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Agreement and Differences between Fat Estimation Formulas Using Kinanthropometry in a Physically Active Population

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Abstract: The importance of fat mass estimation in multiple areas related to health and sports has led to the emergence of a large number of methods and formulas for its estimation. The aim of the present study was to compare the agreement and differences between different formulas for estimating fat mass by anthropometry. Eighty-seven subjects underwent an anthropometric assessment following the protocol from the International Society for the Advancement of Kinanthropometry (ISAK). The fat percentage was calculated with 14 different formulas for men and with 12 different formulas for women. In the case of men, they were proposed by Durnin-Womersley, Yuhasz, Faulkner, Carter, Peterson, Katch-McArdle, Sloan, Wilmore, Evans, Lean, Reilly, Civar, Hastuti, and Kerr. In the case of women, the equations used were those proposed by Durnin-Womersley, Yuhasz, Faulkner, Carter, Peterson, Katch-McArdle, Sloan, Wilmore, Evans, Lean, Thorland, and Kerr. Significant differences were found between the formulas in both men (8.90 ± 2.17% to 17.91 ± 2.84%; $p < 0.001$–0.016) and women (15.33 ± 2.94% to 28.79 ± 3.30%; $p < 0.001$–0.004). It was observed that in the case of men, the Carter and Yuhasz formulas and the Civar and Faulkner formulas showed moderate agreement with each other (CCC = 0.910–0.915). In the case of women, it was observed that the Carter and Yuhasz formulas showed moderate agreement with each other (CCC = 0.974). In conclusion, the formulas used for the estimation of lipid mass in anthropometry reported significantly different results between them and were therefore not comparable.

Keywords: adipose tissue; body fat; body weight; fat tissue; sports; health; kinanthropometry; performance; skinfolds

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1. Introduction

The importance of body fat in multiple areas such as health, due to its association with various pathologies and their comorbidities, or sports, due to its relationship with the optimization of physical performance, has led the scientific community to look for different ways to quantify it [1–3]. However, in the classical approach to fat mass estimation, one of the main problems in estimating body composition, and more specifically its adipose component, has been the confusion in using the terms fat, lipids, and adiposity as synonyms, when they are not [4,5]. In this respect, body composition, regardless of the method used, can be approached based on five levels of increasing complexity [6–8]. Model 1, at the atomic level, considers body mass as the sum of the amount of hydrogen; carbon; oxygen; nitrogen, calcium, phosphorus, and other atoms. Model 2, at the molecular level, considers body mass as the sum of lipid mass and lipid-free mass, including water, proteins, carbohydrates, and minerals. Model 3, at the cellular level, considers body mass as the sum of fat mass, intracellular water, intracellular solids, extracellular water, and extracellular solids. Model 4, at the tissue level, considers body mass as the sum of adipose tissue, skeletal muscular mass, bone mass, and lean soft tissue, which includes connective tissue,

and residual mass. Finally, Model 5 is based on a whole-body level of complexity, in which body mass is the sum of different body segments, such as the head, trunk, and limbs [7,8]. In this respect, it is important to differentiate that the adipose mass considers the totality of the adipocyte's components, 90% of which is fat and the remaining 10% water, minerals, proteins, etc. Of this fat component, 16% corresponds to glycerol and the remaining 83% corresponds to the lipid component inside the fat cell [7,8]. However, these three concepts have classically been used as homonyms in the estimation of body composition, inducing errors around 8–10% in the approach to the adipose component [9].

Considering the impossibility of measuring body composition directly, for which in vivo dissection would be necessary [10], previous studies have described a large number of methods to determine the adipose component of a subject, among which dual X-ray absorptiometry (DXA), bioimpedance (BIA) and anthropometry stand out as the most widely used [6]. DXA is based on absorptiometry through which the attenuation of emitted photons is detected [11]. This method estimates adipose mass using a tissue model approach (model 4) [6,7]. The most important advantages of this method are its ease of application, safety, and non-invasive nature [10]. However, it also has important disadvantages, such as the variability between devices, the difficulty in evaluating subjects taller than 190 cm, and its low accessibility [12]. On the other hand, BIA is a method based on the electrical conductivity properties of the different tissues of the human body [13]. This method performs lipid mass estimation using a molecular model approach (model 2) [7]. It is a fast, easy-to-apply, and non-invasive method, but it has limitations that affect its reliability and validity, calling into question not only the final lipid mass values given, but also the impedance value obtained from which the estimates are made [14]. More specifically, any context where total body water is affected will have a direct impact on impedance and therefore on the estimated lipid component [6,7,15] As a consequence of the above, although it is a relatively inexpensive method, it is only a valid method for assessing populations, but not individuals in particular [14], and its use in clinical practice is also limited because it is not reliable when evaluating the evolution of patients or athletes [16].

In the case of anthropometry, this technique makes it possible to estimate body adiposity by measuring skinfold, as the most commonly anthropometric used variable for this, as well as height, waist girth, and other abdominal girths in a simple, safe, and low-cost way measurements [10,17]. Its main advantage is that the results of the anthropometric assessment are not affected by total body water content or pre-measurement intakes, which facilitates its replicability [18]. Given the simplicity of the technique, and the speed and frequency of implementation that it allows due to its innocuousness, it is one of the fat mass estimation techniques with the best cost/benefit ratio [6]. In turn, when seeking to evaluate changes in adiposity levels over time, skinfold measurements has been proposed as the best tool, especially considering that other methods are affected by factors that are difficult to control and standardize, especially in the clinical setting, such as food intake, hydration levels or daily physical activity [6,18].

From an anthropometric point of view, it is possible to approach adiposity using molecular and tissue models [6,19]. More specifically, anthropometry allows the estimation of lipid mass following the molecular model (Model 2) by means of different equations validated [20–33], being this a double indirect method of estimating body composition since it uses a series of skinfolds to estimate body density through a regression equation; from the data obtained, another formula is used to estimate fat mass [8]. However, in this approach to lipid mass, it should be taken into consideration that lipid estimation formulas have been validated for a specific population with specific socio-demographic characteristics (sex, age, race, sports practice, pathologies, etc.) and should only be applied when the characteristics of the population to be analyzed have exactly the same characteristics [9]. However, the difficulty of doing this and the absence of formulas to assess some subjects whose characteristics do not fit with any of the specified validation populations has meant that classically the formulas are applied even when the population is not the same, and the results of these formulas have been compared as if they were interchangeable, in some

cases not specifying the formula with which a subject or population have been evaluated in both scientific and clinical settings [34–36]. More specifically, in the assessment of adiposity in the active adult population, many formulas have been used [19–33] without taking into consideration, as can be seen in Table 1, the very specific populations for which they were validated. In addition, most of them have been validated using indirect methods as the gold standard, with few formulas being validated in comparison with the direct method such as cadaveric dissection [20,22,30,33].

Table 1. Characteristics and information regarding the validation, variables and estimated component of the formulas used.

Formula	Population Characteristics	Variables Included	Estimated Component	Method of Validation
Durnin-Womersley	Moderately sedentary male and female populations (students, professionals, patients from an obesity clinic, sports clubs, and ballet dancers; four age groups)	Body mass; triceps, biceps, subscapular and supraspinale skinfolds	Lipid mass	Hydrodensitometry
Yuhasz	Elite male and female athletes (Olympic games)	Body mass; triceps, subscapular, supraspinale, abdominal, thigh, and calf skinfolds	Lipid mass	Hydrodensitometry
Faulkner	Male and female swimmers	Body mass; triceps, subscapular, supraspinale, abdominal skinfolds	Lipid mass	Hydrodensitometry
Carter	Elite male and female athletes (Olympic games)	Body mass; triceps, subscapular, supraspinale, abdominal, thigh, and calf skinfolds	Lipid mass	Hydrodensitometry
Peterson	Healthy white male and female adults	Body mass; triceps, subscapular, supraspinale, and thigh skinfolds	Lipid mass	DXA
Katch-McArdle	Physical education activity male and female students from New York (USA)	M = body mass; triceps, subscapular and abdominal skinfolds F = body mass; triceps, subscapular and thigh skinfolds	Lipid mass	Hydrodensitometry
Sloan	White, healthy, South African medicine male and female students (18 to 26 years old)	Body mass; subscapular and thigh skinfolds	Lipid mass	Hydrodensitometry and ultrasound

