Rev Bras Cineantropom Desempenho Hum

original article

https://doi.org/10.1590/1980-0037.2023v25e92458

Agreement and reproducibility of a portable electrical impedance myography device for body fat percentage estimation in normal weight men and women

Concordância e reprodutibilidade de um dispositivo portátil de miografia por impedância elétrica para estimativa do percentual de gordura corporal em homens e mulheres com peso normal

Josiel Gomes Ribeiro[1]
https ://orcid.org/0000-0002-4178-7917
Mateus Rossato[1]
https ://orcid.org/0000-0002-4132-9860
Lucas Bet da Rosa Orssatto[2]
https ://orcid.org/0000-0003-3788-3700
Luhan Ammy Andrade Picanço[1]
https ://orcid.org/0000-0002-7548-421X
Diego Augusto Santos Silva[3]
https ://orcid.org/0000-0002-0489-7906
Ewertton de Souza Bezerra[1]
https ://orcid.org/0000-0003-4397-1715

1 Universidade Federal do Amazonas. Manaus, AM. Brasil.
2 Queensland University of Technology. Faculty of Health. School of Exercise and Nutrition Sciences. Brisbane. Australia.
3 Universidade Federal de Santa Catarina. Florianópolis, SC. Brasil.

Received: January 18, 2023
Accepted: August 21, 2023

How to cite this article
Ribeiro JG, Rossato M, Orssatto LBR, Picanço LAA, Silva DAS, Bezerra ES. Agreement and reproducibility of a portable electrical impedance myography device for body fat percentage estimation in normal weight men and women. Rev Bras Cineantropom Desempenho Hum 2023, 25:e92458. DOI: https://doi.org/10.1590/1980-0037.2023v25e92458

Corresponding author
Josiel Gomes Ribeiro.
Universidade Federal do Amazonas
Av. Gen. Rodrigo Otávio, 5614, 69067-0053, Coroado, Manaus (AM), Brasil.
E-mail: josielg.ribeiroo@gmail.com

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

Abstract — The aim of this study was to investigate the agreement and reproducibility of a portable electrical impedance myography device (EIM - SKULPT®) for body fat percentage (BF%) estimation in young adults. Sixty young adults volunteered for the study (women, n=30, 25.0±7.7 years; 21.5±1.9 kg/m^2; and men, n=30, 21.6±6.3 years; 22.5±1.8 kg/m^2). Participants underwent air displacement plethysmography (ADP) and EIM measurements for agreement analysis. EIM was performed three times on the same day for the within-day reproducibility analysis. Seven days later, 37 participants repeated the EIM measurements for the between-days reproducibility analysis. Comparisons of EIM and ADP methods, and EIM repeated measurements were performed with the paired T-test or one-way ANOVA repeated measures, the Bland-Altman plot, and simple linear regressions. BF% was higher ($p<0.05$) when estimated by EIM (19.91 ± 5.70 for men, and 30.77 ± 5.89 for women) compared to ADP (15.28 ± 5.66 for men, and 27.31 ± 5.98 for women). The Bland-Altman analysis presented a bias of 4.4% (95%CI=-3.4–12.2) and linear regression presented an R^2=0.78. For between-days reproducibility, EIM means did not differ (25.33±7.69 and 24.94±8.30, p=0.890). Thus, while the EIM device exhibited high reproducibility of BF% estimates, caution should be exercised when comparing the results with other techniques for measuring BF%. The EIM device overestimated BF% compared to ADP. However, the EIM measurements presented very good within-day and between-days reproducibility and, thus, the EIM device can be used for longitudinal monitoring of BF%.

Key words: Body composition; Electric impedance; Physical examination.

