

Performance of international growth references to assess nutritional status in a sample of adolescents from Northeastern Brazil

Desempenho das referências internacionais de crescimento para avaliar o estado nutricional em uma amostra de adolescentes do Nordeste do Brasil

Desempeño de referencias internacionales de crecimiento para evaluar el estado nutricional en una muestra de adolescentes del Nordeste de Brasil

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Abstract This study aimed to assess the obesity diagnostic accuracy based on body fat mass (FM) in a sample of adolescents from northeastern Brazil, and to compare their nutritional status classified by the height and body mass index (BMI) references from the World Health Organization (WHO/2007), Centers for Disease Control And Prevention (CDC/2000), International Obesity Task Force (IOTF/2012), Brazil (2006) and MULT (2023). We selected 256 adolescents (10-19y) from the city of Natal, Brazil. Their nutritional status was classified according to the growth references and the obesity classification and the diagnostic accuracy were performed according to their FM, obtained through the Dual-energy X-ray absorptiometry (DXA). The Bland-Altman method was used to verify the concordance among the growth references. The highest obesity prevalence (4.3%) was by applying WHO, CDC and Brazil and the highest critical difference (CD) was found between the BMI references of WHO and MULT (CD = 0.61). The MULT presented the highest values for sensitivity (0.98; 95%CI: 0.96-0.99) and positive likelihood ratio values (+LR) (4.88; 95%CI: 0.85-28.17). Therefore, it seemed to address contemporary growth trends, as it presented great accuracy for diagnosing obesity in this sample of adolescents from northeastern Brazil.

Key words Growth charts, Stature by age, BMI-age, Body composition, Adolescents

Resumo O estudo teve como objetivo avaliar a acurácia diagnóstica na detecção de obesidade a partir da massa gorda (MG) e comparar o estado nutricional classificado pelas curvas de altura e índice de massa corporal (IMC) da World Health Organization (WHO/2007), do Centers for Disease Control and Prevention (CDC/2000), da International Obesity Task Force (IOTF/2012), Brasil (2006) e MULT (2023) em uma amostra de adolescentes da região Nordeste. Foram selecionados 256 adolescentes (10-19 anos) da cidade de Natal, Brasil, classificados pelo estado nutricional de acordo com as curvas de referências. A classificação da obesidade e a acurácia diagnóstica foram estabelecidas de acordo com a MG, obtida por absorciometria de raios-X de dupla energia (DXA), e o gráfico de Bland-Altman foi utilizado para verificar a concordância entre as diferentes curvas de crescimento. A maior prevalência de obesidade (4,3%) foi classificada pela WHO, CDC e Brasil, e a maior diferença crítica (DC) foi encontrada entre as curvas de IMC da WHO e da MULT (CD = 0,61). A referência MULT apresentou a maior sensibilidade (0,98; IC95%: 0,96-0,99) e razão de verossimilhança positiva (RV+) (4,88; IC95%: 0,85-28,17). Portanto, apresentou excelente acurácia para diagnosticar obesidade nessa amostra de adolescentes.

Palavras-chave Gráficos de crescimento, Estatura-idade, IMC-idade, Composição corporal, Adolescentes.

Resumen Este estudio tuvo como objetivo evaluar la precisión diagnóstica en la detección de la obesidad con base en la masa grasa (MG) y comparar el estado nutricional clasificado por las curvas de altura e índice de masa corporal (IMC) de la World Health Organization (WHO/2007), Centers for Disease Control And Prevention (CDC/2000), International Obesity Task Force (IOTF/2012), Brasil (2006) y MULT (2023) en una muestra de adolescentes de la región nordeste. Se seleccionaron 256 adolescentes (10-19 años) de la ciudad de Natal – Brasil y fueron clasificados según el estado nutricional según las curvas de referencia. La clasificación de la obesidad y la precisión diagnóstica se realizaron según la FM, obtenida por absorciometría de rayos X de energía dual (DXA), y se utilizó el gráfico de Bland-Altman para verificar la concordancia entre las diferentes curvas de crecimiento. La prevalencia más alta de obesidad (4,3%) fue clasificada por la WHO, CDC y Brasil y la mayor diferencia crítica (DC) se encontró entre las curvas de IMC de la WHO y MULT (CD = 0,61). La referencia MULT mostró la mayor sensibilidad (0,98; IC95 %: 0,96-0,99) y razón de verosimilitud positiva (LR+) (4,88; IC95%: 0,85-28,17). Por lo tanto, mostró una excelente precisión en el diagnóstico de la obesidad en esta muestra de adolescentes.