Table 1. *Cont.*

Formula	Population Characteristics	Variables Included	Estimated Component	Method of Validation
Wilmore	Healthy male and female students from California University (USA)	M = body mass; abdominal and thigh skinfolds F = body mass; triceps, subscapular and thigh skinfolds	Lipid mass	Hydrodensitometry
Evans	White and Afro-American male and female collegiate athletes (football, basketball, volleyball, gymnastics, swimming and track and field)	Body mass; triceps, abdominal and thigh skinfolds	Lipid mass	DXA
Lean	White and healthy male and female from Glasgow (Scotland)	Body mass; triceps, biceps, subscapular and iliac crest skinfolds	Lipid mass	Hydrodensitometry
Reilly	Professional male soccer players from Premier League clubs (UK)	Body mass; triceps, abdominal, thigh, and calf skinfolds	Lipid mass	DXA
Civar	Male university athletes	Body mass; triceps, biceps, and abdominal skinfolds	Lipid mass	Hydrodensitometry
Hastuti	Healthy male adults from Indonesia	Body mass; triceps, biceps, subscapular, and iliac crest skinfolds	Lipid mass	Deuterium oxide dilution
Thorland	Female athletes from USA national championships (track and field, gymnastics, diving, and wrestling)	Body mass; triceps, subscapular, and iliac crest skinfolds	Lipid mass	Hydrodensitometry
Kerr	Male and female population (6 to 77 years old; cyclists, Canadian elders, children and adolescents from the Coquitlam Growth Study, professional bodybuilders, Montreal Olympic Games athletes and Pan-American Games rowers)	Height; triceps, subscapular, supraespinale, abdominal, thigh, and calf skinfolds	Adipose tissue	Cadaver dissection

M: male; F: female.

While most anthropometric formulas have sought to estimate body lipid mass, Kerr's mathematical model for estimating body composition estimates subcutaneous adipose tissue (model 4) (Table 1), which considers adipose tissue as a whole [19], including in its estimation of other non-lipid components that are part of adipocytes, such as water and proteins, as it is a method of anatomical tissue fractionation [37], the same approach used by DXA, which has classically been considered the gold standard for body composition assessment [6,7]. One of the strongest points of the Kerr formula is that it includes the

person's height in the analysis of adiposity. This allows the three-dimensionality of mass and limb length to be considered [19]. Moreover, its validation on cadavers' objective data from the dissection study carried out in Brussels [19] and its validation on populations with very heterogeneous characteristics makes it a reference value against which to compare adiposity, as has been done in previous studies where it has been used as the best formula for addressing adiposity in anthropometry [5,8,9]. In addition, Kerr's formula is a mathematical model that does not require the estimation of body density, so it is not a double indirect model but an indirect model, being on the same level in this sense as other methods such as DXA, air displacement plestimography or hydrodensitometry or hydrostatic weighing [6,7]. All these characteristics are why the Kerr method has been considered by many anthropometrists to be the gold standard equation within anthropometry for body composition assessment [5,8,9].

A recent study found that the variability in the results obtained with four different anthropometric "fat" estimation formulas (really lipid or adipose mass) was high [5,38]. However, this study did not analyze the differences between the fat estimation formulas according to sex, despite the large differences in the distribution of adiposity between men and women [39], and the influence of biological variability on the validity of this type of formula [38]. Another limitation of this study was that it included formulas for estimating adipose mass and lipid mass, comparing them without making any adjustment, which is not conceptually correct as they are estimating different components, inducing errors around 8–10% [9].

For all the above reasons, a study comparing different "fat" estimation formulas in similar populations, that does not mix formulas where different approaches to body composition are taken [9], and differentiating the results between sexes [39], is therefore necessary in order to find out whether the results obtained by these classically used formulae are comparable or not [9]. Therefore, the aim of the present study was to analyze the differences and the degree of agreement between the most commonly used formulas for lipid estimation, among themselves and in comparison with Kerr's adiposity formula, once their lipid content was estimated; the similarity between the results reported by the different formulas in comparison with Kerr's formula as it is considered the gold standard in anthropometry; as well as to establish their existing relationship with the different sums of skinfolds and BMI according to sex.

2. Materials and Methods

2.1. Design

The present research followed a descriptive, cross-sectional design. The sample recruitment was non-probabilistic by convenience. The calculation to establish the sample size was performed with Rstudio 3.15.0 software (Rstudio Inc., Boston, MA, USA) [40]. The significance level was set at $\alpha = 0.05$. The standard deviation (SD) for total sample was set based on previous studies on the variables lipid percentage (SD = 5.25) and Σ6 skinfolds (SD = 28.55) [8]. Click or tap here to enter text. With an estimated error of (d) 1.05% for lipid percentage and 5.9 mm for Σ6 skinfolds, a sample of 90 subjects for the total group was required. In addition, the sample size for each sex was calculated based on previous research in men (Σ6 skinfolds: SD = 17.89; and lipid percentage: SD = 1.73) [41] and in women (Σ6 skinfolds: SD = 17.66; and lipid percentage: SD = 2.80) [42]. Click or tap here to enter text. With an estimated error of (d) 0.55 and 0.90% for lipid percentage and 5.8 and 5.7 mm for Σ6 skinfolds, a sample of 37 men and women was required, respectively.

2.2. Participants

A total of 91 volunteers from the province of Buenos Aires (Argentina) were included, and their selection was non-probabilistic by convenience. Of these, 37 were male; and 54 were female. The inclusion criteria were: (1) being aged between 18 and 40 years; (2) being physically active, for which the IPAQ questionnaire was used to assess the physical activity level of the volunteers, with the World Health Organization (WHO) Global Physical Activity

Recommendations for Health used as criteria, (3) having a body mass index (BMI) in the normal range according to the WHO (18.5–24.9 kg/m^2) and (4) having neither any disease that could affect body fat nor undergone hormonal or corticosteroid treatment in the three months prior to the evaluation. The exclusion criteria were as follows: (1) within the 24 h prior to the measurement session, they had performed vigorous physical exercise, or 12 h in case of moderate exercise, or any kind of physical exercise on the same day; (2) within the 24 h prior to the measurement session, they consumed products with diuretic properties, or ate a heavy meal; (3) having any injury or pathology that conditioned the taking of measurements; and (4) for female participants, being between the 8th and 21st days of their menstrual cycle.

2.3. Procedure

The Ethics Committee from Catholic University San Antonio of Murcia (Murcia, Spain) reviewed and authorized the protocol designed for data collection, considering the World Medical Association Code (CE062103). All points of the Declaration of Helsinki were followed throughout the process. Participants were informed about the procedure and signed a consent form prior to starting the study. The protocol was registered at ClinicalTrials.gov (ClinicalTrials.gov Identifier: NCT04429581).

First, the participants were asked to complete an ad hoc questionnaire to provide information on basic demographics (sex and age), diseases that could affect body fat (illnesses and injuries in the last six months, chronic illness and surgeries), medication taken regularly, hormonal or corticosteroid treatment (daily or occasional treatment in the last six months), last menstrual period for women, and food intake (24 h dietary recall—24HR) and sports practice (24 h exercise recall) in the last 24 h, based on previous studies [8,42].

They also self-completed the IPAQ questionnaire, previously validated in Spanish, with a good reliability (r = 0.82) and an acceptable validity [43]. In this study, the last 7 days self-administered long form of the IPAQ was used. The questionnaire evaluates physical activity at work, for transportation, during leisure time, and at home. The frequency (per week) and time spent on vigorous- and moderate-intensity activities and the time spent walking are registered for each category, together with the time spent sitting during a workday and on a weekend day. Explanations and practical examples for vigorous and moderate physical activities are given. To be registered, an activity must last at least 10 min, following the methodology of previous studies [43]. For data analysis, moderate intensity was defined as 4 METs (metabolic equivalent task) and vigorous intensity as more than 8 METs [44]. Walking activity was defined as 3.3 METs. One MET is the energy expended at rest and is defined as 3.5 mL $O_2 \times kg^{-1} \times min^{-1}$. Active subjects were considered to be those who had a weekly metabolic expenditure above 600 METs [45].

