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SHORT REPORT

The relation between body mass index and body fat percentage in Brazilian adolescents: assessment of variability, linearity, and categorisation

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ABSTRACT

Reliable but accessible measures to capture body composition are highly important as the world is in an era of obesity-increase. The most used measure, the body mass index (BMI), nevertheless, has been judged as non-reliable to estimate body fat percentage (BF%). The present manuscript assessed the criticisms of BMI as a predictor of BF% and the BMI-based categories of nutritional status. 4164 children/adolescents from 9 to 18 years of age from Porto Velho, Brazil, had their anthropometric and skinfold measures taken. Controlling for socioeconomic status, school (private, public), sex and age, we compared proposed models/variables in the literature relating BMI and BF%. We evaluated the functions and the residual data to understand the variability of BF% estimate per BMI and evaluated three possible categorisations from BMI to predict BF% nutritional status. The function utilising (linear) BMI was the best to predict BF% ($R^2 = 0.70$) with a variability of only 6.49% around the function. Nevertheless, no categorisation of nutritional status was reliable to predict the nutritional status of individuals. BMI is reliable to estimate BF%. Nevertheless, new normative values must be proposed; the original categorisation fails to capture the nutritional status of children/adolescents from this region.

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Body fat percentage (BF%) is associated with several health risks (World Health Organization 2000) and therefore its assessment must be reliable. Additionally, assessment of BF% must be accessible and easily applicable for prevention and individual self-care. The method that aims to guarantee both reliability and accessibility (and the most employed) is the body mass index (BMI) (Keys et al. 1972; World Health Organization 2000). However, BMI has been criticised (see below) (Deurenberg-Yap and Deurenberg 2003; Lewis et al. 2009; Nevill et al. 2011) despite the fact it has continuously shown to be a reliable predictor of BF% (Alves Junior et al. 2017). The present paper investigates the relation between BMI and BF% in children and adolescents to verify whether BMI can be employed as a predictor of BF%. The focus on children and adolescents is strategic given the long-term effects that high BF% at this stage of life has on the rest of life (Singh et al. 2008). Such a study is highly necessary as there are few studies to investigate the usage of BMI to discriminate body fat in children and adolescents (see Alves Junior et al. 2017).

We address three criticisms of BMI as a proxy for BF% (Lewis et al. 2009; Shahar 2009). First, studies demonstrate that BMI does not relate to BF% proportionally (Nevill et al. 2011), but as a second order polynomial (Jackson et al. 2002; Rothman 2008; Duncan et al. 2014) (large BMI values do not relate to increased BF%). Nevill et al. (2011) suggested the usage of iBMI (the inverse of BMI) to satisfy a linear relation to BF%. Second, Deurenberg-Yap and Deurenberg (2003) showed that the categories developed by the World Health Organization (2000) on nutritional status (underweight, normal range, overweight) inappropriately characterise/categorise persons' BF% from specific ethnic groups (Deurenberg-Yap and Deurenberg 2003; Mascie-Taylor and Goto 2007). For instance, Asian populations have a high prevalence of individuals with low BMI but high BF% (Deurenberg-Yap and Deurenberg 2003). Third, even for the "linear part" of the function relating BMI and BF%, BMI might be misleading. BMI can have variations that are not directly related to BF%; e.g., muscular individuals have increased BMI and lower BF%.

We also took into consideration the effect of socio-economic status (SES) or education (i.e., public/private). Given that both SES and education favour different behaviours (i.e., eating, exercising habits, etc.), we anticipate the relation between BMI (a function of weight and height) and BF% (a function of fat) to be modified (Mascie-Taylor and Goto 2007). In children and adolescents, external influence might be even more pronounced as individuals in this age range

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are economically and socially dependent (Aggarwal and Jain 2018).

In this short report, we assessed the relation between BMI and BF% while controlling for age, sex, education and SES. This was done by assessing which function (first or second order polynomial) would better capture the relation between BMI/iBMI and BF%. The non-proportional relationship discussed in the literature might not occur with adolescents (but see Ceccarelli et al. 2020; Duncan et al. 2014), as this was only related to (adults') high BMI values (Jackson et al. 2002; Rothman 2008; Nevill et al. 2011). Nevertheless, Duncan et al. (2014) reported better fit when considering iBMI to predict BF% in children (but see Singhal 2014). Thus, it might still be valid to consider other measures in this age group. Second, considering the WHO categories, we evaluated how many individuals would be miscategorised when considering the BMI measures. Third, we evaluated whether there were regions of the BMI/BF% relation on which the data becomes overly variable.