Resumo — *O objetivo deste estudo foi investigar a concordância e a reprodutibilidade de um aparelho portátil de miografia por impedância elétrica (EIM - SKULPT®) para estimativa do percentual de gordura corporal (GC%) em adultos jovens. Sessenta adultos jovens foram voluntários para o estudo (mulheres, n=30, 25,0±7,7 anos; 21,5±1,9 kg/m2; e homens, n=30, 21,6±6,3 anos; 22,5±1,8 kg/m2). Os participantes fizeram medições de pletismografia de deslocamento de ar (ADP) e EIM para análise de concordância. A EIM foi realizada três vezes no mesmo dia para a análise de reprodutibilidade dentro do dia. Sete dias depois, 37 participantes repetiram as medições do EIM para a análise de reprodutibilidade entre dias. As comparações dos métodos EIM e ADP e medições repetidas do EIM foram realizadas com o teste T pareado ou medidas repetidas ANOVA de uma via, o gráfico de Bland-Altman e regressões lineares simples. O %GC foi maior (p<0,05) quando estimado pelo EIM (19,91 ± 5,70 para homens e 30,77 ± 5,89 para mulheres) em relação ao ADP (15,28 ± 5,66 para homens e 27,31 ± 5,98 para mulheres). A análise de Bland-Altman apresentou viés de 4,4% (IC95%=-3,4–12,2) e a regressão linear apresentou R2=0,78. Para a reprodutibilidade entre dias, as médias do EIM não diferiram (25,33±7,69 e 24,94±8,30, p=0,890). Assim, enquanto o dispositivo EIM exibiu alta reprodutibilidade das estimativas de %GC, deve-se ter cautela ao comparar os resultados com outras técnicas para medir %GC. O dispositivo EIM superestimou %GC em comparação com ADP. No entanto, as medidas de EIM apresentaram reprodutibilidade intradia e entre dias muito boa e, portanto, o dispositivo de EIM pode ser usado para monitoramento longitudinal de %GC.*

Palavras-chave: *Composição corporal; Impedância elétrica; Exame físico.*

INTRODUCTION

According to the World Health Organization[1], obesity has tripled since 1975 in medium and high income countries. Among the obesity-related diseases, type 2 diabetes, cardiovascular diseases, stroke, and some types of cancer can be highlighted[2]. Because of the increase in the population with obesity, public health expenses have increased year by year, causing a burden to health systems all over the world[3]. The proper treatment or prevention of overweight or obesity requires an early diagnosis. In this sense, there is an evident need for low cost and portable methods, that provide accurate and reliable measurements for body fat estimation, which could be adopted in clinical practice[4].

Body fat percentage is typically estimated using different methods, among them, hydrostatic weighing, air displacement plethysmography (ADP), dual energy X-ray absorptiometry (DXA), computed tomography, and magnetic resonance imaging[5]. Regarding the precise and reliable indirect methods for analyzing body composition, ADP stands out for being a quick and easy technique that uses the inverse relationship between pressure (p) and volume (v), based on Boyle's Law (P1V1 = P2V2) to determine body volume[6]. However, although these methods can provide valid estimates of body fat for different populations[7], they are usually high cost and present low portability, which can limit their application in clinical practice.

In recent years, many clinical practice methods have been developed based on indirect techniques, denominated doubly indirect evaluations. Among these techniques, bioelectrical impedance (BIA) stands out, for being a safe, low-cost, fast, and non-invasive method that provides body composition, nutritional status, health, and cell integrity estimates(8). In addition, BIA has been shown to be useful in clinical practice for body fat percentage (BF%) estimation. BIA provides raw parameters such as impedance (Z), resistance (R), and reactance (Xc) and parameters derived from the relationship between R and Xc, such as phase angle (PA) and bioimpedance vector analysis (BIVA), in addition to presenting estimates of BF% through regression equations[8]. Associated with BIA, another method of analyzing body composition is electrical impedance myography (EIM), which is a non-invasive and highly reproducible emerging electrophysiological technique that objectively characterizes body structure and composition, measured through bioimpedance[9]. In this technique, the relationship and normalization of voltage and current amplitudes and phase delays provide a simple approach to measuring impedance magnitude and phase angle[10].

