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A Comparison of Methods for Evaluating Body Composition in Elite Female Soccer Players

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ABSTRACT The aim of the research was to determine an accuracy of measurement based on intra-trial concurrent and convergent validity of body composition (BC). Measurements were obtained via bioelectrical impedance analysis (BIA) in comparison with the hydrodensitometry (HD) method in elite female soccer players (n = 14). BC was measured using three methods: bioelectrical impedance methods BIA 2000M and In Body 3.0, and HD. The fat mass (FM) measured by HD was 16.96±3.86 percent, whereas it was 21.26±5.77 percent when measured with BIA 2000M, and was even higher when measured by the In Body 3.0 device at 23.33±3.52 percent. Effect size between BIA and HD was >0.87, convergent validity was lower than r<0.65, coefficient of determination was lower than $R^2<0.65$, and a standard error of estimation was higher than >2.8. The results of the research showed that, without proper prediction equations for the specific population, the selected bioelectrical impedance analysers cannot be considered valid enough to assess the fat mass of elite female soccer players.

INTRODUCTION

The aim of this study is to determine an accuracy of Body Composition (BC). measurement and assessment based on intra-trial concurrent and convergent validity of BC measures obtained from BIA analysis in comparison with those obtained with the hydrodensitometry (HD) method in soccer players, especially for female.

In terms of energy demands, soccer is a highly-intensive game with great demands on players' physical preparedness as well as players' morphological profiles. Energy consumption in soccer is dominantly aerobic (Nilsson and Cardinale 2015). Quick counterattacks also put high demands on anaerobic capacity, power, and acceleration speed. Intensity running and sprint distance have increased 30-50 percent over the last few years in the English Premier League matches (Bush et al. 2015).

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BC is a key consideration in the physical makeup of high elite players in that one aim of BC assessment is to differentiate and quantify of BC compartments (Sutton et al. 2009). Further, BC assessment also detects symmetry of body active mass distribution in individual segments as injury prevention (Mala et al. 2014).

Based on the explosive character of activities in soccer, a high level of lean body mass (LBM) and low level of fat mass (FM) are necessary. The findings of the studies demonstrate the different influences of the nutritional quality of player diets (Lloyd et al. 2014), of training volume (Lloyd et al. 2014), and of the player's role in estimating their energy demands as a specific player (Carling and Orhant 2010; Rogan et al. 2011).

In regard to high-performance sport, the assessment of BC may define a performance or selection criterion, or may be used to assess the effectiveness of an exercise or nutrition habits of athletes (Ackland et al. 2012). The lack of available publications on the subject provides an insufficient number of parameters to be used for BC assessment (FFM, FM, body cell mass) even when compared with data obtained by different methods.

The methods used in medical and exercise science research are indirect and based on quantitative assumptions. Hydrodensitometry (HD) is based on constant hydration of FFM and density of FM and LBM. Hydrodensitometry, together with dual-energy X-ray absorptiometry (DEXA), are considered "gold standard" methods (Shakeryan et al. 2013), although Ackland et al. (2012) reported that, to date, there is no universally applicable criterion or "gold standard" methodology for BC assessment (FM assessment with accuracy better than one percent). The use of DEXA is popular today, both in practice of elite sport and in scientific studies (Santos et al. 2014). Milsom et al. (2014) present DEXA as an option to assess both whole-body and regional estimates of FM and FFM – variables that are highly responsive to training, nutritional interventions, and injury strategies. Use of DEXA as a diagnostic tool may therefore allow for a more accurate dietary and training prescription that is more readily aligned with optimising body composition to increasing physical performance output (Milsom et al. 2015). Ellis (2000) reported that this method primarily evolved at departments with a focus on body fitness, often relating the measurement to human kinetics, exercise, and sports performance.

The multicomponent model reduces errors in the two-component model related to individual differences in hydration (Mala et al. 2014). Bioelectrical impedance (BIA) assumes constant hydration of LBM, assumes a body model through which current passes equally in all segments, and where variability of results depends on regression equations (Mala et al. 2014). Despite these assumptions, technical simplicity, accessibility, and easy tasks for participants increase the use of the BIA method.

