Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

Accuracy of body fat predictive equations in adolescent boys using deuterium dilution method as reference: comparisons across nutritional and physical activity profiles

Thabata Weber

thabata.k.weber@unesp.br

UNESP, Botucatu, SP, Brazil https://orcid.org/0000-0001-5588-4235

Martina Bassani Lins De Miranda

São Paulo State University https://orcid.org/0000-0001-9704-1412

Beatriz Moreira Magiore

São Paulo State University

Juliana Célia Denadai

São Paulo State University

Joel Mesa Hormaza

São Paulo State University

Michele N. Ravelli

Institute of Oncology Research

Vladimir Eliodor Costa

Stable Isotopes Center

Article

Keywords:

Posted Date: June 11th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-9695844/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: There is **NO** conflict of interest to disclose.

Abstract

Background/Objectives: Accurate assessment of body fat percentage (%BF) is vital for managing obesity in adolescents. We aimed to compare the accuracy of skinfold-based predictive equations (PE) and bioelectrical impedance analysis (BIA) against the deuterium dilution method (DDM) in Brazilian male adolescents with diverse nutritional and physical activity profiles.

Subjects/Methods: A cross-sectional study was conducted with 30 male adolescents (14–19 years), categorized as eutrophic non-athletes (n=14), eutrophic athletes (n=9), or non-athletes with obesity (n=7). %BF was estimated via BIA and five predictive equations (Guedes, Petroski, Sloan, Forsyth, and Slaughter). Agreement was assessed using Bland–Altman analysis, Pearson's correlation, and Lin's concordance correlation coefficient (CCC).

Results: The Slaughter equation based on subscapular and triceps skinfolds (Slaughter SS) showed the best agreement with DDM across all groups (mean bias: 0.9%; 95% CI: -8.52 to 10.33%; CCC: 0.89). BIA demonstrated strong concordance in non-athletes and athletes eutrophic groups (CCC = 0.85) but overestimated %BF in non-athletes individuals with obesity (mean bias: 5.89%). Equations by Guedes, Sloan, and Petroski exhibited significantly higher bias and lower concordance in the group with obesity.

Conclusions: The Slaughter SS equation is the most reliable field method for %BF estimation in this population. BIA is a practical alternative for adolescents with normal body weight but lacks accuracy in those with higher adiposity.

1. Introduction

Accurate assessment of body composition is fundamental in research related to health, nutrition, and physical performance, particularly during adolescence. This life stage represents a critical window of growth and maturation, characterized by significant physiological and behavioral changes that directly influence body composition and how it is measured [1]. In Brazil, the increasing prevalence of obesity alongside rising sedentary behaviors among adolescents further underscores the importance of reliable and context-appropriated assessment methods [2].

A comprehensive evaluation of body compartments, such as total body water (TBW), fat-free mass (FFM), and fat mass (FM), provides important insights into the relationship between nutritional status, physical activity, and risk of metabolic disorders. These data are essential not only for clinical decision-making but also for informing interventions in both healthcare and athletic settings.

Several methodologies are available for assessing body composition; however, they vary considerably in terms of complexity, cost, accuracy, and applicability in field-based conditions [3]. The deuterium dilution method (DDM) is widely recognized as the gold standard to estimate TBW. Once TBW is determined, FFM can be derived, which in turn allows for the estimation of FM and body fat percentage (%BF) using age and sex-specific hydration coefficients (ref). This method is particularly advantageous in adolescent

populations due to its robustness against physiological variations, such as fluctuation in hydration status and water distribution, which frequently occur during this developmental stage. By accounting for these factors, DDM helps to minimize potential biases that may compromise the accuracy of indirect body composition assessment techniques [4].

Although highly accurate, the DDM presents certain limitations, such as the requirement for specialized laboratory infrastructure, trained personnel, and complex logistical procedures. These requirements restrict its use in large-scale epidemiological studies and field-based settings [5].

Given these constraints, indirect and field-based techniques, such as bioelectrical impedance analysis (BIA) and predictive equations (PE) derived from skinfold measurements, are commonly used to estimate %BF, across research, clinical, and athletic contexts. These approaches provide practical and cost-effective alternatives for estimating body composition; however, their accuracy may be influenced by pre-assessment conditions, as well as individual demographic and physiological characteristics [6, 7]. The reliability of PE, in particular, may vary according to the individual's profile (whether eutrophic, athletic, or with obesity), as well as the evaluator’s proficiency at collecting precise skinfold data, highlighting the importance of cross-validating such methods against gold-standard techniques across diverse populations and contexts [8, 9].

Given this scenario, the present study aims to compare the accuracy of commonly used in clinical methods, specifically skinfolds PE and BIA, against the DDM for estimating body fat percentage in male adolescents in Brazil. This comparison seeks to inform the selection of the most appropriate methods for this population, thereby improving the precision of research outcomes and the effectiveness of both health and sport-related interventions, while supporting the development of context-specific recommendations for clinical and epidemiological practice in adolescent health.