Methods

Sample

The sample size was calculated based on a 50% prevalence of overweight and obesity, with sampling error of two percent (confidence interval of 95%). This resulted in a sample of 4162 individuals (47% were females) from 9 to 18 years of age from private and public schools (54% of individuals were from public schools) from the city of Porto Velho. The city, capital of Rondônia state, is localised in the north region of Brazil. According to 2010 census data, Porto Velho has a population of 428,527 habitants and a human development index (HDI) of 0.756 (HDI of Brazil: 0.754).

The selection of participants occurred in three steps: stratified sampling proportional to number of schools per city region (north, south, east and west), school selection per region through random sampling proportional to the region; and random sampling of grades/classes where all students participated in the study. All procedures performed in the study were in accordance with the ethical standards of the ethics committee of Federal University of Rondônia (UNIR). Informed consent was obtained from all individual participants included in the study.

Procedures and data analysis

Data collection was performed between August 2013 and June 2014. The data collection team was composed of professors and staff of the Physical Education, Nursery and Medicine courses of the Federal University of Rondônia (UNIR).

BMI was determined using weight (*TANITA*®, Japan) and height measures (*Sanny*®, Brazil). The classification of nutritional status of children based on BMI was derived in two ways: from *z*-score cutting points (BMI $\geq$ 1 *z*-score and BMI $\geq$ 2 *z*-score for overweight and obesity, respectively) and from the resulting linear model between BMI and BF% (see below). The BF% was derived from triceps and subscapular skinfold measures considering sex, race, and sexual maturation (Slaughter et al. 1988). The skinfold measures were evaluated using a skinfold calliper (*Lange*®, USA) (1 mm resolution) with the following protocol: all measurements were done on the right side of the body with the body at rest in orthostatic position with the tissue being measured with the help of the thumb and index fingers. Two measurements were made for each anatomical site, with the average of the two considered for further analyses. For the triceps skinfold measurement, the anatomical reference was the posterior face of the arm mid-way between the scapular acromion and the ulnar olecranon. For the subscapular skinfold measurement, the anatomical reference was the point 2 cm below the scapular inferior angle with the participant with his arms at the side of the body. The cutting points for BF% categories were $30 \geq$ BF% $\geq$ 20 and BF% $>$ 30 for overweight and obese, respectively, for males; and $35 \geq$ BF% $\geq$ 25 and BF% $>$ 35 for overweight and obese, respectively, for females.

Table S1 (Supplementary File) provides the anthropometric characteristics of the sample. All measurements were performed by a previously trained single evaluator. The evaluator adopted the procedure of two consecutive measurements. If there were differences between the two, a third measurement was performed. Additionally, to estimate the technical measurement error, we followed Norton et al. (2005) and Perini et al. (2005). The evaluator and an experienced researcher collected the anthropometric measures of 20 volunteers and showed values of 3.5 and 4.2% for intra and 5.9% for inter-evaluators (the values had to be below 5% for intra and 7.5% for inter-evaluators).

SES was obtained through the Research Companies Brazilian Association questionnaire[1] that qualifies individuals as pertaining to high (A), medium-high (B), medium (C), medium-low (D) and low status (E).

We measured the normality of BMI, iBMI and BF% using the Kolmogorov-Smirnoff (KS) test. We tested the relation between BMI and iBMI with BF% using Linear Mixed Effects models, using the backward method to eliminate non-significant independent variables using the Bayesian Information Criterion (BIC) and reported the final models. The full models considered were a first and a second order polynomial with either BMI or iBMI as independent variables interacting with sex, age, SES and school type (private and public). All independent variables, except for school type, were considered as random variables (considering also correlation between variables) and the school attended was used as the grouping term (not to be confused with education type). All random variables were also tested in a backward method after the tests for the fixed variables. To compare between final models, we used the likelihood ratio tests and BIC. To verify the matching between BMI categories (using World Health Organization (2000), or z-scores, or the predictions from the fitted model) and BF% categories, we measured the percentage of misclassification and the Cronbach's α.

All analyses were performed in Matlab 2020b and significance was accepted at a level of $p < 0.050$.

Results

Figure S1 (Supplementary File) shows the distribution of BMI, iBMI and BF% as a function of age, sex, and school. BMI, iBMI and BF% deviates significantly from a normal distribution (BMI: KS = 0.97, $p < 0.001$; iBMI: KS = 0.50, $p < 0.001$; %BF: KS = 0.99, $p < 0.001$). Nevertheless, it should be noted that the iBMI transformation does shift the positively skewed BMI distribution closer to normality.

