study results showed that BMI and WC were strongly correlated to BF as estimated by BIA and skinfolds, in both genders, with correlation scores close to or above 0.90.[12,20,23,24] Moderate or weak positive correlations were observed when the reference methods were DEXA, ADP or isotope dilution.[16,17,25] WtHR showed a moderate positive correlation with BF when estimated by ADP and skinfolds.[17,18]

In international performance studies, BMI and WC presented high specificity and low sensitivity in identifying excess BF.[23,26,27] However, in Brazilian studies such as that of Leal et al. (2014),[13] BMI showed high sensitivity and moderate

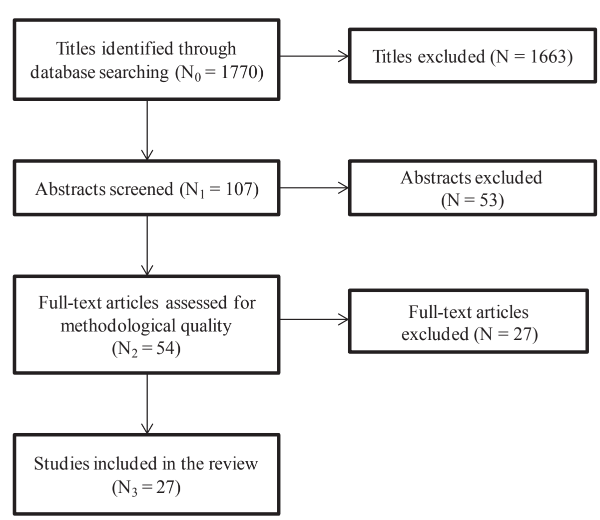

Fig. 3 – Flow chart for selecting studies for this systematic review.

Table 1 – Methodological characteristics and results of the studies included in the systematic review.

Authors (year)	Sample size (n) and population (age; country)	Purpose	Methods tested and reference methods	Correlation coefficient	Sensitivity (Se)/Specificity (Sp) Area under curve (AUC)
Tuan & Wang (2014)[45]	$n = 5355$ 2792 boys and 2563 girls 8 to 19-year-old; USA	To evaluate the performance of anthropometric measures relative to %BF measured by DXA	BMI, WC, WHtR Reference method: DXA	–	BMI: AUC: 0.91 (boys) and 0.90 (girls) WC: AUC: 0.92 (boys) and 0.89 (girls) WHtR: AUC: 0.97 (boys) and 0.94 (girls)
Leal et al. (2014)[13]	$n = 2795$ 1453 boys and 1342 girls 7 to 10-year-old; Brazil	To compare the sensitivity and specificity of BMI-based classification systems and to determine the optimal cut-offs for predicting excess body fatness in schoolchildren	BMI Reference method: ST	–	BMI cut-offs – WHO (2007) Se: 91.0% (boys) e 88.1% (fem) Sp: 90.9% (boys) e 88.8% (fem) BMI cut-offs – Conde & Monteiro (2006) Se: 91.0% (boys) e 88.1% (fem) Sp: 90.8% (boys) e 89.0% (fem)
Golec et al. (2014)[21]	$n = 308$ 161 boys and 147 girls 7 to17-year-old; Poland	To compare two body fat measurement methods (BIA vs Slaughter equation)	BMI, BIA Reference method: ST	BMI × ST: Abdomen: r = 0.75* Subscapular: r = 0.77* Triceps: r = 0.60* Thigh: r = 0.60* Suprailiac: r = 0.73* Calf: r = 0.48* *($P < 0.001$)	–
Michels et al. (2013)[17]	$n = 480$ 251 boys and 229 girls 5 to 11-year-old; Belgium	To investigate the validity of anthropometric measurements/indices and of FM% equations based on anthropometric measurements (skinfolds and BIA), using ADP as the reference method	BMI, Rohrer index, AFA, waist:hip ratio, WHtR and conicity index Reference method: ADP	BMI × ADP: boys: r = 0.51*; girls: r = 0.70* WHtR × ADP: boys: r = 0.51*; girls: r = 0.65* WC × ADP: boys: r = 0.46*; girls: r = 0.63* AFA × ADP: boys: r = 0.67*; girls: r = 0.76* *($P < 0.001$)	–
Lou et al. (2012)[46]	$n = 2847$ 1475 boys and 1372 girls 7 to 12-year-old; China	To investigate whether NC can be used to determine overweight and obesity in Han Chinese children	WC e NC Reference method: BMI	7 to 10-year old children BMI × WC: boys: r = 0.92* to 0.94*; girls: r = 0.86* to 0.90* BMI × NC: boys: r = 0.74* to 0.83*; girls: r = 0.56* to 0.80* WC × NC: boys: r = 0.72* to 0.83*; girls: r = 0.56* to 0.74* *($P < 0.001$)	For NC: Se: 75.5–82.7% (boys) and 80.0–92.5% (girls) Sp: 73.9–91.7% (boys) and 74.7–89.3% (girls) AUC: 0.86 to 0.91 (boys) and 0.84 to 0.93 (girls)

