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Original

A comparison of fat mass and skeletal muscle mass estimation in male ultra-endurance athletes using bioelectrical impedance analysis and different anthropometric methods

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Abstract

Two hundred and fifty seven male Caucasian ultra-endurance athletes were recruited, pre-race, before different swimming, cycling, running and triathlon races. Fat mass and skeletal muscle mass were estimated using bioelectrical impedance analysis (BIA) and anthropometric methods in order to investigate whether the use of BIA or anthropometry would be useful under field conditions. Total body fat estimated using BIA was significantly high (P < 0.001) compared with anthropometry. When the results between BIA and anthropometry were compared, moderate to low levels of agreement were found. These results were in accordance with the differences found in the Bland-Altman analysis, indicating that the anthropometric equation of Ball et al. had the highest level of agreement (Bias = -3.0 ± 5.8 kg) with BIA, using Stewart et al. (Bias = -6.4 ± 6.3 kg), Faulkner (Bias = -4.7 ± 5.8 kg) and Wilmore-Siri (Bias = -4.8 ± 6.2 kg). The estimation of skeletal muscle mass using BIA was significantly (P < 0.001) above compared with anthropometry. The results of the ICC and Bland-Altman method showed that the anthropometric equation from Lee et al. (Bias = -5.4 ± 5.3 kg) produced the highest level of agreement. The combined method of Janssen et al. between anthropometry and BIA showed a lower level of agreement (Bias = -12.5 ± 5.7 kg). There was a statistically significant difference between the results derived from the equation of Lee et al. and Janssen et al. (P < 0.001). To summarise, the determination of body composition in ultra-endurance athletes using BIA reported significantly high values of fat and skeletal muscle mass when compared with anthropometric equations.

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COMPARACIÓN DE LA MASA GRASA Y MUSCULAR ESTIMADA EN ATLETAS VARONES DE ULTRA-RESISTENCIA UTILIZANDO LA BIOIMPEDANCIA ELÉCTRICA Y DIFERENTES MÉTODOS ANTROPOMÉTRICOS

Resumen

Se reclutaron a 257 hombres caucasianos que eran atletas de alto rendimiento, antes de competir en diferentes pruebas triatlón de natación, ciclismo y carrera. Se estimaron la masa grasa y la masa de músculo esquelético utilizando un análisis de impedancia bioeléctrica (BIA) y métodos antropométricos con el fin de investigar si el uso de BIA o de la antropometría sería útil en tales condiciones de campo. La grasa corporal total estimada por BIA fue significativamente mayor en comparación con la antropometría (P < 0,001). Cuando se compararon los resultados entre BIA y antropometría, se encontraron niveles de concordancia bajos a moderados. Estos resultados concuerdan con las diferencias halladas con el análisis Bland-Altman, lo que indica que la ecuación antropométrica de Ball et al. posee el mayor grado de concordancia (desviación = -3,0 ± 5,8 kg) con BIA, con Stewart et al. (desviación = -6,4 ± 6,3 kg), Faulkner (desviación = -4,7 ± 5,8 kg) y Wilmore-Siri (desviación = -4,8 ± 6,2 kg). La estimación de la masa de músculo esquelético fue significativamente superior con BIAS que con antropometría (P < 0,001). Los resultados de la ICC y del método Bland-Altman muestran que la ecuación antropométrica de Lee et al. (desviación = -5,4 ± 5,3 kg) produjo el mayor grado de concordancia. El método combinado de Janssen et al. entre antropometría y BIA mostró el menor grado de concordancia (desviación = -12,5 ± 5,7 kg). Hubo una diferencia estadísticamente significativa entre los resultados derivados de la ecuación de Lee et al. y de la de Janssen et al. (P < 0,001). En resumen, la determinación de la composición corporal en atletas de alto rendimiento utilizando BIA produjo valores significativamente mayores de masa grasa y músculo esquelético en comparación con las ecuaciones antropométricas.