Currently, there are several types of BIA and EIM devices available on the commercial market, classified according to the number of electrodes, the position in which they are placed, the region of the body submitted to the examination, and the type of frequency used[11]. A relatively new EIM device, the SKULPT CHISEL® scanner (Skulpt Inc., San Francisco, CA), is a portable electrical impedance myography (EIM) device that works in a similar way to bioimpedance analysis (BIA). Both EIM and BIA use impedance, which is derived from resistance and reactance[12] .The SKULPT® was developed as a portable EIM device, to assess total and regional body fat percentages, in addition to muscle quality (i.e., measurement of muscle in relation to its size). According to the manufacturer, the device has 12 electrodes and demonstrates some important characteristics (electric current can be applied in a range of frequencies and it also flows more easily along muscle fibers than through them)[13].

Previous studies that compared body fat obtained by BIA and other reference methods, such as ADP, showed that despite the small differences between methods, BIA seems to be a valid method to estimate body fat[14,15]. Although the manufacturer reports that EIM has an accuracy of 1 - 2% for body fat when compared with DXA, its accuracy and reliability were recently tested, and the authors reported no differences for BF% estimates between DXA and EIM in healthy young individuals, concluding that EIM could be an acceptable method for use in adult men and women[12]. In addition, another study showed that although DXA and ADP estimates demonstrated strong agreement with the four-component model, the ADP estimates showed a smaller error than the DXA estimates[16]. In this sense, comparing the estimates of BF% from a new BIA device (i.e., EIM) with the ADP method could be useful for providing health professionals with information on the degree of agreement of these techniques. Thus, the current study aimed to compare the BF% estimates obtained by EIM and ADP in men and women. As a secondary outcome, we tested the within- and between-days reliability of the EIM device. It was hypothesized that EIM would present good agreement and reproducibility for BF% compared to the ADP method.

METHODS

Experimental approach to the problem

The body composition of 60 young adults with a normal body mass index was assessed using electrical impedance myography (EIM) and ADP. The% BF values verified by the EIM were compared against the ADP reference method. Furthermore, the within and between days reliability of the EIM device were tested, and these data were used to verify if there is good agreement and reproducibility between the EIM and ADP methods.

Participants

Sixty healthy young adults were included in the present study (Women, n = 30, 25.0±7.7 years, 57.8±6.4 kg, 1.62±5 m, 21.5±1.9 kg/m2; and Men, n = 30, 21.6±6.3 years, 69.1±8.0 kg, 1.73±6 m, 22.5±1.8 kg/m2); a mean of three measures was adopted for height (ICC=0.97). All participants (n = 60) were included in the agreement and within-day reproducibility, and 37 in the between-days reproducibility procedures (men=18, 23.7±6.5 years, 62.7±10.1 kg, 1.66±8.3 m, 22.3±1.9 kg/m2). To be included, participants were required to be aged between 18 and 45 years and have a BMI between 18 and 24.9 kg/m2, classified as normal weight[1]. Participants with physical impairment, claustrophobia, or any diagnosed disease that would prevent the correct testing procedures were excluded.

Procedures

Participants reported to the laboratory for two visits, in the morning (between 8 a.m. and 12 a.m.), seven days apart. On both visits, body mass was assessed with a digital scale (Tanita Inc., Arlington Heights, IL, USA), height with a stadiometer (SECA®, São Paulo, Brazil), and body fat percentage with Air Displacement Plethysmography (BODPOD, Body Composition System; Life Measurement Instruments, Concord, CA, USA). This measurement was considered the reference value for the agreement analysis, and was taken with a portable electrical impedance myography device (EIM - SKULPT®, San Francisco, USA). Participants were requested to avoid food and water consumption for two hours before the body composition measurements, as recommended in the Bod Pod Operator's manual, and avoid smoking, drinking alcohol, using body-hydrating lotion on the skin, and practicing physical exercise for 24 h before the measurements.

Electrical impedance myography

The EIM device provides limited information about the electrical current frequency and respective algorithms adopted to calculate the body fat percentage. According to the manufacturer, the device emits an electrical current with different frequencies, directions, and depths. Thereafter, an application on a smartphone, connected to the device, provides information regarding the body fat percentage. A quick start option within the application suggests a single measure on the arm, trunk, and thigh, as presented in Figure 1. To address reproducibility, three measurements were conducted on the respective body regions, with a 3 min interval between them. The participant remained in a sitting position during the between-measurements interval. The mean value of the 3 measurements was adopted for the agreement and between-days reproducibility statistics.

