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VALIDITY AND RELIABILITY ANALYSIS AMONG THREE DIFFERENT FAT ASSESSMENT METHODS IN TRAINED INDIAN MALE ATHLETES

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[A]Study Design, [B]Data Collection, [C]Statistical Analysis, [D]Manuscript Preparation

Abstract Background: The present study aims to investigate the criterion validity and reliability of three different BF% assessing methods i.e., skinfold caliper (SF), bioelectrical impedance analysis (BIA), and air-displacement plethysmography (BOD POD). Methods: Present study was conducted on 51 trained male Indian athletes (aged: 19–29 years). The BF% was measured via SF, BIA, and BOD POD with standard protocol. Statistical analysis was done using SPSS software. Results: The BF% from BIA was reported significantly ($p < 0.001$) higher than skinfold (Δ 28.7%), and BOD POD (Δ 25.4%). Very good reliability was found for BOD POD vs skinfold [with ICC = 0.891 (0.809–0.938)] and good reliability for Skinfold vs BIA [ICC = 0.669 (–0.207–0.895)] and BIA vs BOD POD [ICC = 0.736 (–0.164–0.912)]. Pearson's correlation depicted a positive correlation among various BF% methods (Pearson's r varies = 0.800 to 0.849; $p < 0.01$). Limits of agreement were reported significant for skinfold vs BIA ($p < 0.001$, $\beta = –0.530$), and BOD POD vs skinfold ($p < 0.01$, $\beta = 0.453$). Conclusion: Validity analysis depicts that BIA overestimates BF% in male athletes compared to BOD POD and SF methods. All BF% methods were found reliable although BOD POD vs Skinfold depicted major reliability (ICC = 0.891) over other methods.

Key words: body composition, body fat estimate, bioelectrical impedance analysis, BOD POD, skinfold caliper

Introduction

In sports, achieving peak physical performance is not just a goal; it's a prerequisite for success. Accurate body fat percentage assessment is critical in tailoring training regimens, optimizing performance, and ensuring the overall well-being of athletes (Campa et al., 2020; Ackland et al., 2012). Body composition, the proportion of body fat to lean mass, significantly influences an athlete's strength, endurance, agility, and recovery, making it a fundamental metric in sports science and training (Mathisen et al., 2023). Precise body fat percentage assessment is relevant in sports for several reasons. Firstly, an optimal balance between lean muscle mass and body fat is crucial for athletes to achieve their peak power-to-weight ratio, a key determinant of performance in many sports (Huovinen et al., 2015). Secondly, understanding an athlete's body fat distribution can provide insights into injury risk and susceptibility and guide injury prevention strategies (Ezzat et al., 2016). Lastly, body fat assessments play a vital role in monitoring the effectiveness of training programs, allowing for adjustments to optimize performance gains and recovery (Halson, 2014).

Given the diverse range of sports and the unique physical demands each place on athletes, there is a clear need for a nuanced understanding of body composition (Martín-Rodríguez et al., 2024). The importance of individualized training programs tailored to the specific demands of a sport cannot be overstated. Herein lies the significance of a comparative analysis of different body fat assessment methods in the context of sports. The plethora of available methods, such as Anthropometric measurements, Bioelectrical Impedance Analysis (BIA), and advanced techniques like BOD POD, each offers distinct advantages and limitations (Antonio et al., 2019; Esco et al., 2015; Sirirat et al., 2020). A comprehensive understanding of these differences is essential for sports professionals to make informed decisions about the most appropriate method for their athletes. Factors such as accuracy, ease of use, and practicality in sports are crucial considerations (Staśkiewicz et al., 2023).

Previously studies have already been conducted on the functional and analysis differences among various BF% measuring methods (Antonio et al., 2019; Esco et al., 2015; Sirirat et al., 2020; Fields et al., 2002). Although separate test-retest and validity studies were there for BIA, BOD POD, and skinfold measurement not in a comparative manner. The research work was very scanty in terms of comparative study among BOD POD, BIA, and skinfold measures in the adult population (Bi et al., 2018; Burns et al., 2019). And in terms of sports population then to the Indian sports population context, the present study might be one of the pioneer ones. Thus, the present study aims to investigate and standardize the criteria for validity and reliability among three various BF% assessment methods i.e., Air-displacement Plethysmography (BOD POD), Bioelectrical Impedance Analysis (BIA), and Skinfold Caliper (SF).