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Palabras clave: *Atleta. Composición corporal. Grasa corporal. Masa muscular.*

Abbreviations

BIA: Bioelectrical impedance analyses.
DEXA: Dual-energy X-ray absorptiometry.

Introduction

Anthropometric measurements and bioelectrical impedance analyses (BIA) are widely used popular techniques for estimating body composition. However, the principles are completely different.[1] Anthropometric techniques use the measurement of skin-fold thicknesses at various sites, bone dimensions, and limb circumferences. The accessibility of the subcutaneous fat layer and the non-invasive nature of skin-fold measurement have led to many skin-fold applications and derivations of equation.[1] On the other hand, the assessment of body composition using the BIA method is based on the electrical properties of tissues. The resistance (R) of a length of homogenous conductive material of a uniform cross-sectional area is proportional to its length (L) and inversely proportional to its cross sectional area (A).[2] Although the body is not a uniform cylinder and its conductivity is not constant, an empirical relationship can be established between the impedance quotient ($length^2/R$) and the volume of water, which contains electrolytes that conduct the electrical current through the body.[2] The technique involves attaching adhesive surface electrodes to specific sites on the dorsal surface of the hand and anterior surface of the ipsilateral foot of the subject. The applied current is usually in the order of 500 µA for single (50 kHz) frequency machines, or 500 µA to 1 mA for multifrequency machines (5 kHz to 1 MHz), and test times may vary from a few seconds for a single frequency scan to several minutes for a full frequency scan. The raw outputs are generally visible immediately on the analyser as resistance and reactance and subsequently transmitted to a host computer whereby dedicated software processes the data.[3]

In sport, the body composition is an important determinant of performance. It is known that a high fat-free mass, such as a high skeletal muscle mass, is needed to increase power and strength,[4,5] whereas leanness, such as low fat mass, is important in order to perform well in endurance events.[6] In this field, the non-invasive and fast methods, such as skin-folds and BIA, are the most common forms of estimating body composition.[7] Both are considered as level III methods because they are based on prediction equations (double indirect measure).[8] Skin-fold thickness measurements and BIA are two widely used indirect techniques for the assessment of body composition because they are easy to use and non-invasive. Many skin-fold and impedance equations have been developed to predict fat mass and fat free mass from simple anthropometric and bioelectric parameters. Compared with the indirect methods of level II, such as hydrodensitometry, magnetic resonance imaging (MRI) and dual-energy X-ray absorptiometry (DXA), anthropometry and BIA have some advantages. In general these are relatively inexpensive, non-invasive techniques, safe, fast and at the same time reliable, requiring little operator skill and subject cooperation and they are portable, accurate and sensitive in determining both skeletal muscle mass and fat mass.[9,10] The use of BIA in the determination of body composition is especially useful under field conditions in ultra-endurance races.[11,12]

Several investigations have compared the accuracy of measurements of body fat using BIA and skin-fold thickness in non-athletic healthy individuals[13,14,15] and physically active young people,[16] as well as body builders and other power athletes[17] in a mixed sample of athletes from different disciplines, such as football, basketball, volleyball, handball and cycling[18], but not in ultra-endurance athletes. Most of the studies have only compared the methods of estimating body fat and fat mass. However, only a few studies have tried to assess skeletal muscle mass or lean body mass.[19,20,21] To date, no study has tried to estimate both skeletal muscle mass and fat mass in highly trained ultra-endurance athletes in one study. Therefore, the aim of this study was to compare the results of both fat mass and skeletal muscle mass, estimated using BIA and different anthropometric methods, in a large sample of ultra-endurance athletes.