Figure 1. Electrical impedance myography positioning. (A) Arm; (B) Trunk; and (C) Thigh.

Air displacement plethysmograph

All participants were evaluated for body fat percentage by ADP. The evaluation was performed according to the manufacturer's instructions. The ADP device was calibrated through the computation of the ratio of the pressure for an empty chamber and a known volume (56.056 l). The scale attached to the device was also calibrated using a known reference (20kg). After receiving an explanation about the procedures, the participants entered the ADP wearing minimal clothing. A swimming cap was used to decrease hair volume and metal objects on the body were prohibited (for example, earrings, rings, piercings, and so on). The participants remained seated inside the device and at each step of the ADP evaluation the door was opened. The test lasted an average of 4 min. During this phase, the participant's raw body volume was determined according to Boyle's law. Because of the difficulty in assessing the pulmonary volume of the participants', predicted values were used. This procedure did not affect the estimation of body composition[17]. The body density was determined by range of pressure and volume. Finally, BF% was calculated using the Siri equation[18]. The Siri equation is based on the two-compartment model (fat mass and fat-free mass) and ADP is a densitometry method that is also based on the two- compartment model. In addition, when compared to other equations, the Siri equation presents similar estimates[19].

Statistical analyses

All descriptive results are presented as mean ± standard deviation. The Shapiro Wilk and Levene tests were conducted for normality and homogeneity testing, respectively. For agreement assessment, the following tests were conducted: a) paired T-test between body fat percentage obtained by ADP and EIM on the same day; b) Bland-Altman plot for agreement analysis between ADP and BIA results; c) simple linear regressions to verify how much the result of the dependent variable (ADP) was explained by the independent variable (EIM); and d) intraclass correlation coefficients (ICC) and typical error, as a percentage of the coefficient of variation (%CV), were calculated between methods[20]. For the between-days reproducibility assessment, the paired t-test, ICC, and % CV were adopted between the repeated measurements for the EIM. For the within-day reproducibility assessment, one-way ANOVA repeated measures, ICC, and % CV were adopted between the three repeated measurements for the EIM performed on the same day. The SPSS Statistical Software package (version 25.0) and Graph Pad Prism (version 6.0) were used to analyze all data.

RESULTS

Agreement

Body fat (%) results measured by EIM were higher than the ADP results for all participants ($p<0.001$), women ($p<0.004$), and men ($p<0.001$) (Table 1). The Bland-Altman plot confirmed that EIM overestimated body fat (%) compared to ADP for all participants (4.4%), women (4.1%), and men (4.6%) (Figure 2). The linear regression indicated that EIM explained 78%, 52%, and 62% of the variance in the ADP results, for all participants, women, and men, respectively (Figure 2).

Table 1. Body fat (%) comparison between electrical impedance myography and air displacement plethysmography (validity), between electrical impedance myography in day 1 and 2 (between-days reproducibility), and between electrical impedance myography measures 1, 2, and 3 at day 1.

	Agreement		
	All (n = 60)	Men (n = 30)	Women (n = 30)
EIM (%)	25.34 ± 7.94	19.91 ± 5.70	30.77 ± 5.89
ADP (%)	21.30 ± 8.38	15.28 ± 5.66	27.31 ± 5.98
T-Test p-value	<0.001	<0.001	0.004
	Between-days reproducibility		
	All (n = 37)	Men (n = 18)	Women (n = 19)
EIM day 1 (%)	25.33 ± 7.69	19.97 ± 6.05	30.40 ± 5.62
EIM day 2 (%)	24.94 ± 8.30	18.86 ± 5.99	30.69 ± 5.64
T-Test p-value	0.54	0.33	0.64
ICC	0.890	0.716	0.887
TE as CV (%)	6.8	6.7	6.9
	Within-day reproducibility		
	All (n = 60)	Men (n = 30)	Women (n = 30)
EIM1	25.26 ± 8.24	19.99 ± 5.66	30.53 ± 6.93
EIM2	25.49 ± 8.05	20.16 ± 5.79	30.82 ± 6.25
EIM3	25.28 ± 8.05	19.59 ± 5.90	30.98 ± 5.45
One-way ANOVA p-value	0.845	0.452	0.830
ICC	0.926	0.923	0.824
TE as CV (%)	8.9	6.9	10.7