Material & Methods

Subject selection: The present cross-sectional study was conducted on 51 trained male Indian athletes (mean age = 23.29 ±2.64 years) from Sports Authority of India, NSNIS, Patiala. All participants were free from any physical injury, or medication and recruited only after proper clinical examination. Participants had at least 4 years of professional training experience. Data collection was done in the morning sessions and all participants were instructed to restrict alcohol and caffeine-containing drinks as well as to refrain from intense physical activity within 24 hours with a minimum of 12 hours fasting. All the BF% assessment methods were measured on the same day. Informed consent was obtained from each athlete before data collection. The research was undertaken in compliance by following the guidelines of the Helsinki Declaration.

Body weight (kg) and height (cm) were measured by using a Digital BMI Machine (SECA 284, Seca Deutschland, Germany) working with a precision of 0.1 kg, and 0.1 cm respectively, and BMI value in the device was recorded. Tests were conducted under laboratory conditions at a controlled temperature of 22°C (Forejt et al., 2023).

Skinfold Analysis: Skinfold thickness measurements were performed using the GPM Skinfold caliper (DKSH Switzerland Ltd.), working nearest to 0.2 mm. Skinfold measurement was done from four sites i.e., biceps, triceps, subscapular, and suprailiac on the right side of the body following the standard protocol of ISAK (Manual ISAK, 2019). Body density was estimated using the Durnin and Womersely equation (Durnin & Womersely, 1974), and the BF% was then calculated from the Brozek equation (Brožek et al., 1963).

Bioelectrical Impedance Analysis (BIA): A tetra polar method using 8-touch electrodes and multifrequency (6-frequency: 1, 5, 50, 250, 550, 1000 kHz, measuring current: approx. 180μA) BIA device (ACCUNIQ BC 720, SELVAS Healthcare Inc.) was used to measure the BF%. The palms and soles of the participants were cleaned with isopropyl alcohol before testing. Participants were instructed to grip the handle electrodes with fingers and palms correctly, stretch both arms, and spread at a 30° angle with the body. The participants were asked to remove any metal accessories and wear light clothes. Standard guideline as per the manufacturer's manual was followed for the testing (Yang et al., 2018).

Air displacement plethysmography (ADP): The ADP was used to assess the BF% via using the BOD POD, version 5.4.6 (COSMED, Concord, CA, USA). Proper quality control procedure and pre-testing calibration (49.894 L of calibration volume) were done as per the manufacturer's instruction manual (COSMED, 2019). The body density model under the BOD POD was calculated using the Brozek equation (Brožek et al., 1963), and predicted thoracic gas volume was selected. During testing, participants were instructed to breathe normally and remain quiet, still, and relaxed. Two or three volume measurements were carried out (50 sec. each) and conclusive results for weight, body volume, thoracic volume (predicted), body density, fat, and fat-free mass were recorded. Before the study, all participants were instructed to wear Form-fitting Speedo or Lycra/spandex-type swimsuits or single-layer compression shorts (without padding). Wearing a cap to compress the hair on the head was also recommended (Dempster & Aitkens, 1995; Fields et al., 2001).

Statistical analysis: Statistical Package for Social Sciences (SPSS), version 21 (SPSS Inc., Chicago, Il, USA) was used to analyze the data statistically. Data were expressed as mean ± standard deviation (SD). The Shapiro-Wilk test was conducted to check the normality distribution. Criterion validity was assessed with Pearson correlation coefficients to quantify the relationship between fat values measured during three different test protocols (Skinfold, BIA, and BOD POD), whilst two-way ANOVA was used to compare differences in the magnitude of power values calculated among three groups. Correlation coefficients ranging from 0.4–0.59 were categorized as indicating a moderate linear relationship, 0.6–0.79 were categorized as strong, and >0.8 were categorized as very strong (Evans, 1996). The relative reliability of test outcome variables measured from the Skinfold, BIA, and BODPOD was assessed by intra-class correlation coefficients (ICC) using a 2-way random model with absolute agreement and 95% CIs. ICC values were interpreted using the following guidance: 0.41–0.60 as moderate reliability, 0.61–0.80 as good reliability, and >0.81 as very good reliability (Altman, 1991). The absolute reliability of the same data was quantified using the 95% limits of agreement (LOA) method originally described by Bland and Altman (Bland & Altman, 1986). Linear regression analysis was also used using the difference between measurements as the dependent variable, and the average of the measurements as the independent variable to check the proportional biases. Cronbach's alpha is used to measure the internal consistency of test outcome variables and a reliability coefficient of 0.70 or higher is considered "acceptable" in most social science research situations (Taber, 2018). In all cases, a probability level (confidence interval) of 95% was considered to check the significance level.