Laurson et al. (2011)[47]	$n = 8269$ 4273 boys and 3996 girls 5 to 18-year-old; USA	To investigate the validity of using BMI as an estimate of %BF in youth and to identify optimal BMI thresholds for identifying at-risk children and adolescents based on %BF	BMI Reference method: ST	–	Se: 82.8% boys (low risk) and 90.4% (higher risk) and girls 79.0% (low risk) and 88.2% (higher risk) Sp: 91.4% boys (low risk) and 88.9% (higher risk) and 91.4% girls (low risk) and 88.5% (higher risk) AUC: 0.95 (low risk) and 0.96 (higher risk)
Nwizu et al. (2011)[24]	$n = 753$ 377 boys and 376 girls 10 to 18-year-old; Nigeria	To study the relationship between BMI and BF in the assessment of overweight and obesity among adolescent Nigerians	BMI Reference method: BIA	BMI × BF (BIA) boys: $r = 0.49^*$ girls: $r = 0.92^*$ $^*(P < 0.050)$	–
Kehoe et al. (2011)[6]	$n = 618$ 325 boys and 293 girls 6 to 9-year-old; India	To assess agreement between %BF derived from primary reference methods and that from skinfold equations and BIA in Indian children	ST and BIA Reference method: DXA and isotope dilution	Bland-Altman analysis was used to assess agreement Correlation coefficients are not presented	–
Bartok et al. (2011)[48]	$n = 173$ girls 9 to 15-year-old; USA	To assess the validity of BMI percentile for identifying 'overfatness' in a cohort of white, 9-year-old girls	BMI Reference method: DXA	–	9-year-old girls: Se: 92% Sp: 91% (overweight) AUC: 0.96 (overweight) and 0.93 (obesity)
Glässer et al. (2011)[27]	$n = 2132$ 1114 boys and 1018 girls 7 to 14-year-old; Germany	To evaluate the screening performance of BMI and WC for excess adiposity and to investigate the diagnostic accuracy of cut-offs from different international and national reference systems based on BMI and WC	BMI and WC Reference method: ST	–	7 to 10-year-old children: BMI (IOTF): Se: boys 63.4% and girls 62.6%; Sp: boys 96.0% and girls 95.9% WC: Se: boys 51.5% and girls 51.6%; Sp: boys 98.1% and girls 98.6% AUC (BMI): boys 0.94 and girls 0.94 AUC (WC): boys 0.92 and girls 0.93
Taylor et al. (2011)[32]	$n = 778$ 382 boys and 396 girls 5 to 18-year-old; Australia	To determine whether age and sex-specific exponents which properly adjust for height affect the predictive ability of WHtR to correctly discriminate between children with differing fat distribution	BMI, WC, and WHtR Reference method: DXA	–	WHtR and total BF: Se: boys 64% and girls 62%; Sp: boys 94% and girls 92% AUC: boys 0.89 and girls 0.91
Ochiai et al. (2010)[20]	$n = 3750$ 1932 boys and 1818 girls 9 to 10-year-old and 12 to 13-year-old; Japan	To investigate the relationship of BMI to %BF and WC and to examine the influence of gender and obesity on these relationships	BMI and WC Reference method: BIA	BMI × %BF Fourth graders: boys: $r = 0.74^*$ and girls: $r = 0.97^*$ BMI × WC Fourth graders – boys: $r = 0.94^*$ and girls: $r = 0.90^*$ $^*(P < 0.050)$	–

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Table 1 – (*continued*)

