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Validity of body mass index and waist circumference to detect excess fat mass in children aged 7-14 years

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Short title:

BMI and waist circumference to detect excess fat mass

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Abstract

Objectives: To evaluate the screening performance of body mass index (BMI) and waist circumference (WC) for excess adiposity. In addition, the diagnostic accuracy of cutoffs from different international and national reference systems based on BMI and WC was investigated.

Methods: Data from 2132 Jena children aged 7-14 years conducted in 2005/2006 were analyzed. Receiver operating characteristic (ROC) curves were constructed to assess BMI and WC as screening measures for excess adiposity (derived from skinfolds). Sensitivity, specificity and positive predictive values (PPV) were calculated for two BMI-based classification systems (IOTF and German reference) and sample-based WC-cutoffs.

Results: The BMI as well as the WC performed well in detecting excess fat mass, indicated by areas under the ROC curve (AUC) close to 1.0, with slightly greater AUCs for BMI than for WC in both sexes. The specificity of all reference systems was high for both sexes (95 % to 98 %). However, their sensitivities were low (53 % to 67 % in boys; 51 % to 67 % in girls). PPV were higher for the German reference and the sample-based WC cutoffs than the IOTF reference, and higher in girls than in boys.

Conclusions: The setting in which the reference system should be used is important for the selection of the reference system. The results support the use of the BMI-based references for monitoring in epidemiological studies. The sample-based cutoffs for WC should be refined for clinical use on national level.

Keywords: body mass index, waist circumference, excess adiposity, ROC analysis, children

Introduction

The increasing prevalence of obesity is a growing problem in children and adolescents worldwide. Numerous studies have confirmed the strong association between increased fatness and elevated health risks, such as hyperlipidemia, diabetes and hypertension (Eisenmann et al., 2005; Kovacs et al., 2010; Meininger et al., 2010). Despite these concerns, no universally accepted definition of obesity exists. Body mass index (BMI) is commonly used to classify overweight and obesity in children and adolescents (Dietz and Bellizzi, 1999). Therefore, various international and national BMI reference systems have been developed (e.g., IOTF, WHO, CDC) (Cole et al., 2000; Must et al., 1991; Ogden et al., 2002). Because BMI varies with age and sex (Guo et al., 1997), all systems consist of age- and sex-specific percentile curves. However, the percentiles were derived from different populations, and different cutoffs were used to define overweight and obesity (Neovius et al., 2004). These differences make it difficult to monitor global trends. An additional complication is that BMI, as a measure of weight relative to height, is only a proxy measurement of body fatness (Mei et al., 2007), but excess body fat mass is the hallmark of obesity (Sardinha et al., 1999) and related to morbidity and mortality. Because of the limitations of BMI, the use of waist circumference (WC), has been suggested to evaluate adiposity. The measurement of WC may add beneficial to identifying children and adolescents at increased risk of subsequent obesity-related disease, since it has been advocated as an indicator of central obesity (Janssen et al., 2005; Savva et al., 2000). WC is a good predictor of intra-abdominal fat deposition and is related to the development of cardiovascular diseases in adults (Shen et al., 2006; Wang, 2003) as well as in children and adolescents (Brambilla et al., 1994; Goran et al., 2008; Katzmarzyk et al., 2004). In several countries, population-specific WC percentiles for

children and adolescents have been developed (Eisenmann, 2005; Fredriks et al., 2005; Inokuchi et al., 2007; Katzmarzyk, 2004; McCarthy et al., 2001; Moreno et al., 1999).

However, there are currently no agreements about a health-related classification. Several previous studies considered the 90th percentile as a cutoff point for high WC (Fredriks et al., 2005; Maffei et al., 2001; McCarthy et al., 2003; Plachta-Danielzik et al., 2008), whereas other studies consider the 75th or 70th percentile (Moreno et al., 2002; Sarria et al., 2001; Savva et al., 2000). These different cutoffs may, at least in part, be due to ethnic differences in WC percentiles. Population-specific studies are needed to adjust the used cutoff points, because the validity of country-specific WC references for abdominal obesity screening in children and adolescents has not been fully established.