Results

Table 1 summarizes the descriptive statistics of general anthropometric characteristics including age, height, body weight, and BMI. The average height, weight, and BMI were 176.06 ±8.03 cm, 70.60 ±14.27 kg, and 22.57 ±2.88 respectively.

Table 1. Descriptive analysis of general anthropometric variables.

Variables	Age (years)	Height (cm)	Weight (kg)	BMI (kg/m^2)
Mean ±SD	23.29 ±2.64	176.06 ±8.03	70.60 ±14.27	22.57 ±2.88
Min.–Max.	19.00–29.00	161.20–197.10	49.30–107.00	17.98–29.44

Values are expressed as mean ±SD, BMI = body mass index, Min. = minimum value, Max. = maximum value.

Table 2 depicts the comparative analysis result of BF% among three different body composition measuring protocols. The fat % values of the BIA protocol were found to be significantly ($p < 0.001$) higher than the other two methods i.e., skinfold (∆ 28.7%), and BOD POD (∆ 25.4%). The post hoc analysis depicts that the major group mean difference varied among BIA vs skinfold, BOD POD (F value = 17.387). Group variance was found to be lower in the case of SF measures in comparison to higher among both BIA and BOD POD.

Table 2. Comparative analysis of BF% among used fat-measuring methods.

Methods	Mean ±SD	Range	Variance
SF	12.28 ±3.74	16.81	13.96
BIA	17.24 ±5.17	22.90	26.68
BOD POD	12.85 ±4.93	21.50	24.12
F value (sig.)		17.387 ***	
Post hoc		BIA vs SF, BP	

*Values are expressed as mean ±SD, ***p < 0.001, BP = BOD POD, SF = skinfold, BIA = bio-electrical impedance analyzer.*

Table 3 illustrates the comparative analysis of BF% among the used three methods. The result shows very good relative reliability was found for BOD POD vs Skinfold [with ICC = 0.891 (0.809–0.938: 95% CI)] and good relative reliability was found against Skinfold vs BIA [with ICC = 0.669 (–0.207–0.895: 95% CI)], and BIA vs BOD POD [with ICC = 0.736 (–0.164–0.912: 95% CI)]. Pearson's correlation study found a positive and strong correlation among various studied fat-measuring protocols where Pearson's r varies from 0.800 to 0.849 with a statistical significance level of $p < 0.01$. However, the highest level of correlation was found among skinfold vs BIA (Pearson's r = 0.849). Internal consistencies for comparisons of power variables obtained from both tests were calculated using Cronbach's alpha. A higher internal consistency was found for all the measured cases (α varies from 0.888–0.893) including the highest α for both skinfold vs BIA and BOD POD vs skinfold (Cronbach's alpha = 0.893).

Table 3. Intra-class correlation (ICC), Cronbach's alpha of the test variables of Skinfold, BIA, and BOD POD.

Methods	ICC (95% CI)	Pearson's r	Cronbach's alpha
SF vs BIA	0.669 (–0.207–0.895)	0.849**	0.893
BIA vs BOD POD	0.736 (–0.164–0.912)	0.800**	0.888
BOD POD vs SF	0.891 (0.809–0.938)	0.838**	0.893

*** = p < 0.01 level, SF = skinfold, BIA = bio-electrical impedance analyzer, ICC = intra-class correlation, CI = confidence interval.*

Table 4 depicts the linear regression model which revealed the Bland-Altman analysis of male athletes. The linear regression analysis revealed that both means of differences and limits of agreement were only found to be significant in the case of skinfold vs BIA ($p < 0.001$, $\beta = -0.530$), and BOD POD vs skinfold ($p < 0.01$, $\beta = 0.453$) but the regression between BIA vs BOD POD (low $\beta = 0.084$) does not show any significant difference.

