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Agreement between bioimpedance analysis and ultrasound scanning in body composition assessment

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Abstract

Objectives: This study aimed at evaluating the agreement between bioelectrical impedance analysis (BIA) using ABC-02 Medas and A-mode ultrasound (AUS) using BodyMetrix™ BX2000 for fat mass (FM), fat free mass (FFM), and body fat percentage (%BF) in females.

Methods: The cross-sectional, single-center, observational study was performed in 206 female subjects aged 18–67 years. The examination program included measurements of body height and weight along with waist, hip circumferences, and body composition analysis. The measurements were performed by ultrasound scanner and bioimpedance analyzer.

Results: We found that 20.9% of women were obese based on BMI (≥30 kg/m^2), which was significantly lower when using a criterion based on body fat percentage (%BF ≥ 30%) measured with US (53.4%, $p = .0056$) or BIA (54.8%, $p = .0051$). At the group level, both methods were found interchangeable and showed practically negligible differences (0.1% for %BF, 0.5 kg for FM, and 0.4 kg for FFM). Agreement analysis conducted in the whole sample revealed a low level of agreement in estimating %BF ($CCC = {}_{0.72}\,0.77\,{}_{0.82}$) and FFM ($CCC = {}_{0.81}\,0.84\,{}_{0.86}$), and medium level of agreement in estimating FM ($CCC = {}_{0.91}\,0.93\,{}_{0.94}$). The level of agreement in estimating %BF and FFM was improved to the medium level with the use of newly generated prediction equations.

Conclusion: Thus, the proposed equations can be used for conversion of body composition results obtained by AUS into the BIA data.

1 | INTRODUCTION

Body composition analysis is a routine practice in the medical science and used in muscle mass evaluation in the groups of elderly or critically ill subjects and also in the risk assessment of the obesity-related diseases and sarcopenia (Heymsfield et al., 2005). It is also widely used in the epidemiological studies of obesity prevalence, or in the field of the biological anthropology (Kasper et al., 2021; Price & Earthman, 2019). Quantitative analysis of body composition is commonly used in sports including selection procedures of athletes onto championship, monitoring of fitness level, as well as training efficiency. Estimation of body fat and fat free mass are great relevance to efficiency in some kind of sports (gravitational sports, sports with weights categories, gymnastics, and figure skating) where it depends on athletes' body weight and low body fat percentage (Ackland et al., 2012). It is possible to distinguish extremely powerful and accurate reference methods (underwater weighing, air replacement plethysmography, neutron activation analysis, dual energy x-ray densitometry, and computed tomography methods) and indirect or field methods (caliper testing, bioimpedancemetry, ultrasonic scanning, calculation by analytical formulas from simple anthropometric traits) (Heymsfield et al., 2005; Tinsley, 2021). Indirect methods are less accurate but more widespread. This is because they are less time-consuming, cheaper, transportable, have no harmful effects, and have no age limits (Johnson et al., 2017; Pérez-Chirinos Buxadé et al., 2018).

Large databases of bioimpedance analysis results obtained by various analyzers are accumulated in Russia and other countries (Franssen et al., 2014; Pedrera-Zamorano et al., 2015; Soboleva et al., 2014). Since various manufactures produce bioimpedance analyzers, direct comparison of data obtained in different studies is difficult. In the large-scale study conducted recently, where body composition was analyzed in the Russian population, researchers used ABC Medas bioimpedance analyzer manufactured in Russia (Rudnev et al., 2022). Devices for bioimpedancemetry produced in Russia are widely used in other countries (Azerbaijan, Kyrgyzstan, Armenia, Belarus, Kazakhstan, etc.) for medical diagnostics in dietology, endocrinology and surgery, as well as for assessing dynamic changes in the training cycle of athletes. Body composition parameters are derived from population-specific, built-in validated regression formulae including impedance, sex, age, weight, and height. These formulae are constructed by fitting the regression model to a reference method using body composition data from a certain population of specific ethnicity, age, nutritional status and physical activity characteristics (Sergi et al., 2017). In this regard, it is preferable to use equipment whose software takes into account the specific features of a given population. Up to date only one study aimed to assess agreement between body composition estimates obtained by ABC Medas and Tanita analyzers (Rudnev et al., 2020). Several conditions must be met during the bioimpedance analysis procedure, such as absence of a pacemaker and/or metal implants, fasting examination, no physical activity 24 h prior to and immediately before the examination, a ban on drinking alcohol the day before. Moreover, certain conditions that lead to changes in tissue hydration, that is, diseases, certain medications, drinking regimen, may also distort the results (Dehghan & Merchant, 2008). These conditions in some cases impose restrictions on the use bioimpedancemetry. Direct comparison of body composition estimates by bioimpedance analyzers produced by different manufactures is difficult because the equations are not always given by manufactures in open sources or in the manuals (Rudnev et al., 2020). On one hand, it limits the use of bioimpedance analysis in epidemiological and clinical trials studies; on the other hand, it makes data standardization and comparison difficult. ABC Medas equipment is overwhelmingly used in healthcare centers and research institutions (Rudnev & Godina, 2022). However, limitations of BIA (the presence of metal implants and/or a pacemaker, taking certain medications, changes in tissue hydration, examination in the supine position) do not allow using ABC Medas equipment during field screening research studies and examination of population living in remote areas. Using of noninvasive, accurate and chip evaluation method which can be used together or instead of BIA and does not have BIA's limitations is of current interest. To our opinion, ultrasound scanning is that method which is commonly used everywhere except Russian Federation and other members of the Commonwealth of Independent States (CIS).