Tables 1 and Table S2 show the resultant equations for each LME fitting procedure. For BMI, the fit is similar between linear and quadratic functions, while the iBMI showed a higher influence of the second order element of the polynomial (see Figure S2).

From BIC values, the best fit was linear for BMI and quadratic for iBMI. This was confirmed by the Likelihood Ratio Tests (BMI: LRT [5] = −45.81; $p > 0.999$; iBMI: LRT [4] = 474.24; $p < 0.001$). Provided the quadratic iBMI function defeats the purpose of linearising the relation with BF%, we compared linear BMI (BIC = 27678) and linear iBMI (BIC = 28117) models and this showed better results for linear BMI (lower BIC).

The first order polynomial fitting for BMI showed that the relation between BF% and BMI had to be controlled by sex and age (see Table 1). Figure 1(a) shows BF% as a function of BMI and age for girls and boys. For boys there is a decrease in the intercept and increase in the slope with age–contrary to the girls that show a decrease in the slope. This means that increases in BMI reflect lower increases in BF% for boys than girls as they grow older (see also Figure 1b). The BMI x BF% relation varied considerably between schools as demonstrated by the grey curves. Figures 1(b,c) show the variability in predicted models and the variability of BF% per BMI, respectively. We observed that the difference between fitted curves was, on average, 14.23% of BF% when considering the model fitted considering age and sex. The variability is smaller when considering the standard deviation of the residuals of the model 6.49%.

Figure 1(d) shows the matching for the BMI and BF% categories. The WHO z-scores mismatch the actual categories as they classify as normal individuals who are overweight and obese. Using the model resulted in better results – as they are based on the collected data. Still, categorisation was poor. The percentage of misclassification was 63% and 42% for z-score BMI and the linear BMI model prediction, respectively. The Cronbach's α were 0.61 and 0.70 for z-score BMI and linear BMI model prediction, respectively.

Table 1. LME for the linear (1st order polynomial) and quadratic (2nd order polynomial) models using BMI (and covariates) to predict BF%.

BMI (1st order polynomial)			
BIC = 27682		R^2=0.70	
Fixed effects			
	Estimate (± S.E.)	t-stat (4158)	p Value
(Intercept)	15.56 (± 1.06)	14.64	<.001
BMI	2.13 (± 0.09)	23.15	<.001
Sex*Age	−1.59 (± 0.10)	16.19	<.001
Sex*BMI	0.63 (± 0.05)	12.71	<.001
Age*BMI	−0.06 (± 0.01)	4.56	<.001
random effects			
	Estimate	Lower	Upper
(Intercept)	3.41	1.98	5.86
BMI	0.12	0.07	0.20
Sex	2.42	1.64	3.56
Age	067	0.40	1.12
Residual	6.54	6.40	6.68
BMI (2nd order polynomial)			
BIC = 27767		R^2=0.70	
Fixed Effects			
	Estimate (± S.E.)	t-stat (4154)	p Value
(Intercept)	16.52 (± 0.72)	22.84	<.001
School	−3.69 (± 1.06)	3.48	<.001
Sex	−7.07 (± 1.00)	7.09	<.001
School*Age	0.43 (± 0.27)	1.63	.104
Sex*BMI	1.68 (± 0.25)	6.66	<.001
Age*SES	0.08 (± 0.04)	1.97	.049
Sex*Age*BMI	−0.28 (± 0.03)	9.48	<.001
Sex*BMI^2	−0.03 (± 0.01)	2.06	.039
Sex*Age*BMI^2	0.009 (± 0.002)	5.01	<.001
Random effects			
	Estimate	Lower	Upper
Sex	2.21	1.50	3.26
Age	0.59	0.38	0.91
BMI	2.22	1.60	3.09
BMI*BMI^2	−0.85	−0.97	−0.45
BMI^2	0.03	0.02	0.04
Residual	6.51	6.37	6.65

Discussion

In sum, we found that BMI has a linear relation with body fat percentage (even better than with the suggested linear transformation, iBMI [Jackson et al. 2002; Nevill et al. 2011; Duncan et al. 2014]) with residual error around 6.5% of total variability in BF%. Additionally, the categories derived from the WHO guidelines misrepresented over 60% of the individuals. In general, these results indicate that BMI is a reliable and valid proxy of BF% but the WHO categories misrepresent the nutritional status of individuals.