Investigations in adults suggest that WC may also be related to total body fat rather than to visceral fat (Harris et al., 2000). Therefore, WC may serve as a simple measurement for detecting overweight and obesity. For children and adolescents no recommendation exists to either prefer high WC or BMI to identify subjects with excess adiposity, until now (Reilly et al., 2010). The aim of this study was to compare the general screening performance of BMI and WC for excess fatness using receiver operating characteristic (ROC) curves in children and adolescents. This statistical approach was used to compare the different parameters since it caters for misclassification issues which correlation analysis can not. In addition, existing reference systems (IOTF, German BMI-reference and WC) were validated against percentage body fat (% BF).

Subjects and methods

The analyses were based on data of 2132 children (1018 girls and 1114 boys) aged 7 to 14 years from a cross-sectional survey conducted in Jena (Germany) in 2005/2006. For detailed

analysis the children were divided into two age groups (7- 10 and 11- 14 years) according to the approach in the German Health Interview and Examination Survey for Children and Adolescents (KiGGS) (Kamtsiuris et al., 2007).

The Regional Ethics Committee of the Jena University Hospital approved the study. Written informed consent was obtained from the parents.

Anthropometric measurements were taken in the morning hours by three investigators, which were trained in measurement practice. The measurements included stature, weight, WC, and skinfold thickness. Stature and weight were measured using standard anthropometric instruments as described by Martin et al. (Martin and Saller, 1957). Stature was sized to the nearest 0.1 cm using an Anthropometer (Martin). Weight was measured with children wearing minimal clothing using an electronic scale and was recorded to the nearest 100 g. No adjustments were made for clothing. BMI was calculated as body weight in kilograms divided by stature in meters squared. WC was measured over the naked skin horizontally to the narrowest part of the torso, approximately midway between the lowest rib margin and the iliac crest, using an inelastic tape and was recorded to the nearest 1 mm.

Prediction of body fat mass

To predict body fat mass, triceps and subscapular skinfold thickness were measured in triplicate to the nearest 1 mm, according to Tanner and Whitehouse (Tanner and Whitehouse, 1962). For the skinfold thickness measurements a Lange caliper was used. The % BF was derived according to Slaughter et al. (Slaughter et al., 1988) and the age and sex specific 85th percentiles of % BF were used to define excess fatness.

The inter-observer technical error of measurement (TEM) for the triceps skinfold was 0.90 mm and 0.92 mm for subscapular skinfold. The corresponding intra-observer TEM was 0.56 mm for triceps skinfold and 0.45 mm for subscapular skinfold.

Classification of the subjects

For the analysis, subjects were classified according to BMI and WC. To classify the subjects as overweight or obese two BMI-based definitions were used, the international classification system recommended by the IOTF (Cole et al., 2000) and a German reference system (Kromeyer-Hauschild et al., 2001).

The IOTF system, proposed by Cole (Cole et al., 2000), consists of sex-specific percentile curves, which were derived from data from six large, nationally representative, cross-sectional growth studies. In this system, the age- and sex-specific BMI cutoffs that correspond to a BMI of 25 at age 18 were used to identify subjects as overweight.

The German BMI reference data (Kromeyer-Hauschild et al., 2001) have been recommended by the “Arbeitsgemeinschaft Adipositas im Kindes- und Jugendalter” (AGA) to monitor national trends and to screen for overweight and obesity in clinical practice. According to the definition, the prevalence of overweight was estimated as the percentage of children whose BMI was above the 90th age- and sex-specific percentile of this reference.

Recently developed age- and sex-specific WC percentile curves of children from Jena (Kromeyer-Hauschild et al., 2008) were used to classify the investigated subjects, because there is still a lack of national WC percentile curves. Currently, no claim can be made for a cutoff that will identify subjects who are at an elevated health risk. In this study, a cutoff greater than the 90th WC percentile, by sex and age group, was arbitrarily set to detect children and adolescents with high WC.

