

Comparison of methods for estimating body fat percentage using skinfolds, InBody, and DXA: A pilot study

ZLATOŠ VLADIMÍR¹, ŠIMONEK JAROMÍR², VAĐURA JIŘÍ³, KRČMÁR MATÚŠ⁴

^{1,2,4}, Constantine the Philosopher University in Nitra, Department of Physical Education and Sport, Faculty of Education, SLOVAKIA

³ Independent researcher, external specialist in software modeling and data systems and bioimpedance modeling, Brno, CZECH REPUBLIC

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Abstract

Accurate determination of body fat percentage (%BF) is crucial for health assessment, sports diagnostics, and body composition monitoring in both clinical and field settings. Dual-energy X-ray absorptiometry (DXA) is widely regarded as a reference method because of its ability to distinguish fat, lean, and bone tissue with high precision, but its limited accessibility and cost reduce its routine applicability in schools, sports clubs, and practical field environments. Consequently, more accessible methods such as skinfold measurements and bioelectrical impedance analysis (BIA) are frequently used. However, both methods may be influenced by methodological, device-specific, and population-specific sources of bias. The aim of this pilot study was to compare the agreement and systematic deviations among an innovative 10-site skinfold method, the InBody 770 BIA device, and DXA in an adult sample. Ten participants (6 men, 4 women; age 29–62 years) underwent three body fat assessments on the same day under standardized fasted conditions: 1) 10-site skinfold measurement, 2) InBody 770 measurement, and 3) DXA scanning. Data were analyzed using Pearson correlation, Bland–Altman analysis, and Deming regression. Skinfold measurements significantly correlated with DXA ($r = 0.78$, $p = 0.007$) and showed a mean systematic difference of -2.45% . InBody 770 also correlated strongly with DXA ($r = 0.96$, $p = 0.001$), but showed a more pronounced underestimation of %BF (InBody – DXA = -3.98%). Deming regression confirmed distortion relative to the reference in both field methods. The 10-site skinfold method appears to be a transparent, standardized, and practically applicable field approach. The findings should be interpreted as pilot data that identify systematic bias and provide a basis for the design of larger validation studies.

Keywords: anthropometric diagnostics, adiposity assessment, agreement analysis, field validation, methodological bias

Introduction

Assessment of body composition is crucial in sport, clinical practice, and prevention. Among all parameters, the proportion of body fat in absolute values and percentage expression is most commonly monitored, as it is related to health and performance (Heyward & Wagner, 2014). DXA is often referred to in scientific practice as the gold standard or reference method against which the validity of other devices is assessed, due to its accuracy and ability to distinguish fat, muscle, and bone tissue (Nana et al., 2015). However, for routine use it is costly and less accessible; therefore, alternatives such as various models of bioelectrical impedance devices and skinfold measurements are used (Esco et al., 2019). In the literature, both directions of systematic error relative to the reference (overestimation and underestimation) are described, depending on the device, algorithms, hydration, and population characteristics (Ling et al., 2011; Kyle et al., 2004; Sun et al., 2005).

In skinfold measurements, accuracy depends on the number of sites, technique, and the equation used (Ackland et al., 2012; Stewart & Marfell-Jones, 2011; Durnin & Womersley, 1974). From the perspective of assessing the reliability and validity of different InBody models, McLester et al. (2020) conducted a study in healthy men and women, with DXA serving as the reference method. A total of 67 participants took part in the study, and the examined models included InBody 230, 720, and 770. Their study showed that all three models demonstrated a high degree of reliability in %BF measurement as assessed by the intraclass correlation coefficient ($ICC \geq 0.98$). When comparing agreement between InBody devices and DXA, they observed a systematic error in the underestimation of %BF, which was statistically significant in all cases ($p < 0.05$). Similar findings are also reported in the study by Merrigan et al. (2022), where InBody underestimated %BF and the level of agreement with DXA was weak to moderate.

The reliability of skinfold measurements is high when measurements are performed by a trained specialist; however, validity may vary depending on experience, the specific equations into which the measured data are entered, and the population sample being tested. Regardless of the above, skinfold measurement appears to be among the methods least affected by daily activities, food intake, and changes in hydration status (Kerr et al., 2017). In practical settings, coaches, teachers, and health professionals therefore need a method that is low-cost, transparent, reproducible, and sufficiently sensitive to detect meaningful changes in body fat distribution over time.

