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Research article

How Length Sizes Affect Body Composition Estimation in Adolescent Athletes Using Bioelectrical Impedance

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Abstract

Bioelectrical impedance analysis (BIA) is a common practice to assess body composition in athletes, however, when measuring athletes with specific body geometry, its accuracy may decrease. In this study we examined how length dimensions affect body composition estimation and we compared BIA and dual-energy X-ray absorptiometry (DXA) assessments in three sports. 738 male adolescent athletes (15.8 ± 1.4 years) from three sports (soccer, basketball, and handball) were measured. Body composition was estimated by BIA (InBody 720) and by DXA (Lunar Prodigy). Differences between the two methods were tested by Bland-Altman analysis and by paired t-test. ANOVA was used for intergroup comparisons. Pearson correlation and multivariate linear regression was used to look for the relationship between segmental lean body mass and length dimensions. $BIA_{InBody\ 720}$ consistently underestimated percent body fat (PBF) and overestimated lean body mass (LBM) than DXA. The magnitude of the differences between the two methods varied among the examined sports. Handball (PBF = 8.3 ± 2.4 %; LBM = -5.0 ± 2.1 kg) and basketball players (PBF = 8.8 ± 2.3 %; LBM = -5.3 ± 1.8 kg) had significantly larger differences between the two methods than soccer players (PBF = 6.4 ± 2.2 %; LBM = -3.1 ± 1.4 kg). There was a negative correlation between differences in segmental LBM estimation and length sizes (trunk length, upper extremity length, lower extremity length). The highest correlation was found for lower extremity (r = -0.4). Longer lower extremity resulted in greater difference in LBM estimation. The differences between the sport disciplines are most probably attributed to body height differences. Length dimensions result in overestimation of LBM with BIA, thus body composition assessment with $BIA_{InBody\ 720}$ needs to be carefully interpreted in athletes with extreme length sizes, especially, with basketball players.

Key words: Young athletes, DXA, bioimpedance method, lean mass, body fat.

Introduction

Body composition assessments are regularly performed with athletes. One of the most used methods is bioelectrical impedance analysis (BIA). Dual-energy X-ray absorptiometry (DXA) may also offer body composition assessment; its popularity has increased in recent years and today it has become a widely used method (Slater et al., 2013). DXA provides rapid and non-invasive measurement of whole body and segmental composition. Nevertheless, measurements require expensive equipment and, in some cases, qualified and experienced technicians. For these reasons DXA is impractical for routine measurements in athletic population. In contrary, BIA is a low cost and easy-to-use method with reproducible results (González-Correa, 2018). Due also to its non-invasive nature BIA is often preferred in body composition measurements and practitioners tend to use this method for frequent testing in order to monitor changes in the athletes' body composition during the entire season or to evaluate the efficacy of a specific training or dietary program in body composition (Frisard et al., 2005; Prokop et al., 2016). Both methods have been found to be valid and have showed high reliability in percent body fat (ICC_{DXA} 0.996, ICC_{BIA} 0.983) and fat free mass estimation (ICC_{DXA} 0.994, ICC_{BIA} 0.997) (Schubert et al., 2018). Given that most methods in body composition measurements give indirect assessment, significant differences may exist between different methods (Fogelholm and Lichtenbelt, 1997; Johnson et al., 2012; Kuriyan et al., 2014). Comparisons between BIA and DXA in clinical practice suggest that BIA systematically overestimates lean body mass and underestimates fat mass than DXA (Esco et al., 2015; Gutin et al., 1996; Hurst et al., 2016; Leahy et al., 2012). However, the magnitude of these differences is not consistent. Studies examining underlying factors behind these differences focused mainly on the effects nutritional status has on body composition outcomes performed with BIA or DXA. It was found that higher Body Mass Index (BMI) and mainly larger fat mass result in smaller differences between the two methods (Achamrah et al., 2018; Tompuri et al., 2015; Völgyi et al., 2008). Several studies examined how physical activity levels may affect estimations, nevertheless, findings were inconsistent to draw strong conclusions (Sillanpää et al., 2014; Tompuri et al., 2015; Völgyi et al., 2008). Age, as another factor, seems not to have any effect on the differences between the two methods (Sillanpää et al., 2014).