2. Materials and Methods

2.1. Subjects

This cross-sectional study included a sample of 30 male adolescents aged 14 to 19 years, recruited from the cities of Botucatu and Taboão da Serra, in the state of São Paulo, Brazil. Subjects were categorized into three distinct groups based on nutritional status and physical activity level: eutrophic non-athletes (n = 14), athletes (n = 9), and non-athletes with obesity (n = 7). Nutritional status was classified using BMI-for-age z-scores according to the World Health Organization (WHO) growth reference standards, with obesity defined as a z-score greater than + 2 [10]. Adolescents were considered athletes if they engaged regularly in structured training and participated in competitive football matches as members of a regional youth team.

All subjects underwent body composition assessment through skinfold-based anthropometry, deuterium dilution method (DDM) and BIA. Saliva samples were collected immediately after the BIA procedure, at which point the deuterium oxide (D_2O) dose was administered.

Were excluded individuals that had chronic medical conditions, used medications that could affect body water balance, or declined to provide biological samples required for isotopic analysis.

2.2. Ethics

The research protocol was conducted according to the principles of the Declaration of Helsinki and approved by the Human Research Ethics Committee of The Medical School (FMB) of São Paulo State University (UNESP), under approval number 7.393.628. Written consent was obtained from a parent or legal guardian.

2.3Skinfold-based anthropometry

Anthropometric evaluations included measurements of body weight, height, and multiple skinfold thicknesses (SKF) and circumferences (C). All anthropometric assessments were conducted by a single trained evaluator using the same skinfold caliper throughout the entire study, to minimize intra- and inter-observer variability and ensure methodological consistency [6].

Predictive equations commonly employed to the adolescent population were used to estimate body fat percentage from anthropometric data. These included equations developed by, Guedes, 1995 [11], Petroski, 1996 [12], Sloan et al., 1967 [13], Forsyth & Sinning, 1973 [14] and Slaughter et al., 1988 [8], according to information presented in Table 1. The selection of these equations was based on their applicability to adolescent populations, in line with the World Health Organization definition of adolescence (10–19 years). A comprehensive set of anthropometric variables was collected to apply these equations, including: calf C, calf SKF, thigh SKF, midaxillary SKF, triceps SKF, abdominal SKF, suprailiac SKF, subscapular SKF and arm C. Each measurement was taken in triplicate, with the mean value used in the calculations.

Table 1
Summary of skinfold predictive equations

Reference	Target population range	Equation
Guedes, 1995 [11]	17–27 years	BD = 1.1714 − 0.0671 × Log_{10}(triceps + suprailiac + abdominal)
Petroski, 1996[12]	18–61 years	BD = 1.10726863 − 0.00081201 × (subscapular + triceps + suprailiac + calf C) + 0.00000212 × (subscapular + triceps + suprailiac + calf C) − 0.00041761 × (age)
Sloan *et al.*, 1967[13]	18–26 years	BD = 1.1043–0.001327 × (thigh) − 0.001310 × (subscapular)
Forsyth & Sinning, 1973[14]	14–19 years (athletes)	BD = 1.10647 − 0.00162 × (subscapular) − 0.00144 × (abdominal) − 0.00077 × (triceps) + 0.00071 × (midaxillary)
Slaughter *et al.*, 1988 [8]	Children and adolescents	%BF = 0.735 × (triceps + calf SKF)
		[(a)] %BF = 0.783 × (triceps + subscapular) + 1.6
		[(b)] %BF = 1.21 × (triceps + subscapular) − 0.008 × (triceps + subscapular)^2 − 3.4
		[(c)] %BF = 1.21 × (triceps + subscapular) − 0.008 × (triceps + subscapular)^2 − 5.5

[(a)] for the sum of triceps and subscapular skinfold thickness > 35 mm; [(b)] for the sum of triceps and subscapular skinfold thickness < 35 mm and age < 16; [(c)] for the sum of triceps and subscapular skinfold thickness < 35 mm and age ≥ 16;

Body fat percentage (%BF) was estimated from body density (BD) using the Siri equation [15]. Age-specific constants were applied to account for physiological differences during adolescence: %BF = (507/BD) – 464, for participants aged 13–14 years, %BF = (503/BD) – 459, for those aged 15–16 years, and %BF = (498/BD) – 453, for those aged 17–19 years.

2.4 Deuterium dilution method

Each subject provided a baseline saliva sample, followed by ingestion of an oral dose of deuterium oxide (D_2O) of 0.12 g/kg of body weight, with a purity of 99.8 atm%. After a four-hour equilibration period, a second saliva sample was collected. During the equilibration period, subjects remained in the study location, with no food or water intake [16].

All samples underwent cryogenic distillation and were analyzed using isotope ratio mass spectrometry (IRMS) to determine deuterium enrichment. The analytical system consisted of a high-temperature conversion elemental analyzer (Flash HT) with reverse-flow configuration, equipped with an automatic

liquid sampler (AS3000), coupled to an isotope ratio mass spectrometer (Delta V Advantage) via a gas interface (ConFlo IV), all from Thermo Scientific®, Bremen, Germany. For each analysis, 0.1 µL of the sample was injected, with a helium flow rate of 90 mL/min into the reactor. To avoid memory effects, each sample was analyzed five consecutive times, and the first measurement was discarded.

Deuterium/hydrogen (D/H) ratios were expressed as relative abundance (xD), calculated according to the standard isotopic ratio VSMOW-SLAP and expressed in ppm [17]. Results were normalized using the three-point anchoring method with water standards (IAEA-607, VSMOW2 and SLAP2), performed after every set of twenty-five samples. For final calculations, the average of the remaining four replicates was used [18].