Silveira et al. (2020) conducted a study comparing skinfold measurement equations against DXA in adults. Their results indicate that the determination of %BF through skinfold measurements underestimated results in older participants (60+ years). They explain these results by differences in fat distribution with increasing age and changes in skin compressibility, which may significantly affect the validity of the obtained results. Similar findings were also presented by Chambers et al. (2014), where in older individuals not all regression equations accurately predicted %BF, either due to larger measurement error or systematic overestimation/underestimation.

Based on the findings of the above-mentioned studies, we decided to propose an accessible, standardized, and transparent 10-site method for estimating %BF using caliper skinfold measurements, which should have high practical utility in relation to DXA. Our model does not include age as a variable entering the regression equation. The aim of this pilot study was to compare the 10-site skinfold caliper method, InBody 770, and DXA, to determine the validity of the obtained data and identify systematic deviations, while also presenting differences between traditional and innovative skinfold measurement approaches.

Material & methods

Study design

The study design is shown in Figure 1. The sample size reflects the feasibility-oriented nature of the study, constrained by the need for same-day standardized measurements using DXA and bioimpedance methods. All three measurements on the individual devices were performed on the same morning, in a fasted state, under standardized laboratory conditions.

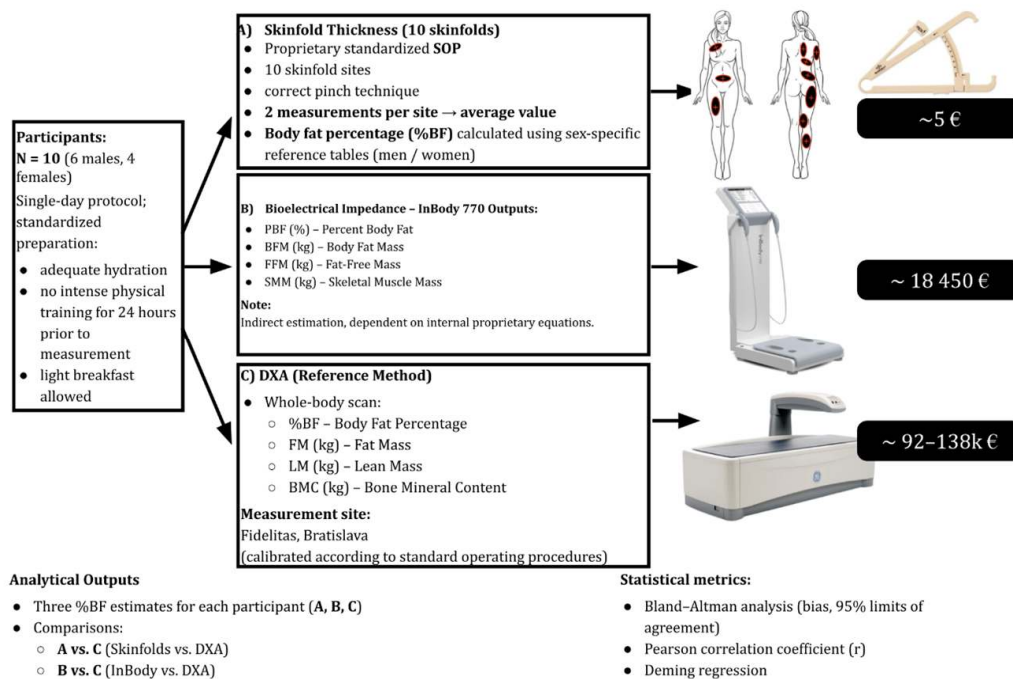


Figure 1. Study design

Participants

The research study included 10 adult individuals, of whom 6 were males and 4 were females aged 29–62 years, who were regularly physically active. The mean age of the participants was 44.1 ± 9.5 years, mean height was 174.2 ± 8.9 cm, and mean body mass was 71.6 ± 11.5 kg; mean %BF according to DXA was $21.3 \pm 7.1\%$. Exclusion criteria included acute illnesses, medications affecting hydration, and pregnancy. All participants signed informed consent to participate in the experiment. This study was approved by the institutional ethics committee in accordance with the Declaration of Helsinki under the number UKF/197/2024/191013:002.