Although hydrodensitometry and DEXA provide more accurate reference methods, portability is a major limitation when BC measurements are needed in field testing such as during national team meetings. There are only few publications which present comparisons of the reference method and results of BIA analysis in elite female athletes (Esco et al. 2015; Mala et al. 2015); most of studies focus on male elite sport, adolescent athletes (Aerenhouts et al. 2015), or non-sporting populations (Sillanpaa et al. 2014). Another problem is the use of the term "elite athletes" when referring to different performance levels (from athletes regularly exercising in the club, members of professional clubs, members of the national team, etc.).

METHODOLOGY

Study Sample

The participants consisted of elite female Czech national-level players (n = 14, age = 24.4±3.7 years, body height = 168.8±6.1 cm, body mass = 62.1±5.0 kg).

The players received a verbal, written description of the study and procedures before testing and completed a written informed consent form that was approved by the ethical committee of Charles University.

Body Composition Assessment

Measurements were performed in the morning before breakfast (7:30-8:30 a.m.). BC was measured using three methods, namely the hydrodensitometry and the bioelectrical impedance methods (two different equipment) under the standard conditions (Kyle et al. 2004).

The players did not take any medications, or pharmacological agents that could affected the results of the measurement (alcohol, caffeine) before testing (24 hours prior to the measurements). Moreover, 48 hours before the measurement the subjects did not perform strenuous physical exercise.

Body mass (BM) was assessed by a scale (SECA 769, Hamburg, Germany) and body height (BH) by a stadiometer (SECA 242, Hamburg, Germany).

Hydrodensitometry

During HD measurement, the researchers used a water tank (90x110x14 cm) with a mounted chair and digital scale (AND, Japan) with an accuracy of 0.001 g. The weight of the measuring construction was calibrated so that each player's net weight was recorded. In one immersion, the researchers recorded body weight under water twice while the recording was related to mean value of scale oscillation for a period of 2 s. Overall, the researchers conducted 5 immersions which resulted in 10 recordings. The best trial (the greatest weight) was selected for further assessment. The measuring construction was attached to a computer with software which derived body density, amount of FM and active mass in each participant's body by means of a specific formula (Siri 1961), assuming a constant density of body active mass (1.10 $g.cm^{-3}$) and fat mass (fat 0.90 $g.cm^{-3}$) and constant hydration of body active mass (73.2 %). Residual volume was taken into account as a constant (Organ et al. 1994).

Bioelectrical Impedance Methods (BIA 2000M, InBody 3.0)

The researchers used the whole-body BIA with the phase-sensitive whole-body tetrapolar bioelectrical impedance measurement device (BIA 2000M, Data Input GmbH, Germany). The researchers recorded the following BC variables: FFM and percentage of FM. During the measurement, subjects lay on their backs on a non-conductive surface with stretched lower limbs without socks or shoes and with upper limbs lying loosely near the body. After degreasing of the skin, four measuring electrodes were affixed on the right-side limbs, two electrodes were distally located on the dorsum of ipsilateral hand and foot and two proximally from the previous ones. The measurement took approximately 30-45 seconds.

Bioelectrical Impedance Analysis in Body 3.0

The next method used for BC assessment was multi-frequency BIA analyser InBody 3.0 (Biospace, Korea) for recording FM and FFM. During the measurement, subject stood with degreased bare feet on bipedal electrodes and held bimanual electrodes with the hands (the principle of eight-point tetrapolar touch points). The measurement took approximately 120 s. Body weight was recorded with an accuracy of 1 g.

Statistical Analysis

All data are reported as means ± standard deviation. Data normality was set using Shapiro-Wilk test and homoscedasticity was verified using Bartlett test. The one-way ANOVA was used for evaluation of BF as dependent variables. Bonferroni's post-hoc test we used for evaluation of multiple means comparisons of the tested methods. Intra-class correlation (ICC) was calculated for assessment of intra-trial concurrent validity as inter-method variance on total variance using a two-mixed model for consistency. ICC result lower than 0.8 was considered fair, 0.8-0.9 good and higher than 0.9 excellent agreement (Donner and Eliasziw 1987). Cohen's coefficient of effect size "d" was used for evaluation differences between the means of the BC methods. Linear regression analyses and Bland Altman limits of agreement were also used for data processing (Bland and Altman 1986). Alpha level was set at 0.05. Data analysis was assessed by IBM, SPSS® 21 version (IBM, SPSS, Chicago, IL, 2012).