Differences in body composition estimates may exist also between devices based on the same technology, but from different manufacturers. Sheperd et al. (2012) compared assessments from two DXA scanner manufacturers (Lunar Prodigy vs. Hologic) and they found significant differences in percent body fat (mean difference 2%). Demura et al. (2004) conducted a similar study with Bioimpedance analyzers using single- and multifrequency and compared the results to DXA. Differences between BIA analyzers were significant (Demura et al., 2004). The existing body of evidence therefore suggests that body composition assessments are method- and device specific and this should be considered when evaluating the results.

BIA assessment is based on measurement of the impedance to the electrical current sent through the body. Then, impedance is used indirectly to estimate lean body mass and fat mass (Kushner, 1992). Impedance depends on the length and the diameter of the conductor, and the

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specific resistance of the tissue. Thus, length dimensions have a direct effect on impedance measurement and consequently on body composition estimation. Length dimensions are an important characteristic in athletes, who generally demonstrate larger body height compared to the general population (Popovic et al., 2013) and extreme whole body or segmental length sizes can be usual and even desirable in many sports. Therefore, the primary purpose of this study was to examine how length dimensions affect body composition estimation. A secondary purpose was to examine the differences in body composition estimation between BIA and DXA measurements in young male athletes.

Methods

Participants

738 male adolescent athletes were measured (age range: 12-18 years), who participated in three sports (soccer, basketball, handball). Athletes were registered players of Hungarian sport clubs or sport academies. Athletes arrived at the laboratory between 8.00 and 9.00 am. First, they took part in anthropometric measurements. Then, their body composition was assessed by bioelectrical impedance analysis (BIA) and within two hours by a dual-energy X-ray absorptiometry (DXA). The main characteristics of the athletes are shown in Table 1. The study was approved by the University's Ethics Committee and the parents/guardians signed a declaration of consent.

Anthropometry

42 body sizes were recorded and performed according to the recommendations of the International Biological Program by the Martin method (Martin and Saller, 1957; Weiner and Lourie, 1969). In this study body height (cm), sitting height (cm), hip height (cm) and upper extremity length (cm) were included in the analysis. Upper extremity length (cm) was calculated indirectly (shoulder height (cm) – finger height (cm)). Hip height was considered as lower extremity length and sitting height as a measure of trunk length. Longitudinal dimensions were determined using an anthropometer (DKSH Switzerland Ltd, Zurich, Switzerland).

Bioelectrical impedance analysis

12 hours before the test the athletes were asked to refrain from any exercise or food consumption. For BIA assessment InBody 720 (Biospace Co., Seoul, Korea) was used. Skin resistance was measured through an eight-point tactile-electrode at different frequencies (1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz, 1 MHz). Lean body mass and fat mass were determined from the impedance values using the manufacturer's regression equations, based on the principle that different tissues have different water content and thus different electrical conductivity (Kushner, 1992). The eight-point tactile-electrode allows the analysis of lean mass of each body segment (trunk, right and left limbs) (Bedogi et al., 2002). Components used in further analysis were lean body mass (LBM), fat mass (BF) and percent body fat (PBF) as well as segmental lean mass (LBM_{ARM}, LBM_{TRUNK}, LBM_{LEG}).

Dual-Energy X-ray Absorptiometry

A Lunar Prodigy DXA scanner was used (General Electric, Madison, USA) as a reference method. This is the lowest radiation exposure method of imaging techniques (Lin, 2010). During the procedure, an X-ray tube with a special filter emitted a high and a low energy beam onto the surface of the body, while measuring the degree of absorption of the rays. The device determines the amount of bone and soft tissue components by differentiating between bone and non-bone area units (Toombs et al., 2012). The exact mass of the 3 body components based on the degree of absorption was calculated for bone mineral, fat mass and lean body mass. Mass values were given not only for the whole body but also for the five segments of the body (right arm, left arm, trunk, right leg, left leg).