2.5. Bioelectrical impedance analysis

Body composition was assessed using bioelectrical impedance analysis (BIA), performed with a Biodynamics® Model 450 (Biodynamics Corp., Shoreline, WA, USA) device under standardized conditions. These included a minimum fasting period and a brief resting phase prior to measurement to ensure fluid balance. Assessments were conducted with participants in the supine position, with arms and legs relaxed and not touching each other. Electrodes were placed on the dominant side of the body. Four surface electrodes were positioned on the dorsal side of the hand and foot—specifically, proximal to the metacarpophalangeal joint, between the distal prominences of the radius and ulna, and between the medial and lateral malleoli, respectively [19].

2.6. Statistical analysis

Descriptive statistics were calculated for all body composition estimates. Agreement between field methods (predictive equations and BIA) and the reference method (deuterium dilution) was assessed using Bland–Altman analysis. [20]. To explore potential variations in performance across subgroups, analyses were stratified by nutritional status and physical activity level. Additionally, Pearson's correlation coefficient and Lin's concordance correlation coefficient (CCC) were computed to evaluate both linear association and agreement between methods [21, 22]. Statistical analyses and plots were performed using R software version 5.4.1 (R Foundation for Statistical Computing, Vienna, Austria).

Additionally, the authors used the Large Language Model (LLM) Gemini (Google) to assist in manuscript formatting and language refinement according to the journal's guidelines. The authors take full accountability for the content and accuracy of the work.

3. Results

The overall sample consisted of 30 male adolescents, with a mean age of 17.43 ± 1.58 years, mean body weight of 83.71 ± 26.20 kg, and height of 1.75 ± 0.08 m. Table 2 presents the anthropometric and body composition characteristics of the participants, including values obtained by skinfold-based predictive equations, bioelectrical impedance analysis, and the deuterium dilution method, organized by groups according to nutritional status and physical activity level.

Table 2
Descriptive values (Mean ± SD and Range) of body fat percentage (%BF) obtained by different methods in eutrophic non-athletes, athletes, and non athletes with obesity subjects.

	Eutrophic non-athletes (n = 14)		**Athletes (n = 9)**		**Non-atheletes with obesity (n = 7)**	
	Mean ± SD	**Range**	**Mean ± SD**	**Range**	**Mean ± SD**	**Range**
%BF DDM	17.41 ± 4.33	10.82–24.63	12.84 ± 5.67	7.04–24.49	35.61 ± 6.67	24.53–43.57
%BF BIA	13.15 ± 4.66	8.07–24.23	13.58 ± 4.28	8.45–20.11	29.72 ± 6.67	20.52–40.15
%BF Guedes	12.16 ± 4.66	5.07–22.18	7.53 ± 4.19	4.34–16.00	21.46 ± 3.46	14.42–24.83
%BF Petroski	24.05 ± 4.85	18.95–36.80	19.47 ± 3.80	15.66–26.62	39.25 ± 7.08	28.91–49.69
%BF Sloan	11.83 ± 4.84	4.79–22.36	7.31 ± 2.40	4.81–11.02	24.22 ± 8.63	14.59–37.19
%BF Forsyth	13.41 ± 6.89	4.84–32.16	7.63 ± 3.13	4.68–13.46	29.69 ± 7.38	16.36–40.02
%BF Slaughter C (calf)	17.00 ± 6.58	8.35–28.20	13.50 ± 5.82	8.35–25.26	28.72 ± 7.68	20.85–42.90
%BF Slaughter SS (subscapular)	16.77 ± 6.79	8.88–32.14	12.50 ± 5.93	6.84–24.21	33.66 ± 7.32	25.03–43.88

For eutrophic non-athlete adolescents, the Slaughter et al. (1988) equation using calf and triceps skinfolds (Slaughter C) (Fig. 1D) demonstrated the best agreement with the reference method, with a bias of 0.41% and a standard deviation (SD) of 6.13%. The narrowest limits of agreement (–11.61% to 12.42%) further support its relative accuracy. The Slaughter et al. (1988) equation based on subscapular and triceps skinfolds (Slaughter SS) (Fig. 1E) also performed well (0.64 ± 6.61%). In contrast, the Sloan et al. (Fig. 1F) and Guedes (Fig. 1B) equations showed higher positive biases (5.58 ± 5.33% and 5.25 ± 4.75%, respectively), while the Petroski (1996) equation (Fig. 1C) markedly overestimated body fat percentage (–6.63 ± 5.01%), indicating poor agreement with the isotopic method. Additionally, BIA (Fig. 2B) showed satisfactory agreement in this group, with a bias of 4.26 ± 4.13% and moderate variability.

Among athletes, the Slaughter SS equation yielded the best performance, with the lowest bias (0.34 ± 2.52%) and the tightest agreement limits (–4.61% to 5.28%). The Slaughter C equation also performed acceptably (–0.66 ± 2.36%), whereas the Petroski (1996) equation continued to substantially

overestimate %BF (−6.63 ± 4.44%). BIA also performed well among athletes, with a bias of − 0.74 ± 2.72%, indicating good agreement with the deuterium dilution method.