Palabras clave Gráficas de crecimiento, Altura-edad, IMC-edad, Composición corporal, Adolescentes

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Introduction

Monitoring body mass and body fat mass (FM) throughout childhood and adolescence is crucial for identifying potential health and nutritional risks that may persist into adulthood¹⁻³. Body composition analysis plays a crucial role in detecting excessive body FM and mass, with Dual-energy X-ray absorptiometry (DXA) recognized as a reference technique for this purpose^{4,5}. However, despite its accuracy, DXA's widespread use in population studies is limited due to costliness and the need to carry out the tests in a specialized laboratory with trained staff^{6,7}.

In this way, the growth standards/references are the main tool for monitoring children and adolescents' nutritional status at a population level^{8,9}. This non-invasive and easily applicable method eliminates the need for expensive equipment¹⁰. Additionally, even though the BMI growth charts don't directly measure adiposity, they exhibit high sensitivity in detecting overweight and obesity, displaying a robust positive correlation with body fat^{11,12}. However, there are valid concerns about the development of these growth standards/references, particularly regarding their consideration of the complex interplay of environmental, genetic, and cultural factors influencing growth patterns between regions/countries¹³⁻¹⁵. Studies pointed out that growth can be affected by several factors including environmental, genetic predispositions, and socio-economic-political-emotional (SEPE) conditions¹³⁻¹⁶. Furthermore, cultural practices and dietary habits significantly shape growth trajectories, emphasizing the need for comprehensive and culturally sensitive approaches in developing growth standards/references¹⁵.

Several international growth standards/references have been widely utilized over the years^{8,9}. A growth standard represents the growth of a 'healthy' population, serving as a role model. Conversely, a growth reference outlines the growth patterns observed within a specific sample of individuals, reflecting their current growth trends¹⁷.

For instance, the 2006 World Health Organization (WHO)¹⁸ growth charts qualify as growth standards as they were developed based on a sample of health children with optimal health and nutrition conditions, including exclusive breastfeeding for at least three to four months of age^{8,18}. In contrast, growth charts from the Centers for Disease Control and Prevention (CDC, 2000)¹⁹, the WHO (2007)²⁰, and the International Task Obesity Force (IOTF, 2000/2012)^{21,22} are

considered growth references, as they capture growth patterns observed in various populations but may not necessarily represent an ideal standard^{8,17}.

In addition, to these well-known international growth references, there is the MULT growth reference (2023)^{23,24}, developed using longitudinal data from multiethnic children and adolescents across 10 countries, which has recently been released. Alongside these international growth references, there is the Brazil-specific BMI growth reference developed by Conde and Monteiro in 2006²⁵.

Furthermore, while these growth references play a crucial role in assessing nutritional status at the population level, there remains a lack of consensus regarding which one is most appropriate for Brazilians, particularly for adolescents^{8,9}. Therefore, the aim of this study was to compare the nutritional status classified by the height and BMI references from the CDC (2000)¹⁹, BRAZIL (2006)²⁵, WHO (2007)²⁰, IOTF (2012)²², and MULT (2023)^{23,24} and to evaluate their diagnostic accuracy in detecting obesity based on body adiposity in a sample of adolescents from northeastern Brazil.

Methods

Data from adolescents were obtained from a previous study carried out by researchers at the Federal University of Rio Grande do Norte (UFRN), Brazil, between January 2018 and April 2019⁶. That study aimed to develop and cross-validate fat-free mass (FFM) predictive equations using bioelectrical impedance analysis, with DXA as the reference method⁶. Its convenience sample consisted of 257 adolescents (128 girls), aged 10 to 19 years, from the city of Natal, Northeast Brazil, who were recruited through publicity among participants in university extension projects of the Physical Education Department of UFRN and two social projects maintained by the federal government⁶.

For this study, the total non-probabilistic sample of the previously carried out study was considered, therefore, we used the G*Power 3.1.9.7 package to calculate the power of the sample by the exact two-tailed test of comparison of proportions, adopting an effect size of 0.1, α error of 0.05, and constant proportion of 0.5^{6,26}. Thus, the calculated power of the sample was 0.88. Demographic data such as sex (determined by the presence or absence of the Y chromosome at birth), age (in months), anthro-

pometric measurements of weight and height, and body composition measurements based on DXA were selected⁶. These anthropometric and body composition examinations were performed by highly trained health professionals who followed a standardized examination protocol to ensure data quality^{4,6,27,28}. Additionally, all subjects were measured without personal belongings that could interfere with the anthropometric and DXA assessments^{6,27}. All data collections were conducted in a single visit by each participant to the laboratory to perform, after an overnight fasting, sequentially, anthropometric measurements, and DXA assessments⁶.