Materials and methods

Subjects

Two hundred and fifty seven Caucasian male ultra-endurance athletes were recruited, in the 2009 season, from various swimming, cycling, running and triathlon competitions. The physical characteristics of the subjects are illustrated in table I. All the races were held in Switzerland. These races were the 'Marathon Swim' in Lake Zurich (26.7 km open-water ultra-swim), the 'Swiss Cycling Marathon' with 720 km of non-stop cycling, the '100-km Lauf Biel', and 'IRONMAN SWITZERLAND'. All the athletes were contacted via a separate newsletter from the organisers upon inscription to the races and informed about the planned investigation. The subjects were informed of the experimental procedures and gave their informed written consent prior to the investigation. The investigation was

Table I
Physical characteristics of the subjects (n = 257)

	Mean ± SD
Age (years)	43.8 ± 9.0
Body mass (kg)	76.2 ± 8.9
Height (cm)	180.0 ± 6.9
Body mass index (kg/m^2)	23.5 ± 2.1

approved by the Ethical Committee of St. Gallen, Switzerland.

Measurements

All the measurements were performed on the day before the start of each race. One experienced investigator performed all the measurements in an identical manner. Body mass was measured using a commercial scale (Beurer BF 15, Beurer, Ulm, Germany) to the nearest 0.1 kg. Body height was measured using a stadiometer to the nearest 1.0 cm. Body mass index (kg/m^2) was calculated using body mass and body height.

Bioelectrical impedance analysis (BIA)

All the individuals underwent at least one single-frequency BIA measurement (average of two measurements). The measurement was performed on the right side of the body using 800- A and 50-kHz alternating sinusoidal current and a standard tetrapolar technique (BIA 101 Impedance Analyzer, AKERN, Florence, Italy). BIA was performed under standardised conditions: a quiet environment, an ambient temperature of 22 C – 24 C and after resting in the supine position for 20 min. After the electrode sites were cleaned with isopropyl alcohol, electrode patches using a self-adhesive conducting gel (Kendal Care, Resting ECG Electrode, TYCO Healthcare Group LP, Mansfield, MA, USA) were attached. The electrodes were placed proximal to the metacarpal-phalangeal joints in the middle of the dorsal side of the right hand, and just below the transverse (metatarsal) arch on the superior side of the right foot. The whole-body impedance vector components, resistance (*R*) and reactance (*Xc*), were measured at the same time. Fat mass and skeletal muscle mass were determined using BODYGRAM-Software (AKERN S.r.I. Bioresearch, Florence, Italy).

Anthropometric measurements

All the anthropometric measurements were taken by the same investigator to ensure reliability. Skin-fold data were obtained using a skin-fold calliper (GPM-Hautfaltenmessgerät, Siber & Hegner, Zurich, Switzerland) and recorded to the nearest 0.2 mm. The skin-fold measurements were taken once for the entire eight skin-folds and were then repeated twice more by the same investigator; the mean of the three times was then used for the analyses. The timing of the taking of the skin-fold measurements was standardised to ensure reliability. According to Becque et al.[22] the readings were performed 4 s after applying the calliper. Intra- and inter-measurer agreement was assessed using data from 27 male runners prior to an ultra-marathon, based on the measurements taken by the two experienced primary care physicians.[23] Intra-class correlation (ICC) within the two measurers was excellent for all anatomical measurement sites and for various summary measurements of skin-fold thicknesses (ICC > 0.9). Agreement tended to be higher within than between the investigators, but still reached excellent reliability (ICC > 0.9) for the summary measurements of skin-fold thicknesses. The circumferences of the limbs were measured using a non-elastic tape measure (cm) (KaWe CE, Kirchner und Welhelm, Germany) and followed the guidelines of the International Society for the Advancement of Kinanthropometry.[24] The circumference of the upper arm was measured at the mid-upper arm, and thigh at mid-thigh and calf at mid-calf.