Statistical analysis

Receiver operating characteristic (ROC) curves were used to evaluate the general performance of BMI and WC in reflecting excess fatness, assessed by % BF >85th percentiles for boys and girls, respectively. To adjust BMI, and WC for age in these analysis, all individual data were converted into standard deviation scores (SDS) according the formula:

SDS = some $/L(t)S(t)$ where X = individual BMI/WC-value, L = Box-Cox power, M = median, and S = coefficient of variation for individual age (t) and sex from the reference group. The ROC curves were constructed by first calculating the sensitivity and specificity. Sensitivity was defined as the probability that BMI or WC would classify subjects with excess fatness correctly as having excess adiposity (true-positive rate). Specificity was defined as the probability of classifying subjects correctly in not having excess fatness (true-negative rate). The series of sensitivities were plotted on the y-axis against the corresponding values of 1-specificity on the x-axis. The area under the curve (AUC) determined with these ROC analyses can be used as a global measure of the overall accuracy of BMI and WC in screening for excess fat mass. The AUC can take values between 0 and 1, where 1 is a perfect screening test and also the perfect discrimination between subjects with, and without excess fatness. We examined the ROC performance for BMI and WC (SDS-values) for boys and girls separately. The validity of the two BMI-based systems (IOTF, German reference) and the 90th percentile of WC to detect excess fat mass, defined by the 85th percentile of % BF, were evaluated by comparing their sensitivity, specificity and positive predictive values. Whereas, the positive predictive value (PPV) is the probability of being truly fat when a subject is classified as having excess fat mass by screening method.

Statistical analyses were performed using SPSS version 15.0.

Results

Various characteristics of the subjects are presented in Table 1. The study population consisted of 52.3% boys. Despite similar mean BMI values, girls had significantly smaller WC values and higher levels of % BF than boys.

The prevalence of overweight varies by the classification system used (Table 2). The BMI-based IOTF reference produced higher estimates for overweight in both sexes than either the BMI-based German reference or the WC criteria. In boys, similar rates for overweight were found using the BMI-based German system or the WC criteria. There are no significant sex differences in the prevalence rates.

Figure 1 demonstrates the ROC performance of BMI and WC stratified by sex. Both parameters performed well on average in identifying excess fat mass, as indicated by AUCs greater than 0.9. Although the AUCs were not significantly different from each other, a trend was observed suggesting that the ROC performance of BMI was better than that of WC in predicting excess fat mass in both sexes. In girls, the ROC performance of WC was slightly better than in boys.

Table 3 indicates the number and type of classifications produced by the two BMI-based reference systems (IOTF and German reference) for boys and girls, respectively. In both sexes, the proportion of subjects having truly no excess fat mass correctly identified as true-negatives was higher using the German reference compared to the international reference. The proportion of subjects that were correctly identified with excess adiposity (true-positives) was higher using the IOTF reference for boys as well as girls. Both BMI-based references resulted in a higher proportion of false-negatives subjects than false-positives in both sexes. This imbalance was more pronounced with the German reference.

Figure 2 shows BMI plotted against % BF, with reference lines indicating the assumed threshold (85th percentile = 1.04 SDS) to define excess fat mass (horizontal line) and the 90th percentile (1.28 SDS) to define overweight (vertical line).

In figure 3 WC was plotted against % BF with the above mentioned threshold for % BF (horizontal line) and the 90th percentile to detect high WC (vertical line). The WC criteria resulted in comparable numbers and types of classifications than did the BMI-based German

reference for boys (8.3 % true-positives; 82.7 % true-negatives) as well as for girls (8.1 % true-positives; 82.9 % true-negatives).

Sensitivity and specificity rates as well as PPV for the investigated classification systems (IOTF, German reference, and WC) are presented in Table 4. All investigated cutoff points were highly specific in detecting subjects with excess adiposity. However, the sensitivity rates were low. The IOTF reference system showed higher sensitivity, but lower specificity than did the other systems. Only marginal difference in the sensitivity and specificity rates were found between the German BMI-based reference and the WC-based criteria.

Boys had slightly higher sensitivity values than girls when using the BMI-based German reference and the WC classification systems whereas when using the IOTF system the sensitivity rates were marginally higher, but only in girls. Whereas the age differences in the specificity of all classification systems were only small, higher sensitivity rates were found in the older age group than in the younger ones, in both sexes.