The whole-body composition analysis was conducted using the Lunar Prodigy equipment, NRL 41990 model (GE Lunar, Madison, WI, United States)⁶. The equipment was calibrated weekly, using the *Calibration Phantom*, according to the manufacturer's instructions⁶. Participants were scanned while lying supine along the longitudinal axis of the table⁶. Their feet were placed together and secured at the level of the fingers to immobilize the legs, while their hands were positioned in a prone position within the scanning region^{6,27}. Participants were instructed to remain still during the scanning process, and the staff followed the procedures recommended by the manufacturer and Nanna *et al.* (2015)^{4,6}.

The participants' body composition was estimated by the iDXA, version 13.6 enCore™ 2011 software (GE Healthcare Lunar, Madison, WI, USA), as described in a study involving a sample of Brazilian Army cadets^{6,29}. Total body measurements were conducted to assess FM, bone mineral content (BMC), and lean soft tissue (LST)^{6,29}. The FFM was calculated by the sum of the BMC and LST (FFM = BMC + LST) values^{6,29}. The reproducibility of the variables estimated by DXA was determined using the coefficient of variation (CV%) and the technical error of measurement (TEM)^{6,29}.

In the selection process, the quality data analysis was performed and participants with implausible height-for-age and/or BMI-for-age values were excluded ($n = 1$)³⁰. Implausible values were those below -6 standard deviations (SD) or above +6 SD of the WHO (2007) reference height values or those below -5 SD or above +5 SD of the WHO (2007) reference BMI values^{20,30}.

Concerning the obesity classification, the FM estimated by DXA was used to calculate a Fat Mass Index (FMI), as proposed by Kelly *et al.* (2009)³¹. The FMI is obtained by dividing the FM (kg) by the squared height (m)³¹. The obesity

classification according to the participant's FMI was performed based on the cut-off's values for FMI (percentile 95th) proposed by De Oliveira *et al.* (2023)³², while for the BMI was performed according to the values proposed by the CDC (2000)¹⁹, Brazil (2006)²⁵, WHO (2007)²⁰, IOTF (2012)²², and MULT (2023)²⁴ BMI references.

The diagnostic accuracy, defined as the proportion of all tests that give a correct result, was performed for the CDC (2000)¹⁹, Brazil (2006)²⁵, WHO (2007)²⁰, IOTF (2012)²², and MULT (2023)²⁴ BMI growth references based on the obesity diagnostic classified by the FMI^{31,32}. Furthermore, sensitivity, specificity, and positive and negative likelihood ratios (+LR/-LR) were calculated in R using the epiR package, with a significance level of 5% and a 95% confidence interval^{33,34}.

In order to compare the growth references, the prevalence of normal height and stunting was estimated applying the height references from CDC (2000)¹⁹, WHO (2007)²⁰, and MULT (2023)²³. Moreover, the prevalence of underweight, normal weight, overweight, and obesity was calculated according to the BMI reference values of the CDC (2000)¹⁹, Brazil (2006)²⁵, WHO (2007)²⁰, IOTF (2012)²², and MULT (2023)²⁴. For the MULT (2023)²⁴ BMI reference, the optimized cut-off points³⁵ were applied for both sexes: a) underweight for percentile < 3rd; b) overweight for percentile $\geq 85^{\text{th}}$; c) obesity for percentile $\geq 98^{\text{th}}$. To assess the agreement between the CDC (2000)¹⁹, Brazil (2006)²⁵, WHO (2007)²⁰, IOTF (2012)²², and MULT (2023)^{23,24} growth references, the Bland-Altman³⁶ plots were performed based on the z-scores of BMI and height. All these statistical analyses were performed in R software version 4.2.3 for macOS³⁷.