Estimation of fat mass

Body fat in absolute values (kg) was estimated using one anthropometric equation for the general population and four specific equations for the athletic population: Ball et al.[25] for the general population = 0.465 + 0.180* (S7SF) – 0.0002406* $(S7SF)^2$ + 0.0661* (age), where S7SF is the sum of skin-fold thickness of pectoralis, axillar, triceps, subscapular, abdomen, suprailiacal and thigh mean in mm; age is in years. The result in percent body fat was converted to fat mass in kg using body mass. To estimate body fat in athletes the following four equations were applied: Faulkner for the athletic population = 0.153* (S4SF) + 5.783, where S4SF is the sum of skin-fold thickness of triceps, subscapular, abdomen and suprailiac in mm.[26] Estimation of body density using the equation of Wilmore et al. for the athletic population = 1.0988 – 0.0004* (S7SF), where S7SF is the sum of skin-fold thickness of triceps, subscapular, biceps, suprailiac, abdomen, mean thigh and mean calf in mm.[27] Then body fat was estimated using the equation of Siri[28]: (495/body density) – 450. In addition, the method of Stewart et al. for the athletic population = 331.5* (abdominal) + 356.2* (thigh) + 111.9 m – 9,108, where abdominal is the thickness of abdominal skin-fold in mm, thigh is the thickness of thigh skin-fold in mm and *m* is body mass in kg.[29]

Estimation of skeletal muscle mass

Muscle mass (MM) was estimated using the anthropometric equation of Lee et al.[30] with MM = Ht* (0.00744 * CAG^2 + 0.00088* CTG^2 + 0.00441 * CCG^2) + 2.4* sex – 0.048* age + race + 7.8 where Ht = height, CAG = skin-fold-corrected upper arm girth, CTG = skin-fold-corrected thigh girth, CCG = skin-fold-corrected calf girth, sex = 1 for male; age is in years; race = 0 for white and 1 for black. Furthermore, MM was also estimated following the combined method of Janssen et al.[19] using anthropometric variables and resistance from bioelectrical impedance measurements

Table II
Estimation of body fat using a bioimpedance (BIA) device and anthropometric equations (n = 257)

Method	*Body fat (kg)*	*ICC*
Bioimpedance	14.8 ± 6.7	
Anthropometry		
Ball et al.[25]	11.9 ± 4.3*	0.62
Stewart et al.[29]	8.4 ± 4.6*	0.56
Faulkner[26]	10.2 ± 3.3*†	0.55
Wilmore et al.-Siri[27,28]	10.0 ± 4.8*†	0.60

ICC: intra-class correlation coefficient (ICC) between BIA and anthropometry methods.
*Statistical difference ($P < 0.001$) between BIA and anthropometric equations.
†Statistical difference ($P < 0.001$) between Ball et al. (2004) and Stewart et al. (2000) equations compared with Faulkner (1968) and Wilmore-Siri (1987-1961).

with MM = (Ht^2/R* 0.401) + (gender* 3.825) + (age* – 0.071) + 5.102 where Ht is body height in cm; R is resistance in ohms; for gender, men = 1, and age is in years.

Statistical analysis

One-way ANOVA was used to compare differences in body fat and muscle mass values determined by using a BIA device and anthropometric equations. In addition, the intra-class correlation coefficient (ICC) was used to determine the level of relative agreement between the BIA and anthropometry methods. Bland-Altman analysis was used to determine absolute limits of agreement. An α-level of $P < 0.05$ was considered statistically significant. Statistical analysis was performed using SPSS for Windows software (Version 15.0, SPSS, Inc., Chicago, IL).