Statistical analysis

Differences between the methods were analyzed by Bland-Altman analysis (Bland and Altman, 1986) and by paired t-test (with Cohen's d effect sizes (ES)). Regression and validity statistics were conducted (r, R^2, intercept, slope, standard error of estimates (SEE), total error (TE)). The magnitude of differences between BIA and DXA estimations across the three sports were examined with one-way ANOVA (Scheffe's post hoc test). The relationship between length sizes and segmental lean mass differences was investigated by Pearson's correlation and multivariate linear regression. The following assumptions were checked: linearity between dependent and each of the independent variables, normality (with Box-Cox transformation where normality was violated), homoscedasticity and multicollinearity. Level of significance was determined at $p < 0.05$.

Results

$BIA_{InBody\ 720}$ estimated significantly lower BF and PBF and significantly higher LBM than DXA for all three groups. The magnitude of these differences varied between the sports (Figure 1).

Table 1. Characteristics of the athletes (mean±SD).

	All	Soccer	Handball	Basketball
N	738	490	99	149
Age (years)	15.8±1.4	16.0±1.3	15.4±0.9	15.3±1.7
Body height (cm)	178.5±9.3	175.8±7.6	182.8±7.1	184.5±11.7
Body mass (kg)	67.2±11.7	64.7±9.2	74.7±12.5	70.4±15.2
Body Mass Index (kg/m²)	21.0±2.4	20.9±2.0	22.3±3.2	20.5±2.8
Training age (years)	9.3±2.7	9.9±2.4	6.1±2.1	8.5±2.8
Training time (hours/week)	9.7±2.7	9.7±2.5	9.0±3.2	12.2±3.4