Note. Descriptive statistics are presented as mean and standard deviation. EIM: electrical impedance myography; ADP: air displacement plethysmography; ICC: Intraclass correlation coefficient; TE as CV: typical error as coefficient of variation.

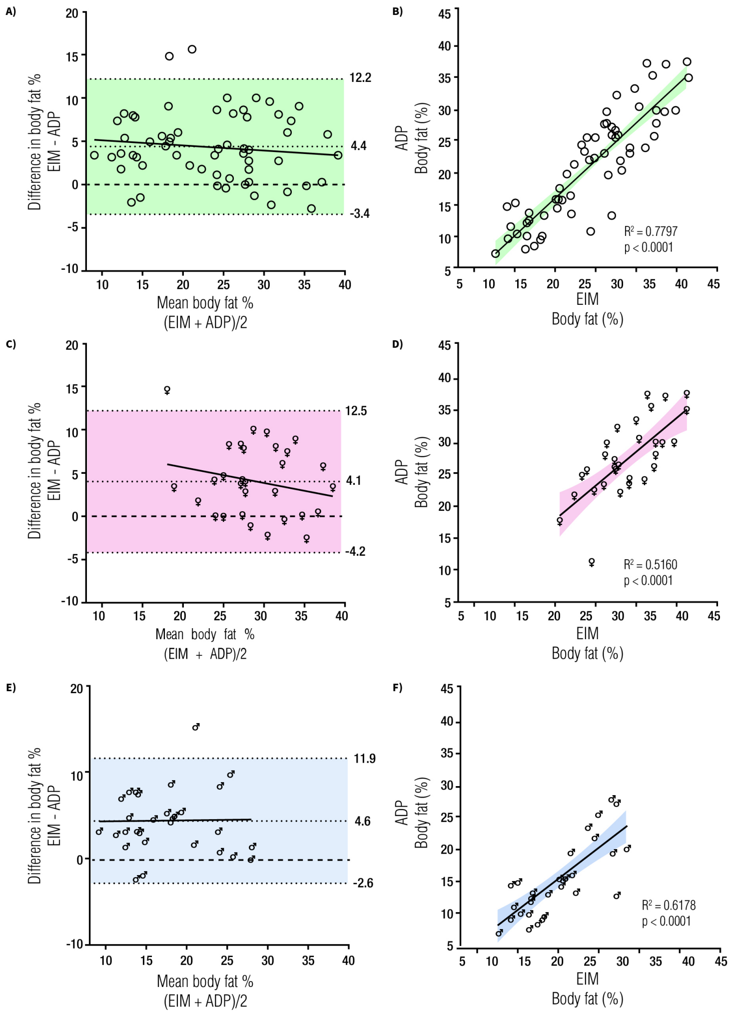

Figure 2. Bland-Altman plots and simple linear regression between ADP and EIM measurements of body fat (%), for all participants (A and B), women (C and D), and men (E and F). Dotted lines in the colored area of the Bland-Altman plots depict mean bias and 95% confidence interval. EIM: electrical impedance myography; ADP: air displacement plethysmography.

Within and between-days reproducibility

There was no difference in body fat (%) for EIM measured on days 1 and 2 (between-days reproducibility). A good ICC for all participants (n = 37) and women (n = 19), and a moderate ICC for men (n = 18) were presented. The typical error remained between 6.7 and 6.9%. There were no differences in body fat (%) for EIM when performing 3 measures on the same day (within-day reproducibility). An excellent ICC[21] was found for all participants (n = 60) and men (n = 30), and a good ICC for women (n = 30). The typical error remained between 6.9 and 10.7% (Table 1).