Authors (year)	Sample size (n) and population (age; country)	Purpose	Methods tested and reference methods	Correlation coefficient	Sensitivity (Se)/Specificity (Sp) Area under curve (AUC)
Nambiar et al. (2010)[18]	$n = 2773$ 1395 boys and 1378 girls 8 to 16-year-old; Australia	To develop WHtR cut-offs for overweight and obesity based on the 85th and 95th percentiles for the %BF in a cohort of children and adolescents	WHtR Reference method: ST	8 to 10-year-old: WHtR × %BF: boys r = 0.65* and girls r = 0.61* *($P < 0.010$)	WHtR: 8 to 10-year-old children Boys – Se: 80% Sp: 79% (P85) and Se: 96% Sp: 90% (P95) Girls – Se: 91% Sp: 68% (P85) and Se: 93% Sp: 82% (P95) AUC: 0.90 (P85); 0.96 (P95) boys 0.88 (P85); 0.90 (P95) girls
Wickramasinghe et al. (2009)[26]	$n = 282$ 158 boys and 124 girls 5 to 15-year-old; Sri Lanka	To determine the reliability of BMI based cutoff values in diagnosing obesity among Sri Lankan children	BMI, WC, and WHtR Reference method: isotope dilution	BMI × %BF: boys: r = 0.68*; girls: r = 0.32* WC × %BF: boys: r = 0.66*; girls: r = 0.31* WHtR × %BF: boys: r = 0.36*; girls: r = 0.21* *($P < 0.001$)	For BMI: Se: 23.6% (boys) and (girls) 16.2%; Sp: 100% (boys and girls)
L'Abée et al. (2010)[16]	$n = 30$ 13 boys and 17 girls 6 to 7-year-old; Netherlands	To compare total body fat, assessed by different methods in non-obese children	BMI, skinfold thicknesses, and BIA Reference method: isotope dilution and DXA	BMI × %BF (isotope dilution): r = 0.65* BMI × %BF (DXA): r = 0.67* *($P < 0.010$)	–
Planinsec et al. (2009)[40]	$n = 5613$ 2841 boys and 2772 girls 6 to 12-year-old; Slovenia	To analyze overweight and obesity in children on the basis of BMI and triceps skinfold thickness	BMI Reference method: triceps skinfold thickness	BMI × triceps skinfold thickness: boys: r = 0.79* girls: r = 0.78* *($P < 0.010$)	–
Bonaccorsi et al. (2009)[19]	$n = 449$ 239 boys and 210 girls 8-year-old; Italy	To assess the body composition of 8-year-old children living in Livorno through the integration of bioelectrical and anthropometric evaluations	BMI and arm circumference Reference method: BIA	BMI × %BF (BIA): boys: r = 0.82*; girls r = 0.84* Arm circumference × %BF (BIA): boys: r = 0.87*; girls: r = 0.89* *($P < 0.050$)	–
Hassan et al. (2008)[49]	$n = 1283$ 681 boys and 602 girls 6 to 11-year-old; Egypt	To investigate the degree of correlation between waist circumference measurements and adiposity	WC Reference method: BIA and ST	WC × BMI: boys: (8.5-year-old) r = 0.78*; girls: (8.5-year-old) r = 0.52* WC × %BF (BIA): boys: (8.5-year-old) r = 0.78*; girls: (8.5-year-old) r = 0.52* *($P < 0.001$)	–