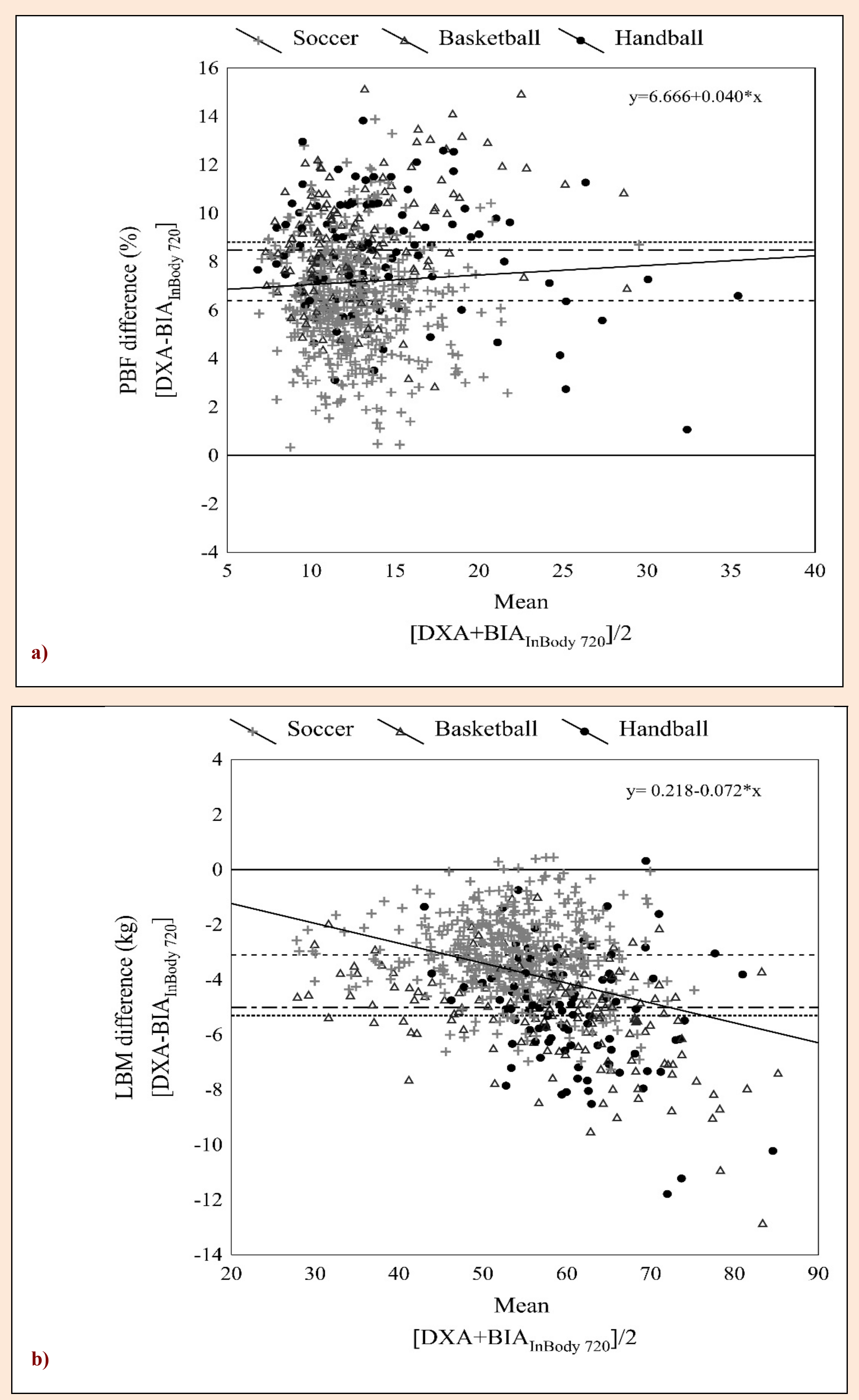

Figure 1. Differences between DXA and BIA with Bland-Altman analysis in a) Percent Body Fat, b) Lean Body Mass. dotted line: mean of soccer players; twodash line: mean of handball players; dashed line: mean of basketball players.

Basketball players produced the largest differences; with $BIA_{InBody\ 720}$ underestimating PBF by 8.8% and overestimating LBM by 5.3 kg. Compared to basketball and handball players, the differences between the two methods were significantly smaller for soccer players, where BIA estimated lower PBF by 6.4% and higher LBM by 3.1 kg

(Tables 2 and 3).

Significant differences were found in somatotype, especially in length sizes, and in body composition between sports. Soccer players demonstrated significantly smaller length dimensions than basketball players and handball players. Body height was similar for handball and basketball players, however, there was a difference in the length of the lower limbs, basketball players had significantly longer lower limbs than handball and soccer players. Additionally, handball players had significantly higher PBF and soccer players had significantly lower LBM compared to athletes of the other two sports (Table 4).

The relationship between the length of each segment (trunk length, upper extremity length, lower extremity length) and the difference in lean mass estimates of that segment (LBM_{TRUNK}, LBM_{ARM}, LBM_{LEG}) was analyzed. Correlation analysis revealed a negative correlation in all cases. This relationship was the largest for the lower extremity ($r = 0.4$; $p < 0.05$). Longer lower extremity resulted in greater lean mass differences (Figure 2). Multivariate linear regression results showed that the length of the trunk, upper extremity, and lower extremity together accounted for the 27% of the total variance of the differences between the two methods. The effects of all independent variables were significant with the lower limb length having the largest effect (Table 5). Athletes, with a lower extremity length of more than 110 cm [corresponding to the 97th percentile of Hungarian 18-year-old boys (Bodzsár and Zsákai, 2012)] had significantly larger differences in lean body mass estimation.

Table 2. Descriptive statistics of body composition by $BIA_{InBody\ 720}$ and DXA.

		$BIA_{InBody\ 720}$ (mean±SD)	DXA (mean±SD)	Effect size (Cohen's *d*)
Soccer	BF (kg)	6.1±2.4*	10.3±2.5	3.1
	PBF (%)	9.3±3.0*	15.7±2.9	2.9
	LBM (kg)	55.5±7.6*	52.4±7.4	2.3
Basketball	BF (kg)	6.1±3.5*	12.3±4.3	3.6
	PBF (%)	8.6±3.7*	17.4±4.3	3.8
	LBM (kg)	60.8±12.8*	55.5±12.0	2.9
Handball	BF (kg)	8.2±6.3*	14.6±6.4	3.2
	PBF (%)	10.4±5.9*	18.7±5.4	3.5
	LBM (kg)	62.8±8.0*	57.8±7.4	2.4

BF: body fat, PBF: percent body fat, LBM: lean body mass. BIA: bioelectrical impedance analysis, DXA: dual-energy X-ray absorptiometry. *significant difference between DXA and BIA, $p < 0.001$.