Regarding ethical aspects, the Natal survey was conducted according to the ethical principles for research involving human subjects, laid down in the Declaration of Helsinki and the Brazilian resolution CNS 466/12^{38,39}. It was approved by the Research Ethics Committee of the University Hospital Onofre Lopes – HUOL/UFRN under number 34804414.7.0000.5292⁶. The legal guardians of the adolescents were informed about the research and gave their consent for participation by signing the Informed Consent Form (ICF)⁶. In addition to that, the participants themselves, if capable of understanding, also signed an assent form⁶. The details of these protocols, as well as their approvals from the ethics committees, can be found in previous studies^{6,27,40}.

Results

After excluding implausible values, 256 subjects (50.0% males) were included in the analysis. The demographic characteristics of the sample are shown in Table 1.

Regarding diagnostic accuracy, as shown in Table 2, the IOTF (2012)²² obesity percentiles presented the lowest values for specificity (0.60; 95%CI:0.15-0.95) and +LR (2.44; 95%CI: 0.83-7.14). Further, MULT (2023)²⁴ presented the highest values for sensitivity (0.98; 95%CI: 0.96-0.99) and +LR (4.88; 95%CI: 0.85-28.17), and CDC (2000)¹⁹, Brazil (2006)²⁵, and WHO (2007)²⁰, presented the same values for sensitivity (0.97; 95%CI: 0.94-0.99) and +LR (4.86; 95%CI: 0.84-28.06).

The nutritional status of the participants is presented in Figures 1 and 2. The prevalence of stunting was higher applying the height references from CDC (2000)¹⁹ (9.0%), and MULT (2023)²³ (8.6%) when compared to the WHO

(2007)²⁰ (3.9%). On the other hand, the highest underweight prevalence (7.8%) was achieved by applying the CDC (2000)¹⁹ BMI growth chart, and the highest obesity prevalence (4.3%) was by applying the WHO (2007)²⁰, CDC (2000)¹⁹ and Brazil (2006)²⁵ BMI growth charts. The IOTF (2012)²² reference presented the lowest prevalence of obesity (3.5%), and the MULT (2023)²⁴ BMI reference showed the lowest prevalence for underweight (2.3%).

In the agreement analysis (Figure 3), the Bland-Altman plots showed the lowest critical difference (CD) between the height references of WHO (2007)²⁰ and MULT (2023)²³ (CD = 0.30). For BMI, the lowest CD was between the MULT (2023)²⁴ and IOTF (2012)²², and the highest was between WHO (2007)²⁰ and MULT (2023)²⁴ (CD = 0.61). Moreover, the difference between MULT (2023)²³ and WHO (2007)²⁰ height references presented a negative tendency, while the difference between MULT (2023)²⁴ and WHO (2007)²⁰ BMI references presented positive values in the right extremity.

Discussion

This study presented valuable insights into the nutritional diagnosis based on body composition analysis in a sample of adolescents from northeastern Brazil. Notably, the MULT (2023)²⁴ BMI reference demonstrated its relevance, especially in establishing obesity cutoffs, presenting the best diagnostic accuracy among the BMI growth references for this sample.

When compared to WHO (2007)²⁰ growth reference, the MULT (2023)²³ presented a higher height median, leading to a correspondingly higher prevalence of stunting. These findings are similar to the studies conducted in European countries and Australia, which also have

Table 1. Demographic characteristics of the study population sample.

Age (years)	Male		Female	
	n	%	n	%
10y	20	7.8	19	7.4
11y	29	11.3	28	10.9
12y	19	7.4	13	5.1
13y	18	7.0	14	5.5
14 to 15y	13	5.1	11	4.3
16 to 17y	11	4.3	7	2.7
18 to 19y	18	7.0	36	14.1
Total	128	50	128	50

y: years; n: number of subjects; %: percentage.

Source: Authors.

Table 2. Sensitivity, specificity, diagnostic accuracy, and the positive and negative likelihood of the five BMI references.

Overall (n = 256)	Sensitivity	95%CI	Specificity	95%CI	+LR	95%CI	-LR	95%CI	Diagnostic accuracy	95%CI
CDC (2000) ¹⁹	0.97	0.94-0.99	0.80	0.28-0.99	4.86	0.84-28.06	0.03	0.01-0.08	0.97	0.94-0.99
BRAZIL (2006) ²⁵	0.97	0.94-0.99	0.80	0.28-0.99	4.86	0.84-28.06	0.03	0.01-0.08	0.97	0.94-0.99
WHO (2007) ²⁰	0.97	0.94-0.99	0.80	0.28-0.99	4.86	0.84-28.06	0.03	0.01-0.08	0.97	0.94-0.99
IOTF (2012) ²²	0.98	0.95-0.99	0.60	0.15-0.95	2.44	0.83-7.14	0.04	0.05-0.85	0.97	0.94-0.99
MULT (2023) ²⁴	0.98	0.96-0.99	0.80	0.28-0.99	4.88	0.85-28.17	0.03	0.01-0.07	0.97	0.94-0.99

n: number of subjects; 95%CI: 95% confidence interval; +LR: positive likelihood ratio; -LR: negative likelihood ratio.