From the end of the 20th century, A-mode ultrasound (AUS) has been used as a quantitative method for body composition analysis (Wagner, 2013). AUS has several advantages besides common use and low cost. It can be used both in hospital settings and in field studies. AUS scanner able to collect data of skinfold thickness, so it can replace calipers. Moreover, AUS allows using various protocols of measurements along with equations. All of the above makes ultrasound scanning a promising method of measuring body fat mass and fat free mass content in the field of anthropology, medical science, as well as in nutritional and sport science. AUS procedure lacks limitations that BIA has. Unlike the caliper testing, during the ultrasound scanning procedure the skinfold thickness is recorded in the normal state (not in the folded) that allows more accurate determination of the border between subcutaneous fat and muscle and thus, individual characteristics of subjects does not affect the measurements; hence, accuracy and reliability of the estimates are improved (Wagner & Teramoto, 2020). AUS scanner BodyMetrix™ (IntelaMetrix, USA) is a commonly used equipment for body composition analysis. BodyMetrix™ software allows conducting examinations in the group of patients aged 6 years and older (Wagner, 2013). Eleven equations can be used in predicting body composition depending on the number of sites where the skinfold thickness is measured. BodyMetrix™ has been used recently for the first time to assess body composition in the Russian population (Bondareva & Parfenteva, 2021).

The present study aimed to assess agreement of measurement of body fat percentage, fat mass and fat free mass obtained by locally manufactured bioimpedance analyzer ABC-02 Medas and A-mode ultrasound scanner BodyMetrix™ in a group of female participants.

2 | MATERIALS AND METHODS

2.1 | Ethical approval

All volunteers who participated in the study were aware of the objectives and methods of the study and gave their informed consent. The Ethics committee of the Lopukhin Federal Research and Clinical Center of Physical-Chemical Medicine of Federal Medical Biological Agency approved the study design and data analysis procedures (No. 2022/12/06 dated December 06, 2022).

2.2 | Sample characteristics

In 2022–2023, at the Lopukhin Federal Research and Clinical Center of Physical-Chemical Medicine of Federal Medical Biological Agency and Endocrinology Research Centre the cross-sectional, observational, anthropometric study was performed where 206 female subjects 18–67 years of age were recruited.

The examination program included measurements of body height (KAFA tools, Russia) and weight (Seca, Germany), waist and hip circumferences by measuring tape, body composition by ultrasound scanner BodyMetrix™ BX2000 and bioimpedance analyzer ABC-02 Medas (Figure 1). During the survey, subjects were asked about their ethnicity, athletic status and their physical activity (its regularity and intensity). Subjects who were professional athletes or exercised more than 3 times per week were excluded from the dataset. Nutritional status was defined by BMI: underweight (BMI < 18.5 kg/m^2), normal weight (BMI ≥ 18.5 and ≤ 24.9 kg/m^2), overweight (BMI ≥ 25.0 and ≤ 29.9 kg/m^2), and obese (BMI ≥ 30.0 kg/m^2). Moreover, obesity was defined if body fat percentage obtained by ultrasound scanner and BIA was equal to or higher than 30%—the recommended one for all ages' threshold value (De Lorenzo et al., 2006).

2.3 | Body composition analysis using the A-mode ultrasound scanner BodyMetrix™

During the scanning procedure, the torso- and the limb-located skinfold thickness was measured (Baranauskas et al., 2017) at sites corresponding to the traditionally measured ones. Measurement was repeated up to 5 times at each site; the mean value was calculated. Ultrasound viscous gel "Mediagel" (Gelteck-Medica, Russia) was used as a coupling medium. All measurements were done at the right side of the body. Quantitative assessment of body composition was done according to 7-sites Jackson-Pollock equation (Jackson et al., 1980). All calculations were performed using BodyViewProFit software (IntelaMetrix, Inc., Livermore, CA). Body fat mass and fat-free mass were calculated from the body fat percentage computed by BodyViewProFit and the subject's body mass.

