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Agreement between Body Fat Estimation Methods: From Durnin and Womersley Equation to Bioimpedance

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Abstract

Introduction: The Durnin-Womersley equation (DWe) for estimating body fat (%BF) and bioelectrical impedance analysis (BIA) generally give similar results, but in some cases the differences are striking, which could be related to the distribution of fat in some individuals. The objective of this study was to analyze the agreement between both methods and investigate their relationship with the distribution of fat mass. **Methods:** A sample of 326 individuals (201 women and 125 men), aged between 18 and 74 years, was analyzed. Their %BF was determined by DWe and BIA, using a Tanita RD545 scale. Height, waist, and hip circumferences were also analyzed. Absolute differences between methods (DWe-BIA) were analyzed using simple linear correlation, Bland-Altman analysis, and chi-square tests with GraphPad Prism 8 software. **Results:** There is high agreement between methods; Bland-Altman analysis showed a mean bias of -1.545 points (-10.58 to 7.49), with a higher proportion of cases in which DWe underestimates the %BF calculated by BIA (approximately 2/3 of cases). The higher the value obtained by BIA, the greater the underestimation of DWe. No association was found between height and DWe-BIA differences. An increment in age was associated with a greater probability of overestimation by DWe. Higher values for waist, hip, and waist/height and hip/height ratios were related to a greater probability of underestimation of %BF by the DWe. **Conclusions:** The DWe tends to underestimate the %BF in relation to that estimated by BIA, as the latter increases. On the other hand, an increment in waist and hip circumferences also increases the probability that this equation underestimates %BF.

Keywords: Anthropometry, Electric bioimpedance, Body composition, Waist circumference, Hip circumference

Resumen

Introducción: La ecuación de Durnin-Womersley (DWe) para estimación de grasa corporal (%BF) y la bioimpedancia eléctrica (BIA) generalmente arrojan resultados similares, pero en ciertos casos las diferencias son llamativas, lo cual podría estar relacionado con la distribución de la grasa en algunas personas. El objetivo del presente trabajo fue analizar la concordancia entre ambos métodos e indagar su relación con la distribución de la masa grasa. **Métodos:** Se analizó una muestra de 326 individuos (201 mujeres y 125 hombres), con edades entre 18 y 74 años. Se determinó su %BF mediante DWe y BIA, utilizando una balanza Tanita RD545. Se midió su talla y circunferencias de cintura y cadera. Se analizaron las diferencias absolutas (DWe-BIA) entre métodos mediante correlación lineal simple, análisis de Bland-Altman y pruebas de chi-cuadrado con el programa GraphPad Prism 8. **Resultados:** Existe una alta concordancia entre métodos; el análisis de Bland-Altman mostró un sesgo medio de -1,545 puntos (-10,58 a 7,49), con una mayor proporción de casos en los que DWe subestima el %BF calculado por BIA (aproximadamente 2/3 de los casos). A mayor el valor obtenido por BIA, mayor subestimación de DWe. No se encontró asociación entre la talla y las diferencias DWe-BIA. Una mayor edad se asoció con mayor probabilidad de sobreestimación por parte de DWe. Mayores valores de cintura, cadera y los índices cintura/talla y cadera/talla se relacionaron con una mayor probabilidad de subestimación del %BF por parte de la DWe. **Conclusiones:** La DWe tiende a subestimar el %BF en relación al estimado mediante BIA, a medida que aumenta este último. Por otra parte, un incremento en las circunferencias de cintura y cadera también aumenta la probabilidad de que esta ecuación subestime el %BF.

Palabras Clave: Antropometría, Bioimpedancia eléctrica, Composición corporal, Circunferencia de cintura, Circunferencia de cadera

Introduction

Fat mass percentage is a world widely used measure to assess physical fitness and aesthetic characteristics, but it is also related to several health markers. This value is also used to serially evaluate the efficiency and effectiveness of nutritional and physical activity treatments. Various indirect methods have been used to estimate it for many years, with varying degrees of accuracy, but also with varying degrees of affordability and practicality.

Over 50 years ago, Durnin and Womersley published their equations (DWe) for estimating body fat from the summation of four skinfold thicknesses. They validated their measurements with body density measured by underwater weighing and used 481 women and men aged 16–72 years (Durnin and Womersley 1974). The original publication of this equation has become the most cited scientific article in the history of the British Journal of Nutrition, and has stimulated hundreds of investigations over the decades (Heymsfield and Strauss 2022).