For non-athletes with obesity adolescents, the Slaughter SS equation maintained the best agreement, with bias of 1.95 ± 2.20% and limits of agreement from − 2.36% to 6.26%. The Forsyth & Sinning (1973) equation followed (Fig. 1A), with a higher positive bias (5.92 ± 3.47%). Other equations, such as Guedes (1995), Sloan et al. (1967), and Slaughter C, showed pronounced underestimation of %BF, with biases of 14.14%, 11.39%, and 6.88%, respectively. The Petroski (1996) equation was the only one to overestimate body fat in this group (−3.64 ± 3.08%). In contrast to the other groups, BIA overestimated %BF in non-athletes with obesity adolescents (Fig. 2B), with a bias of 5.89 ± 3.10%, indicating lower accuracy in individuals with higher adiposity.

Concordance between the %BF estimates obtained from skinfold equations and BIA, compared with the %BF measured by the DDM was evaluated using Lin's concordance correlation coefficient (CCC), where a value of 1.00 indicates perfect concordance. Concordance was classified as negligible (0.00–0.10), weak (0.10–0.39), moderate (0.40–0.84), strong (0.85–0.95), and very strong (0.96–1.00). BIA showed strong concordance with DDM (CCC = 0.85), indicating good agreement **(**Fig. 2A**)**. Among the anthropometric equations, Slaughter SS demonstrated the highest concordance (CCC = 0.89), also classified as strong **(**Fig. 3E**)**. The other equations showed moderate concordance: Forsyth & Sinning (CCC = 0.79) **(**Fig. 3A**)**, Slaughter C (CCC = 0.77) **(**Fig. 3D**)**, Petroski (CCC = 0.76) **(**Fig. 3C**)**, Sloan et al (CCC = 0.65) **(**Fig. 3F**)**, and Guedes (CCC = 0.56) **(**Fig. 3B**)**.

Overall, the Slaughter SS equation consistently demonstrated the best performance across the evaluated groups, while BIA emerged as a viable alternative, particularly among non-athletes and athletic adolescents, its accuracy decreased in individuals with higher adiposity.

4. Discussion

In this study, the deuterium dilution technique was employed as the reference method to assess body composition and compare it with other field methods. This technique is widely regarded as the gold standard due to its high precision, safety, and reproducibility, particularly in pediatric populations. By providing accurate estimates of TBW and, consequently, of FFM and FM it minimizes biases arising from population-specific assumptions inherent in predictive equations, including those associated with BIA [23, 24, 25]. Its validity as a benchmark in adolescent studies is well supported, ensuring methodological rigor and enhancing the reliability of our comparisons with field techniques [16, 23, 24].

The comparison of body composition (%BF) assessed by the deuterium dilution technique with estimates derived from skinfold-based predictive equations and BIA revealed that the accuracy of these alternative methods varies substantially according to nutritional status and physical activity level. Overall, the Slaughter equations, particularly the version based on subscapular and triceps skinfolds (Slaughter SS), consistently showed the closest agreement with the deuterium dilution method across eutrophic non-athletes athletic, and non-athletes with obesity groups, displaying the lowest biases and

narrowest limits of agreement relative to the reference method (Fig. 7b). These findings indicate that Slaughter SS performs best among the evaluated equations rather than implying absolute superiority across all conditions, and they align with previous studies demonstrating the high validity of the Slaughter equations in youth populations with normal weight and regular physical activity [8, 25, 26]

The superior performance of the Slaughter SS equation over the other evaluated models likely reflects its use of anatomical sites that capture consistent patterns of fat distribution during adolescence. By contrast, equations such as those by Guedes (1995) and Sloan (1967) exhibited higher mean biases and broader limits of agreement, particularly in adolescents with obesity. While these models are widely applied in both national and international contexts, they were originally developed for different populations and may lack validation for adolescents with higher adiposity, which can limit their accuracy in such groups [11, 13, 14].

The Petroski (1996) equation showed lower concordance and less consistent agreement with the reference method, particularly in comparison to Slaughter SS. Its performance varied across adiposity levels, and in the present sample it tended to show discrepancies that reduce its applicability in adolescent populations. While it remains widely used in Brazilian studies, it was developed from adult populations and does not fully capture the physiological characteristics of adolescence. These findings are consistent with previous evidence emphasizing the limited transferability of adult-derived models to younger populations [12].

The BIA device used in this study showed good agreement with the reference method in eutrophic non-athletes and athletic adolescents, with relatively low biases and strong concordance (CCC = 0.85). In contrast, among adolescents with obesity, BIA tended to overestimate %BF, reflecting reduced accuracy in individuals with higher adiposity. This pattern is consistent with previous studies [7, 24, 27, 28], and is likely related to alterations in hydration status and tissue conductivity in individuals with increased fat mass. These observations are further supported by Resende et al. (2011), who reported that BIA overestimated FFM and TBW while underestimating FM when compared with deuterium dilution in adolescents with obesity [25].

All anthropometric measurements were performed by a single trained evaluator using calibrated equipment to minimize technical measurement error. Nevertheless, variability was observed across some equations, highlighting the limitations of applying generalized predictive models to diverse adolescent populations.