2.4 | Body composition analysis using bioimpedance analyzer (ABC-02 Medas SRC Medas, Russia)

Bioimpedance (BIA) was measured at 50 kHz frequency according to common tetrapolar scheme "wrist-ankle." Electrodes (F3001 FIAB, Italy) were placed on the right side of the body when the subject was at the supine position (Rudnev et al., 2020). Throughout the period of data collection, the same examiner performed the measurements. The time between ultrasound scanning and impedance measurement did not exceed 15 min. At the

FIGURE 1 ABC-02 Medas (A) and BodyMetrix™ BX2000 (B).

beginning of examination day and before the first impedance measurements, the resistance (R_c) and reactance (X_c) were calibrated by a special calibrator with which all analyzers ABC-02 Medas are equipped. The resistance (R_c) and reactance (X_c) values did not vary by more than 1%. The absolute content of body fat mass and fat free mass as well as body fat percentage were calculated using ABC01-0362 software.

2.5 | Statistical analysis

When analyzing the agreement of paired measurements, we were guided by international standards (CLSI EP09-A3) and the Guidelines for Reporting Reliability and Agreement Studies (GRRAS) (Kottner et al., 2011). Parameters of location, variation, and type of distribution were estimated using PAST software (https://www.nhm.uio.no/english/research/resources/past/). Multiple pairwise comparison was performed by ESTIMATION STATISTICS software (https://www.estimationstats.com/#/analyze/paired). The following tests were used to check if the data distribution was equal to normal: Shapiro–Wilks, Anderson–Darling, Lilliefors, Jarque-Bera. In the calculation procedures of all the criteria, with the exception of Shapiro–Wilk, the Monte Carlo algorithm was implemented. Since the distribution of the body composition estimates was non-normal, the paired difference Wilcoxon test was used to assess the difference between body fat percentage (%BF), fat mass (FM, kg), and fat free mass (FFM, kg) obtained by BIA and AUS. Effect size was calculated according to Hedges' *g* formula for paired samples. Effect size is recommended in the different practical guides (Grissom & Kim, 2005), it helps understand the magnitude of differences found, whereas statistical significance examines whether the findings are likely to be due to chance. Spearman's correlation coefficients were calculated to assess association. Data visualization using Gardner–Altman plots was performed for paired mean difference; Bland–Altman plots (https://huygens.science.uva.nl/BA-plotteR/) and robust non-parametrical Passing–Bablok regression (Passing–Bablok Regression and CUSUM Test) were performed to visualize agreement. Lin's concordance correlation coefficient (*CCC*) was calculated to quantify agreement. We used the following verbal scale for assessing *CCC*: <0.90 poor, 0.90–0.95 moderate, 0.95–0.99 substantial (high), >0.99 almost perfect (Akoglu, 2018). The Bonferroni correction was used as a correction for multiple comparisons.

3 | RESULTS

1. Anthropometric characteristics of the sample

The sample included subjects with various nutritional status determined by BMI: 12 (5.8%) underweight; 115 (55.8%) normal weight; 36 (17.5%) overweight; 43 (20.8%) obese subjects, 19 of which had BMI ≥ 35 kg/m^2. The initial characteristics of the samples are shown in Table 1. Spearman correlation coefficient between body fat percentage, fat and fat-free mass obtained by BIA and AUS were $\text{rho}_{BF} = {}_{0.78}\ 0.83\ {}_{0.87}$, $\text{rho}_{FM} = {}_{0.96}\ 0.97\ {}_{0.98}$, and $\text{rho}_{FFM} = {}_{0.91}\ 0.93\ {}_{0.95}$ ($p < .0001$). Here and

TABLE 1 Sample characteristics.

	Location parameters		Variation		
Feature	*M*	*Me*	*Min*	*Max*	*SD*
Age, years	$_{32}$ 35.4 $_{37}$	$_{34}$ 35 $_{36}$	18	67	$_{11.6}$ 12.7 $_{13.8}$
Body height, cm	$_{166}$ 167 $_{169}$	$_{164}$ 165 $_{167}$	153	194	$_{8.1}$ 9.3 $_{10.3}$
Body weight, kg	$_{65}$ 71.6 $_{80.4}$	$_{64}$ 66.7 $_{70}$	42	142	$_{12.0}$ 14.1 $_{16.2}$
Body fat percentage US	$_{29}$ 30 $_{31}$	$_{28}$ 30 $_{32}$	15	45.3	$_{5.4}$ 6.4 $_{7.8}$
Body fat percentage BIA	$_{31}$ 32 $_{33}$	$_{28}$ 31 $_{32}$	13	57	$_{7.1}$ 8.3 $_{9.4}$
Fat mass US, kg	$_{21}$ 23 $_{24}$	$_{18}$ 20 $_{22}$	8	64	$_{8.7}$ 10.9 $_{11.6}$
Fat mass BIA, kg	$_{22}$ 24 $_{26}$	$_{19}$ 21 $_{23}$	6	81	$_{13.1}$ 14.5 $_{16.2}$
Fat free mass US, kg	$_{45}$ 48 $_{48}$	$_{44}$ 46 $_{47}$	32	85	$_{8.8}$ 10.0 $_{11.9}$
Fat free mass BIA, kg	$_{46}$ 47 $_{48}$	$_{44}$ 45 $_{46}$	34	70	$_{6.0}$ 6.5 $_{7.1}$
Waist circumference, cm	$_{76}$ 79 $_{81}$	$_{73}$ 75 $_{76}$	55	144	$_{13.4}$ 16.8 $_{18.0}$
Hip circumference, cm	$_{98}$ 101 $_{102}$	$_{97}$ 99 $_{101}$	79	148	$_{10.9}$ 11.4 $_{13.9}$
BMI, kg/m^2	$_{24}$ 26 $_{27}$	$_{23}$ 23 $_{24}$	16	58	$_{6.0}$ 7.5 $_{8.6}$

Note: 95% CI are given as subscripts.
Abbreviations: BIA, ABC-02 Medas; *M*, mean; Me, median; SD, standard deviation; US, BodyMetrix™.