The PPV, as the probability that a truly adipose person classified as having excess fat mass by the reference criteria, was slightly higher for girls than boys (Table 4). In both sexes, the IOTF reference resulted in lower PPVs compared to the two other references. Older girls showed higher PPVs when using the two BMI-based references than younger ones, whereas in younger girls higher PPVs using the WC-based reference were found. In boys, only small differences between the two age groups occurred with marginally higher PPVs in younger boys for the IOTF and the WC reference.

Discussion

The results of the study suggest that BMI and WC performed well in detecting excess fat mass in children and adolescents. Simple waist circumference measurements appeared to have

a similar performance to BMI for screening of excess adiposity, with only slightly lower AUCs than BMI in both sexes.

From the different reference systems (IOTF, German reference and WC) analyzed in this study, none achieved optimal rates of sensitivity; however, specificities were high in both sexes. The diagnostic accuracy using the German BMI-based reference is nearly the same compared to the sample-based 90th WC-percentile.

This highly specific but insensitive nature of the reference systems has already been reported in other studies for BMI (Deurenberg-Yap et al., 2009; Mei et al., 2007; Neovius et al., 2004) as well as WC (Katzmarzyk et al., 2004; Taylor et al., 2000). However, large discrepancies between the sensitivity and specificity rates in the different studies were found. These rates, as well as the number of misclassified subjects, varied also between the three classification systems investigated in this study. The present study found only small differences in sensitivity and specificity between boys and girls, whereas other studies report higher but inconsistent sex differences, which were either more sensitive for boys or for girls (Deurenberg-Yap et al., 2009; Neovius et al., 2004; Reilly et al., 2000).

The differences in the sensitivity and specificity rates may be explained by the choice of reference data or adopted cutoff values from the different classification systems (Deurenberg-Yap et al., 2009). However, they may also be due to the method used to assess body fat mass as well as the definition of excess adiposity.

Prediction of body fat mass

A variety of elaborated methods to assess body fat mass exist, such as dual-energy X-ray absorptiometry, bioelectrical impedance or densitometry by air-displacement plethysmography. However, these techniques require expensive equipment and are therefore limited to clinical settings. The current study estimated % BF from skinfold thickness measurements, which were frequently used as measures for body fat mass in population-based

work (Deurenberg-Yap et al., 2009; Mei et al., 2007). Though, limitations are associated with the caliper-method, which may result in inaccurate estimates of body fat. The reliability of skinfold thickness measurement can be affected by inter- and intra-observer variability and by the prediction equation used. Several regression equations incorporating different skinfold measurements have been developed to predict body fatness. However, they are population-specific and may not apply to all individuals. A study by Steinberger et al. (Steinberger et al., 2005) showed high correlations of % BF estimates according the Slaughter formula in comparison to % BF estimated with DXA in 11- to 17-year-old. Rodriguez et al. (Rodriguez et al., 2005) recommend the use of the Slaughter equation for adolescent girls and boys in field and clinical studies. Despite these problems, body fatness estimated from measurements of skinfold thickness is reasonably well for the use in large field studies (Moreno et al., 2006; Steinberger et al., 2005; Teixeira et al., 2001).

Definition of excess body fat

In a study by Neovius et al. (Neovius et al., 2004), it was shown that the choice of % BF cutoffs in evaluations of BMI-based classification systems has a large impact on sensitivity and specificity. However, Neovius et al. and other studies (Neovius et al., 2004; Sardinha et al., 1999; Williams et al., 1992) used fixed % BF cutoffs (BF>25% for boys and >30% for girls) to define excess fatness in children. This approach, however, is questionable because the amount of body fat varies with age and sex (Taylor et al., 2002). An application of the above mentioned fixed % BF cutoffs to our data resulted in changed prevalence rates. These changes are due to a systematic overestimation of older boys and a systematic underestimation of the fraction of younger girls with excess adiposity, when fixed cutoffs are applied compared to the percentile-based cutoffs (% BF > P85) (data not shown). Similar findings for girls were reported in other studies (Neovius et al., 2004; Taylor et al., 2002).