Table 3. Regression results and mean differences in body composition estimation between $BIA_{InBody\ 720}$ and DXA.

								Limits of agreement		
		r	R^2	b	Slope	SEE	TE	CE±1.96 SD	Upper	Lower
Soccer	BF (kg)	0.84	0.71	4.92	0.88	1.45	2.05	4.2±2.7	6.9	1.5
	PBF (%)	0.72	0.52	9.20	0.70	2.98	2.54	6.4±4.3	10.7	2.1
	LBM (kg)	0.98	0.97	-0.95	0.96	0.47	1.76	-3.1±2.7	-0.4	-5.8
Basketball	BF (kg)	0.92	0.85	5.38	1.12	1.32	3.87	6.2±3.4†	9.6	2.8
	PBF (%)	0.84	0.72	8.84	1.00	2.38	4.75	8.8±4.5†	13.3	4.3
	LBM (kg)	0.99	0.98	-0.87	0.93	0.51	3.33	-5.3±3.6†	-1.7	-8.9
Handball	BF (kg)	0.95	0.90	6.56	0.97	1.23	2.51	6.3±3.9†	10.2	2.4
	PBF (%)	0.91	0.83	10.02	0.84	1.94	2.89	8.3±4.7†	13.0	3.6
	LBM (kg)	0.96	0.93	2.10	0.89	1.08	2.24	-5.0±4.1†	-0.9	-9.1

BF: body fat, PBF: percent body fat, LBM: lean body mass. b: intercept, SEE: Standard error of the estimate, TE: Total error, CE: Constant error. † Significant difference from soccer players, $p < 0.05$.

Table 4. Length dimensions and body composition of the athletes (mean±SD)

	Soccer	Handball	Basketball
Body height (cm)	175.8±7.6	182.8±7.1†	184.5±11.7†
Trunk length (cm)	92.4±4.3	94.6±3.5†	94.7±6.3†
Upper extremity length (cm)	75.7±3.9	79.8±3.5†	80.7±5.7†
Lower extremity length (cm)	98.6±4.9	104.0±5.1†‡	105.7±7.3†
L/Ht	0.561±0.013	0.569±0.011†‡	0.573±0.012†
Mean BF (kg)	8.2±2.4	11.4±6.3†‡	9.2±3.9†
Mean PBF (%)	12.5±2.7	14.6±5.5†‡	13.0±3.9
Mean LBM (kg)	53.9±7.5	60.3±7.6†	58.2±12.4†

L/Ht: lower extremity length/body height. BF: body fat, PBF: percent body fat, LBM: lean body mass. † Significant difference from soccer players, $p < 0.05$. ‡ Significant difference from basketball players, $p < 0.05$.

Discussion

The purpose of this study was to examine differences in body composition outcomes between a commonly used bioimpedance analyzer ($BIA_{InBody\ 720}$) and DXA in adolescent male athletes of different body dimensions. This is important in order to understand the accuracy of $BIA_{InBody\ 720}$ assessments in an athletic population with specific