Bioimpedance analysis (BIA), a doubly indirect method, was introduced into clinical practice in the following decade, rapidly gaining popularity for percentage of body fat (%BF) estimation due to the quality of its results, its speed, portability, and its—currently—low cost (Lukaski et al. 1985). Throughout its history, it has also evolved, moving from complex, static devices to new portable ones and wearable technology (Mehra el al. 2025). Currently, the method considered the reference by the scientific community for estimating body fat mass is Dual-energy X-ray absorptiometry (DXA), but due to its high costs it is only affordable for very high-resource institutions (Aragon et al. 2017; Marra et al. 2019).

Despite the criticisms, re-evaluations, and considerations that have been made about the DWe, its utilization is still habitual and has become a classic in the scientific literature. For this reason, its use in current clinical practice coincides with that of BIA, since both methods are inexpensive, noninvasive, and applicable in a wide variety of health and disease situations (Fogelholm and van Marken Lichtenbelt 1997; Marin-Jimenez et al. 2022; Silva et al. 2023). However, the constant observation of similarities or differences between both strategies leads us to believe that some other variable may partly explain why in some individuals there are more than ten points of difference between the methods, while in others similarities and coincidences are prevalent. For these reasons, some researchers have periodically made other proposals for estimating fat mass, including more anthropometric measurements such as circumferences and/or bone diameters besides skinfolds in the regression equations, providing more accuracy than using skinfolds alone (Garcia et al. 2005; Reinert et al. 2012; Lee et al. 2021; Bennouar et al. 2023).

The objective of this investigation was to analyze the concordance between the %BF estimated by the DWe and the BIA, and to investigate the relationship among the differences between both methods and the distribution of fat mass.

Materials and Methods

A sample of 326 Caucasian individuals (201 women and 125 men) aged between 18 and 74 years was studied. They were non-probabilistically recruited, following a routine nutritional consultation. The assessment was conducted in the morning, between 7:30 and 9:00 a.m., after a light breakfast. Participants were asked to avoid strenuous physical exercise in the preceding 12 hours. Volunteers gave their informed consent for participation in this research study and the anonymous use of their data.

Anthropometric Measurements

Anthropometric variables were obtained by an expert measurer following the International Society for the Advancement of Kinanthropometry (ISAK) protocol (Esparza-Ros and Vaquero-Cristóbal 2023). For this purpose, the following variables were determined using the respective instruments:

- Height (in cm): measured with a Seca 213 portable stadiometer (Seca Deutschland, Hamburg, Germany), with the subject barefoot.
- Waist and hip circumferences (in cm): using a flexible, inextensible steel tape (Mednib, Buenos Aires, Argentina).

- Skinfolds (in mm): triceps, subscapular, biceps and iliac crest, using a SlimGuide caliper. These measurements were evaluated on the right side of the body and recorded twice (or three times if the difference between the two was greater than 5%), and the mean or median of the values was considered, depending on the case, respectively.

Bioimpedance Analysis

This measurement was performed according to previously described protocols and materials (Messina 2024). The analysis was performed after the anthropometric evaluation, using a Tanita RD-545 HR scale, with the individual in underwear, and following the manufacturer's instructions.

Additional Calculations

The %BF was calculated using the DWe in its various age ranges, according to the individual's sex (Durnin and Womersley 1974). The absolute difference between methods was then calculated using the formula:

Difference between methods = %BF DWe - %BF BIA

Thus, positive values indicate that the DWe overestimates the %BF compared to the BIA, while negative values indicate that the DWe underestimates the %BF compared to the BIA.

Data analysis

GraphPad Prism 8 (GraphPad Software, Inc.) was used. Descriptive statistics included the arithmetic mean and standard deviation (Table 1). Normality of the samples was assessed by the D'Agostino-Pearson normality test. Then, the following tests were performed:

- Spearman's correlation: Figure 1.
- Bland-Altman analysis (bias and agreement limits): Figure 1.
- Nonlinear curve fitting: Figures 2, 3 and 4.
- Chi-square test for trend: Figure 5.