Second, all the measurements were performed in a single session in a room with a standardized temperature of 24 °C, between 8:30 am and 1:30 pm. The anthropometric variables were taken following the protocol from the International Society for the Advancement of Kinanthropometry (ISAK) [46]. Basic measurements such as body mass and height, together with triceps, subscapular, biceps, iliac crest, supraspinal, abdominal, thigh, and leg skinfolds were taken by an ISAK level 3 certified anthropometrist. To measure the body mass, the subject stood with minimal clothing in the center of the scale without support and with the weight distributed evenly on both feet. Regarding height, it was measured after having positioned its head in the Frankfort plane during a deep breath. All skinfold measurements followed the same technique. The nearer edge of the contact faces of the caliper was applied 1 cm away from the skinfold landmark done before and at the same depth that the digits that hold the fold were located. Measurements were recorded two seconds after the full pressure of the caliper was applied. A SECA 862 weighing scale (SECA, Hamburg, Germany) with an accuracy of 100 g was used for body mass, a SECA 213 portable stadiometer (SECA, Hamburg, Germany) with an accuracy of 0.1 mm was used for height measurement, and a Harpenden calliper (Harpenden, London, UK) with an accuracy of 0.2 mm was used for skinfolds. Each measurement was taken twice. If

the difference between them was greater than 1% for the basic measurements or greater than 5% for the skinfolds, a third measurement was taken. The final value considered for data analysis was the mean if two measurements were taken or the median if three measurements were taken. The intra-evaluator technical error of measurement (TEM) was 0.01% for basic measurements and 1.12% for skinfolds.

For the estimation of lipid mass and its percentages in men, all the equations that had been validated in a young population were used: they were proposed by Durnin-Womersley [20], Yuhasz [21], Faulkner [22], Carter [23], Peterson [24], Katch-McArdle [25], Sloan [26], Wilmore [27], Evans [28], Lean [29], Reilly [32], Civar [31], and Hastuti [33]. In the case of women, the equations used were those proposed by Durnin-Womersley [20], Yuhasz [21], Faulkner [22], Carter [23], Peterson [24], Katch-McArdle [25], Sloan [26], Wilmore [27], Evans [28], Lean [29], and Thorland [30]. In both cases, the formula proposed by Kerr was also included, although as it is a formula that estimates adiposity, its lipid content was calculated by linear regression assuming a minimum percentage error with Martin's formula [19,47].

Body mass index (BMI) (body mass in kg/height in m^2), the sum of four skinfolds (triceps, subscapular, biceps, and supraspinal), the sum of six skinfolds (triceps, subscapular, supraspinal, abdominal, thigh and leg), and the sum of eight skinfolds (triceps, subscapular, biceps, iliac crest, supraspinal, abdominal, thigh, and leg), were also calculated.

2.4. Statistical Analysis

The distribution (Kolmogorov–Smirnov test), kurtosis, and asymmetry of the variables were calculated. Levene's test was used to assess the homogeneity of the variables. The analysis of skewness and kurtosis showed a platykurtic distribution for all variables. As a normal and homogeneous distribution of the variables was found, parametric tests were performed. Descriptive statistics were performed for the variables analyzed. Differences between adiposity equations were analyzed by a one-way analysis of variance (ANOVA) for repeated measurements. The Bonferroni post hoc adjustment was used to analyze differences between groups when these differences were significant. The effect size for the pairwise comparisons was calculated with Cohen's D. The confidence interval (CI) of the differences (95% CI) was included. Threshold values for effect size were set as $\geq$0.2 (small), $\geq$0.5 (moderate), and $\geq$0.8 (large). Percentile analysis of the different variables was also included. The software used in the statistical analysis was SPSS (v.23, IBM, Endicott, NY, USA). Agreement between equations was determined using Lin's concordance correlation coefficient (CCC), including precision (ρ) and accuracy (Cb) indexes, and by McBride's strength concordance (almost perfect > 0.99; substantial > 0.95 to 0.99; moderate = 0.90–0.95; and poor < 0.90), following previous research [48,49]. A Pearson's correlation test and a Bland–Altman test were used to determine the agreement and interchangeability between the different equations. For Pearson's correlation, the following ranges were established: r < 0.5 for low correlation, 0.5–0.7 for moderate correlation, and >0.7 for high correlation [50]. The software used to perform Lin's concordance correlation, Pearson's correlation, and the Bland–Altman test was MedCalc Statistical Software v.20.106 (Mariakerke, Belgium). For all the statistical tests, the significance level was set a priori at $p \leq 0.05$.

3. Results

Socio-demographic characteristics were mean age: 26.3 ± 6.25 years old; mean body mass: 70.83 ± 6.13 kg; men height: 175.30 ± 6.42 cm for men; and mean age: 26.53 ± 5.39 years old; mean body mass: 58.02 ± 6.70 kg; mean height: 161.87 ± 5.57 cm for women.

3.1. Descriptive Analysis and Differences between Lipid Mass Estimation Formulas

Descriptive analysis of BMI, sum of 4, 6, and 8 skinfolds and lipid percentages estimated by the different formulas for males and females are shown in Table 2. Differences between lipid percentage formulas were significant for both men (mean diff = −9.88–9.03; p < 0.001–0.016;

ES = 0.05–0.70; 95%CI = −11.57–10.33) and women (mean diff = −12.01–13.46; $p < 0.001$–0.010; ES = 0.00–5.37; 95%CI = −12.79–14.27). Therefore, a pairwise comparison of the formulas was performed, the results of which are shown in Tables 3 and 4 for males and females, respectively. Significant differences were found in the pairwise comparison for most of the formulas for both males and females.

Table 2. Descriptive analysis of anthropometric variables and lipid percentages in men and women.

Variable	Men (n = 37)		Women (n = 54)	
	Mean ± SD	Max.–Min.	Mean ± SD	Max.–Min.
BMI	23.03 ± 1.39	24.48–19.35	22.07 ± 1.54	24.50–18.50
∑4 skinfolds (mm)	35.50 ± 11.71	63.50–19.75	46.60 ± 14.22	80.10–22.25
∑6 skinfolds (mm)	60.14 ± 20.64	120.25–36.25	85.26 ± 21.61	133.75–42.50
∑8 skinfolds (mm)	78.30 ± 27.35	153.25–44.75	106.83 ± 28.28	170.25–51.25
% Carter	8.90 ± 2.17	15.21–6.38	16.77 ± 3.34	24.28–10.15
% Civar	12.40 ± 2.65	20.22–9.35	-	- -
% Durnin	12.95 ± 3.76	21.63–7.21	23.38 ± 5.07	35.72–13.03
% Evans	17.72 ± 3.17	27.24–13.92	15.33 ± 2.94	21.88–8.81
% Faulkner	12.11 ± 2.15	18.02–9.49	18.90 ± 3.56	27.98–13.11
% Hastuti	17.91 ± 2.84	24.84–14.17	-	- -
% Katch	10.71 ± 3.04	19.17–6.81	18.37 ± 2.93	25.63–13.02
% Kerr	16.04 ± 4.89	33.39–10.47	22.73 ± 5.41	39.71–10.57
% Lean	14.50 ± 4.59	24.84–7.25	26.31 ± 4.11	35.51–17.56
% Peterson	18.78 ± 4.30	29.56–12.00	28.79 ± 3.30	33.88–21.88
% Reilly	11.45 ± 2.33	18.10–8.84	-	- -
% Sloan	9.73 ± 3.67	21.01–5.48	21.46 ± 3.54	29.06–14.94
% Thorland	-	- -	20.03 ± 5.55	33.20–10.67
% Wilmore	14.03 ± 3.10	23.48–10.06	23.92 ± 2.03	28.43–20.51
% Yuhasz	8.90 ± 2.17	15.22–6.39	16.77 ± 3.34	24.28–10.15

BMI: body mass index; %: percentage of fat mass.

Table 3. Differences between lipid formulas in mean of percentages in men.

Formulas	Mean Differences ± Standard Error	95%CI (Lower; Upper)	p Value	Cohen's d
% Carter–% Peterson	−9.887 ± 0.398	−11.570;−8.205	$p < 0.001$	2.90
% Carter–% Katch	−1.814 ± 0.179	−2.572;−1.056	$p < 0.001$	0.69
% Carter–% Sloan	−0.831 ± 0.304	−2.117;0.454	$p = 1.000$	0.28
% Carter–% Wilmore	−5.135 ± 0.213	−6.036;−4.234	$p < 0.001$	1.92
% Carter–% Evans	−8.829 ± 0.182	−9.598;−8.059	$p < 0.001$	3.25
% Carter–% Lean	−5.607 ± 0.492	−7.687;−3.526	$p < 0.001$	1.56
% Carter–% Reilly	−2.551 ± 0.70	−2.848;−2.254	$p < 0.001$	1.13
% Carter–% Civar	−3.503 ± 0.140	−4.093;−2.912	$p < 0.001$	1.45
% Carter–% Hastuti	−9.018 ± 0.189	−9.819;−8.217	$p < 0.001$	3.57
% Civar–% Hastuti	−5.515 ± 0.176	−6.259;−4.770	$p < 0.001$	2.49
% Durnin–% Yuhasz	4.054 ± 0.385	2.417;5.673	$p < 0.001$	1.32
% Durnin–% Faulkner	0.833 ± 0.366	−0.716;2.383	$p = 1.000$	0.27
% Durnin–% Carter	4.050 ± 0.385	2.422;5.678	$p < 0.001$	1.32
% Durnin–% Peterson	−5.837 ± 0.348	−7.310;−4.364	$p < 0.001$	1.44
% Durnin–% Katch	2.236 ± 0.311	0.919;3.553	$p < 0.001$	0.66
% Durnin–% Sloan	3.219 ± 0.460	1.274;5.163	$p < 0.001$	0.87
% Durnin–% Wilmore	−1.085 ± 0.403	−2.788;0.618	$p = 1.000$	0.31
% Durnin–% Evans	−4.779 ± 0.397	−6.458;−3.099	$p < 0.001$	1.37
% Durnin–% Lean	−1.557 ± 0.268	−2.690;−0.424	$p < 0.001$	0.37
% Durnin–% Reilly	1.499 ± 0.406	−0.218;3.216	$p < 0.001$	0.48
% Durnin–% Civar	0.547 ± 0.358	−0.968;2.062	$p = 1.000$	0.17