Keys et al. (1972) demonstrated that BMI was better than other measures but acknowledged that "body density measurement with an acceptable degree of accuracy remains a difficult and time-consuming procedure that could not be considered for routine use or for population surveys." Still, another measure was postulated, the iBMI. We found that BMI explained variability in the data better than the iBMI, which challenges previous studies (Jackson et al. 2002; Rothman 2008; Nevill et al. 2011). The differences could have occurred from the fact that these studies were based on adult populations. The argument for the iBMI was that there was a deviation from linearity at high values of BMI–a value typically above adolescent's BMI. Our findings also challenge Ceccarelli et al. (2020) and Duncan et al. (2014) who did not find differences or favoured, respectively, iBMI in comparison to BMI in Italian and Portuguese children, respectively. Ceccarelli et al. (2020) did not correct for sexual maturation in the BF% calculation (as we did) and had a smaller age range than our study, which might explain the differences between their results and ours. For the results of Duncan et al. (2014), it is worth discussing whether there are differences between iBMI and BMI–the reported difference of 0.2% in adjusted R^2 could have occurred by chance (see also Singhal 2014). Nevertheless, Duncan et al. (2014) data differs

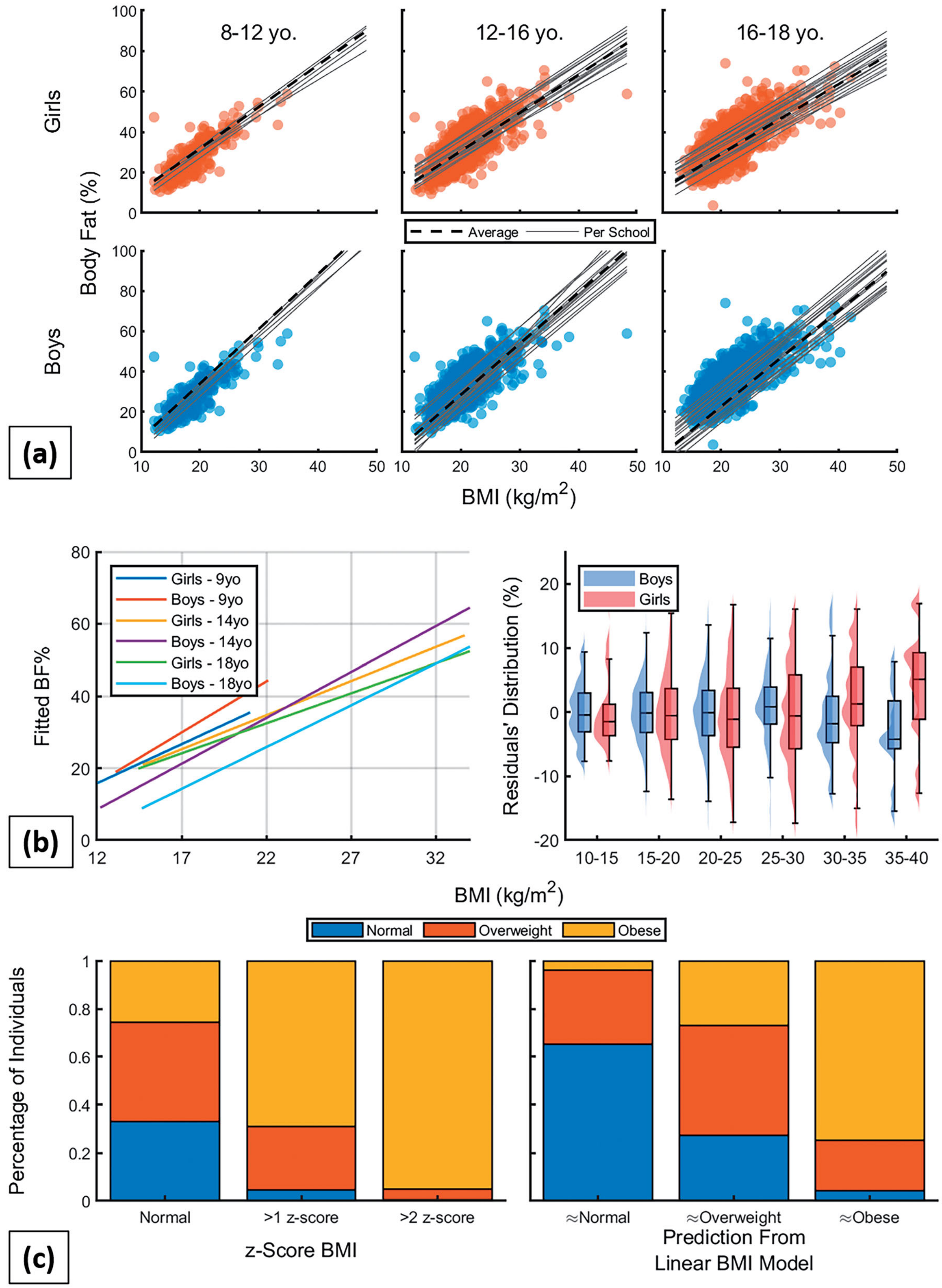

Figure 1. (a) Linear mixed effect (LME) model fitted per age group and sex. The plotted function (dashed line) used the median of the age per age group. (b – left) The different models relating BF% to BMI values considering age and sex. (b – right) Residuals' distribution of the fitted function as a function of BMI. (c) Mismatch between predicted and actual categories when considering BMI z-score (left) or prediction from the fitted model (right) in predicting categories from BF%.

from ours in that their BF% measure was derived from DEXA (but see Freedman et al. 2015).

Considering the residual standard deviation (from the BMI model), one could claim that 6.5% of residual standard deviation of BF% variance is overly large if one is to use this model to predict or monitor BF%, which we agree with (see the full distribution in Figure 1(b)). However, the variability when considering different individuals, *per se*, is not problematic. If the purpose is to follow trends of an individual over time, it is desirable that future research identifies typical and atypical weight gains within an individual in this population through increments of BMI or auxiliary measures (see Brannsether et al. 2017). Despite the fact that the issue of monitoring BMI is beyond the scope of the present paper, a full surveillance program (including health education principles for the population) is required for capturing the peculiarities of the population which would allow monitoring and "guiding" BMI trends (see Dietz et al. 2009).