Results

The characteristics of the final sample are described in Table 1:

Table 1. Characteristics of the sample

Characteristics of the sample									
Age range (year)	Total			Female			Male		
	n	%BF DWe	%BF BIA	n	%BF DWe	%BF BIA	n	%BF DWe	%BF BIA
18-19	18	25.6 ± 7.4	29.5 ± 8.6	11	29.2 ± 5.6	33.8 ± 6.0	7	19.9 ± 6.1	22.7 ± 7.9
20-29	86	24.8 ± 9.0	27.7 ± 10.4	49	30.4 ± 7.0	33.5 ± 9.2	37	17.4 ± 5.3	20.1 ± 6.1
30-39	111	26.3 ± 7.1	28.6 ± 9.6	56	31.4 ± 4.8	34.7 ± 8.1	55	21.1 ± 4.9	22.5 ± 6.8
40-49	64	31.2 ± 7.4	31.5 ± 9.9	45	34.5 ± 5.4	35.2 ± 8.8	19	23.6 ± 5.5	22.8 ± 6.2
50 +	47	36.5 ± 6.7	34.5 ± 8.4	40	38.0 ± 5.5	36.1 ± 7.5	7	27.7 ± 6.9	25.0 ± 7.8
Total	326	28.3 ± 8.7	29.9 ± 10	201	33.1 ± 6.4	34.8 ± 8.4	125	20.7 ± 5.9	22.0 ± 6.7

Results expressed as mean ± standard deviation.

As it can be seen in Figure 1, there is a high positive correlation between the methods (top panel). However, since this statistical analysis does not indicate agreement (Singhal and Siddhu 2011), the Bland-Altman plot (bottom panel) shows a tendency for the higher the %BF (i.e., the higher the mean between methods), the more negative the differences between them tend to become. As it will be seen later, this finding implies a greater likelihood of the DWe underestimating the %BF the higher this tends to be (Figure 2).

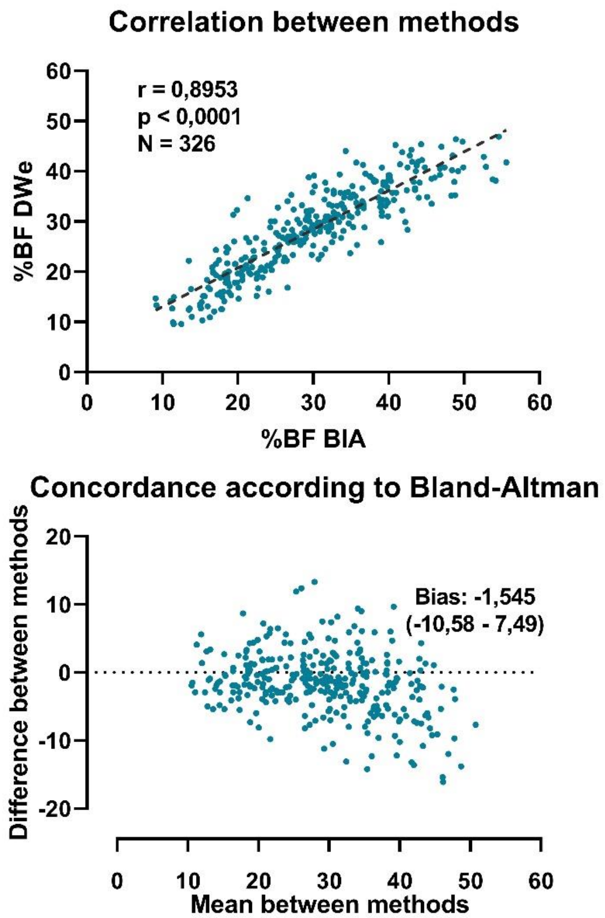

Figure 1. Agreement between methods

The following observation shows that, as the %BF measured by BIA increases, the probability of the DWe underestimating the value also increases (Figure 2). A closer look at the graph reveals that above 30% fat mass (estimated by BIA, vertical dotted line), the fitting curve inflects and rapidly descends. In fact, above 30% BF estimated by BIA, the DWe will underestimate the value in 80.1% of cases (i.e., the points are below the horizontal dotted line), while it will do so in 55.2% of cases when the %BF is less than 30%.