Table 3. *Cont.*

Formulas	Mean Differences ± Standard Error	95%CI (Lower; Upper)	*p* Value	Cohen's d
% Durnin–% Hastuti	−4.968 ± 0.268	−6.103;−3.832	$p < 0.001$	1.49
% Evans–% Lean	3.222 ± 0.452	1.309;5.134	$p < 0.001$	0.82
% Evans–% Reilly	6.277 ± 0.148	5.652;6.902	$p < 0.001$	2.25
% Evans–% Civar	5.326 ± 0.188	4.530;6.122	$p < 0.001$	1.82
% Evans–% Hastuti	−0.189 ± 0.243	−1.216;0.838	$p = 1.000$	0.06
% Faulkner–% Carter	3.217 ± 0.120	2.711;3.722	$p < 0.001$	1.49
% Faulkner–% Peterson	−6.671 ± 0.436	−8.514;−4.827	$p < 0.001$	1.96
% Faulkner–% Katch	1.403 ± 0.172	0.677;2.128	$p < 0.001$	0.53
% Faulkner–% Sloan	2.385 ± 0.397	0.709;4.062	$p < 0.001$	0.79
% Faulkner–% Wilmore	−1.918 ± 0.202	−2.774;−1.063	$p < 0.001$	0.72
% Faulkner–% Evans	−5.612 ± 0.254	−6.687;−4.537	$p < 0.001$	2.07
% Faulkner–% Lean	−2.390 ± 0.488	−4.455;−0.326	$p = 0.007$	0.67
% Faulkner–% Reilly	0.665 ± 0.181	−0.101;1.432	$p = 0.254$	0.29
% Faulkner–% Civar	−0.286 ± 0.165	−0.983;0.410	$p = 1.000$	0.12
% Faulkner–% Hastuti	−5.801 ± 0.189	−6.599;−5.003	$p < 0.001$	2.30
% Katch–% Sloan	0.982 ± 0.323	−0.384;2.348	$p < 0.001$	0.29
% Katch–% Wilmore	−3.321 ± 0.180	−4.080;−2.562	$p < 0.001$	1.08
% Katch–% Evans	−7.015 ± 0.173	−7.745;−6.285	$p < 0.001$	2.26
% Katch–% Lean	−3.793 ± 0.389	−5.438;−2.148	$p < 0.001$	0.97
% Katch–% Reilly	−0.738 ± 0.195	−1.563;0.088	$p = 0.185$	0.27
% Katch–% Civar	−1.689 ± 0.139	−2.279;−1.099	$p < 0.001$	0.59
% Katch–% Hastuti	−7.204 ± 0.152	−7.848;−6.560	$p < 0.001$	2.45
% Kerr–% Carter	7.002 ± 0.491	5.140;8.864	$p < 0.001$	1.89
% Kerr–% Civar	3.697 ± 0.508	1.772;5.622	$p < 0.001$	0.93
% Kerr–% Durnin	2.862 ± 0.601	0.582;5.141	$p = 0.003$	0.71
% Kerr–% Evans	−1.625 ± 0.363	−3.001;−0.248	$p = 0.007$	0.41
% Kerr–% Faulkner	3.731 ± 0.542	1.676;5.787	$p < 0.001$	1.04
% Kerr–% Hastuti	−1.875 ± 0.507	−3.798;0.047	$p = 0.065$	0.47
% Kerr–% Katch	5.359 ± 0.459	3.618;7.100	$p < 0.001$	1.31
% Kerr–% Lean	1.563 ± 0.566	−0.586;3.711	$p = 0.824$	0.32
% Kerr–% Peterson	−2.717 ± 0.439	−4.383;−1.052	$p < 0.001$	0.60
% Kerr–% Reilly	4.658 ± 0.473	2.863;6.454	$p < 0.001$	1.20
% Kerr–% Sloan	6.368 ± 0.351	5.037;7.699	$p < 0.001$	1.46
% Kerr–% Wilmore	2.013 ± 0.418	0.428;3.599	$p = 0.002$	0.49
% Kerr–% Yuhasz	7.162 ± 0.492	5.295;9.029	$p < 0.001$	1.89
% Lean–% Reilly	3.056 ± 0.499	0.945;5.166	$p < 0.001$	0.84
% Lean–% Civar	2.104 ± 0.456	0.176;4.032	$p = 0.016$	0.56
% Lean–% Hastuti	−3.411 ± 0.330	−4.806;−2.016	$p < 0.001$	0.89
% Peterson–% Katch	8.073 ± 0.315	6.743;9.403	$p < 0.001$	2.17
% Peterson–% Sloan	9.056 ± 0.303	7.773;10.339	$p < 0.001$	2.26
% Peterson–% Wilmore	4.752 ± 0.394	3.084;6.420	$p < 0.001$	1.27
% Peterson–% Evans	1.059 ± 0.312	−0.259;2.376	$p = 0.544$	0.28
% Peterson–% Lean	4.280 ± 0.253	3.212;5.348	$p < 0.001$	0.96
% Peterson–% Reilly	7.336 ± 0.385	5.706;8.966	$p < 0.001$	2.12
% Peterson–% Civar	6.384 ± 0.383	4.764;8.005	$p < 0.001$	1.79
% Peterson–% Hastuti	0.869 ± 0.290	−0.357;2.096	$p = 1.000$	0.24
% Reilly–% Civar	−0.952 ± 0.149	−1.581;−0.322	$p < 0.001$	0.38
% Reilly–% Hastuti	−6.466 ± 0.219	−7.391;−5.542	$p < 0.001$	2.49
% Sloan–% Wilmore	−4.304 ± 0.351	−5.786;−2.821	$p < 0.001$	1.27
% Sloan–% Evans	−7.977 ± 0.213	−8.896;−7.098	$p < 0.001$	2.33
% Sloan–% Lean	−4.776 ± 0.479	−6.800;−2.751	$p < 0.001$	1.15
% Sloan–% Reilly	−1.720 ± 0.272	−2.869;−0.571	$p < 0.001$	0.56
% Sloan–% Civar	−2.672 ± 0.336	−4.091;−1.252	$p < 0.001$	0.83
% Sloan–% Hastuti	−8.186 ± 0.329	−9.576;−6.797	$p < 0.001$	2.49
% Wilmore–% Evans	−3.694 ± 0.182	−4.464;−2.924	$p < 0.001$	1.18
% Wilmore–% Lean	−0.472 ± 0.470	−2.459;1.515	$p = 1.000$	0.12

Table 3. *Cont.*

Formulas	Mean Differences ± Standard Error	95%CI (Lower; Upper)	*p* Value	Cohen's d
% Wilmore–% Reilly	2.584 ± 0.230	1.610;3.557	$p < 0.001$	0.94
% Wilmore–% Civar	1.632 ± 0.233	0.646;2.618	$p < 0.001$	0.57
% Wilmore–% Hastuti	−3.883 ± 0.265	−5.004;−2.762	$p < 0.001$	1.31
% Yuhasz–% Faulkner	−3.212 ± 0.120	−3.717;−2.706	$p < 0.001$	1.49
% Yuhasz–% Carter	0.005 ± 0.000	0.005;0.005	$p < 0.001$	0.00
% Yuhasz–% Peterson	−9.882 ± 0.398	−11.565;−8.20	$p < 0.001$	2.90
% Yuhasz–% Katch	−1.809 ± 0.179	−2.567;−1.051	$p < 0.001$	0.69
% Yuhasz–% Sloan	−0.826 ± 0.304	−2.112;0.459	$p = 1.000$	0.28
% Yuhasz–% Wilmore	−5.130 ± 0.213	−6.031;−4.229	$p < 0.001$	1.92
% Yuhasz–% Evans	−8.824 ± 0.182	−9.593;−8.054	$p < 0.001$	3.25
% Yuhasz–% Lean	−5.602 ± 0.492	−7.682;−3.521	$p < 0.001$	1.56
% Yuhasz–% Reilly	−2.546 ± 0.70	−2.843;−2.249	$p < 0.001$	1.13
% Yuhasz–% Civar	−3.498 ± 0.140	−4.088;−2.907	$p < 0.001$	1.45
% Yuhasz–% Hastuti	−9.013 ± 0.189	−9.814;−8.212	$p < 0.001$	3.57

NOTE: displayed with a grey background when the pairwise comparison is sig.