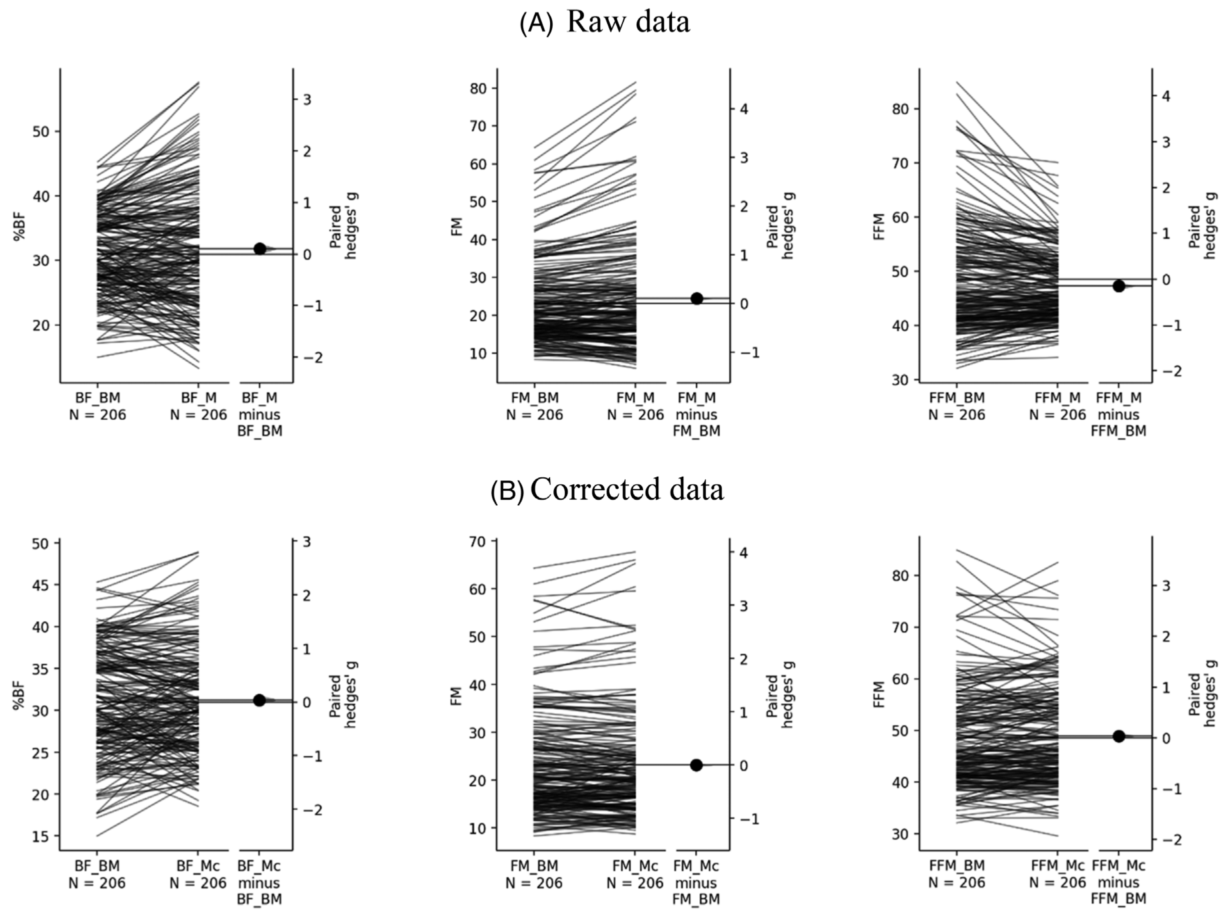

FIGURE 2 Gardner–Altman plot for %BF, FM, and FFM in the studied sample. Individual values and effect size. BM, BodyMetrix™ BX2000; M, ABC-02 "Medas."

below, 95% confidence intervals are shown in subscript as recommended (Louis & Zeger, 2009). At the group level, no significant differences were found between two methods in estimating body fat mass ($p = .48$), fat free mass ($p = .26$), and body fat percentage ($p = .72$). At the group level, effect size was close to zero (Figure 2), that is, no mean differences ($g_{BF} = {}_{-0.1}\ 0.0\ {}_{0.1}$, $g_{FM} = {}_{0.06}\ 0.1\ {}_{0.14}$, and $g_{FFM} = {}_{-0.22}\ -0.15\ {}_{-0.08}$).