Source: Authors.

noticed this pattern, indicating that children and adolescents in these regions displayed taller stature than those referenced in the WHO (2007)²⁰ height reference⁴¹⁻⁴³.

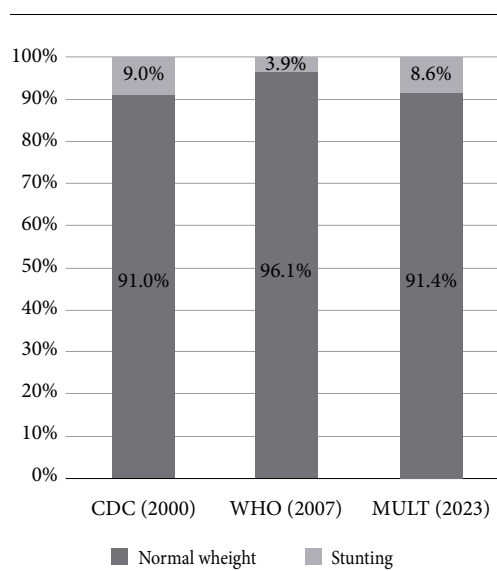


Figure 1. Prevalence of stunting of the three international height references.

Source: Authors.

Additionally, research conducted by the NCD Risk Factor Collaboration (NCD-RisC/2020) across 200 countries and territories reveals that emerging economies have experienced the most significant growth in height over the last three decades⁴⁴. This positive trend in height in developing nations is due to improvements in their healthcare systems and socioeconomic conditions^{18,20,45}. This explains why height references based on data from children born before the 1990's, like those from CDC (2000)¹⁹ and WHO (2007)²⁰, tend to show lower median heights in contrast to references derived from more recent decades. MULT (2023)²³ height reference offers an advantage over the WHO (2007)²⁰ reference because it was developed using height data from multiethnic children born more recently, potentially overcoming the secular trend in height.

Regarding obesity classification, even though there were no significant variations among the growth references in this study, the MULT (2023)²⁴ BMI reference showed the most optimal performance. This observation aligns with findings from a previous study we conducted, which assessed international growth references for diagnosing obesity in schoolchildren from Santos, Brazil⁴⁶. In that study, the MULT (2023)²⁴ BMI reference presented the best +LR and - LR combination based on body

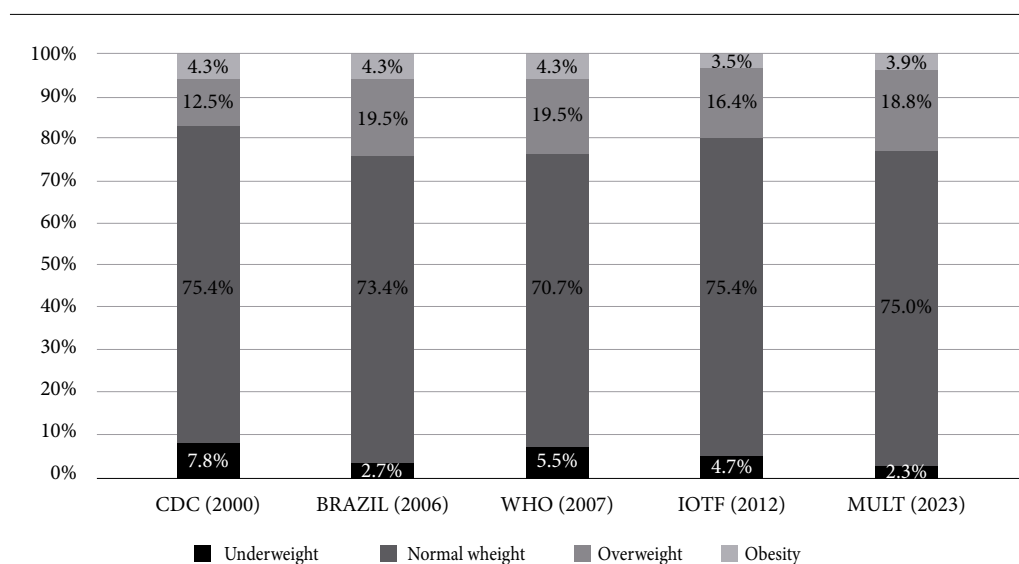


Figure 2. Nutritional status classification of the five BMI references.