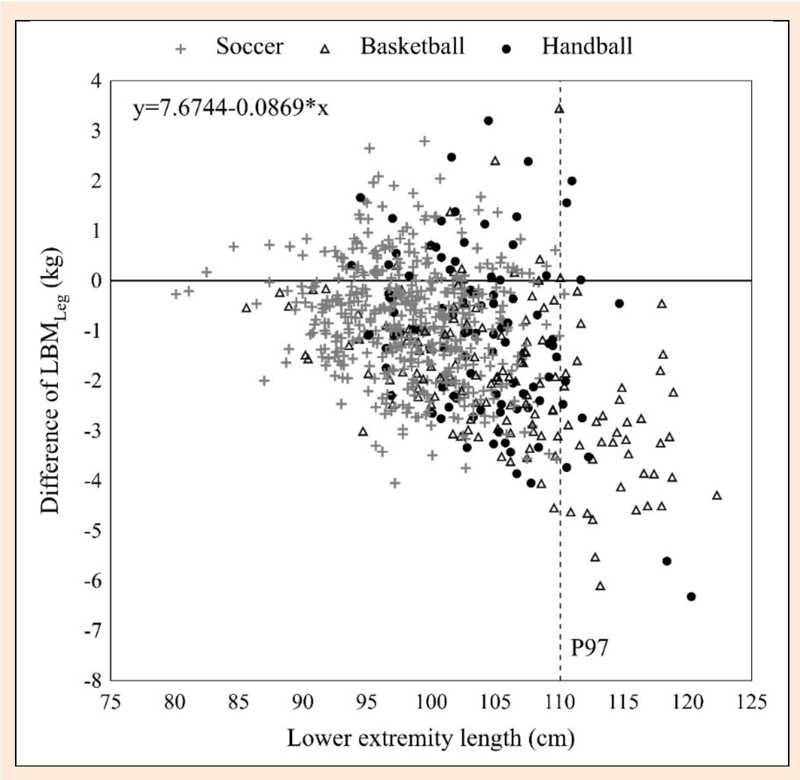

Figure 2. **Relationship between lower extremity length and the difference in lower extremity Lean Body Mass outcome between DXA and BIA. P97: 97th percentile.**

Table 5. **Multiple linear regression results for the differences in LBM estimation between BIA$_{InBody\ 720}$ and DXA.**

R = 0.52; R^2 = 0.27; SE of estimate = 12.52; p < 0.001				
	b	**SE of b**	***t*(734)**	**p**
Intercept	138.3	9.1	15.2	<0.001
Trunk length (cm)	$-4.4*10^{-8}$	$1.6*10^{-8}$	-2.7	<0.01
Upper extremity length (cm)	1.4	0.26	5.4	<0.001
Lower extremity length (cm)	-1.9	0.18	-10.7	<0.001

LBM: Lean Body Mass

anthropometric characteristics. Body composition estimates may be influenced by several factors (e.g. manufacturer, single or multifrequency impedance, regression equations), therefore it should be noted, that the results of this study refer only to the outcomes of InBody 720 analyzer. The main finding was that segmental length dimensions affect body composition estimations resulting in larger differences between the two methods.

In line with previous research examining full body measures (Esco et al., 2015; Gutin et al., 1996; Hurst et al., 2016; Leahy et al., 2012; Tompuri et al., 2015; Völgyi et al., 2008), BIA$_{InBody\ 720}$ underestimated fat mass and percent body fat and overestimated lean body mass compared to DXA. In earlier studies BMI, age, or physical activity level were examined as possible factors behind differences between BIA and DXA. It seems, that in certain BMI categories (16≤BMI<18.5 and BMI≥40) estimate differences in BF decrease (Achamrah et al., 2018). In obese subjects, differences of percent body fat decreased to 1.6% from 5.8% in normal-weight subjects. Furthermore, increase in BMI results also in a decrease in LBM difference. Völgyi et al. (2008) reported mean LBM differences between BIA and DXA of 3.2 kg in normal-weight subjects, and of 1.5 kg in obese subjects, suggesting a better agreement between the two methods with the increase in BMI. In contrary to BMI, age or physical activity level seem not to affect differences between BIA and DXA assessments (Sillanpää et al., 2014). In the latter study, 18 to 88 years old males and females were divided in 10-year intervals; differences between BIA and DXA were similar across the entire age range.

BMI values in our sample were typically within normal range with mean percent body fat between 10-16%. It is less likely therefore, that BMI and fat mass values in this study would affect body composition estimates. On the other hand, athletes mainly from handball and basketball quite often have extreme length dimensions, since such anthropometric attributes are preferred already in young age during talent identification and athletes' selection (Gall et al., 2010; Mohamed et al., 2009; Torres-Unda et al., 2013). Both Bland-Altman analysis and regression results suggest that segmental length dimensions affect body composition estimates, accounting for 27% of the total variance between BIA$_{InBody\ 720}$ and DXA differences. Higher body height and longer appendicular length result in larger differences between the two methods. Body height is unlikely to have any effect in DXA measurements, thus larger differences in LBM are most probably attributed to an overestimation of LBM with $BIA_{InBody\ 720}$.