Procedure / Test protocol / Measures / Instruments**1) Innovative 10-site skinfold method**

Measurements were performed on the right side of the body at 10 sites: chest, triceps, subscapular, suprailiac (hip area), rib area, abdomen, gluteal, thigh, knee, and calf (Figure 2). The pinching and reading technique were performed according to ISAK (The International Society for the Advancement of Kinanthropometry), with each site measured twice (if the difference was > 0.5 mm, a third measurement was taken and the median value was evaluated). The final value represented the sum of skinfolds from the 10 sites in mm. The estimation of %BF was obtained by a linear transformation calibrated against DXA, without the need to include the participant's age in the equation. The aim is transparency (no proprietary coefficients), better capture of gluteofemoral distribution, and morphological sensitivity.

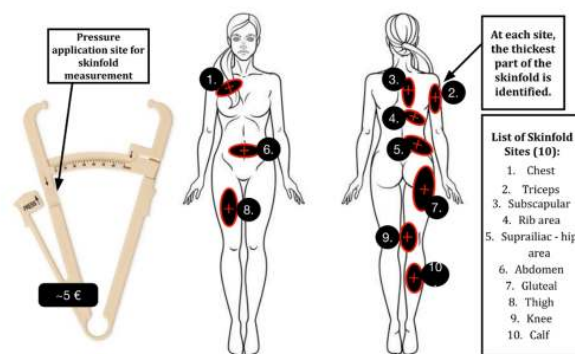


Figure 2. Ten skinfold measurement sites, identification of the thickest point, and caliper positioning

Original equations (Figure 3) (e.g., Jackson–Pollock, Durnin–Wommersley) use 3–7 sites and often include age in polynomial relationships, are sensitive to sex-related fat distribution, and may under- or overestimate at the extremes. Our method uses 10 sites, including areas important for women (gluteofemoral distribution), and a linear model without the need to include age, which reduces model bias and preserves physical interpretability (Figures 4 and 5).

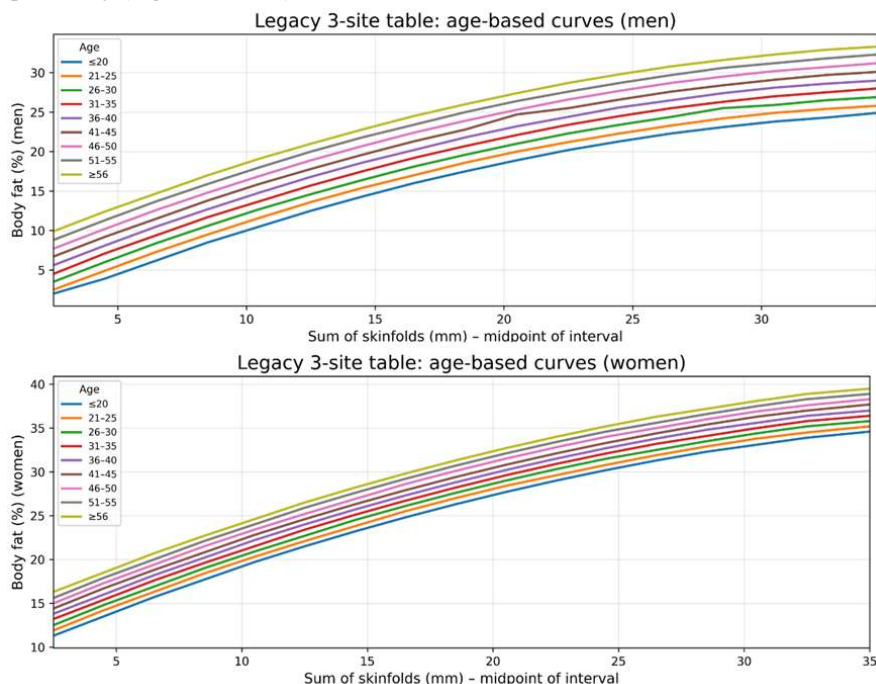


Figure 3. Original curves of the 3-site method (Jackson–Pollock) for men and women