As mentioned above, one out of five participants (20.9%) had obesity according to BMI. The assessment of obesity by %BF ≥ 30% using the BIA and AUS showed similar estimates (53.4 and 54.8, respectively), which was significantly higher than the assessment based on BMI ($p = .0056$).

2. Agreement analysis between ABC-02 Medas and BodyMetrix™ used to estimate fat mass, fat free mass and body fat percentage. Development of new prediction equations

At the group level, Bland–Altman analysis revealed small systematic bias by ${}_{0.0}\ 0.1\ {}_{0.19}$% in body fat percentage, ${}_{-0.8}\ -0.5\ {}_{0.2}$ kg in fat mass and ${}_{-0.3}\ 0.4\ {}_{0.8}$ kg in fat free mass estimating that confirm an insignificant effect size. Limits of agreement calculated for fat mass, fat free mass and body fat percentage were wide, (near 14 kg for FM and FFM and 17% for %BF) (Table 2). However, Bland–Altman analysis revealed that at the low body fat mass values, ultrasound scanning overestimated it compared to bioimpedance analysis. For fat free mass estimates in the range of low values, BIA overestimates this parameter compared to AUS (Figure 3).

Agreement analysis conducted in the whole studied sample revealed a poor agreement in individual level estimating body fat percentage ($CCC = {}_{0.72}\ 0.77\ {}_{0.82}$) and fat free mass ($CCC = {}_{0.81}\ 0.84\ {}_{0.86}$). For fat mass estimates agreement can be described as moderate ($CCC = {}_{0.91}\ 0.93\ {}_{0.94}$) (Akoglu, 2018).

Since a low level of agreement between AUS and BIA did not allow direct comparison of these two techniques in body composition evaluation at the individual level, new regression equations for predicting body composition from AUS and BIA (Figure 4) were developed. Original regression coefficients were used to correct BIA's body composition estimates: BF_BIAc = (BF_BIA + 13.8)/1.46, FM_BIAc = (FM_BIA + 5.13)/1.28, and

TABLE 2 Agreement analysis in raw and corrected data.

Parameter	BF, %	FM, kg	FFM, kg
Raw data			
CCC	$_{0.72}\ 0.77\ _{0.82}$	$_{0.91}\ 0.93\ _{0.94}$	$_{0.81}\ 0.84\ _{0.86}$
Bias	$_{0.0}\ 0.1\ _{0.19}$	$_{-0.8}\ -0.5\ _{0.2}$	$_{-0.3}\ 0.4\ _{0.8}$
Upper LoA	$_{6.34}\ 7.8\ _{10.18}$	$_{3.63}\ 4.67\ _{5.35}$	$_{6.56}\ 9.5\ _{14.13}$
Lower LoA	$_{-12.19}\ -9.45\ _{-7.9}$	$_{-13.7}\ -9.88\ _{-6.54}$	$_{-5.28}\ -4.58\ _{-3.5}$
LoAs difference	17.2	14.6	14.1
Effect size	$_{-0.1}\ 0.0\ _{0.1}$	$_{0.06}\ 0.1\ _{0.14}$	$_{-0.22}\ -0.15\ _{-0.08}$
Corrected data			
CCC	$_{0.78}\ 0.83\ _{0.87}$	$_{0.96}\ 0.97\ _{0.98}$	$_{0.90}\ 0.93\ _{0.94}$
Bias	$_{-0.74}\ -0.08\ _{0.28}$	$_{-0.19}\ 0.03\ _{0.5}$	$_{-0.87}\ -0.25\ _{0.24}$
Upper LoA	$_{4.46}\ 6.38\ _{7.01}$	$_{3.56}\ 4.17\ _{5.1}$	$_{3.83}\ 5.43\ _{8.51}$
Lower LoA	$_{-7.32}\ -6.51\ _{-5.48}$	$_{-5.18}\ -4.36\ _{-3.63}$	$_{-7.45}\ -6.38\ _{-5.04}$
LoAs difference	12.9	8.5	11.8
Effect size	$_{-0.05}\ 0.04\ _{0.12}$	$_{-0.04}\ 0.00\ _{0.03}$	$_{-0.01}\ 0.04\ _{0.09}$

Note: 95% CI are given as subscripts.

Abbreviations: BF, %, body fat percent; *CCC*, Lin's concordance correlation coefficient; FFM, kg, fat free mass; FM, kg, fat mass; LoA, limit of agreement; RC, repeatability coefficient.

FFM_BIA*c* = (FFM_BIA − 14)/0.68. Then, the corrected BIA's body composition estimates (BF_BIA*c*, FM_BIA*c*, and FFM_BIA*c*) were used for the following agreement analysis.