DISCUSSION

The present study aimed to compare the body fat percentage estimated by the EIM and ADP devices, and to test the reproducibility of the EIM device in men and women. The main findings suggest that % body fat estimated by

EIM is overestimated for women (4.1%) and men (4.6%), when compared with ADP. It should be noted that for 23 women (76.6%) and 28 men (93.3%), the EIM results were higher than the ADP results. In addition, the device did not present significantly different values for body fat percentage when tested on the same day or on different days, for both men and women.

To the best of our knowledge, this is the first study to compare the accuracy and reproducibility of fat percentage measurements obtained using ADP and EIM. A similar study was developed[12], in which the authors assessed the accuracy of the fat percentage results obtained by EIM with the values obtained by DXA and BIA. The reproducibility of EIM was evaluated on 3 different days. The results did not show significant differences between the methods and the authors also reported correlations above 0.93 between EIM and DXA. In addition, the authors reported high reproducibility of the measurements performed by EIM[12]. In the findings of the current study the fat percentage data obtained by EIM demonstrated a high correlation with the reference measure (ADP), in addition to presenting good reproducibility between days.

Studies that compared body fat percentage values obtained through ADP and BIA indicate that there are no significant differences in the percentage of fat between the methods, and that they present high correlation[14,22,23]. The body fat percentage is estimated based on the Siri equation[18], considering the body density (body mass/ body volume) measured by the ADP device[24]. Conversely, the EIM manufacturer does not provide details about the algorithm used to estimate body fat percentage, only mentioning that it uses electrical currents with different frequencies, directions, and depths. We believe that the overestimation of the results observed for the EIM, of 4.1% for women and 4.6% for men, is because we only used 3 measures (Figure 1), one of which was evaluated in the abdominal region. In this way, body composition analysis could be performed differently between men and women, possibly adding measures concentering more on the lower trunk and lower limbs in women, and with the addition of an upper limb region in men.

Studies that evaluate the agreement and reproducibility of low-cost and portable devices that assess body composition are important because they allow the equipment to be used in public health services to monitor acute and chronic changes in body composition. It was found that patients with acute/critical illness are particularly vulnerable to muscle loss and alterations in body fluids, negatively impacting clinical outcomes[25]. The evaluation of these parameters in hospital environments is often subjective and imprecise, which creates discrepancies in identity and difficulty in assessing longitudinal changes. In this sense, BIA seems to be a good strategy to use in these contexts, since it provides information on both body composition and hydration status[26]. In addition, we presented high interclass correlation coefficients within and between days for MIE, and this characteristic is important for a clinical scenario, because it guarantees feasibility during treatment to control overweight.

It is important to acknowledge limitations in the study design; we included only individuals with a normal BMI, and the absence of information on the algorithm used from the manufacturer of the EIM, which limited our understanding of the findings during the agreement analysis between EIM and ADP. Some strong positive points should also be mentioned; we adopted seven days for between-days reproducibility analysis, which, in our opinion, reflects a more specific clinical scenario during overweight treatment. In addition, ADP was shown to be a more specific method to analyze body fat, and this was the first study to compare EIM and ADP.

CONCLUSION

In conclusion, EIM presents good within- and between-days reliability, however, it can overestimate the body fat percentage compared to ADP for both men and women. Health and fitness professionals could be encouraged to use EIM for longitudinal body fat monitoring.

COMPLIANCE WITH ETHICAL STANDARDS

Funding

The study was supported by the National Council for Scientific and Technological Development and the Coordination for the Improvement of Higher Education Personnel. This work was carried out within the framework of the Health Sciences research program at the Federal University of Amazonas. The authors would like to thank the Fundação de Amparo à Pesquisa do Estado do Amazonas (FAPEAM) for the master's scholarship granted to JGR.

Ethical approval

All volunteers gave written informed consent, and the study was approved by the local Human Research Ethics Committee and conducted in accordance with the Helsinki declaration. This study was approved by the Research Committee of the Federal University of Amazonas (CAAE: 30542020.2.0000.0008, number of the ethical report 3.985.520).