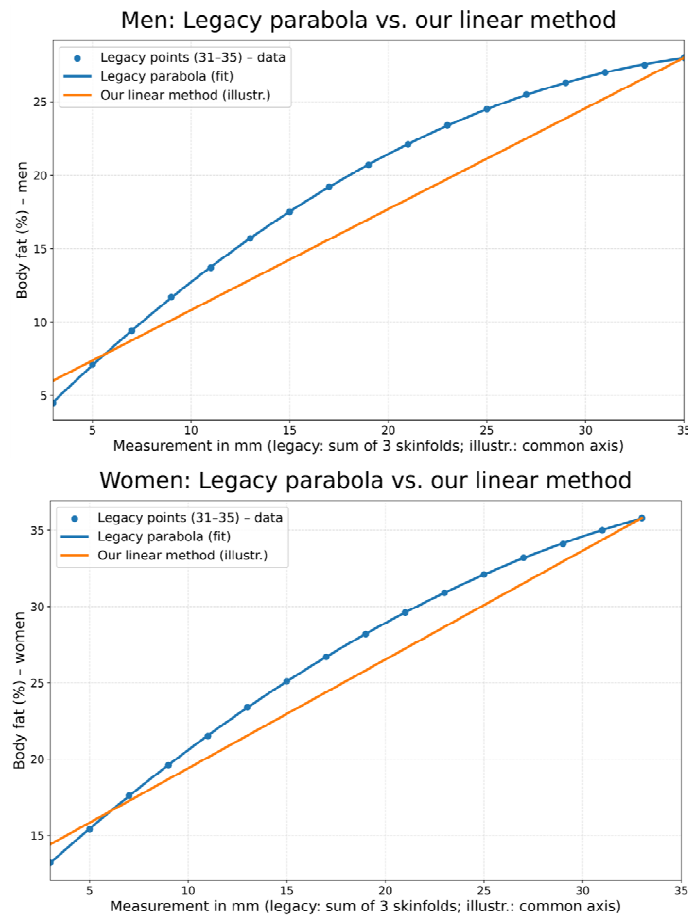


Figure 4. Comparison of the parabolic (legacy) and linear (10-point) models

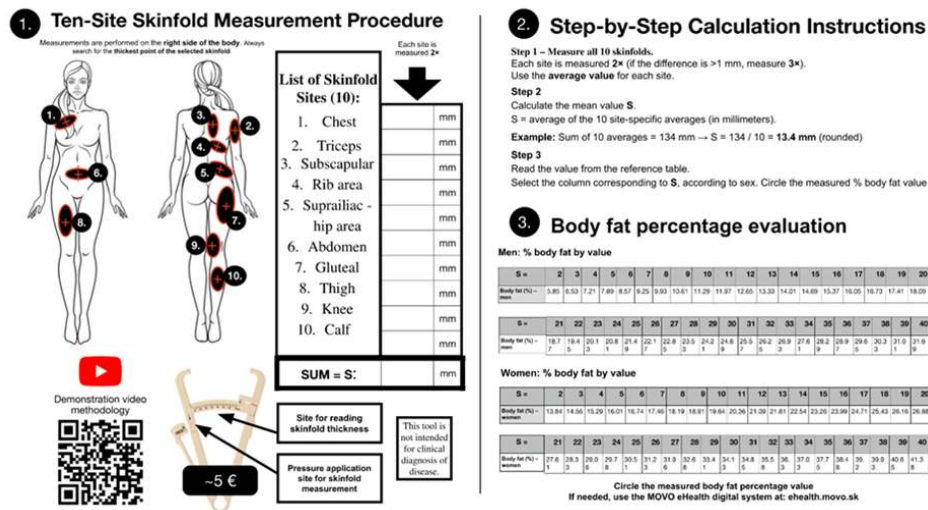


Figure 5. Field manual and standardized optimized protocol for the 10-site method

2) Bioelectrical impedance (InBody 770)

Measurement was performed barefoot in a standing position according to the manufacturer's manual (InBody 770 User's Manual, 2015). Participants refrained from food/fluids/activity for ≥ 3 hrs prior to the measurement. The device calculated %BF from multifrequency segmental impedance and phase angle (internal algorithms).

3) DXA Whole-body scans were performed using the GE Lunar Prodigy device, used for the measurement of bone mineral density and body composition analysis. In scientific studies, this device serves as a reference against which the validity of other devices is compared. The device has been demonstrated in multiple studies to be reliable with low coefficients of variability (Margulies et al., 2005; Shepherd et al., 2006; Williams et al., 2006).