Results

The estimation of body fat

Total body fat estimated using BIA was significantly high ($P < 0.001$) compared with the anthropometric equations (table II). Additionally, when the results between BIA and anthropometry were compared using ICC-analysis, moderate to low levels of agreement were found (table II). These results were in accordance with the differences found in the Bland-Altman analysis (fig. 1), indicating that the equation of Ball et al.[25] for the general population had the highest level of agreement (Bias = -3.0 ± 5.8 kg) using BIA in comparison with the anthropometric equations of Stewart et al.[29] (Bias = -6.4 ± 6.3 kg), Faulkner[26] (Bias = -4.7 ± 5.8 kg)

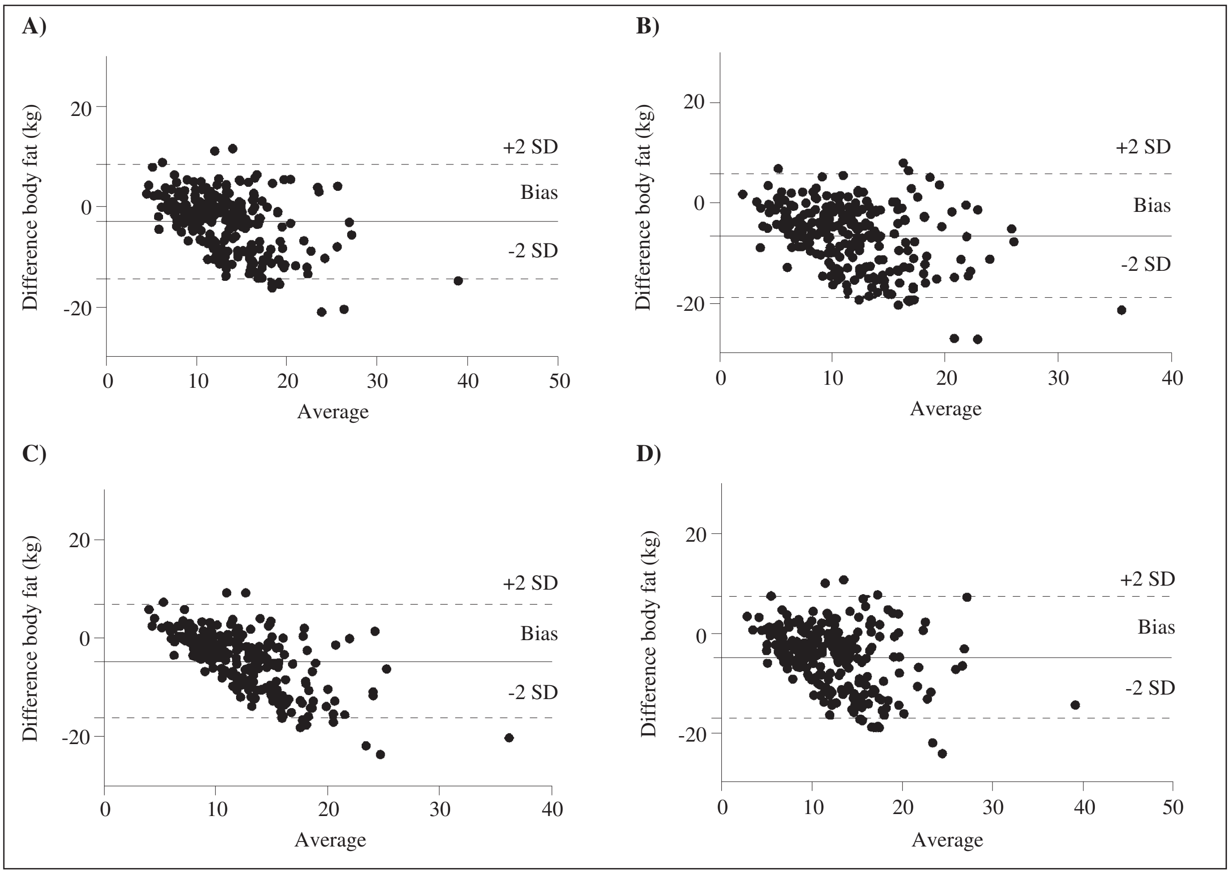

Fig. 1.—Bland-Altman plots comparing body fat (kg) estimation between: a) Ball et al.[25] equation and BIA; b) Stewart et al.[29] and BIA; c) Faulkner et al.[26] and BIA; d) Wilmore et al -Siri[27,28] and BIA.