Cutoffs for BMI and WC

The use of the sample-based 90th percentile of WC as a cutoff for excess fat mass in the present study was somewhat arbitrary. This percentile was chosen as a conventional cutoff in clinical terms, to ensure adequate numbers for statistical analysis and to compare the results with those of other authors (Fredriks et al., 2005; Li et al., 2006; McCarthy et al., 2003). Before WC can be used as a screening instrument, an appropriate cutoff for identifying children at risk and data on metabolic abnormalities and high fat mass is needed. This cutoff should minimize the number of false-positives to avoid stigmatization, but this could mean that many true-positives will be missed. For public health intervention or monitoring, the sum of sensitivity and specificity should be maximized to reduce misclassifications.

Recommendation for practical use

The recommendation of a system to detect adiposity depends on the setting in which the reference system should be used (Neovius et al., 2004). BMI can provide a general description of adiposity characteristics in a healthy pediatric population and is convenient for the estimation of body fatness in epidemiological studies. For international comparisons the BMI-based reference system recommended by the IOTF, which showed the highest sensitivity rates for their cutoffs, allows to obtain acceptable and comparable prevalence rates at the global level. At the national level, given the probable population differences in relative risks at certain BMI values, the German BMI-based reference is likely to be more suitable.

BMI is a valid and reproducible ratio, however, it is less accurate in predicting fatness in an individual child (Ellis et al., 1999; Fredriks et al., 2005). In terms of clinical practice and health promotion, measurements of WC, rather than BMI should be used as a screening instrument. WC has been shown to have a good relationship with abdominal fat in children, which appears to play a special role as a risk factor for later metabolic and heart diseases (Fredriks et al., 2005; Wells and Fewtrell, 2008). In clinical settings the identification and treatment of children with abdominal adiposity is important, because there is considerable

evidence that, centralization of fat during adolescence increases the risk for metabolic complications in adulthood (Cameron et al., 2009).

Moreover, BMI has significant limitations for monitoring the treatment of overweight and obese subjects over time. Increases in activity may promote both gains in lean mass and losses of fat stores, resulting in weight (and BMI) maintenance. Because BMI cannot discriminate between relative changes in fat and lean mass, WC measurements may prove beneficial in this context.

Limitations

Limitations of the presented study, as mentioned above, include the methodological aspect of the assessment of body fat mass and the debatable choice of % BF cutoff to define excess adiposity, as well as the sample-based 90th percentile of WC as a cutoff for excess fatness. To evaluate these cutoffs, health-related criteria such as hypertension, hyperlipidemia and impaired glucose tolerance should be taken into consideration in further studies.

In conclusion, BMI and WC predicted a high proportion of children and adolescents with excess fat mass in a sample of 7- to 14-year-old. The international BMI-based reference is a compromise to obtain acceptable, comparable prevalence estimates at the global level. The German BMI-based reference and the WC-based system yield comparable sensitivities and specificities which are acceptable for population-based screenings to identify German children and adolescents with excess fatness. The arbitrarily chosen cutoff for WC should be refined according the health outcome.

Conflict of interest

The authors have no conflict of interests.

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Figure 1 Receiver operating characteristic curves for body mass index (BMI-SDS) and waist circumference (WC-SDS) in boys (a) and girls (b) and the corresponding area under the curve (AUC).

Figure 2 Body mass index (BMI-SDS) vs. percentage body fat (% BF-SDS) in boys (a) and girls (b). The x-axis reference line denotes BMI cutoff (90th percentile) and y-axis reference line denotes % BF cutoff (85th percentile) for excess adiposity.

Figure 3 Waist circumference (WC-SDS) vs. percentage body fat (% BF-SDS) in boys (a) and girls (b). The x-axis reference line denotes WC cutoff (90th percentile) and y-axis reference line denotes % BF cutoff (85th percentile) for excess adiposity.

Table 1 Characteristics of the study population.