$BIA_{InBody\ 720}$ used in this study divides the body into five cylinders (trunk, right/left arm and right/left leg) and estimates body composition based on the volume of total body water according to the equation ($V = L^2/Z$, where V: total body water (TBW), L: length of the cylinder, Z: impedance). From total body water LBM is estimated assuming a constant water concentration in lean mass according to the formula $LBM = 0.73 \times TBW$ (Kushner, 1992; Kyle et al., 2004). Increase of TBW leads to an increase in LBM estimation and vice-versa. Length dimensions raised to the second power in the numerator exponentially increase TBW. So even a small increase in length dimensions can significantly increase TBW and consequently LBM estimation. This was the case for the three groups in our study. Soccer players, usually not differing significantly from the general population in body dimensions (Gontarev et al., 2016), compared to handball and basketball players were shorter and had significantly smaller difference in body composition outcomes between $BIA_{InBody\ 720}$ and DXA (PBF = 6.4%, LBM = -3.2 kg). In contrary, handball and basketball players exhibiting usually significantly higher body height than the general population (Popovic et al., 2013), had larger differences between $BIA_{InBody\ 720}$ and DXA assessments.

Additionally, handball and basketball players in our sample, differed not only in body height, but also in their segmental length proportions (lower limbs to body height and lower limbs to trunk), which is also an important aspect in BIA assessments. In the equations used by the manufacturer in estimating lean body mass, instead of segmental lengths $BIA_{InBody\ 720}$ takes into account measured body height and assumes a constant ratio between segmental lengths and body height according to: $\alpha = L/Ht$, where α is the constant ratio typical to a specific population, L is segmental length and Ht is body height (Zafiropoulos, 2015). This constant is included in TBW estimation. However, when body proportions differ from the constant ratio, TBW and in turn LBM estimation are affected. Based on the results, among segmental lengths lower limbs length had the strongest effect on segmental LBM estimation. These body proportions are reflected in the ratio of lower limbs to body height. Mean value of this ratio for 18 years old boys in Hungary is 0.562 (Bodzsár and Zsákai, 2012). As already mentioned, soccer players' body dimensions do not differ from that of the general population, handball and basketball players on the other hand usually do not follow standard body geometry. They had proportionally longer lower limbs in relation to their body height compared to normative data from the Hungarian population (Table 4). In this case, in the five-cylinder based model assumed and actual length dimensions are different, which lead to an increase in TBW and consequently in LBM. In our sample, basketball players had the largest lower limbs to body height ratio and the largest difference in PBF and LBM estimate (PBF = 8.8%, LBM = -5.3 kg). This emphasizes once more the sensitivity of segmental LBM estimations to lower limbs length. The effects of length dimensions become more profound above the 95^{th} percentile in body height according to normative data from the general population (Bodzsár and Zsákai, 2012).

Conclusion

Assessment and evaluation of body composition is an important part in athletes' training and preparation. However, since most common measurements give indirect assessments of body composition, when evaluating the results all factors that may affect the estimations should be taken into consideration. Findings in this study suggest that the accuracy of Bioimpedance Analysis, as measured with InBody 720 analyzer, may decrease in athletes with higher body height and body proportions different than that of the general population (mainly longer lower limbs). Length dimensions affect body composition estimations by overestimating lean body mass. This is a critical aspect to be considered, especially when measuring basketball players who quite often have extreme length sizes and also highlights the need to develop equations specific to a population with such characteristics.

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Key points

- We examined the relationship between lengths sizes and body composition estimation.
- Length sizes are an important characteristic in athletic population.
- Longer length sizes and especially longer lower limbs result in overestimation of lean body mass with BIA.
- The accuracy of BIA measurements may decrease in athletes with length dimensions and body proportions significantly different than that of the general population.

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