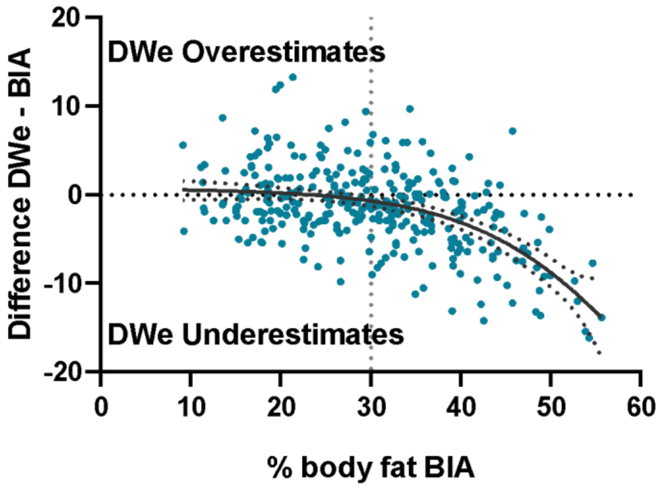

Figure 2. Dot plot showing a greater DWe underestimation as %BF estimated by BIA increases

Upper panels of Figure 3 show that as age increases, the absolute difference between the %BF estimated by both methods tends to become positive, meaning that the probability that DWe overestimates the BIA estimate also increases. This observation was similar in both women and men. Moreover, height is not a good predictor of the differences between DWe and BIA, as observed in the lower panels. No clear trends are seen in them, with a practically similar dispersion of points between the area of overestimation (above the dotted line) and the area of underestimation (below the dotted line), in both women and men. In the entire data series observed in this work (lower left panel), 67.5% of cases fell below the dotted line, and the remaining 32.5% fell above it.