RESULTS

Mean values of FM in female players were significantly lower in HD method in comparison to BIA methods (Fig. 1). The BF measured by HD was 16.96±3.86 percent, compared to a BIA 2000M measurement of 21.26±5.77 percent. Mean value of BF was even higher when measured by InBody 3.0 (23.33±3.52%). Analysis of variance revealed a significant difference between BF recorded by HD and BIA 2000M ($p<0.05$) as well as when recorded by HD and InBody 3.0 ($p<0.01$).

The results showed high effect size between HD and BIA methods (Table 1). Even between two BIA analyses, medium effect size was found ($d = 0.41$). Correlation analysis showed a significant relationship ($p<0.05$) between the compared methods, however, satisfactory value was only achieved between BIA 2000M versus InBody ($r = 0.90$) (Table 2). Intra-class correlation only revealed excellent agreement between BIA methods (BIA 2000M versus InBody 3.0) (Table 3). The comparison of HD and BIA methods showed fair agreement.

Table 1: Effect size in different methods of BC assessment

Effect Size (Cohen's "d")	*HD*	*BIA 2000M*	*InBody 3.0*
HD	-	0.88	1.69
BIA 2000M	0.88	-	0.41
InBody 3.0	1.69	0.41	-

Legend: HD – hydrodensitometry

Figures 2, 3, and 4 depict Bland-Altman plots which assess limits of agreement (LOA) between HD, BIA 2000M, and InBody 3.0. Table 4 presents systematic bias mean and LOA between selected BC methods. Bland-Altman plots document wide variations between measurement methods in FM, ranging from -6.26 to 4.43.