Conflict of interest statement

The authors have no conflict of interests to declare.

Author Contributions

Research concept, study design, literature review and writing of the manuscript: JGR. Research concept and study design and literature review: LAAP. Contributed to the research design: MR, ESB, LBRO; Contributed to the acquisition and analysis of the data: ESB; Contributed to the interpretation of the data: DASS, MR, ESB. All authors have critically reviewed the manuscript, agree to be fully responsible for ensuring the integrity and accuracy of the work, and have read and approved the final manuscript.

REFERENCES

1. WHO: World Health Organization. Obesity and overweight [Internet]. Geneva; 2018 [cited 2021 Mar 7]. Available from: https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight

2. Vucenik I, Stains JP. Obesity and cancer risk: evidence, mechanisms, and recommendations. Ann N Y Acad Sci. 2012;1271(1):37-43. http://dx.doi.org/10.1111/j.1749-6632.2012.06750.x. PMid:23050962.
3. Canella DS, Novaes HMD, Levy RB. Medicine expenses and obesity in Brazil: an analysis based on the household budget survey. BMC Public Health. 2015;16(1):54. http://dx.doi.org/10.1186/s12889-016-2709-6. PMid:26790622.
4. Smith-Ryan AE, Fultz SN, Melvin MN, Wingfield HL, Woessner MN. Reproducibility and validity of A-mode ultrasound for body composition measurement and classification in overweight and obese men and women. PLoS One. 2014;9(3):e91750. http://dx.doi.org/10.1371/journal.pone.0091750. PMid:24618841.
5. Wells JCK, Fewtrell MS. Measuring body composition. Arch Dis Child. 2005;91(7):612-7. http://dx.doi.org/10.1136/adc.2005.085522. PMid:16790722.
6. Fields DA, Goran MI, McCrory MA. Body-composition assessment via air-displacement plethysmography in adults and children: a review. Am J Clin Nutr. 2002;75(3):453-67. http://dx.doi.org/10.1093/ajcn/75.3.453. PMid:11864850.
7. Silva DRP, Ribeiro AS, Pavão FH, Ronque ERV, Avelar A, Silva AM, et al. Validity of the methods to assess body fat in children and adolescents using multi-compartment models as the reference method: a systematic review. Rev Assoc Med Bras. 2013;59(5):475-86. http://dx.doi.org/10.1016/j.ramb.2013.03.006. PMid:24119380.
8. Martins PC, Hansen F, Silva AM, Silva DAS. Fluid distribution and cell integrity indicators evaluated by bioelectrical impedance in university athletes: comparison between team sports and individual sports. Physiol Meas. 2019;40(1):015004. http://dx.doi.org/10.1088/1361-6579/aaf8cd. PMid:30557857.
9. Schwartz DP, Dastgir J, Salman A, Lear B, Bönnemann CG, Lehky TJ. Electrical impedance myography discriminates congenital muscular dystrophy from controls. Muscle Nerve. 2016;53(3):402-6. http://dx.doi.org/10.1002/mus.24770. PMid:26179210.
10. Sanchez B, Rutkove SB. Electrical impedance myography and its applications in neuromuscular disorders. Neurotherapeutics. 2017;14(1):107-18. http://dx.doi.org/10.1007/s13311-016-0491-x. PMid:27812921.
11. Reis AD Fo, Ravagnani FCP, Oliveira MPP, Fett CA, Zavala AA, Coelho-Ravagnani CF. Comparação entre diferentes aparelhos de bioimpedância para avaliação do percentual de gordura. Rev Bras Ciênc Mov. 2011;19(2):5-12.
12. McLester CN, Dewitt AD, Rooks R, McLester JR. An investigation of the accuracy and reliability of body composition assessed with a handheld electrical impedance myography device. Eur J Sport Sci. 2018;18(6):763-71. http://dx.doi.org/10.1080/17461391.2018.1448458. PMid:29544083.
13. Czeck MA, Raymond-Pope CJ, Prescott E, Bisch KL, Dengel DR. Body fat percent assessment between electrical impedance myography and dual X-ray absorptiometry. Am J Hum Biol. 2020;32(2):e23330. http://dx.doi.org/10.1002/ajhb.23330. PMid:31566850.
14. Biaggi RR, Vollman MW, Nies MA, Brener CE, Flakoll PJ, Levenhagen DK, et al. Comparison of air-displacement plethysmography with hydrostatic weighing and bioelectrical impedance analysis for the assessment of body composition in healthy adults. Am J Clin Nutr. 1999;69(5):898-903. http://dx.doi.org/10.1093/ajcn/69.5.898. PMid:10232628.
15. Hillier SE, Beck L, Petropoulou A, Clegg ME. A comparison of body composition measurement techniques. J Hum Nutr Diet. 2014;27(6):626-31. http://dx.doi.org/10.1111/jhn.12197. PMid:24387134.
16. Ng BK, Liu YE, Wang W, Kelly TL, Wilson KE, Schoeller DA, et al. Validation of rapid 4-component body composition assessment with the use of dual-energy X-ray absorptiometry and bioelectrical impedance analysis. Am J Clin Nutr. 2018;108(4):708-15. http://dx.doi.org/10.1093/ajcn/nqy158. PMid:30099474.