Table 4. Differences between lipid formulas in mean of percentages in women.

Formulas	Mean Differences ± Standard Error	95%CI (Lower; Upper)	*p* Value	Cohen's d
% Carter–% Peterson	−12.018 ± 0.191	−12.796;−11.240	$p < 0.001$	3.62
% Carter–% Katch	−1.594 ± 0.331	−2.942;−0.247	$p = 0.004$	0.51
% Carter–% Sloan	−4.689 ± 0.190	−5.463;−3.914	$p < 0.001$	1.36
% Carter–% Thorland	−3.252 ± 0.380	−4.802;−1.703	$p < 0.001$	2.59
% Carter–% Wilmore	−7.147 ± 0.220	−8.046;−6.249	$p < 0.001$	0.46
% Carter–% Evans	1.444 ± 0.138	0.883;2.005	$p < 0.001$	2.55
% Carter–% Lean	−9.534 ± 0.264	−10.609;−8.458	$p < 0.001$	0.71
% Durnin–% Yuhasz	6.610 ± 0.303	5.375;7.846	$p < 0.001$	1.33
% Durnin–% Faulkner	4.487 ± 0.273	3.375;5.599	$p < 0.001$	0.88
% Durnin–% Carter	6.610 ± 0.303	5.375;7.846	$p < 0.001$	1.33
% Durnin–% Peterson	−5.408 ± 0.352	−6.843;−3.972	$p < 0.001$	1.13
% Durnin–% Katch	5.015 ± 0.532	2.847;7.185	$p < 0.001$	1.03
% Durnin–% Sloan	1.922 ± 0.317	0.631;3.213	$p < 0.001$	0.37
% Durnin–%Thorland	3.358 ± 0.281	2.213;4.504	$p < 0.001$	0.14
% Durnin–% Wilmore	−0.537 ± 0.450	−2.371;1.297	$p = 1.000$	1.67
% Durnin–% Evans	8.054 ± 0.382	6.498;9.610	$p < 0.001$	0.58
% Durnin–% Lean	−2.923 ± 0.288	−4.097;−1.750	$p < 0.001$	0.56
% Evans–% Lean	−10.978 ± 0.302	−12.209;−9.747	$p < 0.001$	1.29
% Faulkner–% Carter	2.124 ± 0.150	1.511;2.736	$p < 0.001$	0.62
%Faulkner-%Peterson	−9.894 ± 0.253	−10.927;−8.862	$p < 0.001$	2.88
% Faulkner–% Katch	0.529 ± 0.370	−0.979;2.038	$p = 1.000$	0.16
% Faulkner–% Sloan	−2.565 ± 0.250	−3.401;−1.728	$p < 0.001$	0.72
%Faulkner–%Thorland	−1.128 ± 0.336	−2.499;0.242	$p = 0.476$	1.73
%Faulkner-%Wilmore	−5.024 ± 0.254	−6.058;−3.989	$p < 0.001$	1.09
% Faulkner–% Evans	3.567 ± 0.239	2.594;4.541	$p < 0.001$	1.93
% Faulkner–% Lean	−7.410 ± 0.267	−8.499;−6.321	$p < 0.001$	0.24
% Katch–% Sloan	−3.094 ± 0.404	−4.743;−1.445	$p < 0.001$	0.95
% Katch–% Thorland	−1.658 ± 0.537	−3.847;0.532	$p = 1.000$	2.20
% Katch–% Wilmore	−5.553 ± 0.230	−6.490;−4.615	$p < 0.001$	1.04
% Katch–% Evans	3.038 ± 0.363	1.558;4.518	$p < 0.001$	2.22
% Katch–% Lean	−7.939 ± 0.424	−9.668;−6.211	$p < 0.001$	0.37
%Kerr–%Carter	6.107 ± 0.343	4.882;7.333	$p < 0.001$	1.33
%Kerr–%Durnin	−0.465 ± 0.396	−1.880;0.949	$p = 1.000$	0.10

Table 4. *Cont.*

Formulas	Mean Differences ± Standard Error	95%CI (Lower; Upper)	*p* Value	Cohen's d
% Kerr–% Evans	7.325 ± 0.436	5.769;8.881	$p < 0.001$	0.75
%Kerr–%Faulkner	3.933 ± 0.392	2.534;5.332	$p < 0.001$	0.84
% Kerr–% Katch	4.331 ± 0.554	2.352;6.309	$p < 0.001$	1.00
% Kerr–% Lean	−3.611 ± 0.454	−5.233;−1.990	$p < 0.001$	0.49
%Kerr–% Peterson	−6.085 ± 0.464	−7.743;−4.427	$p < 0.001$	1.35
% Kerr–% Sloan	1.247 ± 0.415	−0.233;2.728	$p = 0.262$	0.28
%Kerr–%Thorland	2.601 ± 0.440	1.028;4.173	$p < 0.001$	0.29
%Kerr–%Wilmore	−1.188 ± 0.512	−3.016;0.640	$p = 1.000$	1.70
% Kerr–% Yuhasz	5.999 ± 0.340	4.784;7.214	$p < 0.001$	1.33
% Peterson–% Katch	10.424 ± 0.318	9.126;11.721	$p < 0.001$	3.34
% Peterson–% Sloan	7.330 ± 0.190	6.553;8.106	$p < 0.001$	2.14
% Peterson–%Thorland	8.766 ± 0.389	7.181;10.351	$p < 0.001$	1.78
%Peterson–%Wilmore	4.871 ± 0.229	3.937;5.805	$p < 0.001$	4.31
% Peterson–% Evans	13.462 ± 0.198	12.656;14.268	$p < 0.001$	0.67
% Peterson–% Lean	2.484 ± 0.240	1.504;3.464	$p < 0.001$	1.92
% Sloan–% Thorland	1.436 ± 0.315	0.152;2.721	$p = 0.010$	0.85
% Sloan–% Wilmore	−2.459 ± 0.262	−3.527;−1.390	$p < 0.001$	1.88
% Sloan–% Evans	6.132 ± 0.196	5.334;6.931	$p < 0.001$	1.26
% Sloan–% Lean	−4.845 ± 0.236	−5.807;−3.883	$p < 0.001$	0.31
% Thorland–%Wilmore	−3.895 ± 0.497	−5.920;−1.870	$p < 0.001$	3.40
% Thorland–% Evans	4.696 ± 0.460	2.821;6.571	$p < 0.001$	0.74
% Thorland–% Lean	−6.282 ± 0.327	−7.615;−4.948	$p < 0.001$	0.93
% Wilmore–% Evans	8.591 ± 0.214	7.719;9.463	$p < 0.001$	3.07
% Wilmore–% Lean	−2.387 ± 0.339	−3.770;−1.003	$p < 0.001$	1.06
%Yuhasz–%Faulkner	−2.124 ± 0.150	−2.736;−1.511	$p < 0.001$	0.62
% Yuhasz–% Carter	0.000 ± 0.000	0.000;0.000	$p < 0.001$	0.00
%Yuhasz–% Peterson	−12.018 ± 0.191	−12.796;−11.240	$p < 0.001$	3.62
% Yuhasz–% Katch	−1.594 ± 0.331	−2.942;−0.247	$p = 0.004$	0.51
% Yuhasz–% Sloan	−4.689 ± 0.190	−5.463;−3.914	$p < 0.001$	1.36
%Yuhasz–% Thorland	−3.252 ± 0.380	−4.802;−1.703	$p < 0.001$	2.59
%Yuhasz–% Wilmore	−7.147 ± 0.220	−8.046;−6.249	$p < 0.001$	0.46
% Yuhasz–% Evans	1.444 ± 0.138	0.883;2005	$p < 0.001$	2.55
% Yuhasz–% Lean	−9.534 ± 0.264	−10.609;−8.458	$p < 0.001$	0.71

NOTE: Displayed with a grey background when the pairwise comparison is sig.