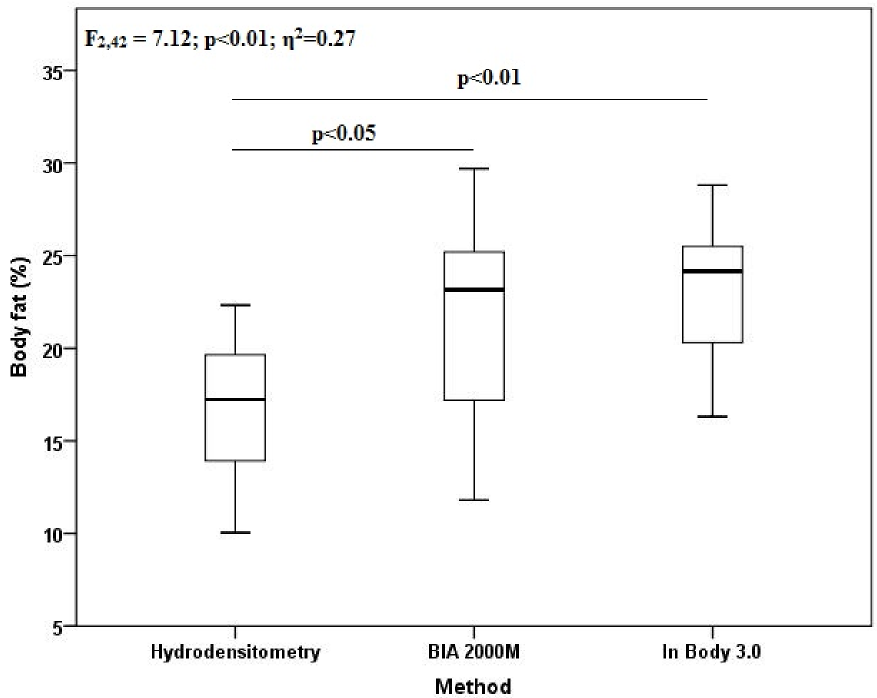

Fig. 1. The comparison of fat mass between selected methods

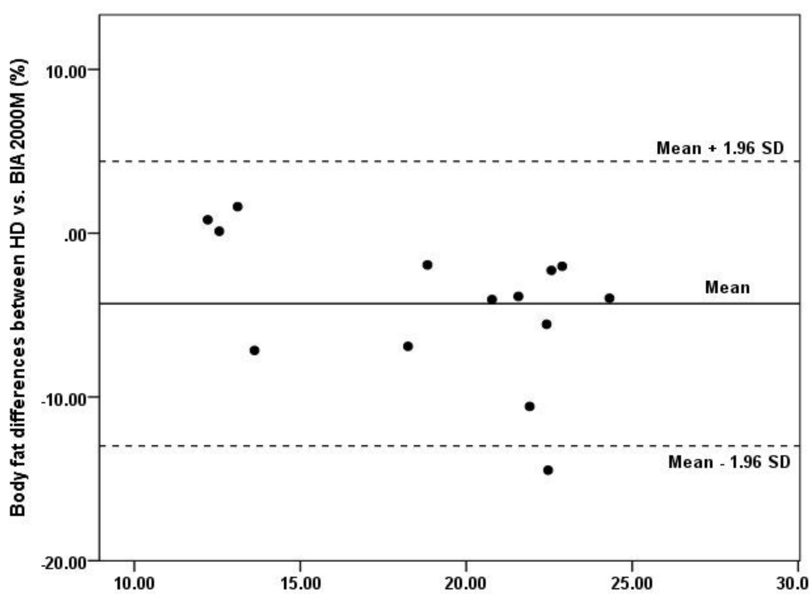

Fig. 2. The comparison between hydrodensitometry and BIA 2000M

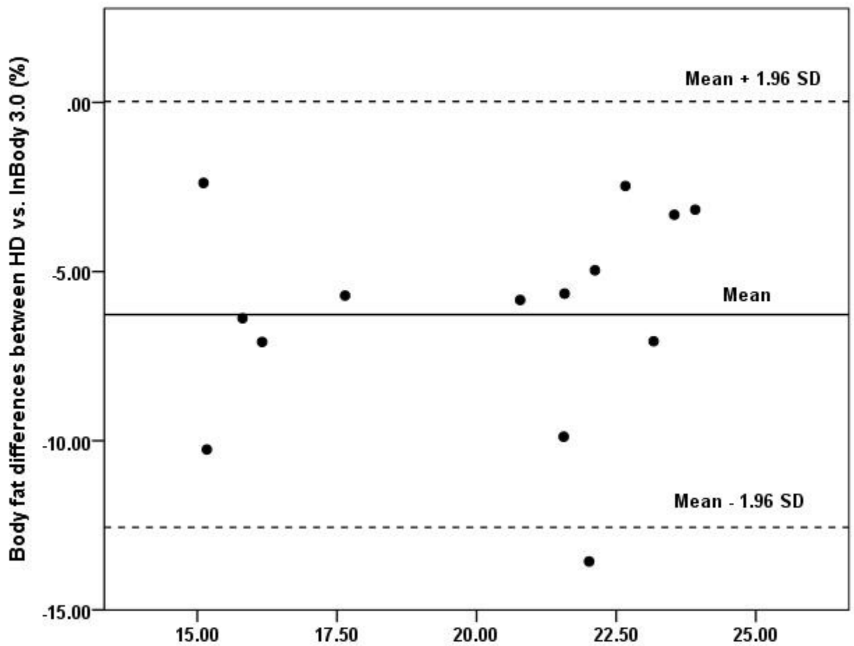

Fig. 3. The comparison between hydrodensitometry and InBody 3.0

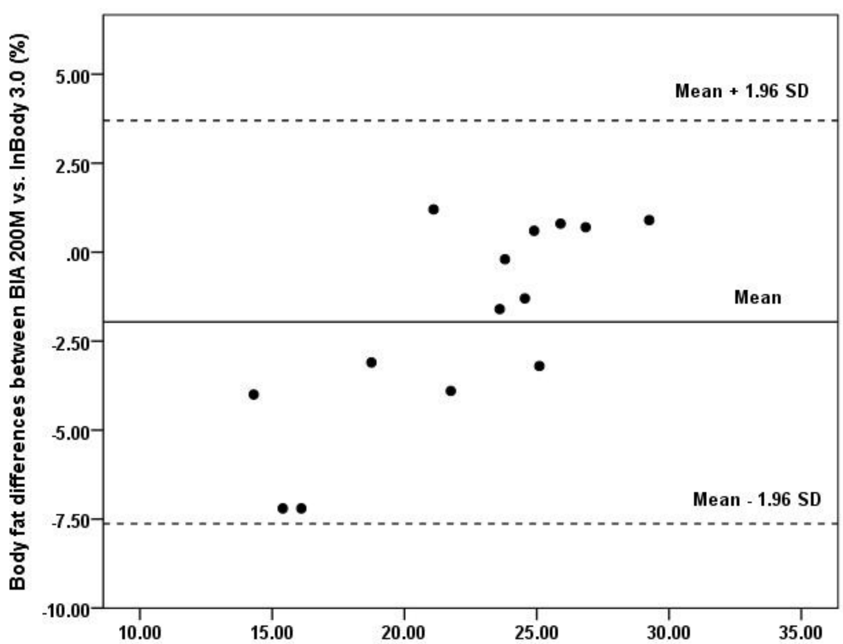

Fig. 4. Mean of means bias BIA 2000M vs. InBody 3.0)%)

Table 2: Pearson correlation coefficient between the selected methods

Pearson correlation (r)

	HD	*BIA 2000M*	*InBody 3.0*
HD	-	0.64	0.63
BIA 2000M	0.64	-	0.9
InBody 3.0	0.63	0.9	-

Legend: HD – hydrodensitometry

LOA ranged between -12.99 and 4.39 with the highest range of discrepancies being noted between HD and BIA 2000M (-12.99, -4.39) (Table 4). Table 5 presents a coefficient of linear regression for estimation of dependent variable (row) when calculated from independent variable (column) and particular constant. The accuracy of the model of linear regression (estimation of the dependent variable from the independent one) is expressed using the coefficient of determination and standard error of mean (SEM) (Table 6). The best result is between the BIA methods when $R^2 = 0.919$ and SEM = 1.446, which explains approximately 92 percent of overall variance.

DISCUSSION

The researchers' recorded values of FM (Fig. 1) are in line with available literature that presents average proportion 14.6-20.1 percent in

Table 3: Intra-class correlation between the selected methods

Intra-Class Correlation for single measure ICC (95% CI)

	HD	*BIA 2000M*	*InBody 3.0*
HD	-	0.74 (0.20 - 0.92)	0.77 (0.28 - 0.93)
BIA 2000M	0.74 (0.20 - 0.92)	-	0.90 (0.69 - 0.97)
InBody 3.0	0.77 (0.28 - 0.93)	0.91 (0.69 - 0.97)	-