Taken together, these findings underscore the importance of selecting body composition assessment methods that are appropriate for the specific characteristics of the population under study. Adolescents exhibit unique physiological and developmental traits, and predictive equations must account for these differences to provide accurate estimates. The need for ongoing validation of field methods, particularly those that are low-cost and easily accessible, is evident, especially for equations widely used in clinical and real-world settings. Furthermore, incorporating factors such as ethnicity, maturation stage, and physical activity level, may improve the accuracy of future predictive models. Evidence suggests that

methodological errors can significantly affect the %BF classification, potentially influencing diagnosis and intervention decisions [8].

This study demonstrates that the Slaughter equations, particularly the Slaughter SS, provided the best overall performance among the evaluated equations, yielding the most accurate and reliable estimates of body fat percentage in male adolescents across different nutritional statuses and physical activity levels. Alternative predictive equations, such as those proposed by Guedes, Sloan, and Petroski, showed substantial limitations, especially among adolescents with obesity, whereas BIA proved practical for eutrophic and athletic groups but tended to overestimate %BF in individuals with higher adiposity. Future research should focus on the development and refinement of predictive models that accurately capture the diversity of adolescent populations, ensuring reliable assessment across both clinical and real-world contexts.

Overall, this study highlights the importance of method selection: accurate evaluation of body composition in adolescents is essential for diagnosis, intervention, and health monitoring, while reliance on generalized adult-based or unvalidated equations can lead to misclassification and suboptimal decision-making.

Declarations

Ethical Approval :

The study was conducted in accordance with the Declaration of Helsinki, and approved by the Human Research Ethics Committee of The Medical School (FMB) of São Paulo State University (UNESP), (protocol code 7.393.628; March 21, 2022).

Competing Interests :

The authors declare no competing interests.

Funding:

This research was funded by Fundação de Amparo à Pesquisa do Estado de São Paulo (FAPESP), grant number 2022/03413-3. VEC is grateful for the research productivity scholarship provided by CNPq (311432/2025–5).

Author Contributions:

Conceptualization, M.B.L.M., V.E.C, T.K.W. and M.N.R; methodology, M.B.L.M., V.E.C and T.K.W.; data collection, M.B.L.M and T.K.W.; data curation M.B.L.M, J.C.D, B.M.M. and J.M.H.; statistical analysis,

M.B.L.M, B.M.M. and J.M.H.; formal analysis M.B.L.M, B.M.M., J.M.H. and V.E.C.; writing—original draft preparation, M.B.L.M., M.N.R, B.M.M, V.E.C. and T.K.W.; writing—review and editing, M.B.L.M, B.M.M., J.M.H. M.N.R and T.K.W.; supervision, V.E.C., and T.K.W.; project administration, M.B.L.M. and T.K.W.; funding acquisition, M.B.L.M., T.K.W. and V.E.C. All authors have read and agreed to the published version of the manuscript.

Acknowledgements:

The authors would like to acknowledge the technical and analytical support provided by Cibele Regina De Souza-Kruliski, Stable Isotope Center “Prof. Dr. Carlos Ducatti”, Institute of Biosciences, São Paulo State University (UNESP), which contributed to the deuterium analyses carried out in this study, and Michele Novaes Ravelli, Director of the Scholler Isotope Ratio Lab, University of Wisconsin, for her support and collaboration.

Data availability statement:

The datasets generated and/or analyzed during the current study are not publicly available due to ethical restrictions and because they are part of an ongoing research project. However, they are available from the corresponding author on reasonable request.

References

1. Bennett JP, Lim S. The Critical Role of Body Composition Assessment in Advancing Research and Clinical Health Risk Assessment across the Lifespan. *Journal of Obesity & Metabolic Syndrome* 2025; 34: 120–137.
2. Sbaraini M, Cureau FV, Ritter J do A, Schuh DS, Madalosso MM, Zanin G *et al.* Prevalence of overweight and obesity among Brazilian adolescents over time: a systematic review and meta-analysis. *Public Health Nutr* 2021; 24: 6415–6426.
3. Wells JCK. Measuring body composition. *Archives of Disease in Childhood* 2005; 91: 612–617.
4. Cataldi D, Bennett JP, Quon BK, Liu YE, Heymsfield SB, Kelly T *et al.* Agreement and Precision of Deuterium Dilution for Total Body Water and Multicompartment Body Composition Assessment in Collegiate Athletes. *The Journal of Nutrition* 2022; 152: 2048–2059.
5. Internationale Atomenergie-Organisation. *Introduction to body composition assessment using the deuterium dilution technique with analysis of urine samples by isotope ratio mass spectrometry*. IAEA: Vienna, 2010.
6. Kyle U. Bioelectrical impedance analysis?part I: review of principles and methods. *Clinical Nutrition* 2004; 23: 1226–1243.
7. Lukaski HC, Bolonchuk WW, Hall CB, Siders WA. Validation of tetrapolar bioelectrical impedance method to assess human body composition. *Journal of Applied Physiology* 1986; 60: 1327–1332.

8. Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD *et al.* Skinfold equations for estimation of body fatness in children and youth. *Hum Biol* 1988; 60: 709–723.
9. Lohman TG, Roche AF, Roche AF, Martorell R (eds). *Anthropometric standardization reference manual*. Human Kinetics Books: Champaign, Ill, 1988.
10. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ* 2007; 85: 660–667.
11. Guedes DP, Guedes JERP. ATIVIDADE FÍSICA, APTIDÃO FÍSICA E SAÚDE. *Rev Bras Ativ Fís Saúde* 2012; 1: 18–35.
12. Petroski EL, Pires Neto CS. VALIDAÇÃO DE EQUAÇÕES ANTROPOMÉTRICAS PARA A ESTIMATIVA DA DENSIDADE CORPORAL EM HOMENS. *Rev Bras Ativ Fís Saúde* 2012; 1: 5.
13. Sloan AW. Estimation of body fat in young men. *Journal of Applied Physiology* 1967; 23: 311–315.
14. Forsyth HL, Sinning WE. The anthropometric estimation of body density and lean body weight of male athletes. *Med Sci Sports* 1973; 5: 174–180.
15. Siri WE. Body composition from fluid spaces and density: analysis of methods. 1956.
16. Schoeller DA. Bioelectrical impedance analysis for the measurement of human body composition: Where do we stand and what is the next step? *Nutrition* 1996; 12: 760–762.
17. Coplen TB. Guidelines and recommended terms for expression of stable-isotope-ratio and gas-ratio measurement results. *Rapid Comm Mass Spectrometry* 2011; 25: 2538–2560.
18. Paul D, Skrzypek G, Fórizs I. Normalization of measured stable isotopic compositions to isotope reference scales – a review. *Rapid Comm Mass Spectrometry* 2007; 21: 3006–3014.
19. Lukaski HC. Methods for the assessment of human body composition: traditional and new. *The American Journal of Clinical Nutrition* 1987; 46: 537–556.
20. Bland JM, Altman DG. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet* 1986; 1: 307–310.
21. Sedgwick P. Pearson's correlation coefficient. *BMJ* 2012; 345: e4483–e4483.
22. Lin LI. A concordance correlation coefficient to evaluate reproducibility. *Biometrics* 1989; 45: 255–268.
23. Wells JC, Fuller NJ, Dewit O, Fewtrell MS, Elia M, Cole TJ. Four-component model of body composition in children: density and hydration of fat-free mass and comparison with simpler models. *The American Journal of Clinical Nutrition* 1999; 69: 904–912.
24. Resende CMM, Camelo Júnior JS, Vieira MNCM, Ferriolli E, Pfrimer K, Perdoná GSC *et al.* Body composition measures of obese adolescents by the deuterium oxide dilution method and by bioelectrical impedance. *Braz J Med Biol Res* 2011; 44: 1164–1170.
25. Rodríguez G, Moreno LA, Blay MG, Blay VA, Fleta J, Sarría A *et al.* Body fat measurement in adolescents: comparison of skinfold thickness equations with dual-energy X-ray absorptiometry. *Eur J Clin Nutr* 2005; 59: 1158–1166.

26. Freedman DS, Horlick M, Berenson GS. A comparison of the Slaughter skinfold-thickness equations and BMI in predicting body fatness and cardiovascular disease risk factor levels in children. *The American Journal of Clinical Nutrition* 2013; 98: 1417–1424.
27. Deurenberg P, Weststrate JA, Seidell JC. Body mass index as a measure of body fatness: age- and sex-specific prediction formulas. *Br J Nutr* 1991; 65: 105–114.
28. Verney J, Metz L, Chaplais E, Cardenoux C, Pereira B, Thivel D. Bioelectrical impedance is an accurate method to assess body composition in obese but not severely obese adolescents. *Nutrition Research* 2016; 36: 663–670.