Source: Authors.

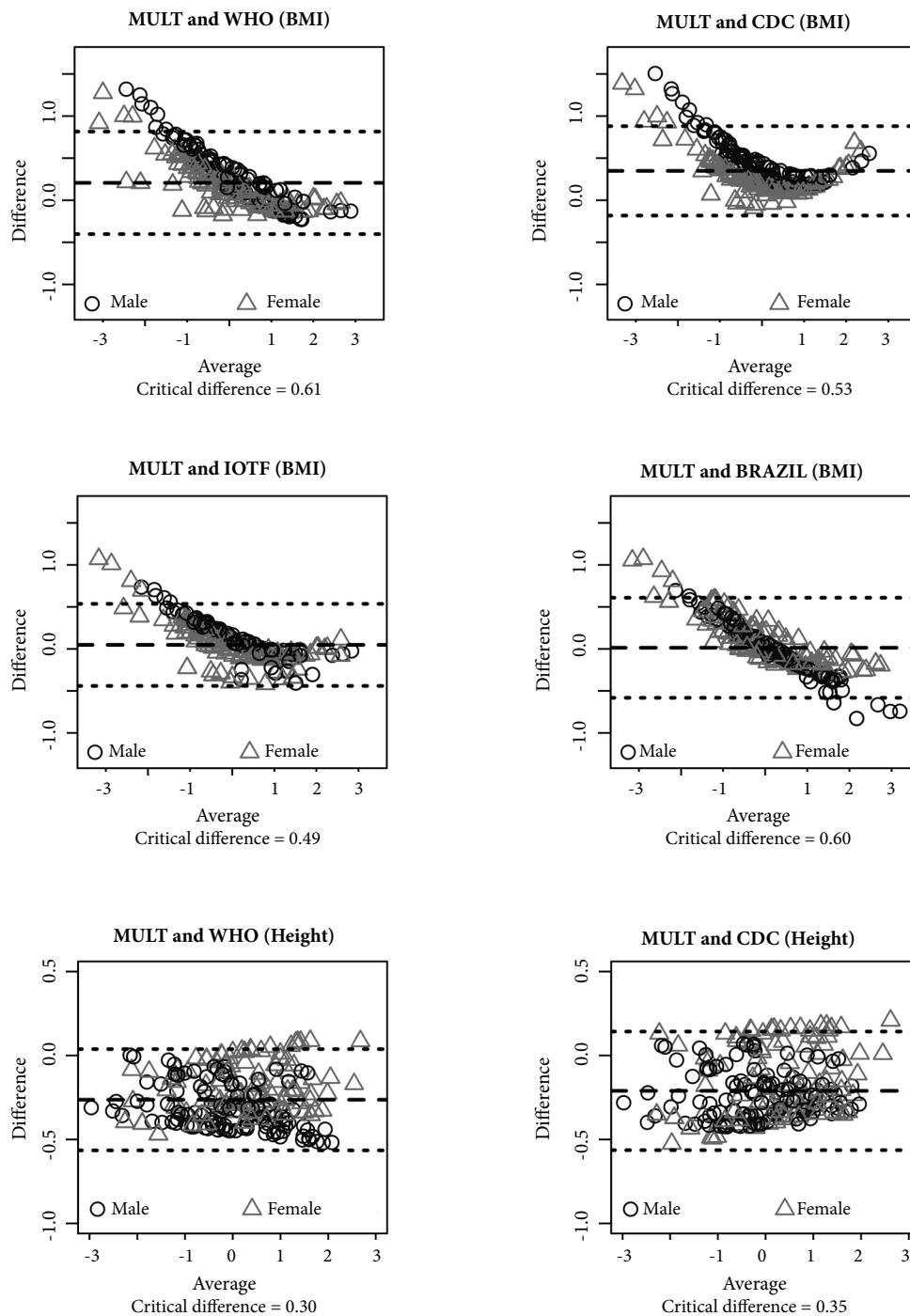


Figure 3. Bland-Altman plot for comparing the five growth references.