Legend: HD – hydrodensitometry

Table 4: Systematic bias between selected body composition methods

Systematic bias mean ± SD (95% CI) [%]

	HD	*BIA 2000M*	*InBody 3.0*
HD	-	-4.30 ± 4.43 (-12.99; 4.39)	-6.26 ± 3.21 (-12.56; 0.03)
BIA 2000M	-4.30 ± 4.43 (-12.99; 4.39)	-	-1.96 ± 2.89 (-7.63; 3.70)
InBody 3.0	-6.26 ± 3.21 (-12.56; 0.03)	-1.96 ± 2.89 (-7.63; 3.70)	-

Legend: HD – hydrodensitometry, SD – standard deviation, CI – confidence interval

Table 5: The linear regression equation (dependent variable are in rows, independent in columns)

Linear regression model $y = \hat{a}_0 + \hat{a}_1 x$

	HD	*BIA 2000M*	*InBody 3.0*
HD	-	7.856 + 0.429x	1.021 + 0.686x
BIA 2000M	5.021 + 0.958x	-	-13.725 + 1.506x
InBody 3.0	13.560 + 0.570x	11.308 + 0.560x	-

Table 6: The coefficient of determination between selected body composition methods

Coefficient of determination of the regression model R^2 *(SEM)*

	HD	*BIA 2000M*	*InBody 3.0*
HD	-	0.641 (3.086)	0.625 (3.138)
BIA 2000M	0.641 (4.611)	-	0.919 (2.370)
InBody 3.0	0.625 (2.860)	0.919 (1.446)	-

Legend: HD – hydrodensitometry, SEM – Standard error of the estimate female national team players and those competing in the highest domestic leagues (Krustrup et al. 2010; Gravina et al. 2011; Datson et al. 2014; Chaud et al. 2015; Esco et al. 2015). Gravina et al. (2011) reported FM = 15.5±2.9 percent in Spanish female players from the highest division. Krustrup et al. (2010) reported 18.5 percent in Danish female players. Chaud et al. (2015) reported 28.5±3.7 percent for female soccer players (n=15, 26.1±2.9 years, 61.8±8 kg, 162.2±5.1 cm). Esco et al. (2015) reported the value of BF of 25.87±5.56 percent (measured using DEXA) and 22.54±5.07 percent (measured using InBody 720) in female athletes.