Data collection and analysis / Statistical analysis

The obtained data were subjected to statistical processing, where first the normality of distribution was assessed using the Shapiro–Wilk test. Subsequently, relational dependence was evaluated using the Pearson correlation coefficient (r), which examines the strength of a linear relationship. Bland–Altman analysis was used to determine the mean difference and 95% limits of agreement (LOA) ($\text{mean} \pm 1.96 \times \text{SD}$ of the differences). A specific relational analysis was performed using the Deming regression method, which accounts for measurement errors in both compared methods (the examined and the reference). Unlike conventional linear regression, which assumes no error in the independent variable, Deming regression allows for error in the independent variable as well. This approach enables a more objective assessment of the relationship between measurement techniques. All analyses were performed using Python (Jupyter Lab) and the numerical libraries Pandas, NumPy, SciPy, Statsmodels, Deming, and the visualization library Seaborn.

Results

Table 1 represents the measured %BF results from the individual devices.

	Skinfold	InBody	DXA
n	10	10	10
Mean	20.51	18.98	22.96
Standard deviation	7.97	9.58	9.66
Minimal value	10.27	8.00	9.00
Quartile 25%	15.16	10.32	16.30
Quartile 50%	18.72	18.35	23.10
Quartile 75%	23.13	25.70	28.82
Maximal value	34.93	36.50	40.30

With regard to data normality, using the Shapiro–Wilk test we found p-values ranging from 0.491 to 0.814 across all three methods. In all cases, the normality of data distribution was satisfied. Basic correlation analysis between the skinfold method and the reference DXA method revealed a high relationship ($r = 0.78$, $p = 0.007$), and the relationship between InBody and DXA was also high ($r = 0.96$, $p = 0.001$).

Measurement validity was assessed using the Bland–Altman method. The results of the comparison between the skinfold method and DXA show a mean systematic measurement error of -2.45% with a standard deviation of 5.64% and limits of agreement ranging from -13.51% to 8.61% (Figure 6). The comparison between InBody and DXA shows a mean systematic measurement error of -3.98% with a standard deviation of 2.36% and limits of agreement ranging from -8.62% to 0.66% (Figure 7).

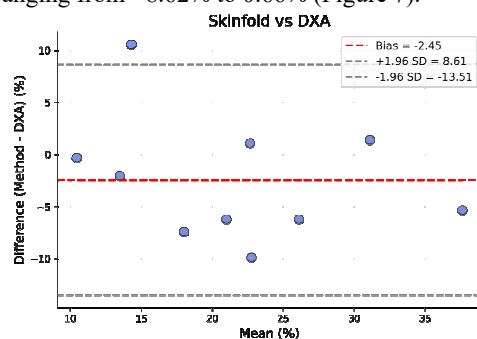


Figure 6. Bland–Altman plot showing agreement between the skinfold method and DXA for the assessment of body fat percentage (%BF). The red dashed line represents the mean bias (-2.45%), while the gray dashed lines indicate the 95% limits of agreement ($+1.96 \text{ SD} = 8.61\%$ and $-1.96 \text{ SD} = -13.51\%$). Individual points represent the differences between methods plotted against their mean values

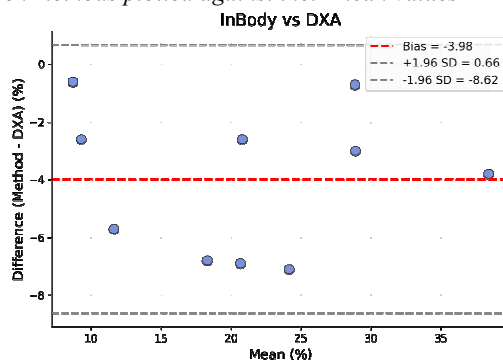


Figure 7. Bland–Altman plot showing agreement between the InBody 770 method and DXA for the assessment of body fat percentage (%BF). The red dashed line represents the mean bias (-3.98%), while the gray dashed lines

indicate the 95% limits of agreement ($+1.96\text{ SD} = 0.66\%$ and $-1.96\text{ SD} = -8.62\%$). Individual points represent the differences between methods plotted against their mean values

Deming regression, which assumes measurement error in both the examined methods (InBody, skinfolds) and the reference method (DXA), showed in both cases a low relationship for the skinfold measurement method vs. DXA ($R^2 = 0.274$, slope = 0.241) and a very weak relationship for InBody vs. DXA ($R^2 = 0.064$, slope = 0.034) (Figure 8).