Using of the corrected BIA's body composition estimates significantly improve agreement between BIA and AUS (Figure 4). Regression lines matched to the line of identity (Figures 2–4, panel B). Use of the new prediction regression equations to estimate fat mass resulted in substantial (high) level of agreement ($CCC = {}_{0.96}\ 0.97\ _{0.98}$) and moderate agreement for fat free mass ($CCC = {}_{0.90}\ 0.93\ _{0.94}$) between AUS and BIA. Differences between two methods in fat and fat-free mass estimations decreased from 500 to 30 g and from 400 to 250 g, respectively. However, using of the corrected values of body fat percentage did not improve agreement between the methods (Table 2). Thus, according to the proposed equations body composition estimated by AUS can be transformed to BIA data for FM and FFM.

4 | DISCUSSION

For the first time, an agreement analysis between body composition estimates obtained by BIA and AUS was performed in the group of female Russian subjects with high rage of morphological characteristics and of various ages. Since AUS is commonly used method of body composition, the equations allow to convert ABC Medas' fat and fat–free mass estimates into ultrasound scanning's estimates.

According to epidemiological studies of obesity conducted in Russia using locally manufactured equipment around 20% of males and 30% of females are obese and the prevalence is increasing with age (Kholmatova et al., 2022). Prevalence of general obesity along with morbid obesity is dramatically increased among adolescents and young adults from Russian Federation. Correlation coefficients between age and body composition were identical and statistically significant but weak for both methods, especially between age and fat-free mass ($\text{rho}_{BF} = {}_{0.45}\ 0.56\ _{0.64}$, $\text{rho}_{FM} = {}_{0.34}\ 0.45\ _{0.56}$, and $\text{rho}_{FFM} = {}_{0.03}\ 0.16\ _{0.29}$). High prevalence of obese and overweight subjects among adults as well as the need for comparison of body composition estimates obtained by different equipment stimulates researchers to find methods suitable for the screening and for field studies in the heterogeneous groups. Indirect techniques for body composition analysis used in the applied and fundamental studies are convenient, portable and inexpensive analogues of "reference" methods (Franssen et al., 2014). Agreement analysis between body composition measurements obtained by various indirect methods is still needed (Kogure et al., 2020; Nickerson et al., 2020).

Reliability between two methods in fat and fat-free mass evaluation was high. According to our data, Lin's $CCC_{FFM} = {}_{0.95}\ 0.99\ _{1.00}$ for BodyMetrix™ and ${}_{0.97}\ 0.99\ _{1.00}$ for ABC-02 Medas. Thus, ABC-02 Medas is similar to devices from other manufacturers and demonstrates a high level of reliability of the BF, %BF, and FFM values in repeated measurements (Bondareva et al., 2023; Dittmar, 2003; Miclos-Balica et al., 2021). Statistical analysis revealed that AUS and BIA had a high level of correlation in body fat mass ($r = {}_{0.96}\ 0.97\ _{0.98}$), fat free mass ($r = {}_{0.91}\ 0.93\ _{0.95}$), and body fat percentage ($r = {}_{0.78}\ 0.83\ _{0.87}$) estimations. Almost negligible values of effect size obtained between two methods in fat, fat-free mass, and body fat percentage (Table 2, Figure 2) allow to conclude that, at the population level, both techniques are interchangeable.

Up-to date, agreement analysis between ABC-02 Medas and reference methods were not performed. Agreement analysis was conducted once when data obtained by ABC-2 Medas was compared to Tanita's data. It was shown that whole-body resistances were highly correlated (rho = 0.95), but FM estimates were significantly higher with the Medas than the Tanita device (median difference in 3.3 kg) with large limits of agreement for the FM difference. That was apparently due to different equations used in Medas' and Tanita's software