The limit of comparison of this study's obtained values is the diversity of the methods used. It is important in clinical, field research, exercise science, and epidemiological investigation to develop an easy, accurate, portable, and inexpensive device for BC assessment.

The correlation coefficient found between the methods was highest between BIA 2000M and InBody 3.0 ($r = 0.90$, $p<0.01$). When comparing the correlation of BIA methods and HD we found the relationship was significant ($p<0.05$) but the coefficient was only 0.63-0.64. McLean and Skinner (1992) reported $r = 0.63$ in female population when comparing FM measured using the method of near-infrared interactance (Futrex-5000) and HD. Maughan (1993) reported the correlation between BIA and HD $r = 0.83$ and reported that, based on those results, BIA is accepted as a valid indicator that could be used instead of HD. Shakeryan et al. (2013) reported correlation $r = 0.736$ and coefficient of determination $R^2 = 0.722$ between FM detected using HD and BIA analysis (Olympia 3.3 device) in male wrestlers. In our case, correlation was lower (BIA 2000M versus HD: $r = 0.74$, InBody 3.0 versus HD: $r = 0.77$). However, the correlation coefficient does not indicate agreement, but merely the strength of relationship between the two variables, and even data points which are in low agreement can produce significant correlation (Bland and Altman 1986; Williams and Bale 1998). Williams and Bale (1998) reported the correlation $r = 0.86$ between BIA analysis and HD in university female athletes. The authors also present standard error of estimate (2%) for regression equations for estimation of the FM based on BIA and HD (reference method). In *our* case, the values were higher (2.86 for InBody 3.0 and 4.61 for BIA 2000M). Esco et al. (2015) reported significant correlation coefficient ($p<0.01$) between the DEXA and InBody 720 for percentage of BF and FFM (standard error of estimate and total error were lowest for FFM).

In Figure 2, the researchers reported the upper limit of agreement for BIA 2000M to be underestimated by 4.4 percent and the lower limit of agreement to be overestimated by -4.3 percent compared with HD results. Similarly, Figure 3 shows the upper limit of agreement for InBody 3.0 to be underestimated by 3.2 percent and the lower limit of agreement to be overestimated by -6.26 percent. Williams and Bale (1998) reported in bioelectrical device BIA 101 (RJL system) in relation to HD that limit of agreement was underestimated by 3 percent and lower limit was overestimated by -5.8 percent. However, conclusions of the study by Williams and Bale (1998) indicate disagreement is larger for the female sample than the male sample. Esco et al. (2015) reported that the InBody 720 underestimated BF by 3.33 percent and overestimated FFM by 2.12 kg in female athletes (n = 45, out of this sample, 24 were collegiate soccer players), compared with DEXA.

In addition to hydrodensitometry, the researchers also consider DEXA as the reference method. Moon et al. (2009) reported that DEXA overestimated BF by 3.71 percent and provided a wide range of individual error (±6.3%) in a group of female athletes. Each method is influenced by several sources of errors and accuracy of estimation of BC parameters. Hydrodensitometry and DEXA are believed to be the "gold standard" for BC assessment (Kyle et al. 2015).