17. McCrory MA, Molé PA, Gomez TD, Dewey KG, Bernauer EM. Body composition by air-displacement plethysmography by using predicted and measured thoracic gas volumes. J Appl Physiol. 1998;84(4):1475-9. http://dx.doi.org/10.1152/jappl.1998.84.4.1475. PMid:9516218.

18. Siri WE. Body composition from fluid spaces and density: analysis of methods. Nutrition. 1993;9(5):480-91. PMid:8286893.

19. Lohman T. Skinfolds and body density and their relation to body fatness: a review [Internet]. Tucson: University of Arizona; 1981 [cited 2021 Jun 26]. Available from: https://arizona.pure.elsevier.com/en/publications/skinfolds-and-body-density-and-their-relation-to-body-fatness-a-r

20. Hopkins WG. Measures of reliability in sports medicine and science. Sports Med. 2000;30(1):1-15. http://dx.doi.org/10.2165/00007256-200030010-00001. PMid:10907753.

21. Koo TK, Li MY. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. J Chiropr Med. 2016;15(2):155-63. http://dx.doi.org/10.1016/j.jcm.2016.02.012. PMid:27330520.

22. von Hurst PR, Walsh DCI, Conlon CA, Ingram M, Kruger R, Stonehouse W. Validity and reliability of bioelectrical impedance analysis to estimate body fat percentage against air displacement plethysmography and dual-energy X-ray absorptiometry. Nutr Diet. 2016;73(2):197-204. http://dx.doi.org/10.1111/1747-0080.12172.

23. Vasold KL, Parks AC, Phelan DML, Pontifex MB, Pivarnik JM. Reliability and validity of commercially available low-cost bioelectrical impedance analysis. Int J Sport Nutr Exerc Metab. 2019;29(4):406-10. http://dx.doi.org/10.1123/ijsnem.2018-0283. PMid:30507268.

24. Brožek J, Grande F, Anderson JT, Keys A. Densitometric analysis of body composition: revision of some quantitative assumptions. Ann N Y Acad Sci. 1963;110(1):113-40. http://dx.doi.org/10.1111/j.1749-6632.1963.tb17079.x. PMid:14062375.

25. Price KL, Earthman CP. Update on body composition tools in clinical settings: computed tomography, ultrasound, and bioimpedance applications for assessment and monitoring. Eur J Clin Nutr. 2019;73(2):187-93. http://dx.doi.org/10.1038/s41430-018-0360-2. PMid:30377307.

26. Mundi MS, Patel JJ, Martindale R. Body composition technology: implications for the ICU. Nutr Clin Pract. 2019;34(1):48-58. http://dx.doi.org/10.1002/ncp.10230. PMid:30586471.