	Boys	Girls
n	1114	1018
Age (years) ^a	10.1 (2.3)	10.0 (2.2)
BMI (kg/m ²) ^b	16.9 (15.6, 19.0)	16.8 (15.5, 19.0)
WC (cm) ^b	59.0 (55.2, 64.6)	57.1 (53.3, 62.1)*
% BF ^b	17.5 (13.9, 23.7)	19.7 (15.9, 24.5)*
Triceps skinfold (mm) ^b	12.0 (9.0, 16.0)	13.0 (10.4, 17.0)*
Subscapular skinfold (mm) ^b	7.0 (5.0, 10.0)	7.8 (6.0, 11.5)*

^a Values are mean (SD).

^b Values are median (25th percentile, 75th percentile).

* Median values were significant different between sexes, P<0.001 (Mann-Whitney U-Test).

Table 2 Prevalence of overweight in children from Jena, age 7 to 14 years, according to different reference systems.

	Boys	Girls
	% (95% CI)	% (95% CI)
IOTF	14.18 (12.21- 16.40)	13.56 (11.55- 15.85)
German reference	10.05 (8.38- 12.00)	8.94 (7.29- 10.90)
WC	10.14 (8.46- 12.10)	9.63 (7.92- 11.65)

IOTF: BMI-based international reference; WC: waist circumference >P90.

Table 3 Number and types of classification to detect excess body fat according to the two BMI-based references, IOTF and German reference.

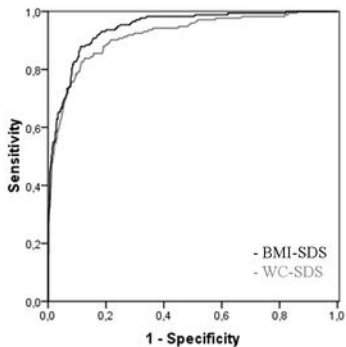
Classification	Boys (n = 1114)				Girls (n = 1018)			
	IOTF		German reference		IOTF		German reference	
	n	%	n	%	n	%	n	%
True-positives	116	10.4	95	8.6	107	10.5	81	7.9
False-positives	42	3.8	17	1.5	31	3.1	10	1.0
True-negatives	899	80.7	924	82.9	829	81.4	850	83.5
False-negatives	57	5.1	78	7.0	51	5.0	77	7.6

IOTF: BMI-based international reference.

Table 4 Sensitivity, specificity and positive predictive values of BMI-based and WC-based references to detect excess adiposity defined by % BF > P85 subdivided by age group.

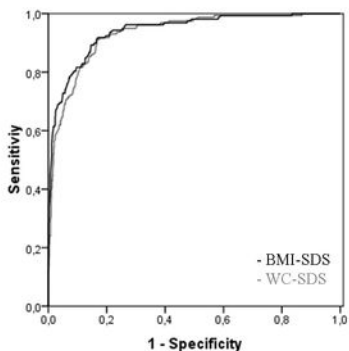
	IOTF	German reference	WC
Sensitivity (%)			
Boys			
7 - 10 years	63.4	52.5	51.5
11 - 14 years	74.3	58.3	56.9
overall	67.1	54.9	53.8
Girls			
7 - 10 years	62.6	46.2	51.6
11 - 14 years	74.6	58.2	52.2
overall	67.7	51.3	51.9
Specificity (%)			
Boys			
7 - 10 years	96.0	98.1	98.1
11 - 14 years	94.9	98.3	97.6
overall	95.5	98.2	97.9
Girls			
7 - 10 years	95.9	98.6	98.6
11 - 14 years	97.1	99.1	97.4
overall	96.4	98.8	98.1
PPV (%)			
Boys			
7 - 10 years	75.3	84.1	83.9
11 - 14 years	71.2	85.7	80.4
overall	73.4	84.8	82.3
Girls			
7 - 10 years	73.1	85.7	87.0
11 - 14 years	83.3	92.9	79.5
overall	77.5	89.0	83.7

IOTF: BMI-based international reference; WC: waist circumference > P90; PPV: positive predictive value.