Figures

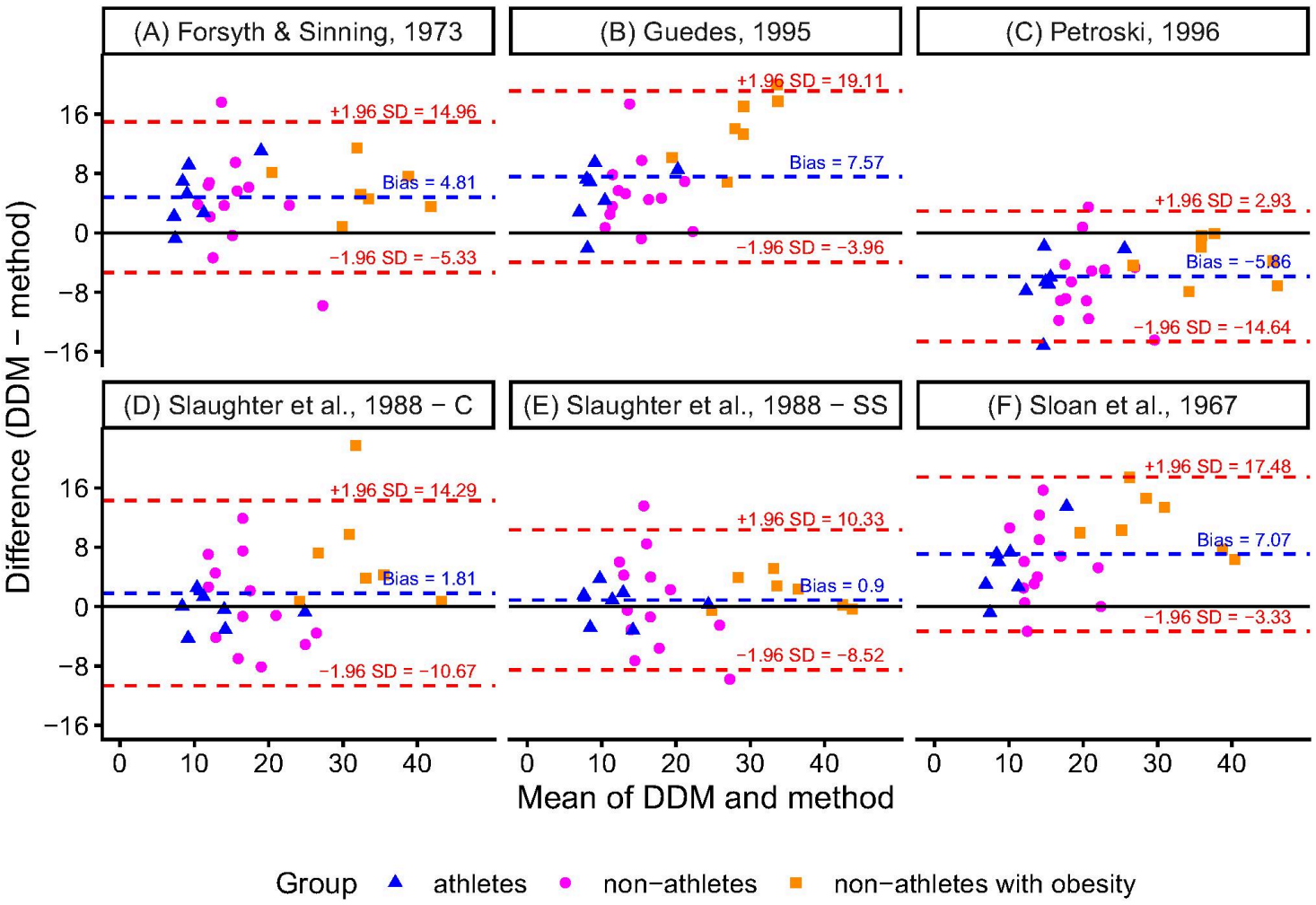


Figure 1

Bland-Altman plots comparing the reference method (DDM) against six predictive equations: (A) Forsyth & Sinning, 1973; (B) Guedes, 1995; (C) Petroski, 1996; (D) Slaughter et al., 1988 - C; (E) Slaughter et al., 1988 - SS; and (F) Sloan et al., 1967.