Wang et al. (2007)[25]	$n = 2493$ 1328 boys and 1165 girls 6 to 18-year-old; China	To compare BMI and WC with DXA based measures of adiposity and to describe the pattern and interrelations of these surrogate and direct adiposity measures in prepubertal and pubertal rural Chinese children	BMI, WC Reference method: DXA	BMI × %BF: boys: (6–11-year old) r = 0.43*; girls: (6–11-year-old) r = 0.40* *($P < 0.010$) WC × %BF: boys: (6–11-year old) r = 0.36*; girls: (6–11-year old) r = 0.27* * ($P < 0.010$)	–
Weili et al. (2007)[50]	$n = 4187$ 1977 boys and 2209 girls 8 to 18-year-old; China	To evaluate the accuracy of the index of WHtR, and propose the optimal thresholds of WHtR in the definition of childhood overweight and obesity in a bi-ethnic Chinese school-aged population	WHtR Reference method: BMI	–	Threshold for overweight: boys – Se: 87%; Sp: 85%; girls – Se: 81%; Sp: 80% Threshold for obesity: boys – Se: 96%; Sp: 93%; girls – Se 90%; Sp: 90% AUC for diagnosing overweight: boys: 0.93 and girls: 0.91 AUC for diagnosing obesity boys: 0.98 and girls: 0.92
Körner et al. (2007)[51]	$n = 676$ 322 boys and 354 girls 7,5 to 9,5-year-old; Germany	To assess the congruency of different estimates for BF content in prepubertal children	BMI, ST, BIA Reference method: mean of five methods using BMI, ST, and BIA	Pairwise scatterplots of %BF as calculated from five different formulas Bland–Altman analysis was used to assess agreement Correlation coefficients are not presented	–
Dencker et al. (2007)[29]	$n = 246$ 138 boys and 108 girls 8 to 11-year-old; Sweden	To explore the association between BMI, BF and BF distribution assessed by DXA in younger children	BMI Reference method: DXA	BMI × %BF r = 0.88 ($P < 0.050$)	–
Yoo et al. (2006)[23]	$n = 892$ 438 boys and 454 girls 8 to 12-year-old; South Korea	To examine the relationships between BMI, PWH and %BF, and to compare their validity based on %BF with the BMI criteria of IOTF	IMC, PWH Reference method: BIA	BMI × %BF: boys: r = 0.92*; girls: r = 0.91* *($P < 0.010$)	IOTF-BMI (obesity) Se = 46% and Sp = 99% IOTF-BMI (overweight) Se = 99% and Sp = 76%
Buison et al. (2006)[36]	$n = 125$ 38 boys and 87 girls 7 to 10-year-old; USA	To compare %BF, FM, and FFM from ADP with DXA and anthropometry, to determine the agreement between techniques	BMI, ST Reference method: ADP and DXA	ST × %GC: r = 0.73* *($P < 0.001$)	–
Soar et al. (2004)[39]	$n = 419$ 215 boys and 204 girls 7 to 9-year-old; Brazil	To determine the percentile levels of the anthropometric indices BMI, waist:hip ratio, and WC and to verify possible correlations among these indices in schoolchildren	BMI, WC, hip circumference, waist:hip ratio	Overweight: BMI × waist:hip ratio r = 0.23 ($P = 0.048$) BMI × WC r = 0.74 ($P < 0.001$) Obese: BMI × waist:hip ratio r = 0.14 ($P = 0.465$) BMI × WC r = 0.54 ($P = 0.003$)	–

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Table 1 – (continued)

Authors (year)	Sample size (n) and population (age; country)	Purpose	Methods tested and reference methods	Correlation coefficient	Sensitivity (Se)/Specificity (Sp) Area under curve (AUC)
da Silva et al. (2010)[12]	n = 1570 808 boys and 762 girls 7 to 12-year-old; Brazil	To describe the proportion of excess weight using different BMI classification criteria and assess the sensitivity, specificity, and agreement among the criteria	BMI Reference method: ST	BMI × sum of skinfold thicknesses boys: r = 0.88*; girls: r = 0.85* BMI × %BF boys: r = 0.86*; girls: r = 0.85* *(P < 0.050)	BMI (Conde & Monteiro criteria): Se = boys: 82.2% (10-year-old children) to 100% (7-year-old children); girls: 93.8% (8-year-old children) to 100% (7, 9 and 10-year olds) Sp = boys: 84.5% (7-year-old children) to 94.5% (8-year-old children); girls: 77.1% (7-year-old children) to 87.1% (10-year-old children) AUC = 0.97
Cocetti et al. (2009)[52]	n = 1286 583 boys and 703 girls 7 to 9-year-old; Brazil	To compare the components of body composition obtained by leg-to-leg BIA and ST measurements in children	BIA Reference method: ST	%BF × ST boys: r = 0.89*, girls: r = 0.77* *(P < 0.001)	–

ADP = air-displacement plethysmography; AFA = arm fat area; BF = body fat; BIA = bioelectrical impedance; BMI = body mass index; DXA = dual X-ray absorptiometry; FFM = fat-free mass FM = fat mass; IOTF = International Obesity Task Force; NC = neck circumference; PWH = percentage-weight-for-height; Se = sensitivity; Sp = specificity; ST = skinfold thicknesses; WC = waist circumference; WHtR = waist-to-height ratio.