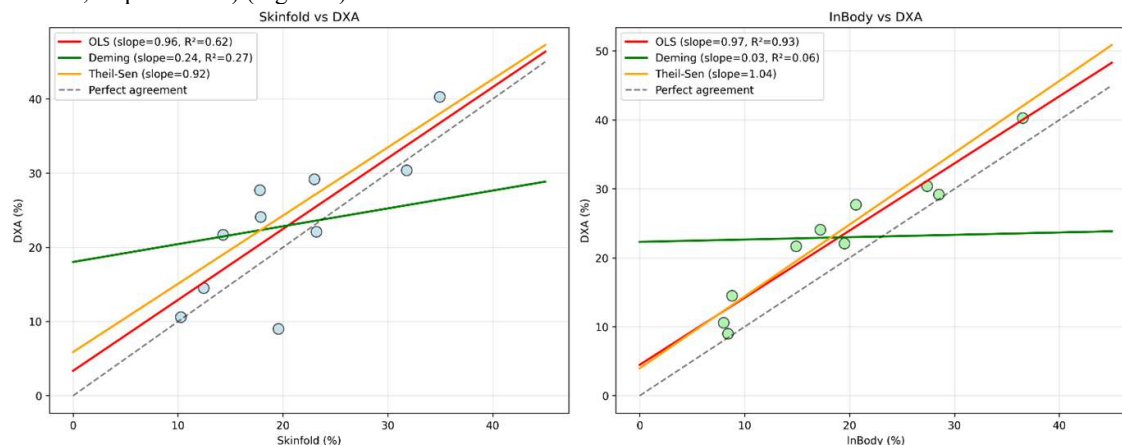


Figure 8. Deming regression analysis comparing skinfold measurements and InBody 770 with the reference DXA method for body fat percentage (%BF). The left panel shows the relationship between skinfolds and DXA, and the right panel shows the relationship between InBody 770 and DXA. Solid lines represent ordinary least squares (OLS), Deming regression, and Theil–Sen regression, while the dashed line indicates perfect agreement (identity line). The plots illustrate low agreement for the skinfold method and very weak agreement for InBody 770 relative to DXA

Discussion

The aim of this study was to verify the accuracy, validity, and mutual agreement between three methods of determining body fat percentage – skinfold thickness measurement (caliper), bioelectrical impedance analysis (InBody 770), and X-ray absorptiometry (DXA), which was used as the reference method. The selection of these methods is based on their common use in sports diagnostics and clinical practice, while DXA has long been considered in the scientific literature as the gold standard for body composition measurement (Nana et al., 2015; Toombs et al., 2012). Importantly, the primary aim of this study was not formal validation, but the exploration of agreement patterns and systematic bias under strictly standardized measurement conditions. Such pilot data are essential for estimating variability and informing sample size calculations for subsequent large-scale studies. The results of the Shapiro–Wilk normality test confirmed that the data distribution from the individual methods was normal ($p = 0.491\text{--}0.814$), which allowed the use of parametric statistical analysis methods. This excludes the influence of nonlinear distortions in data distribution and increases the reliability of the obtained results.

Pearson correlation analysis demonstrated a high linear relationship between skinfold results and DXA ($r = 0.78$, $p = 0.007$) and a very strong relationship between InBody and DXA ($r = 0.96$, $p = 0.001$). These results are consistent with findings from previous research reporting that bioimpedance methods may show strong correlations with DXA, particularly in homogeneous populations (Ling et al., 2011; Karelis et al., 2013). However, as pointed out by Atkinson and Nevill (1998), correlation alone cannot provide information about agreement between methods, because high correlation may exist even in the presence of systematic bias. High correlation may therefore indicate that changes in body fat values are captured by the methods in a similar direction, but not necessarily with the same absolute accuracy. For this reason, it was appropriate to complement the correlation analysis with the Bland–Altman method, which allows better evaluation of systematic differences and limits of agreement between methods (Bland & Altman, 1986).

Bland–Altman analysis showed that the skinfold method on average underestimated body fat values compared to DXA by 2.44%, with a standard deviation of 5.64% and limits of agreement from -13.50% to 8.61% . This indicates considerable individual variability between measurements. Similar differences were also described by Esco et al. (2015) and Nana et al. (2012), who stated that anthropometric methods may exhibit significant differences in accuracy depending on the evaluator's experience, the equation used, and the population on which the equation was originally validated.