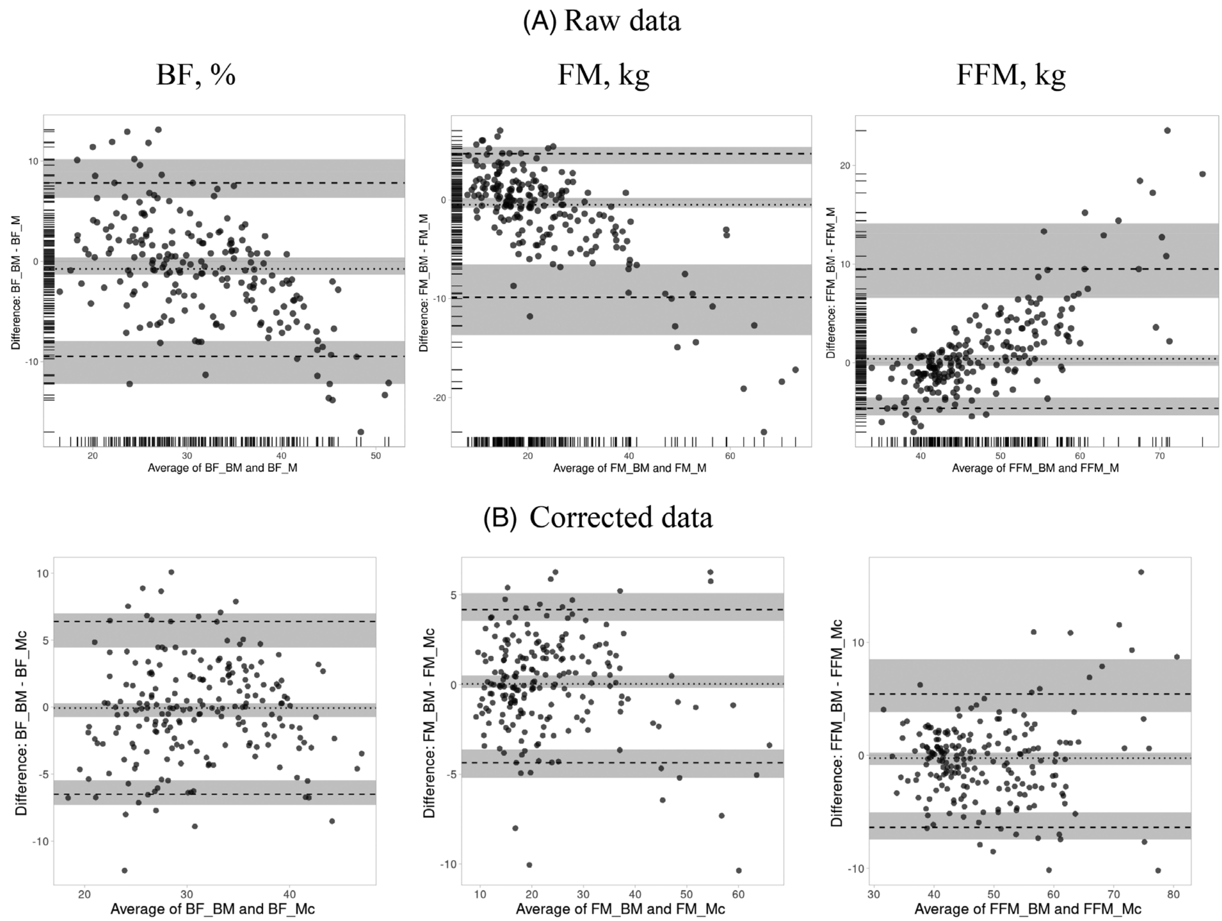

FIGURE 3 Bland–Altman plots of body fat percentage, fat mass, and fat free mass. Dotted line—group bias; dashed line—limits of agreement; gray zone—95% confidence intervals. Average value (US + BIA)/2 is shown on the *X* axis; difference between US and BIA results is shown on the *Y* axis.

(Rudnev et al., 2020). In the group of college students, no differences between BodyMetrix™ and air displacement plethysmography in fat and fat-free mass estimation was found (Johnson et al., 2017). However, the sample size was small (33 males and 44 females) and include only physically active college students. In the group of Brazilian female subjects, it was shown that BIA and caliperometry underestimated body fat percentage compared to DEXA (Baranauskas et al., 2017). High correlation was found between AUS and BIA ($r = 0.86$), and AUS and air displacement plethysmography ($r = 0.87$) when comparing AUS, BIA and air displacement plethysmography results (Nickerson et al., 2020). Comparison of AUS with the three-compartment model of body composition revealed that AUS underestimated body fat percentage by 4.7% and overestimated fat free mass by 4.4 kg in the overweight and obese subjects (Esco et al., 2018). Miclos-Balica et al. reported neither differences in body composition estimates between AUS and air displacement plethysmography, nor systematic discrepancy (Miclos-Balica et al., 2021). Comparison analysis of BIA spectroscopy, BIA, DEXA, air displacement plethysmography with "reference" five-component model of body composition revealed that at the group level BIA spectroscopy and BIA had low group-level errors (CE < 1.0%; $R^2 \geq 0.94$; equivalence with 5C) with somewhat poorer individual-level performance (95% LoA ≤ 6.2%) (Tinsley, 2021).

Despite of high identity of body composition estimates obtained by two methods as well as high correlation coefficients at the group level, differences between BIA and AUS can be significant at the individual level. This is also indicated by low and medium values of concordance correlation coefficients for body fat percentage and fat-free mass, and fat mass, respectively (Table 2). Differences in body fat mass estimates obtained by two methods were increasingly more pronounced with the increase in BMI and body fat percentage (Figure 3A). With a decrease in BMI and, as a result, body fat mass, estimates obtained using BIA are getting lower than in AUS. New prediction equations of body fat mass and fat free mass based on the data obtained by ultrasound