Table III
Estimation of muscle mass using a bioimpedance (BIA) device and anthropometric equations (n = 257)

Method	*Muscle mass (kg)*	*ICC*
Bioimpedance	44.9 ± 5.4	
Anthropometry		
Lee et al.[30]	39.5 ± 3.8*	0.53
Jansen et al.[19]	32.3 ± 5.2*†	0.49

ICC: intra-class correlation coefficient between BIA and anthropometry.
*Statistical difference ($P < 0.001$) between BIA and anthropometric equations.
†Statistical difference ($P < 0.001$) between Lee et al. (2000) and Jansen et al. (2000) equations.

and Wilmore – Siri[27,28] (Bias = -4.8 ± 6.2 kg). There were also significant differences ($P<0.001$) between the results from the equation for the general population from Ball et al.[25] and the other three specific equations for the athletic population (table II). Additionally, the estimation of fat mass using the equation of Stewart et al.[29] showed significant differences compared with the results from the equations of both Faulkner[26] and Wilmore – Siri ($P<0.001$).[27,28] On the contrary, these last two equations showed no statistically significant differences between them ($P > 0.99$).

The estimation of skeletal muscle mass

Table III illustrates the results of the estimation of skeletal muscle mass between BIA and those of the anthropometric equations. The estimation of skeletal muscle mass using BIA was showed values significantly ($P < 0.001$) above compared with the results of the anthropometric equations. The results of the ICC and Bland-Altman method showed that the anthropometric equation of Lee et al.[30] (table III and fig. 2) (Bias = -5.4 ± 5.3 kg) produced the highest level of agreement with BIA. On the contrary, the combined method of Janssen et al.[19] between anthropometric and BIA data indicated a lower level of agreement with BIA (table III and fig. 2) (Bias = -12.5 ± 5.7 kg). Additionally, there was a statistically significant difference between the results derived from the equation of Lee et al.[19] and Janssen et al. ($P < 0.001$) (table III).[30]

Discussion

The principal finding of this study was that the results deriving from the BIA device showed significantly high values of body fat and skeletal muscle mass compared with anthropometric equations in ultra-endurance athletes. In body composition studies, body mass is generally divided into two components, fat mass and fat free mass. For practical purposes fat mass and fat free mass are often evaluated utilising skin-fold measurements and BIA and applying specific regres-

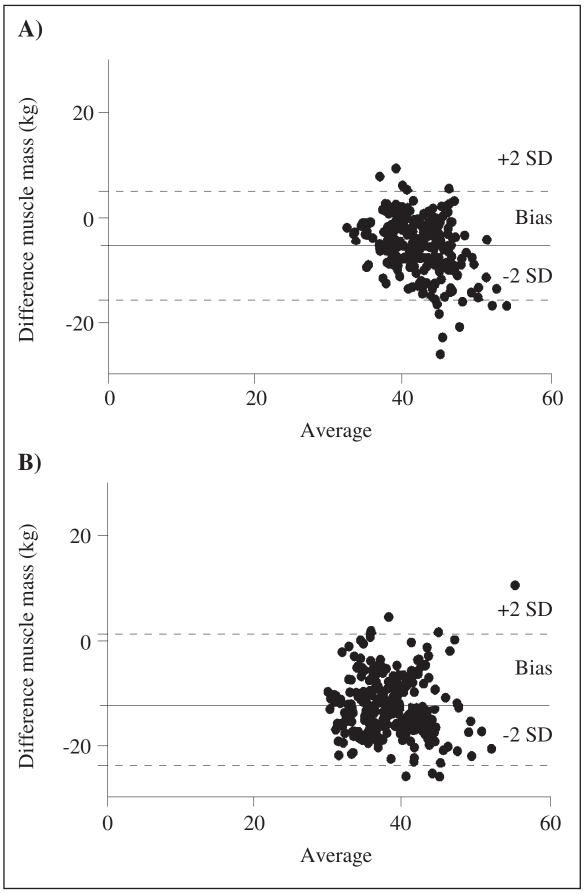

Fig. 2.—Bland-Altman plots comparing skeletal muscle mass estimation between: a) Lee et al.[30] and BIA; b) Janssen et al.[19] and BIA.