Our results support the position that the BMI/BF% relation is not independent of the population being analysed (Deurenberg-Yap and Deurenberg 2003; Mascie-Taylor and Goto 2007). Since we found that different schools predicted different curves within a single city, we can imagine larger variation between states in such a vast country as Brazil. Interestingly, we did not find influences of SES or school type on the curve. It might be that the differences between schools represent how much each school meets public health recommendations rather than who attends it or whether it is paid.

Our investigation on the validity of categories developed by the World Health Organization (2000) demonstrated poor matching with BF%. Skinfold measures might not be perfectly in line with real values of BF% (but see Freedman et al. 2015), but we cannot dismiss the large disparity between BMI categories and actual nutritional status. If the World Health Organization (2000) guidelines do not hold in different populations, studies should identify specific cut-off values of BMI for each population. There is greater accuracy of matching results if, for instance, the ethnicity of the individuals is considered (Deurenberg-Yap and Deurenberg 2003). Nevertheless, it is debateable whether Brazil demonstrates such clear-cut ethnical origin.

The present study discloses the following limitations. First, the use of skinfold measures to capture BF% could have added some distortions on the outcome measure and, thus, can have influenced the results. Second, BF% as an outcome measure seems to be limited as its distribution is constrained (in the upper and lower bound) and might be confounded by the amount of lean tissue. In addition, we acknowledge that BF% might be limited in its relation with nutritional status/body composition and other transformations are needed to circumvent this (see Vanitallie et al. 1990). Note, however, that the usage of these procedures is related to a lengthy discussion in the literature and was considered here with that discussion in mind. These limitations did not preclude the study, however, to provide strong and compelling evidence in favour of a simple and accessible measure to relate to BF%, the BMI. Our final equation is simple and just requires sex, age, and the current BMI to track BF% (at least in the average). This is highly important to facilitate health monitoring and self-care.

In conclusion, this study demonstrated that, as a measure of assessment of body fat percentage, the BMI is more reliable than other proposed measures. Our results, then, provide confidence for the continued use of BMI to infer BF%, and provide a baseline for other studies within Brazil to compare their results. Moreover, within the state of Rondonia, our model can serve as an initial guideline for monitoring obesity in children. Given that other studies demonstrated non-linearities in BMI in relation to BF%, it is desirable for future studies to evaluate whether such a relationship is dependent on the age range studied or fundamental differences between populations. Also, even when controlling for several variables, large variation still exists around the predicted curve and, in agreement with the literature, the general categories of BMI hardly hold for this population.

Disclosure statement

The authors declare no conflict of interest.

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Note

1. Available at http://www.abep.org/criterio-brasil as of December 17, 2018.

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