Table 4. Linear regression model for interpretation of Bland-Altman Plots.

Dependent variable	Independent variable	Unstandardized coefficients (β)	Significance	R^2
Difference of fat in SF vs BIA	Mean of fat in SF vs BIA	–0.530	<0.001***	0.281
Difference of fat in BIA vs BOD POD	Mean of fat in BIA vs BOD POD	0.084	0.558^{ns}	0.007
Difference of fat in BOD POD vs SF	Mean of fat in BOD POD vs SF	0.453	0.001**	0.205

*** = p < 0.01, *** = p < 0.001, ns = not significant, BIA = bio-electrical impedance analyzer, SF = skinfold, R^2 = coefficient of determination.*

Bland-Altman plots illustrating the distribution of the difference scores for BF% between tests of three different fat-measuring methods skinfold, BIA, and BOD POD were depicted in Figures 1A, 1B, and 1C respectively. The upper and lower lines represent 95% confidence intervals with means or bias ±1.96 SD. The LOA between BOD POD vs skinfold, BOD POD vs BIA, and BIA and Skinfold methods varies from +5.895 to –4.735% (Fig. 1A), +1.876 to –10.641% (Fig. 1B), and +10.462 to –0.537%, (Fig. 1C) respectively.

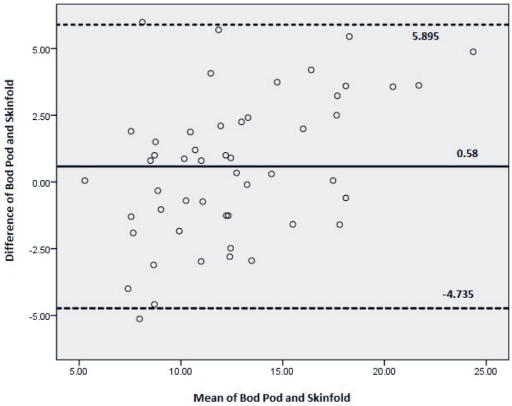

Fig.1 (A)

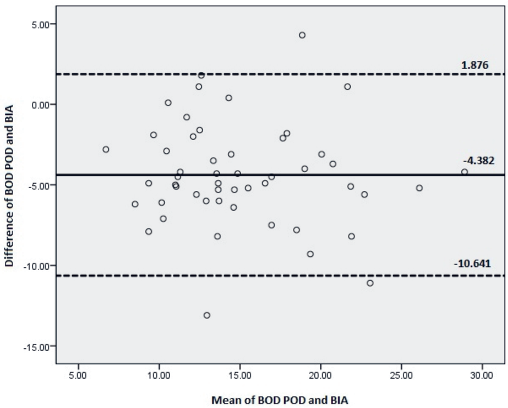

Fig. 1 (B)

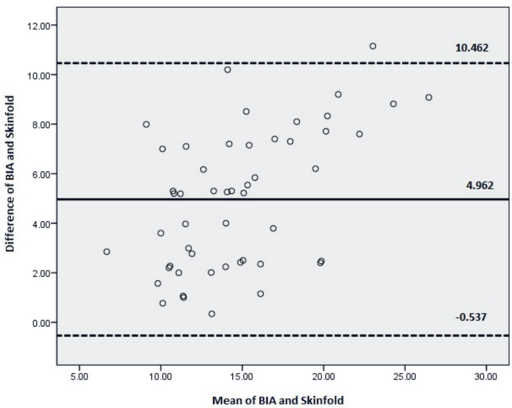

Fig.1 (C)

Figure 1. Bland-Altman plots illustrating the distribution of the difference scores of BF% measures for (A) BOD POD vs Skinfold, (B) BOD POD vs BIA, and (C) BIA vs Skinfold

Discussion

The present results reported that the fat measure from the BOD POD (12.85 ±4.93 %) and SF (12.28 ±3.74%) method was found to be the lowest data set for the present studied population in comparison to the BIA (17.24 ±5.17 %) method. The present study result correlated with previous studies where the range of the BOD POD data was found to be lower in comparison to the bioelectrical impedance data (Bi et al., 2018; Burns & Fu, 2019; Long et al., 2019).