sion equations for age, gender and training. These equations, however, are developed with statistical regression techniques using, as reference methods, different techniques. These techniques have a different precision and degree of accuracy with regard to fat mass and fat free mass measurement.[21,31]

The literature regarding the reliability of BIA in estimating body composition is very equivocal. While some studies assume that BIA shows reliable results in measuring body fat compared with DEXA,[32,33,34] others argue that BIA over- or underestimates body fat.[9,17,35,36,37,38,39] It is obvious that BIA has some limits. Fogelholm et al.[37] investigated, in a meta-analysis using 54 papers, the comparability of different methods to assess body fat percentage against underwater weighing. BIA overestimated percent body fat whereas the skin-fold equation of Jackson et al.[40] showed a relative underestimation.

Kitano et al.[41] compared dual-energy X-ray absorptiometry (DEXA), skin-fold thickness and bioelectrical impedance analysis (BIA) in 155 young Japanese females in order to evaluate body composition. They found significant differences in the values among the three methods, with the skin-folds providing the lowest body fat mass and percentage, and dual-energy X-ray absorptiometry the highest. Swartz et al.[42] compared

BIA with hydrostatic weighing and found no differences in percent body fat. However, the range of individual error scores was large. Several studies have compared anthropometric equations with BIA in the estimation of body fat. Martin Moreno et al.[15] compared anthropometric equations, skin-fold thicknesses and BIA in estimating body fat in 149 healthy individuals. The anthropometric equations provided different body fat estimates than those derived from skin-fold measurements and BIA, and the authors recommended that the methods should not be used interchangeably. Aristizábal et al.[35] compared anthropometric methods with BIA in estimating percent body fat in 70 females and 53 males. For both sexes, the anthropometric methods showed higher values. Porta et al.[16] investigated four different BIA devices and compared them with an anthropometric method. In males, the level of agreement between the anthropometric method and the four BIA devices was poor to moderate. Huygens et al.[17] applied BIA and anthropometric equations in order to estimate body composition in male power athletes and body builders. Anthropometric equations could accurately estimate the body composition in this specific group of athletes. However, the sum of skin-folds attained the most accurate estimate of subcutaneous fatness while BIA was not considered as accurate.

Ostojic[18] investigated 216 male professional athletes using skin-fold thicknesses and BIA in estimating body fat. Their athletes showed no significant differences in percent body fat between the two methods. We also investigated male athletes using the same methods; however, we came to a different result with significant differences between the anthropometric methods and BIA. The reason for the different findings might be the sample of athletes. While we investigated a rather heterogeneous group of ultra-endurance athletes such as swimmers, cyclists, runners and triathletes, Ostojic[18] used a rather homogeneous group of team-sport athletes. Their 219 male professional athletes were members of the Serbian Olympic team in Athens from the disciplines of football, basketball, volleyball, handball, cycling and a few others. However, Clark et al.[36] also compared skin-fold equations and BIA in athletes. BIA was significantly different from hydrostatic weighing and yielded the mean difference, the lowest correlation, the highest standard error of estimate and the highest total error. The Jackson and Pollock[43] skin-fold equation provided the most valid prediction of hydrostatic weighing-determined percent body fat.