3.2. Agreement and Concordance between Lipid Mass Estimation Formulas

Tables 5 and 6 show Lin's CCC between formulas. It can be observed that in the case of men, the Carter and Yuhasz formulas and the Civar and Faulkner formulas showed a moderate agreement with each other (CCC = 0.910–0.915). In the case of females, the Carter and Yuhasz formulas showed a moderate agreement with each other (CCC = 0.974). The rest of the formulas showed poor agreement. Table 7 presents the results corresponding to the Bland–Altman test for men and women, comparing the results found in the different formulas with those found with the Kerr formula after converting the result of the Kerr formula into lipid mass. Differences were observed between all formulas in males, and also in females, with the exception of the Kerr formula with the Durnin formula ($p = 0.245$). For men, the Yuhasz, Carter, and Sloan formulas showed the highest lipid underestimation as compared to Kerr, while the Peterson, Hastuti, and Evans formulas showed an overestimation. In women, the Yuhasz, Carter, and Evans formulas were underestimated relative to Kerr, while the Peterson and Lean formulas showed an overestimation.

Table 5. Lin's concordance correlation coefficient between the different formulas in men.

Variable		Lin's Concordance Correlation Coefficient		
		CCC	ρ	Cb
% Civar	% Carter	0.496	0.916	0.541
	% Durnin	0.700	0.838	0.836
	% Evans	0.318	0.932	0.341
	% Faulkner	0.915	0.919	0.996
	% Hastuti	0.287	0.930	0.308
	% Katch	0.801	0.966	0.830
	% Kerr	0.467	0.843	0.554
	% Lean	0.607	0.843	0.720
	% Peterson	0.467	0.843	0.554
	% Reilly	0.850	0.932	0.911
	% Sloan	0.558	0.823	0.678
	% Wilmore	0.753	0.912	0.826
	% Yuhasz	0.440	0.958	0.459
% Carter	% Durnin	0.532	0.907	0.586
	% Evans	0.159	0.917	0.173
	% Faulkner	0.626	0.979	0.639
	% Hastuti	0.140	0.892	0.157
	% Katch	0.774	0.915	0.846
	% Kerr	0.271	0.850	0.319
	% Lean	0.323	0.778	0.415
	% Peterson	0.163	0.883	0.184
	% Reilly	0.607	0.916	0.662
	% Sloan	0.839	0.892	0.941
	% Wilmore	0.328	0.842	0.389
	% Yuhasz	0.910	0.935	0.973
% Durnin	% Evans	0.417	0.768	0.542
	% Faulkner	0.819	0.924	0.886
	% Hastuti	0.451	0.909	0.496
	% Katch	0.652	0.862	0.757
	% Kerr	0.579	0.695	0.833
	% Lean	0.856	0.894	0.958
	% Peterson	0.466	0.865	0.539
	% Reilly	0.535	0.767	0.698
	% Sloan	0.520	0.744	0.698
	% Wilmore	0.662	0.722	0.918
	% Yuhasz	0.355	0.816	0.435
% Evans	% Faulkner	0.311	0.864	0.360
	% Hastuti	0.875	0.880	0.994
	% Katch	0.249	0.940	0.265
	% Kerr	0.788	0.952	0.828
	% Lean	0.552	0.807	0.684
	% Peterson	0.824	0.910	0.905
	% Reilly	0.240	0.993	0.242
	% Sloan	0.228	0.932	0.245
	% Wilmore	0.553	0.954	0.580
	% Yuhasz	0.136	0.984	0.138
% Faulkner	% Hastuti	0.295	0.904	0.326
	% Katch	0.800	0.935	0.855
	% Kerr	0.450	0.767	0.587
	% Lean	0.597	0.790	0.756
	% Peterson	0.289	0.847	0.341
	% Reilly	0.772	0.850	0.908
	% Sloan	0.228	0.932	0.245
	% Wilmore	0.713	0.846	0.844
	% Yuhasz	0.434	0.901	0.482

Table 5. *Cont.*

Variable		Lin's Concordance Correlation Coefficient		
		CCC	ρ	Cb
% Hastuti	% Katch	0.229	0.952	0.240
	% Kerr	0.632	0.808	0.782
	% Lean	0.607	0.959	0.633
	% Peterson	0.864	0.959	0.901
	% Reilly	0.193	0.881	0.219
	% Sloan	0.187	0.840	0.222
	% Wilmore	0.454	0.855	0.531
	% Yuhasz	0.116	0.927	0.125
% Katch	% Kerr	0.401	0.858	0.468
	% Lean	0.540	0.884	0.611
	% Peterson	0.247	0.918	0.269
	% Reilly	0.856	0.932	0.918
	% Sloan	0.786	0.836	0.940
	% Wilmore	0.582	0.944	0.616
	% Yuhasz	0.730	0.967	0.756
% Kerr	% Lean	0.695	0.736	0.944
	% Peterson	0.632	0.941	0.671
	% Reilly	0.399	0.957	0.417
	% Sloan	0.407	0.922	0.442
	% Wilmore	0.718	0.893	0.804
	% Yuhasz	0.240	0.938	0.255
% Lean	% Peterson	0.632	0.941	0.671
	% Reilly	0.454	0.809	0.561
	% Sloan	0.435	0.771	0.564
	% Wilmore	0.731	0.791	0.924
	% Yuhasz	0.283	0.843	0.336
% Peterson	% Reilly	0.215	0.915	0.235
	% Sloan	0.234	0.903	0.260
	% Wilmore	0.437	0.841	0.520
	% Yuhasz	0.136	0.927	0.146
% Reilly	% Sloan	0.711	0.935	0.760
	% Wilmore	0.583	0.931	0.626
	% Yuhasz	0.580	0.986	0.588
% Sloan	% Wilmore	0.434	0.826	0.526
	% Yuhasz	0.785	0.924	0.850
% Wilmore	% Yuhasz	0.301	0.948	0.318

Table 6. Lin's concordance correlation coefficient between the different formulas in women.

Variable		Lin's Concordance Correlation Coefficient		
		CCC	ρ	Cb
% Carter	% Durnin	0.460	0.958	0.480
	% Evans	0.808	0.888	0.910
	% Faulkner	0.823	0.959	0.858
	% Katch	0.578	0.677	0.854
	% Kerr	0.443	0.922	0.480
	% Lean	0.198	0.851	0.233
	% Peterson	0.120	0.886	0.136
	% Sloan	0.453	0.886	0.511
	% Thorland	0.610	0.866	0.704
	% Wilmore	0.185	0.910	0.203
	% Yuhasz	0.974	0.974	1.000

Table 6. *Cont.*

Variable		Lin's Concordance Correlation Coefficient		
		CCC	**ρ**	**Cb**
% Durnin	% Evans	0.257	0.834	0.308
	% Faulkner	0.645	0.963	0.669
	% Katch	0.324	0.625	0.519
	% Kerr	0.847	0.850	0.996
	% Lean	0.707	0.891	0.793
	% Peterson	0.438	0.881	0.498
	% Sloan	0.768	0.892	0.860
	% Thorland	0.762	0.886	0.860
	% Wilmore	0.594	0.905	0.656
	% Yuhasz	0.419	0.932	0.450
% Evans	% Faulkner	0.521	0.830	0.628
	% Katch	0.372	0.576	0.647
	% Kerr	0.293	0.875	0.335
	% Lean	0.133	0.832	0.160
	% Peterson	0.081	0.860	0.094
	% Sloan	0.313	0.903	0.346
	% Thorland	0.433	0.844	0.513
	% Wilmore	0.114	0.846	0.135
	% Yuhasz	0.806	0.897	0.899
% Faulkner	% Katch	0.636	0.657	0.969
	% Kerr	0.587	0.864	0.680
	% Lean	0.298	0.867	0.344
	% Peterson	0.166	0.853	0.194
	% Sloan	0.700	0.898	0.780
	% Thorland	0.812	0.917	0.885
	% Wilmore	0.309	0.915	0.337
	% Yuhasz	0.808	0.944	0.856
% Katch	% Kerr	0.370	0.661	0.559
	% Lean	0.180	0.664	0.271
	% Peterson	0.111	0.732	0.152
	% Sloan	0.406	0.602	0.675
	% Thorland	0.568	0.739	0.768
	% Wilmore	0.226	0.828	0.273
	% Yuhasz	0.613	0.707	0.868
% Kerr	% Lean	0.587	0.783	0.750
	% Peterson	0.367	0.790	0.464
	% Sloan	0.746	0.845	0.884
	% Thorland	0.738	0.823	0.897
	% Wilmore	0.546	0.864	0.631
	% Yuhasz	0.451	0.927	0.487
% Lean	% Peterson	0.731	0.911	0.802
	% Sloan	0.497	0.910	0.546
	% Thorland	0.484	0.919	0.527
	% Wilmore	0.546	0.884	0.618
	% Yuhasz	0.208	0.880	0.236
% Peterson	% Sloan	0.278	0.919	0.303
	% Thorland	0.286	0.911	0.313
	% Wilmore	0.311	0.906	0.343
	% Yuhasz	0.126	0.916	0.137

Table 6. *Cont.*

Variable		Lin's Concordance Correlation Coefficient		
		CCC	ρ	Cb
% Sloan	% Thorland	0.839	0.965	0.870
	% Wilmore	0.571	0.900	0.634
	% Yuhasz	0.126	0.916	0.137
% Thorland	% Wilmore	0.433	0.951	0.456
	% Yuhasz	0.642	0.903	0.711
% Wilmore	% Yuhasz	0.191	0.920	0.207

Table 7. Inter-formula comparison for lipid percentage estimation in men and women.