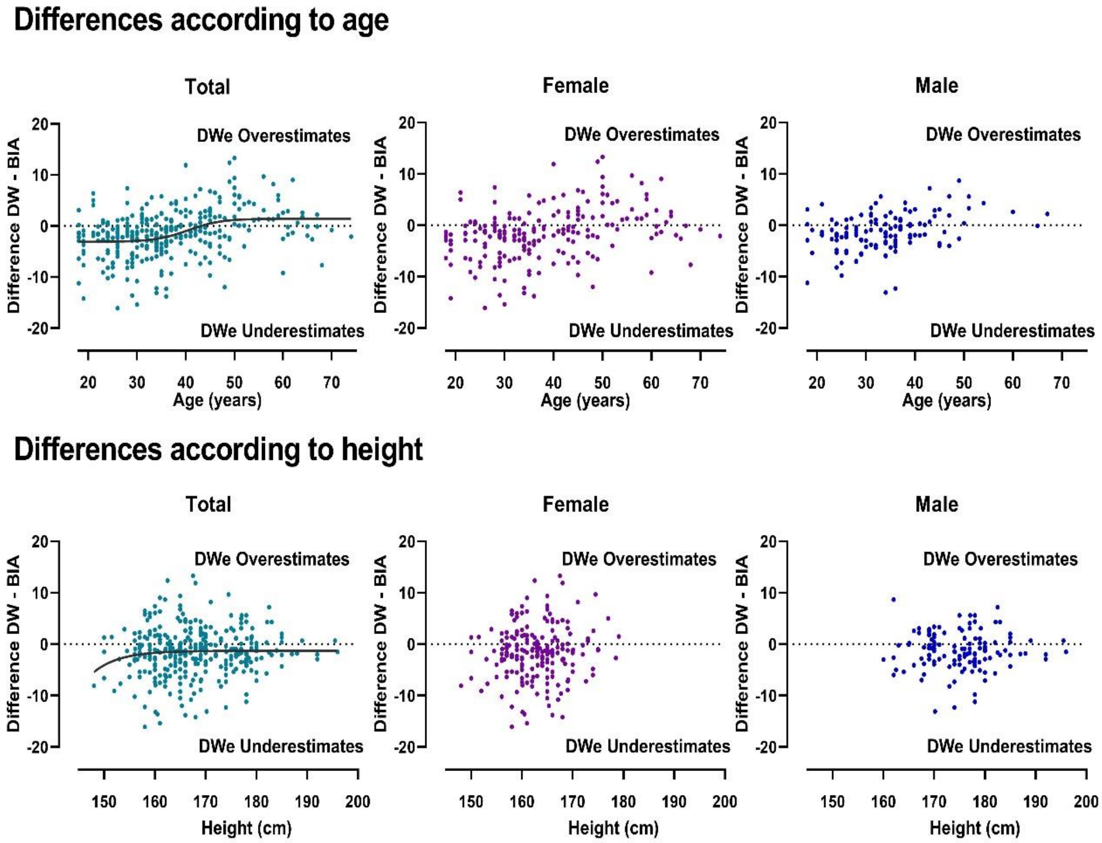

Figure 3. Differences between DWe and BIA according to age and height

Furthermore, the scatter plots in Figure 4 show a clear negative trend as waist and hip measurements, and their respective relationships with height (waist-to-height ratio and hip-to-height ratio) increase. In other words, as these variables increase, the DWe is more likely to underestimate the %BF that would be obtained using BIA. This finding was significant in both women and men, with some notable cases of differences of more than 15 percentage points between methods.

Finally, Figure 5 details the percentages of cases in which the DWe underestimated or overestimated the %BF calculated by the BIA. That is, when the DWe–BIA difference was positive, the case was counted as "overestimated," and vice versa. This qualitative analysis confirms that as the age range (established by the DWe) increases, the probability that the DWe underestimates what was observed with the BIA is lower ($p<0.0001$, graph A, consistent with Figure 3). Meanwhile, across the different height ranges (arbitrarily established, graph B), the proportions of underestimation/overestimation remained practically constant. Regarding the probability that the DWe underestimates what was measured with BIA according to arbitrary ranges of waist and hip circumferences and their relationships with height, it can be observed that in all cases it increased significantly from left to right (graphs C-F, $p<0.05$ in all cases). Of particular interest are the upper ranges of each measure, where in approximately 80% or more of cases the DWe underestimates the %BF observed by BIA.

Discussion

In this study, we aimed to analyze the agreement between two methods widely used in clinical practice for estimating body fat percentage. Although both are considered "doubly indirect" and have not been validated here with a direct reference method, the fact that the differences between them are random motivated the analysis related to fat distribution.