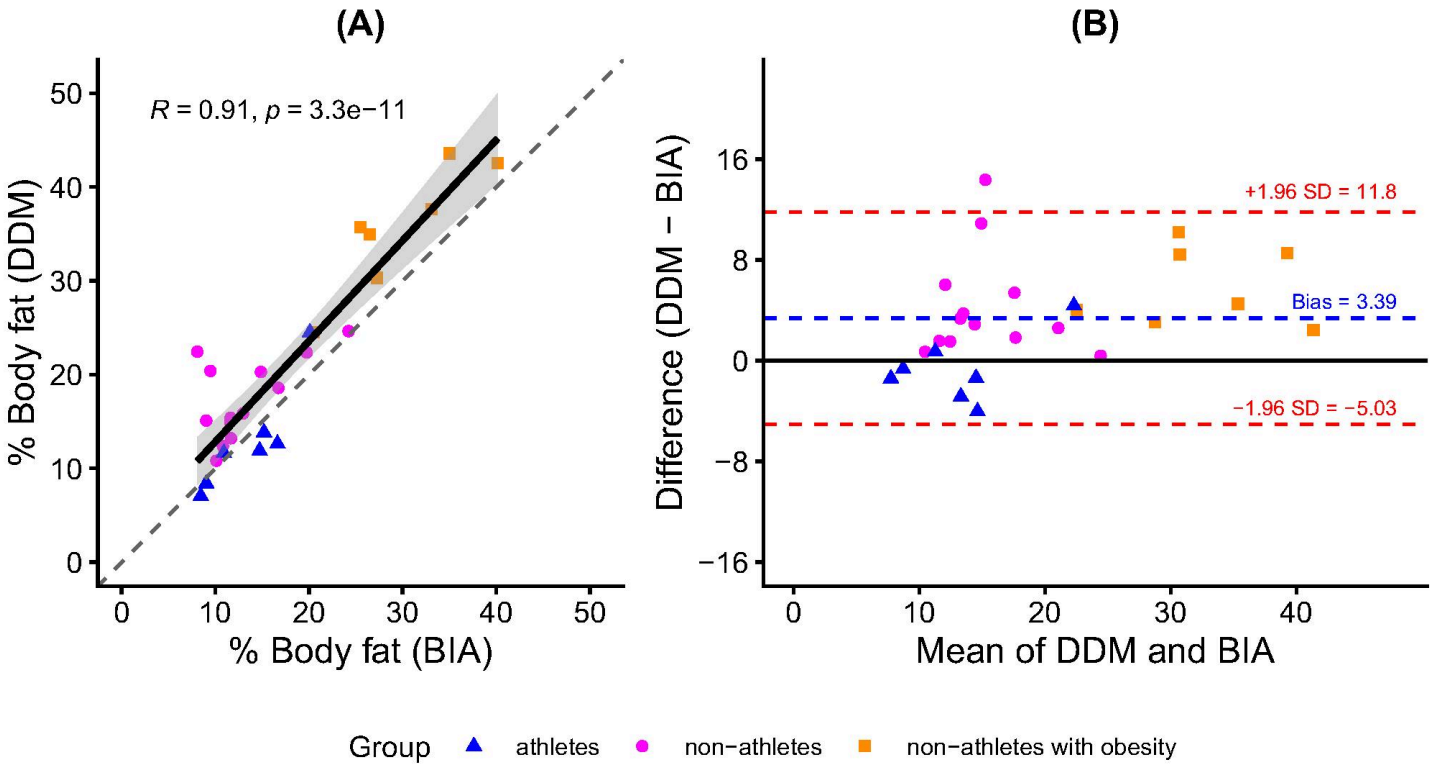


Figure 2

Analysis of the relationship and agreement between the reference method (DDM) and Bioelectrical Impedance Analysis (BIA).

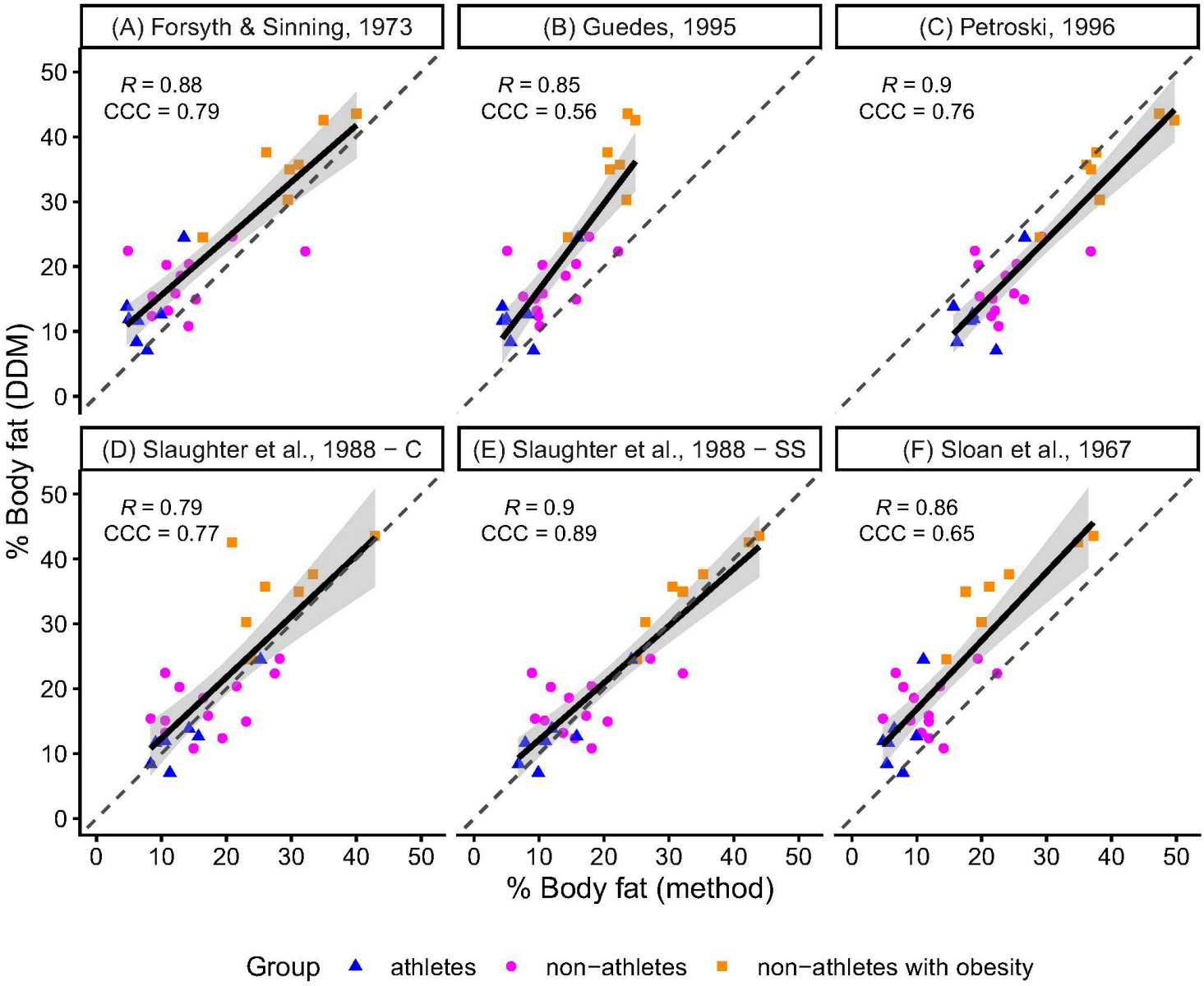


Figure 3

Validation of Bioelectrical Impedance Analysis (BIA) and anthropometric equations against the Deuterium Dilution Method for body fat percentage estimation: Linear regression and Bland-Altman plots.