One might assume that the precision of estimating body fat with the number of included skin-fold thicknesses might increase. We used the anthropometric methods of Ball et al.[25] using seven skin-folds, Faulkner[26] using four skin-folds, and Wilmore et al. –Siri[27,28] using seven skin-folds. The equation of Ball et al.[25] showed the highest level of agreement.[25] There was a significant difference between the results of Ball et al. and the other three equations in the estimation of body fat in an athletic population.[25] However, Moon et al.[44] could demonstrate that more than three skin-fold sites did not improve percent body fat values. Also Stout et al.[45] could demonstrate that estimating percent body fat using the sum of three skin-folds showed the lowest standard error of estimation and total error, as well as the highest validity coefficient, when compared with near-infrared interactance and BIA. The equation of Jackson and Pollock[43] was found to be particularly appropriate for the estimation of body density in adolescent athletes in another study.[46]

Apart from fat mass, we also intended to estimate skeletal muscle mass by using both BIA and anthropometric methods. Anthropometry has been used as a simple, non-invasive and inexpensive method for measuring skeletal muscle mass.[47] In a recent study, anthropometric indices have been validated for estimating total body skeletal muscle mass in humans.[30] The validation of BIA in estimating skeletal muscle mass has also been carried out. Janssen et al.[19] determined skeletal muscle mass by using BIA and magnetic resonance imaging in a multiethnic sample of 388 men and women aged 18-86 years. They concluded that BIA provides valid estimates of skeletal muscle mass in healthy adults varying in age and adiposity. However, the prediction equation derived from data on Caucasians obtained using the whole BIA analysis overestimated the whole skeletal muscle mass in an Asian cohort. Kuriyan et al.[48] compared total body muscle mass estimation using BIA and anthropometric measurements. The simple anthropometric methods have been validated against more sophisticated and relatively more accurate methods of estimating of body composition. De Lorenzo et al.[49] evaluated fat mass and fat free mass using different techniques, such as dual-energy X-ray absorptiometry and different impedance equations. While they found no differences in percent body fat between dual-energy X-ray absorptiometry and the impedance equations, the mean value of fat free mass measured using dual-energy X-ray absorptiometry was significantly higher than that predicted by the impedance equations. Tanaka et al.[50] compared BIA with magnetic resonance imaging in estimating skeletal muscle mass. BIA produced systematic errors and resulted in an overestimation of skeletal muscle mass determined by magnetic resonance imaging. Kyle et al.[20] investigated 444 healthy volunteers between 22 and 94 years and estimated muscle mass using BIA and dual-energy X-ray absorptiometry. They concluded that the BIA method was a valid method for estimating skeletal muscle mass when compared with dual-energy X-ray absorptiometry.

We found an overestimation of both skeletal muscle mass and fat mass by using BIA. BIA is a body composition method that measures tissue conductivity and is based on the relationship between the volume of a conductor and its electrical resistance.[51] Because skeletal muscle mass is the largest tissue in the body and it is an electrolyte-rich tissue with a low resistance, muscle is a dominant conductor.[52,53] When a current flows through the body it is partitioned among different tissues according to their individual resistances and volumes. Because skeletal muscle mass has both a large volume and a low resistance, most of the BIA current flows through skeletal muscle mass.[52] Presumably, these endurance trained athletes differ in skeletal muscle mass and fat mass compared with the other populations investigated in the above-mentioned studies. Another explanation could be that we used a single frequency BIA while other studies used devices with multifrequency.

Although we had a large sample size, we did not determine the hydration status of the subjects. Changes in hydration status may be interpreted incorrectly as changes in the athlete's body fat content when using BIA.[54,55]

In conclusion, BIA and anthropometry techniques are not interchangeable in ultra-endurance athletes. In agreement with the development of anthropometric equations and measurement protocols for specific populations, such as athletes, in recent decades, it seems that the anthropometry technique could be more reliable than BIA. However, in the absence of well-trained personnel in anthropometric measurements, the BIA method could be useful in assessing body composition in ultra-endurance athletes, ensuring that measurements are taken in the same physiological state and day time conditions, such as in a fasted state in the early morning.

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