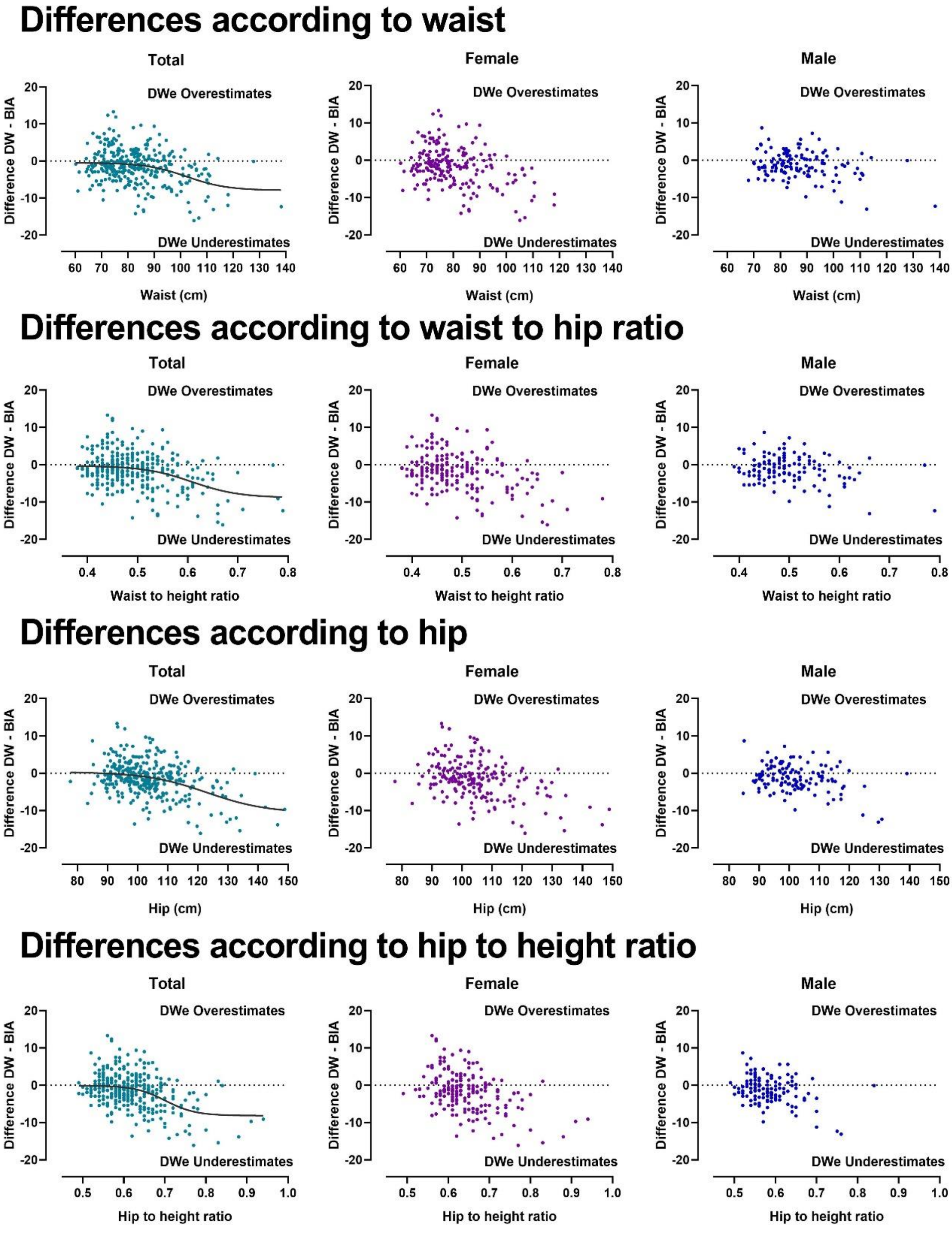

Figure 4. Differences between DWe and BIA according to waist, hip and their ratios to height

From a chemical perspective, both models analyzed in this study (DWe and BIA) estimate fat mass using the lipid molecular model, but since both are "doubly indirect," they accumulate two sources of error (Vaquero-Cristóbal 2023). Initially, we proposed the Bland-Altman analysis, which is the best strategy to evaluate agreement between methods when the true estimated value is unknown (Bland and Altman 1986). Subsequently, a trend toward increasing negative differences between methods was found with larger waist and hip circumferences in both sexes.

The usefulness and validity of anthropometric methods for estimating %BF is not without criticism and counterproposals. For several decades, it has been observed that both anthropometric formulas and BIA exhibit certain errors (or large differences compared to reference methods), especially when additional considerations such as fat distribution, sex and ethnicity are considered. Given the global trend of increasing obesity in the population, it becomes necessary to continue researching on %BF estimation to optimize the use of resources and improve patient diagnosis and follow-up. Of particular interest to this research is the fact that the DWe does not predict %BF uniformly across ethnicities (Davidson et al. 2011).