specificity in both genders; while in Silva et al. (2010),[12] it showed high sensitivity and high specificity. In two studies, WtHR also performed well in identifying excess BF, with high sensitivity and high specificity.[18,50]

Of all studies analyzed, 21 (77.8%) described some type of limitation, the most commonly cited (44.4%) being the small sample size, which hindered generalization of the results. The assessment of risk of bias in individual studies according to Downs and Black (1998)[8] indicated a low risk, although we identified possible risk of bias, such as selection bias in studies that only included white girls[48] or Caucasian schoolchildren,[29] and measurement bias in a study that did not control for fluid intake or physical activity before the assessment of BF using BIA[52] and in a study that used BMI as a reference method to test the performance of the WtHR.[50]

Discussion

This systematic review identified that BMI and WC are frequently used as indicators of BF, and many studies have been published in the last ten years examining the performance of these indicators. The advantages offered by these indicators are the ease of obtaining them, their harmlessness, and their affordability, which are aspects that make them suitable for large epidemiological studies.

Despite the discussion about the ability of BMI to predict BF in children,[16,40] our results showed that there is a strong positive correlation between BMI or WC and BF, as estimated by BIA or skinfolds.[12,20,24] It is therefore possible that BMI and WC estimate BF because the high degree of correlation suggests a single measurement space. The moderate positive correlations between BMI or WC and BF, as estimated by DEXA, APD or hydrometry,[16,17,25,29] which are considered more accurate measurements of BF, still raise some uncertainty regarding the ability of these indicators to measure BF in this age group, justifying further studies that have a proven methodological quality.

BF measurement is complex because the nutritional status appears to interfere with the method performance. In the Steiberger et al. (2005)[30] study, the correlation between BMI and BF identified by DEXA was stronger among children with a higher percentage of BF (r = 0.9) than among leaner children (r = 0.5). Freedman et al. (2013)[31] compared the accuracy of BMI and the sum of the triceps and subscapular skinfold measurements in identifying BF in 8-to-19-year-olds, taking DEXA as reference, and they observed that both are equally valid in identifying those with excess BF; however, in children or adolescents with a low percentage of BF, the preference should be for skinfolds.

More recently WtHR has been used increasingly. The results of our systematic review suggest that this is a useful indicator for identifying children with a higher percentage of BF, and an increased risk of developing cardiovascular diseases;[18,25,32] its major advantage is that it proposes a single cut-off point (WtHR ≥ 0.50), regardless of gender and age, and is easily interpreted.[33]

However, Pereira et al. (2011)[28] described problems with the use of WtHR in adolescents. Three young people with a waist measurement over P90 did not present WtHR ≥ 0.50, given that they were above P95 for height in the sample, while two young girls with WtHR ≥ 0.50 did not present a large WC, one of them being in P5 for height. Because it is a compound indicator, greater knowledge of the size of the influence of height on the WC measurement is needed. According to the literature, very tall children tend to present a greater WC.[34] Recent research suggest that increased height is associated with greater cardio-metabolic risk regardless of adiposity. Dividing WC by height in very tall children may therefore mask their cardio-metabolic risk.[35]

The literature shows that skinfolds seem to be a better choice than BIA when such equipment as DEXA and ADP is not available.[36] Michels et al. (2013)[17] following Bland and Altman (1986)[22] compared WC as measured by ADP with the sum of the triceps and subscapular skinfolds, the percentage of BF by using predictive equations and the percentage of BF by BIA, in 5-to-11-year-old children. The method closest to ADP was the sum of skinfold measurements, while the amplitude of the limits of agreement for BIA indicated lack of agreement between methods.

The decision whether to use BIA or skinfolds also depends on operational aspects. In the case of skinfolds, standardized procedures must be followed strictly in order to ensure the accuracy of the measurements, reducing inter- and intra-observer variability. Measurements should be taken on the right-hand side of the body and at least two measurements should be taken at each site, and the average of the measurements should be calculated.[5,37] In this review the studies were observed to be disparate both in terms of the side of the body and in terms of the number of measurements taken.

The advantage of identifying anthropometric indicators such as BMI, WC and WtHR, which perform well in identifying BF, is that they are preferable in epidemiological studies. This is because skinfold measurements take longer to execute, and are more invasive than weighing, measuring height, and bodily perimeters.[31] Another difficulty is the taking of skinfold measurements in obese children, because it is hard to palpate the measurement points, and the calliper may not open wide enough to carry out the measurement.[37] With BIA, apart from the greater cost associated with the device, accessory equipments may need to be transported to the research field (e.g. stretcher), and children may feel nervous while electrodes and wires are being placed.