Source: Authors.

fat mass evaluated via skinfold measurements⁴⁶. Additionally, another study involving school-children and adolescents from the United States highlighted that among international BMI

growth references, the MULT (2023)²⁴ exhibited the highest diagnostic accuracy for identifying obesity based on fat mass index (FMI) calculated using DXA³².

Moreover, while the CDC recommends its own growth reference for children and adolescents aged 2 to 19 years in the United States, there is evidence that the CDC (2000)¹⁹ BMI growth reference overestimates the prevalence of obesity in certain populations, such as student-athletes aged 11 to 19 years⁴⁷. Similar prevalence overestimations have been noted in other countries, including South Africa and Saudi Arabia^{48,49}.

The Brazil (2006)²⁵ BMI reference presented similar performance to the WHO (2007)²⁰ reference, which is consistent with the findings of a study conducted with a national sample of adolescents aged from 11 to 17 years old from the five Brazilian regions⁵⁰. In that national study, the authors observed that the Brazil (2006)²⁵ and WHO (2007)²⁰ presented a close prevalence for overweight (Brazil = 20.6%; WHO = 20.1%)⁵⁰. Another study conducted with schoolchildren aged 7 to 10 years old from the city of Florianópolis, Brazil also found similarities on the performance of the BRAZIL (2006)²⁵ and WHO (2007)²⁰ in detecting excess body fat⁵¹. It suggested that the classification accuracy could be improved by refining cutoffs, which is an advantage of the IOTF (2012)²² and MULT (2023)²⁴ classification systems⁵¹. These systems use the adult BMI cutoff value of 30 kg/m² to establish the obesity percentile at the final age, aligning with a well-known adult risk factor for non-communicable diseases and making the transition from adolescence to adulthood smoother^{22,24,52}.

However, while the IOTF (2012)²² BMI reference has been recommended for worldwide use and has shown good accuracy for the European population, it exhibited relatively lower +LR for our sample. This discrepancy could be attributed to the composition of IOTF (2000/2012)^{21,22} population sample, as it lacks representation from African countries, which may impact its coefficient of variation. Additionally, the IOTF's age limit of 2 to 18 years may be a limitation, as there is evidence of growth beyond 18 years, particularly for boys^{21,22,53}.

The major strengths of this study include the use of anthropometric data collected by trained health professionals, aimed at reducing measurement errors and social desirability bias, as

well as the use of DXA to assess body composition, considered a reference method for estimating fat mass⁴. However, limitations include a small, non-representative sample, only from one capital in the Northeastern region of the country, in addition to the absence of a reference to determine obesity in children and adolescents based on body composition, underscoring the need for further validation of FMI use and appropriate cutoffs for obesity³². Although this study has limitations regarding the sample, it is important to highlight that we conducted DXA examination, which provides great accuracy in diagnosing body fat⁴. Due to its high cost, DXA is rarely used in large-scale population studies, underscoring the significance and quality of this study, even though its conclusions cannot be generalized regionally or nationally^{4,54}.

Furthermore, a systematic review underscored the ongoing increase in overweight and obesity prevalence among Brazilian adolescents, highlighting the crucial need for effective nutritional surveillance in the country⁵⁵. Our study contributes to this by evaluating the accuracy of existing growth charts in detecting obesity, based on DXA, which is a reference method. Thus, this emphasizes the relevance of the MULT (2023)²⁴ growth reference in diagnosing the nutritional status of adolescents based on body composition. However, it also suggests that further research is essential to validate its effectiveness on a broader scale for diagnosing obesity among children and adolescents nationally and internationally.

In summary, this study underscores the practical applications of MULT growth references (2023)^{23,24} in shaping public health policies. Developed using data from multiethnic children born more recently (1990s-2000s), presenting growth charts from birth to 20 years old for height and BMI, and demonstrating remarkable accuracy for diagnosing obesity, it seems to reflect the contemporary growth trends^{32,46}. In this way, by incorporating the MULT (2023)^{23,24} growth reference into nutritional surveillance programs, healthcare practitioners and policymakers can more effectively identify at-risk populations and tailor interventions to address the ongoing challenges of stunting, overweight and obesity.

Collaborations

MH Oliveira conceptualized the study, conducted the statistical analysis, and drafted the manuscript. G Ferrari, BGAT Cabral, and PMS Dantas contributed to writing and reviewing the manuscript. RF Costa supervised the statistical analysis and critically revised the manuscript. All authors approved the final manuscript.

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