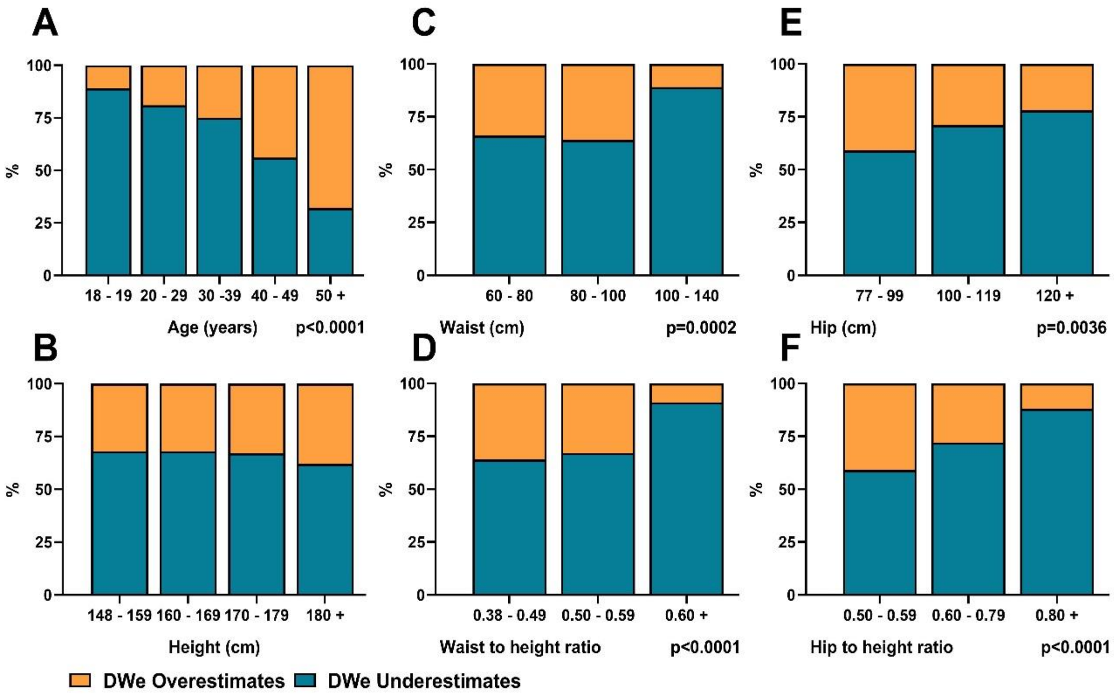

Figure 5. Qualitative analysis of DWe overestimation/underestimation according to age, height, waist and hip measurements

However, a recent systematic review found strong evidence in favor of the DWe for estimating %BF in most White, Caucasian, African American, Hispanic, and Asian adults (Marin-Jimenez et al. 2022). It also has strong evidence in normal-weight and overweight groups. However, it is not valid in individuals with obesity and, like all anthropometric formulas, can be highly influenced by the experience of the measurers, the instrumentation used, and other factors specific to the individuals being measured, including physiological status, sex, and ethnicity. In other studies, the DWe has shown high concordance with fat estimation using DXA. In African American and Caucasian women, this equation is one of the least likely to overestimate %BF (Cedillo et al. 2022).

On the other hand, it has been observed that anthropometric equations and BIA may overestimate %BF when compared to hydrostatic weighing in women with a greater upper-body fat distribution, while they tend to be more accurate when the fat distribution pattern is in the lower half (Swan and McConnell 1999). In obese individuals, BIA also has its disadvantages in estimating %BF, since it can over- or underestimate it (Blew et al. 2002; Reinert et al. 2012). More recently, anthropometric formulas for estimating %BF and even BIA have been shown to be invalid with respect to results obtained by DXA, considering estimates in percentage and kilograms, in both sexes (Mecherques-Carini et al. 2024). DWe has in fact been shown to underestimate %BF compared to DXA. Comparisons of observed values among various anthropometric methods (using BIA as a reference) generally yield diverse results, especially when the sample is divided by sex and age (Escamilla et al. 2024). The same is true when comparing BIA and DXA, and even more so when adding the dimensions of body regions in addition to the entire body (Silva et al. 2025). For these reasons, the methods should not be directly comparable or interchangeable. When comparing individuals, populations, or recording evolution over time, and even when comparing with a reference, the same methodology should always be maintained (Vaquero-Cristóbal et al. 2020; Mecherques-Carini et al. 2022; Smolik et al. 2025).

Limitations and considerations of the study

This study did not use any of the two most accurate reference methods (Dual-Energy X-ray Absorptiometry (DXA) and Air Displacement Plethysmography (ADP)) which are expensive and often unavailable. Secondly, the age groups were not homogeneous in their sample size or composition, as can be seen in Table 1. Third, although the BIA has been used in children and adolescents (Orsso et al. 2022; Sleiman et al. 2024), this study only worked with those over 18 years of age, in order to emulate the age ranges proposed by the DWe. Fourth, the use of BMI was discontinued because, though it is still widely used in clinical practice, recent research and consensus have highlighted its extensive limitations for the diagnosis and prognosis of obesity (Sweatt et al. 2024; Kok et al. 2024; Wu et al. 2024). Finally, although the anthropometric measurements were performed by two qualified anthropometry professionals, there may be interpersonal differences, depending on the level of training and experience (Gordon and Bradtmiller 1992; Kouchi et al. 1999). To minimize this error, the necessary precautions were taken (Arroyo et al. 2010).

Conclusions

The DWe tends to underestimate the %BF relative to the BIA estimate as the latter increases, especially above 30%. Furthermore, an increase in waist and hip circumferences also raise the likelihood that this anthropometric equation will underestimate %BF.

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Luisina Andrea Capone: Investigation, Resources, Visualization. María Victoria Muscia: Investigation, Visualization, Writing – Original Draft. Diego Nicolás Messina: Conceptualization, Formal analysis, Resources, Visualization, Writing – Review & Editing.

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Conflicts of Interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Informed Consent Statement

All the athletes included in the study provided written informed consent.

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