(a)

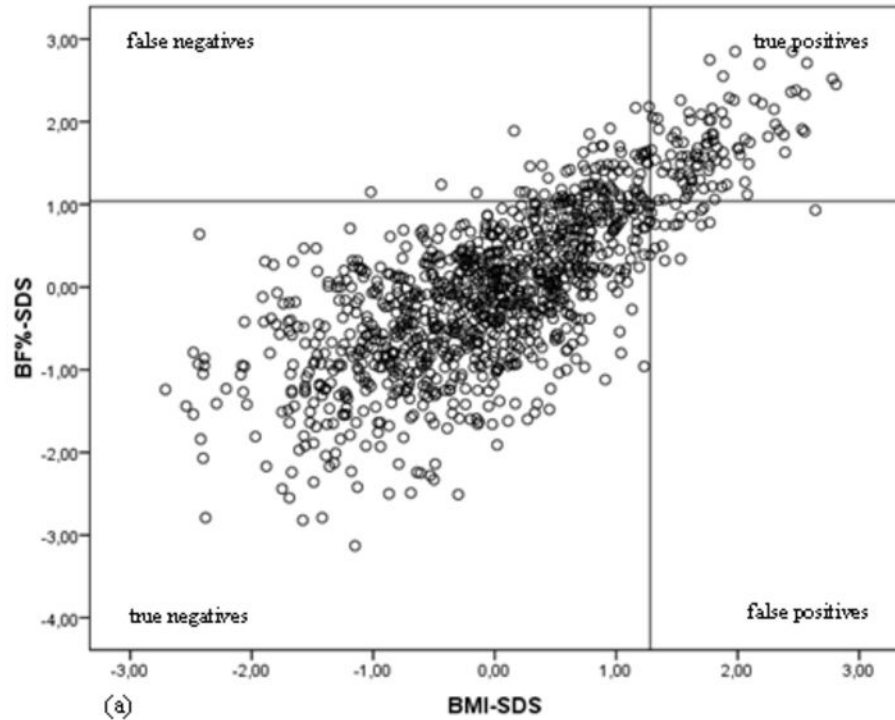
	AUC (95% CI)
BMI-SDS	0.943 (0.926; 0.961)
WC-SDS	0.917 (0.893; 0.942)



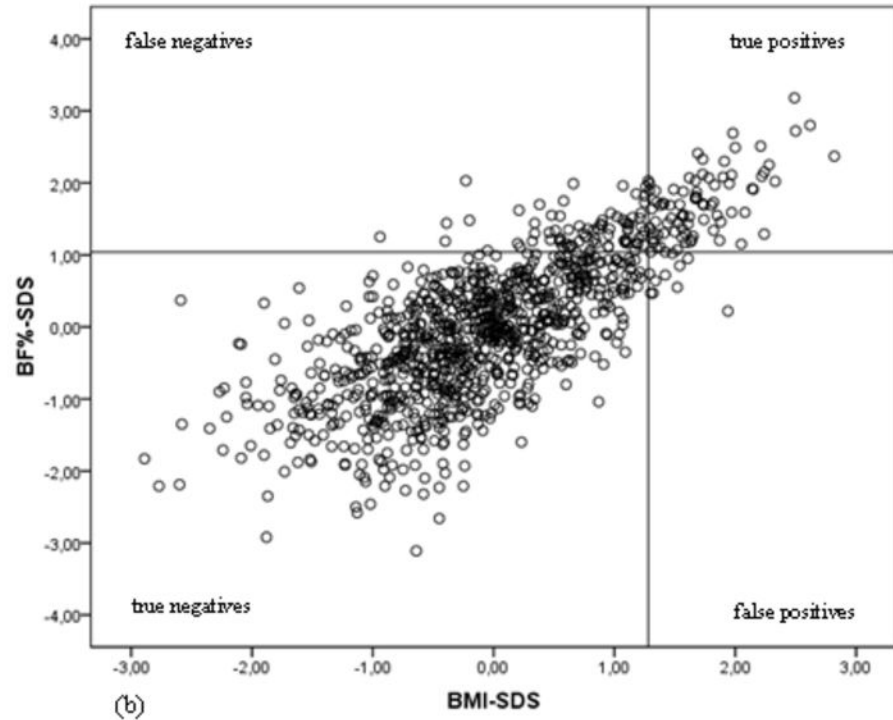
(b)

	AUC (95% CI)
BMI-SDS	0.941 (0.921; 0.961)
WC-SDS	0.933 (0.912; 0.953)