Increased interest in comparing body composition via various methods has led to a focus on several studies evaluating the effectiveness of different methods. Earlier research found that the accuracy of BIA and SF measurements for BF% was affected by the participant's body weight status (Oeffinger et al., 2014; Aandstad et al., 2014). On the other hand, the BF% assessed by the BIA method was significantly higher when compared with hydrostatic weighing and SF measurements for both male and female athletes, suggesting that BIA may overestimate BF% and the BIA method depends on the hydration status of the individual (Schubert et al., 2019). The dehydration state can lead to an overestimated BF% and over-hydration can lead to an underestimate of the BF% (Burns & Fu, 2019; Ekingen et al., 2022; Willians & Bale, 1998). Interestingly SF is another reliable and validated method to measure BF% but the data accuracy in SF truly depends on the skill set of the scientist (Aandstad et al., 2014; Lohman & Pollock, 1981).

Group variance is lower in the case of SF (variance = 13.96) whereas the variance for BIA (variance = 26.68) and BOD POD (variance = 24.12) was found to be much higher when compared with the SF data. However, intra-class variance was found to be nil when compared between BIA and BOD POD. Depending on the differences among the group variance and ICC the present study reported excellent reliability found against BOD POD vs Skinfold [ICC = 0.891 (0.809–0.938)], while the other two aspects BIA vs BOD POD [ICC = 0.736 (–0.164–0.912)], and Skinfold vs BIA [ICC = 0.669 (–0.207–0.895)] depicted good reliability. Pearson's correlation coefficient showed a significant ($p < 0.01$) strong correlation while the binomial correlation among various BF% methods.

The BOD POD method tends to give slightly higher fat measures than the skinfold method and much variability between the two methods was present as indicated by the relatively large LOA (+5.895 to – 4.735%, Fig. 1A), this could be due to individual differences in body composition (Duren et al., 2008). The mean difference between the BOD POD and BIA methods is shifted towards negative values, indicating a systematic bias (Fig. 1B). The LOA (+1.876 to –10.641%, Fig. 1B) is quite wide, suggesting a substantial level of disagreement between BOD POD and BIA methods. In the case of the BIA and Skinfold method (Fig. 1C), there is a systematic bias, BIA method is consistently higher than the Skinfold method across the range of measurements (Schubert et al., 2019). The limits of agreement are wide (+10.462 to –0.537%, Fig. 1C), which suggests that the two methods have substantial variability in their differences.

Overall, the linear regression analysis through the Bland-Altman plot depicted that the mean of difference and LOA were found to be significantly different among both SF vs BIA ($p < 0.001$) and BOD POD vs SF ($p < 0.01$). The present result might be due to the narrow range and variance of SF (range = 16.81, and variance = 13.96) in comparison to both BIA and BOD POD with comparatively wider ranges and variance (Montgomery et al., 2017). This finding suggests that while each method has its merits, reliance on a single method for body fat assessment may lead to skewed interpretations of an athlete's physical composition.

Limitation

The present samples were male athletic population (19–29 years) and non-obese type; thus, it limits the study in terms of generalizing the study result from younger - older, obese - sedentary, and even from a gender perspective. The study has another limitation regarding using selected/ specified BIA devices (single and multi-frequency; even brand-wise device variations) and prediction equations used for BF% estimation via the SF method. Lastly, the thoracic gas volume for BOD POD assessment was an estimated value that might be counted as another limitation.

Conclusion

The present study underscores significant methodological discrepancies while measuring BF via various methods. Validity analysis of the present result depicts that BIA overestimates BF% in male athletes in comparison to BOD POD and SF methods. The variation in the limit of agreement study via the Bland-Altman plot analysis depicted a significant difference among both SF vs BIA and BOD POD vs SF. The study also reported a narrow range and variance for SF (range = 16.81, and variance = 13.96) in comparison to both BIA and BOD POD which have wider range and variance comparatively. Pearson's correlation coefficient showed a significant ($p < 0.01$) strong correlation while the binomial correlation among various BF% methods. Among all three BF% measuring methods, BOD POD vs Skinfold (ICC = 0.891) depicted very good reliability. In contrast, the other two aspects BIA vs BOD POD (ICC = 0.736), and Skinfold vs BIA (ICC = 0.669) depicted good reliability. All the BF% methods used in the present study were reliable and validated for BF% assessment and can be used according to the need of the test and availability of the equipment. However, the longitudinal studies for monitoring purposes should not interchange BF% measuring methods.

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