Equation	Variable (Mean ± SD)	Pearson's r (*p*)	Kerr—Equation				
			Mean Diff	95% CI	95% Limits of Agreement		*p*
					Lower Limit	Upper Limit	
Men							
Durnin	2.862 ± 0.601	0.695	2.86	1.64 to 4.08	−4.30	10.03	0.000
Yuhasz	7.162 ± 0.492	0.938	7.16	6.16 to 8.16	1.29	13.03	0.000
Faulkner	3.731 ± 0.542	0.767	3.73	2.63 to 4.83	−2.73	10.19	0.000
Carter	7.002 ± 0.491	0.850	7.00	6.01 to 8.00	1.15	12.86	0.000
Peterson	−2.717 ± 0.439	0.838	−2.72	−3.61 to −1.83	−7.95	2.52	0.000
Hastuti	−1.875 ± 0.507	0.808	−1.88	−2.90 to −0.85	−7.92	4.17	0.001
Katch	5.359 ± 0.459	0.858	5.36	4.43 to 6.29	−0.11	10.83	0.000
Sloan	6.368 ± 0.351	0.922	6.37	5.66 to 7.08	2.19	10.55	0.000
Wilmore	2.013 ± 0.418	0.892	2.01	1.17 to 2.86	−2.97	7.00	0.000
Evans	−1.625 ± 0.363	0.952	−1.62	−2.36 to −0.89	−5.95	2.70	0.000
Reilly	4.658 ± 0.473	0.957	4.66	3.70 to 5.62	−0.99	10.30	0.000
Civar	3.697 ± 0.508	0.843	3.70	2.67 to 4.73	−2.35	9.75	0.000
Lean	1.563 ± 0.566	0.736	1.56	0.41 to 2.71	−5.19	8.32	0.009
Women							
Carter	6.107 ± 0.343	0.922	6.11	5.42 to 6.80	1.12	11.10	0.000
Durnin	−0.465 ± 0.396	0.850	−0.47	−1.26 to 0.33	−6.22	5.29	0.245
Evans	7.325 ± 0.436	0.875	7.33	6.45 to 8.20	0.99	13.66	0.000
Faulkner	3.933 ± 0.392	0.864	3.93	3.15 to 4.72	−1.76	9.63	0.000
Katch	4.331 ± 0.554	0.661	4.33	3.22 to 5.44	−3.72	12.39	0.000
Lean	−3.611 ± 0.454	0.783	−3.61	−4.52 to −2.70	−10.21	2.99	0.000
Peterson	−6.085 ± 0.464	0.790	−6.08	−7.02 to −5.15	−12.83	0.67	0.000
Sloan	1.247 ± 0.415	0.845	1.25	0.42 to 2.08	−4.78	7.27	0.004
Thorland	2.601 ± 0.440	0.823	2.60	1.72 to 3.48	−3.80	9.00	0.000
Wilmore	−1.188 ± 0.512	0.864	−1.19	−2.21 to −0.16	−8.63	6.25	0.024
Yuhasz	5.999 ± 0.340	0.927	6.00	5.32 to 6.68	1.05	10.94	0.000

Percentile relationships between BMI, skinfold sum, and adiposity formulas in men and women, respectively, can be found in Tables 8 and 9.

Table 8. Percentile relationships between BMI, skinfold sum, and adiposity formulas in men.

Percentile	BMI (kg/m^2)	∑8 Skinfolds (mm)	∑6 Skinfolds (mm)	∑4 Skinfolds (mm)	% Kerr	% Durnin	% Yuhasz	% Faulkner	% Carter	% Peterson	% Katch	% Sloan	% Wilmore	% Evans	% Lean	% Reilly	% Civar	% Hastuti
10	21.04	51.90	41.65	23.3	19.59	8.47	6.96	9.88	6.95	13.79	7.56	6.39	10.68	14.42	8.88	9.12	9.94	14.94
20	21.43	56.91	44.19	25.15	21.20	9.07	7.22	10.44	7.22	14.83	8.41	7.16	11.12	15.16	9.93	9.72	10.36	15.35
30	22.59	61.10	47.10	28.00	22.27	10.73	7.53	10.77	7.53	16.18	8.77	7.71	11.94	15.90	11.11	9.94	10.54	15.97
40	23.10	64.40	50.10	29.85	22.64	11.19	7.85	10.95	7.84	16.95	9.33	8.30	12.95	16.16	12.78	10.19	10.94	16.90
50	23.21	69.50	53.50	33.25	23.67	12.32	8.20	11.48	8.20	18.00	9.81	8.85	13.27	16.88	14.37	10.85	11.32	17.33
60	23.54	77.50	59.59	35.85	24.57	13.26	8.84	11.87	8.84	18.86	10.26	9.24	14.23	17.77	14.64	11.37	12.37	17.75
70	23.97	83.46	63.55	39.92	25.53	15.00	9.26	13.03	9.25	20.41	11.88	9.69	15.04	18.79	16.76	11.79	13.22	19.04
80	24.34	92.55	71.75	42.29	28.62	16.96	10.12	13.40	10.12	22.06	12.71	11.61	16.58	19.74	19.65	13.18	14.05	20.05
90	24.62	135.33	100.66	58.42	32.39	18.42	13.16	15.57	13.15	25.68	15.30	15.49	18.55	22.54	21.56	14.93	16.97	22.98

BMI: body mass index; %: percentage of fat mass.

Table 9. Percentile relationships between BMI, skinfold sum, and adiposity formulas in women.

Percentile	BMI (kg/m^2)	∑8 Skinfolds (mm)	∑6 Skinfolds (mm)	∑4 Skinfolds (mm)	% Kerr	% Durnin	% Yuhasz	% Faulkner	% Carter	% Peterson	% Katch	% Sloan	% Wilmore	% Evans	% Lean	% Thorland
10	20.13	70.37	57.87	28.50	24.64	15.68	12.53	14.76	12.53	23.93	14.60	16.75	21.08	11.16	20.46	13.15
20	20.73	77.75	63.00	32.25	27.32	18.68	13.33	15.46	13.33	25.27	15.56	17.88	21.99	12.51	22.10	13.74
30	21.33	89.62	72.62	36.12	28.76	20.20	14.82	16.68	14.82	27.14	16.64	19.18	22.35	13.62	24.67	16.06
40	21.71	98.00	79.50	42.00	29.74	22.76	15.88	17.88	15.88	28.03	17.29	20.12	23.65	15.08	25.89	17.89
50	22.02	111.05	89.25	47.75	32.31	23.44	17.39	18.49	17.39	29.20	18.31	21.87	23.75	15.84	26.79	20.76
60	22.29	115.75	92.00	52.30	33.65	24.93	17.82	19.61	17.82	30.27	19.39	22.40	24.48	16.70	27.93	21.93
70	22.96	123.37	95.37	53.62	34.37	26.29	18.34	20.54	18.34	31.26	20.14	23.44	25.32	17.04	28.88	22.96
80	23.58	128.50	102.70	57.50	35.68	27.80	19.47	21.90	19.47	32.05	20.59	24.45	25.82	17.49	29.29	25.09
90	24.36	140.25	113.87	65.32	36.91	29.66	21.20	23.55	21.20	32.95	21.83	26.55	26.33	18.34	30.82	26.52

BMI: body mass index; %: percentage of fat mass.