Fig 1

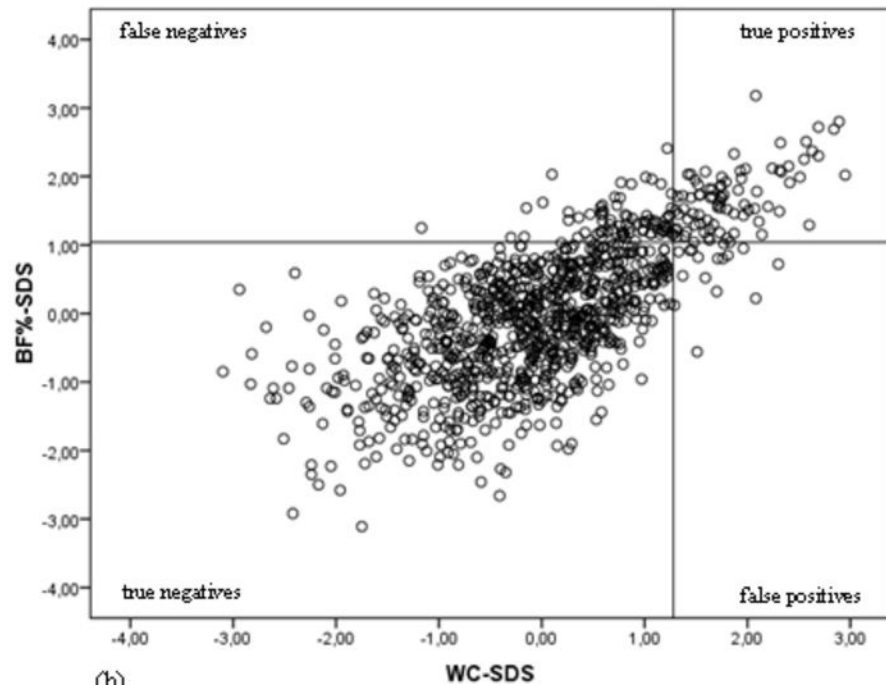
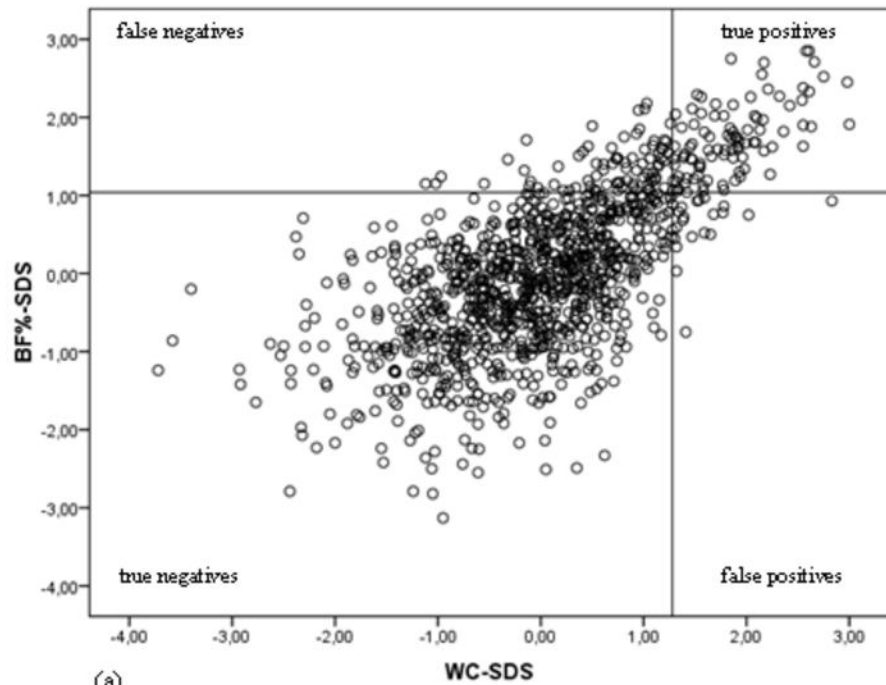


(a)



(b)

Fig 2



(a)

(b)

Fig 3