Comparing methods, different strategies were used in statistical analyses—Pearson's moment–product correlation coefficient being the most frequently-used. It should be pointed out that the presence of a statistically significant correlation between methods does not necessarily indicate agreement.[38] As Bland and Altman (1986)[22] stated, the significance test (H_0:$\rho = 0$) is irrelevant for the investigation of agreement, since it is expected that methods with the same purpose (here, measuring BF) will be related. What would be more informative in this case is the Confidence Interval for the correlation coefficient (ρ), which was not commonly carried out in these studies.

The comparison of methods by correlation coefficient in validity studies is frequent in the literature. Eighteen of the 27 articles included performed Pearson or Spearman correlation coefficient calculations. Fourteen studies used other statistical analyses to supplement the investigation about the performance in identifying BF, and correlation coefficients were the only analytical method in four studies.[20,24,39,40]

Some studies used kappa statistics to investigate agreement. This index was proposed by Cohen (1960)[41] as an *ad hoc* measurement that indicates the agreement between two observers beyond what would be expected by chance. In studies aiming to analyze agreement between two methods, there are more appropriate methods than the kappa coefficient for a study of agreement, such as the strategy proposed by Bland and Altman (1986).[22] However, as was pointed out in 1987 by Maclure and Willett and as has been observed for three decades, studies still use kappa for this purpose with categorical variables; this choice is questionable.[42]

In this type of study, beyond the agreement proposed by Bland and Altman,[22] performance analysis can be carried by identifying cut-off points for BMI and other anthropometric indicators that optimize sensitivity and specificity in the correct classification of individuals who may or may not present the feature of interest, with the construction of ROC curves taking one method as reference.[43] Using this methodology, international studies investigating the performance of BMI and WC in identifying children with excess BF reported high specificity but low sensitivity,[23,26,27] and the possibility of generating many false-negatives, while studies in Brazil found greater sensitivity scores.[12,13]

In a recent study, Aeberli et al. (2013)[44] identified that a compound BMI-WC score was able to increase sensitivity in the prediction of obesity in 6-to-13-year-old schoolchildren compared with either of the indicators individually. However, more evidence is needed in order to confirm the superiority of the BMI-WC score in estimating BF.

In accordance to the present study, other systematic reviews recently published addressed the ability of BMI to identify adiposity in children. Javed et al. (2015)[53] conducted a meta-analysis including studies that used performance analysis and showed that BMI is a very specific but less sensitive method. The authors concluded that, despite its limitations in diagnosing obesity at the individual level, BMI remains worthwhile for epidemiological studies.

In the systematic review performed by Simmonds et al. (2014)[54], while childhood BMI was not a good predictor of adult obesity and morbidities, its performance for the diagnostic of obesity during childhood was considered reasonably good, with high specificity and moderate sensitivity.

The present systematic review adds to other systematic reviews in the literature because we considered not only BMI but also other simple measures of adiposity, like WC and WtHR. Besides, we considered different study designs other than diagnostic performance studies, including correlation and agreement studies, and discussed operational aspects as well as methodological issues involved in statistical analysis, in order to present a more comprehensive view of the topic.

We highlight that the studies included were heterogeneous in terms of study population, design, statistical analysis and outcomes measured; therefore statistical aggregation was not conducted. Another limitation is that two electronic databases were used in the initial selection of the studies, although they were the most important in terms of dissemination of international studies (PubMed) and Latin American studies (Scielo). Despite our comprehensive selection of studies, the choice of only these two databases can allow for selection bias. There is also a risk of publication bias as in any systematic review, considering that studies with positive results present a higher chance to be published.

In conclusion, the literature reviewed indicated a strong correlation between BMI and WC with BF measured by BIA and skinfolds, and performance studies reinforced that BMI is reasonably good in identifying excess BF. The results of the review therefore favour the possibility of using anthropometric indicators—above all BMI and WC—when more accurate techniques such as DEXA and ADP are unfeasible. The review also shows features that make them advantageous for epidemiological studies in a child population, since they are easy and safe to obtain and well tolerated by the children.

Author statements

Ethical approval

Not required in the author's institution for a systematic review.

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Competing interests

None declared.

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