4. Discussion

The main objective of the present investigation was to analyze the differences and agreement between the most commonly used formulas for lipid estimation between themselves and in comparison with Kerr's adiposity formula, once its lipid content was estimated, and to compare the results reported by the different formulas with those found with Kerr's formula. This is important because the present research is the first to take into consideration that, while most anthropometric equations estimate lipid mass by addressing body composition from a molecular fractionation point of view, the only exception is the Kerr formula, which seeks to estimate adipose mass from the tissular model. As the estimation of these formulae is not comparable, the lipid content of the Kerr formula was calculated from the Martin´s formula [49], formulated by linear regression on cadavers and therefore with a very high validation power.

The results indicated that there were significant differences between most of the formulas, ranging from 8.90 ± 2.17% to 17.91 ± 2.84% for men, and from 15.33 ± 2.94% to 28.79 ± 3.30% for women. In the same vein, most of the formulas showed poor concordance (CCC < 0.900). In fact, the Bland–Altman test also showed differences in the results reported in most equations with respect to Kerr's formula. These results agree with those found in the literature, supporting the idea that there are differences when using different skinfold-based equations for lipid mass estimation in active adults [5]. These differences could be due to the heterogeneity of the samples with which the equations were validated (Table 1), as very different inclusion and exclusion criteria were used in the design [19–33].

Another possible reason is that all formulas, with the exception of Kerr, performed a linear regression analysis to estimate lipid percentage from anthropometry [21,23,24,26,27,31]. This is the estimation of the body density from the skinfolds included a process carried out by regression considering the skinfolds and the density given in the validation sample of each formula [9]. From this density value, the lipid mass present is estimated. This statistical strategy makes each formula specific to the study population included. The formulas only consider lipid levels and bodies similar to those included during their validation [9]. This could explain why the Yuhasz and Carter formulas, validated on elite athletes, showed the lowest mean values in this research [21,23].

Moreover, the method of validation of these formulas was not uniform, which could affect the equations reported by the different formulas (Table 1). In this regard, while Kerr's formula was validated by dissection of cadavers [19], most of the others used an indirect method such as hydrodensitometry for their validation [20–22,25–27]. Hydrodensitometry is an indirect method for estimating body composition that has several limitations, such as not being validated on cadavers [9]. Another of its limitations is that, as different densities are involved in the lipid estimation by this method, the estimation is influenced by the total body water. Thus, we find contaminating factors for the estimation of body composition by hydrodensitometry factors, such as renal and hepatic pathologies, but also diet, exercise, or the consumption of certain supplements such as creatine [6,7]. In turn, hydrodensitometry requires the assignment of constant values for fat mass (0.900 g/cm^3) and fat-free mass (1.100 g/cm^3) [6,7]. However, cadaveric studies have shown that fat-free mass density varies widely between subjects, as it encompasses a wide variety of tissues with very different characteristics [51]. These limitations were evident in previous studies, where American football players were analyzed by hydrodensitometry, and some of them, being very lean and African-American, yielded negative body lipid values [9]. Taking into account the importance of the selection of the validation method for the reliability of the formula, and the problems presented by hydrodensitometry as a method for estimating body composition [6,7], this could be one of the main reasons for the differences found between the different formulas. Regarding the validation of the formula, the case of Peterson's formula is curious, as it was validated on the basis of the results from Durnin's anthropometric formula [24], thus being a dual indirect method of estimating body composition. There are only three formulas included in the study that were validated with DXA [28,32]. Although DXA has been scientifically considered the gold standard method

for validating body composition in the absence of the possibility of cadaver dissection, this method has a major limitation when estimating lipid percentage, as it assumes that the amount of fat on bone tissue is the same as the amount of fat on soft tissues [52]. On the other hand, Hastuti's formula used deuterium oxide dilution as a validation method [33], a technique widely used to estimate body water percentage and body composition in animals, although it is in complete disuse in humans. Its main limitation is that it is highly dependent on the body water present, and therefore any factor affecting these values also alters the lipid percentage reported [53].

On the other hand, other very relevant factors that explain the differences between formulas are the anthropometric variables included in it (Table 1). Durnin included only four skinfolds (triceps, biceps, subscapular, and supraspinal), while Thorland [30], Civar, and Katch only included the triceps, subscapular and iliac crest skinfolds, with all these cases not analyzing the adiposity present in the lower limbs [20,25,31]. This is a major disadvantage especially for women, who tend to accumulate fat in the lower trunk and lower limbs [39]. Furthermore, these excluded skinfolds showed the highest correlation with the constants used in cadavers [54]. In Reilly's case [32], the formula includes triceps, abdominal, thigh, and calf skinfolds. Sloan [26] and Wilmore [27] only include two skinfolds in their analysis. The first covered the subscapular and thigh skinfolds [26], while the second incorporated abdominal and thigh skinfolds [27]. This results in too many body segments being excluded from the analysis, with their validity questioned [55]. Kerr, Carter, and Yuhasz, instead, include six skinfolds that were evenly distributed throughout the body: two from the upper body (triceps and subscapular), two from the central area (supraspinal and abdominal), and two from the lower limbs (thigh and calf) [19,21,23]. This makes more sense from a biological significance point of view, as the inclusion of more skinfolds covers more possible areas of fat accumulation [55]. Kerr adds the strength of including height in his assessment, which allows the three-dimensionality of masses to be considered. This is very relevant when working with subjects who have a great variability in height, as in the case of athletes, children, and adolescents [9]. In fact, previous studies showed an under- and overestimation error of up to 30% when applying the Durnin and Wilmore formulas to extreme populations such as dwarfs and subjects with achondroplasia [56].

Another factor that could explain the differences found between the different equations is the measurement protocol used for the validation of the formulas and the anthropometric measurements. Thus, Kerr followed the same protocol as that used by Ross for the Phantom stratagem in 1974 [57], which has many similarities with the ISAK protocol used for taking measurements in the present research, with the Australian school being the basis of the origin of ISAK [48]. In turn, part of their validation was done with cadaver data, to which the Ross protocol was applied [19]. Durnin and Lean followed the Weiner protocol, which performs measurements on the left side of the body contrary to the ISAK method [58]. There are contradictory results on whether the distribution of adiposity is symmetrical between the dominant and non-dominant side. Thus, while some manuals state that there are no significant differences in the thickness of skinfolds depending on the side analyzed [46], other studies have found that asymmetric losses of adipose content may occur when caloric expenditure is unilateral or focused on a certain area [59,60]. This could mean that the side chosen for the anthropometric measurement could influence the results obtained. Another interesting fact is that the Weiner protocol proposes taking the thigh skinfold with the subject's leg flexed at 90º, while ISAK proposes taking it with the leg extended [58]. This can clearly lead to differences in the distribution of adiposity in the area, and consequently to different values for the skinfolds yielded [58]. Moreover, in most cases, as with Yuhasz, Carter, Wilmore, Katch, Sloan, and Peterson, the protocol followed was not specified [21,23–27]. This relativizes the importance given to standardization and the taking of measurements during the validation of their formulas, despite it being a fundamental factor in the taking of anthropometric measurements. In this sense, the non-standardization of measurements or the use of different protocols leads to errors that make comparisons

difficult, limiting the advantages of the anthropometric method in the estimation of the lipid component [61].

A significant finding of the present investigation was that in females, no significant differences were found between the Kerr and Durnin formulas, despite the fact that these formulas showed low concordance in both males and females (SCC = 0.579–0.847). In addition, the Bland–Altman test showed that both formulas reported similar results. This could be due to the fact that both equations included a population with similar characteristics [19,20], although there were large differences in the skinfolds and body areas included. Following these promising results, more research is needed in this regard.

It is important to mention that the present study has certain limitations, mainly related to the study population included. The participants included in the present research are physically active and healthy individuals without excessive adiposity. However, the characteristics of the populations included in the validation of the different equations differ in some socio-demographic characteristics with respect to the population of the present research. This license has been allowed, as this is common practice in both the scientific and clinical fields, due to the difficulty of finding a formula validated in a population with the exact characteristics of the study population in each case. Future research should address the validity of these formulas in different populations in relation to the gold standard (DEXA).

Regarding the practical applications of this research, given the great heterogeneity found between the results reported by the different formulas, we recommend the use of Kerr's formula in both sexes for the assessment of active young people, while Durnin's formula can also be used in the case of women.

5. Conclusions

Differences were found between the formulas for estimating body lipid levels with anthropometry. In addition, most of them showed poor agreement. This is evidence that their results are not comparable and highlights the need to use the same formula both when comparing using references, and when assessing progress in the same subject. In this case, Kerr's formula is positioned as the best alternative, as it was validated on cadavers, included six skinfolds from different body segments, and followed a standardized protocol during its validation, and it is currently the most widely used worldwide.

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