However, these methods also have their limits and sources of error which are subsequently reflected in results of BC. Ellis (2001) reported 2-3 percent variability of accuracy for absolute FFM for hydrodensitometry, 1-4 percent variability for DEXA and 2-8 percent variability for BIA methods. In the case of estimation of FM, accuracy for absolute mass is influenced by >5 percent for HD, ~5 percent for DEXA and >8 percent for BIA analysis. One of the possible errors is inaccurate determination of residual lung volume (LV) during the measurement under water. Air remaining in the lungs will make the client more buoyant and affect the validity of the measurement (Mala et al. 2014). While HD measures body volume, body density is calculated and error of its determination is dependent on correct determination of residual LV. The greatest error in determination of residual LV accounts for biological variability, technical error, and the effect of learning or fatigue from being under water. Despite the popularity of HD measurement over several years, this two-component model assumes the density of FFM is constant. The assumption constant hydration for BIA methods is 73 percent for FFM (Moon 2013; Sillanpaa et al. 2014), which may lead to the estimation error for the FM and FFM, especially because FFM hydration levels deviate considerably in active individuals (Sillanpaa et al. 2014). As reported by Ackland et al. (2012), this assumption is clearly violated in many groups of athletes. Moreover, it is well known that FFM varies with gender, ethnicity, growth, sexual maturation, physical activity and ageing (Ellis 2000). In athletes, the error of estimation is mostly influenced by biological factors such as hydration status, ratio of protein to mineral, and altered bone mineral density (Fornetti et al. 1999). Therefore, it is necessary to take these facts into account and to interpret results correctly, especially in "lean athletes". Results of the study by Vescovi et al. (2002) showed that HD underestimated the FM by 8 percent in lean female athletes.

Bioelectrical impedance methods are commonly used for their advantages, such as being inexpensive, non-invasive, portable, quick, and safe to operate, and neither requires a high degree of technical skill nor client's discomfort as does HD. Mala et al. (2014) reported that, in the case of proper standardisation of methods, instrumentation, and subject preparation, this non-invasive BC assessment approach can easily and quickly provide accurate and reliable estimates of FFM and TBW in healthy populations. However, in sport populations, results may be influenced by higher inaccuracy. Sillanpaa et al. (2014) report that in highly-active and moderately-active young men BIA significantly overestimated the percent of BF. On the other hand, measurement of BC variables using BIA requires careful preparation and meeting the standardised conditions with an aim to eliminate sources of errors (Kyle et al. 2004). González-Correa and Caicedo-Eraso (2012) reported more than 30 variables or factors which are sources of error in measurement using BIA and which are reflected in the final estimation of BC variables. For instance, the percentage of error in single frequency BIA analyser and multi-frequency analyser should be 10.4 percent (Thomson et al. 2007). Estimated prediction error for FFM in BIA is 5-6 percent (Kyle et al. 2015).

The results also demonstrate highly significant relationship between all of the methods used to measure body fat percentage. According to authors of professional literature, there is no prediction equation for calculation of BF for elite female players (national team level) based on BIA. Fornetti et al. (1999) reported a prediction equation for FFM for female athletes (track and field, tennis, softball, volleyball, basketball, crew, gymnastic, cross-country, field hockey, golf, soccer, swimming and diving) based on BIA as follows:

$$FFM = (0.272^{*}ht) + (0.461^{*}wt) - (0.036^{*}resistance) + (0.101^{*}x_c) - 11.567$$

Where: ht = body height, wt = body weight, x_c = reactance

Overall, based on these results the researchers cannot recommend the bioelectrical devices used (BIA 2000M, InBody 3.0) as valid tools for assessment of BF percentage in female players, without the use of correct prediction equations for the given sporting population. Analysis of variance revealed significant differences between the compared groups, effect size between BIA and HD was >0.87, convergent validity was lower than $r < 0.65$, coefficient of determination was lower than $R^2 < 0.65$ and standard error of estimation was higher than SEM > 2.8.

CONCLUSION

Exact determination of the proportion of FM in athletes is used to optimize body weight and diet regimen. Although BIA analysis and HD methods are not interchangeable in body fat measurement, thanks to correct regression equations and error of estimation it is possible to determine the parameters of BC using BIA in elite female players. BIA could be used in screening, for a large population study, but in the case of measurement for scientific purposes it is necessary to use a more exact reference method, that is, to use particular regression equations for the given population of athletes. Results of the study are only valid for elite female soccer players, which is a specific group.

RECOMMENDATIONS

Along with increasing the number of studies in the field of BC, the researchers' results could be helpful in good practice, interpretation of data, and replicability of measurements. The data can only be interpreted correctly if the clinical staff (athletic trainer, physiologist, nutritionist, physician, fitness coach, research scientist, etc.) is aware of the limits of underestimation and overestimation of the methods used for assessment of BC. Further research should focus on validation of easy, portable, and rapid analysis of BC in specific groups of population – elite athletes of both sexes and also in relation to subject's age and ethnicity.

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