The InBody method showed a mean systematic error of -3.97% with a standard deviation of 2.36% and limits of agreement from -8.62% to 0.66% . This result indicates a slight underestimation of body fat compared to DXA, which is consistent with studies highlighting the tendency of bioimpedance methods to underestimate body fat in physically active individuals (Bilsborough et al., 2014; Kyle et al., 2004). The main reasons include the influence of hydration, ambient temperature, and current electrolyte balance, which affect the electrical conductivity of tissues (Dehghan & Merchant, 2008). Based on these results, it can be concluded that although

both field methods (skinfolds and InBody) show relatively good correlation with DXA, their individual accuracy is limited and may lead to systematic bias. Therefore, their use is recommended mainly for monitoring relative changes over time in the same individuals, rather than for comparing absolute values between different measurement techniques (Moon, 2013; Ackland et al., 2012).

Deming regression, which accounts for measurement error in both methods, provided an important complement to interpretation. In the comparison of skinfolds with DXA, a low coefficient of determination was found ($R^2 = 0.274$, slope = 0.241), and in the comparison of InBody with DXA, a very low coefficient was found ($R^2 = 0.064$, slope = 0.034). These results indicate that the predictive ability of these methods relative to the reference standard is limited, particularly for absolute body fat values. Differences between methods can be explained by their different measurement principles. DXA uses dual-energy X-ray absorption to distinguish fat, muscle, and bone components (Nana et al., 2015). The bioimpedance method estimates body composition based on electrical current conductivity, making it sensitive to body fluid volume (Kyle et al., 2004), while skinfold measurement is based on prediction equations that may not be valid for all populations (Jackson & Pollock, 1978).

From a practical perspective, skinfold and InBody methods may be suitable for field monitoring of changes in body composition in sports diagnostics, clinical practice, or population screenings. Their advantages are accessibility, speed, and simplicity, while the limiting factor is lower accuracy compared to DXA. When interpreting results, professionals should therefore consider possible systematic biases and ensure measurement standardization (e.g., hydration status, time of day, evaluator experience).

The main limitations of the study include the relatively small number of participants, which may reduce the generalizability of the results. Another factor is the possible influence of non-standardized measurement conditions (e.g., failure to maintain fasting, insufficient hydration), which may significantly affect bioimpedance results. Future studies should include a larger and more heterogeneous sample of participants (different sexes, age groups, levels of physical fitness) and apply standardized measurement protocols. An interesting direction may also be the comparison of new technologies, such as ultrasound and 3D optical methods, with reference DXA measurements. It would also be appropriate to monitor the sensitivity of individual methods to changes following training or nutritional interventions, which would contribute to a better understanding of their applied value in long-term monitoring of athletes' body composition.

Conclusions

The present pilot study showed that both field methods were related to DXA, but neither was fully interchangeable with the reference method. The 10-site skinfold protocol demonstrated a smaller mean deviation from DXA, while InBody 770 showed a more pronounced systematic underestimation of body fat percentage in this sample. These findings confirm that strong correlation alone is not sufficient to demonstrate practical agreement and that absolute values obtained by field methods must be interpreted with caution.

From a methodological perspective, the proposed 10-site skinfold approach offers several advantages over traditional 3–7 site equations: broader anatomical coverage, inclusion of gluteofemoral regions, identification of the thickest skinfold point, a transparent linear transformation without age correction, and practical replicability in field settings. From an applied perspective, the method appears suitable for coaches, teachers, and practitioners who require a low-cost, standardized, and interpretable approach to monitoring body composition. Future studies should validate the method in larger and more heterogeneous samples and further examine its performance across different body types and intervention settings.

DECLARATION OF GENERATIVE AI AND AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

During the preparation of this work, the authors used ChatGPT (OpenAI) in order to support language refinement, structural editing, and the reorganization of selected manuscript sections. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Conflicts of interest

The authors declare no conflict of interest related to this manuscript.

Limitations

This study is limited by the small pilot sample, the absence of test–retest reliability assessment, and the use of one DXA system and one BIA device model. Therefore, the findings should be interpreted as preliminary and methodological rather than definitive for all populations.

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