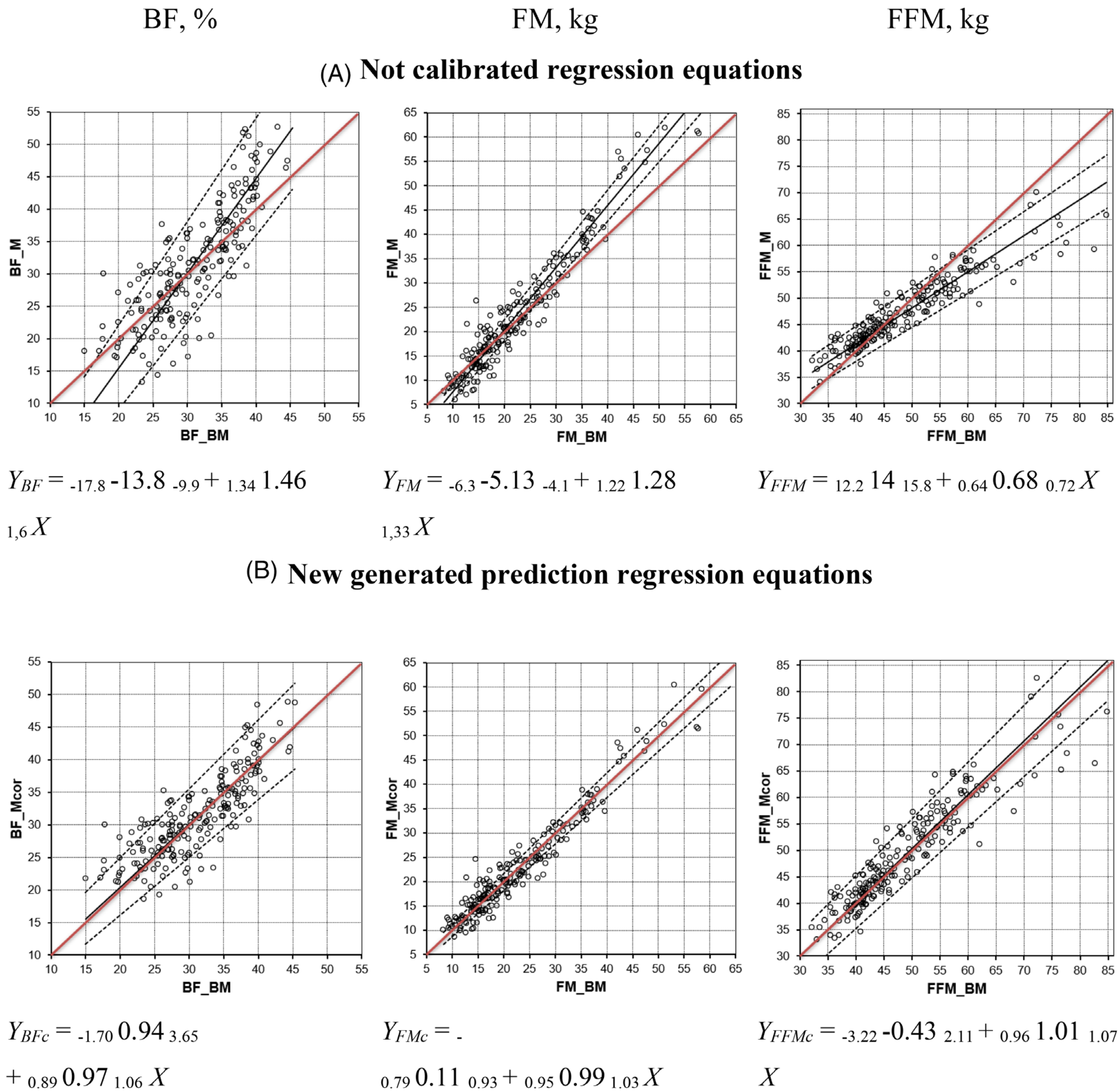

FIGURE 4 Passing–Bablok regression for body composition estimates obtained in paired measurements for BIA and US before and after correction. Black solid lines—regression lines; black dashed lines—prediction intervals; red lines—identity line; 95% CI are given as subscripts. BF, body fat percentage; BF_Mcor, corrected values of BIA body fat percentage; BIA, ABC-02 Medas; BM, BodyMetrix™; FFM, fat free mass in kg; FFM_Mcor, corrected values of BIA fat free mass; FM, fat mass in kg; FM_Mcor, corrected values of BIA fat mass.

scanner BodyMetrix™ and bioimpedance analyzer ABC-02 Medas are reported for the first time. The use of the following equations: BF_BIAc = (BF_BIA + 13.8)/1.46, FM_BIAc = (FM_BIA + 5.13)/1.28, and FFM_BIAc = (FFM_BIA − 14)/0.68 allows to achieve the substantial (high) and moderate levels of agreement between body composition estimates (fat and fat free mass), reduce the systematic bias between measurements as well as correspondence of regression line and line of identity (Table 2, Figures 2–4B). Using the new prediction equations did not improve the level of agreement between two methods in estimating body fat percentage.

Previously we showed that in the group of subjects with morbid obesity the difference in measurements of fat mass can reach 30 kg (Bondareva & Parfenteva, 2021). In the present study, the difference reached 25 kg. Since the studied group included sufficient number of individuals with general and morbid obesity, agreement between fat mass estimates by AUS and corrected values of corrected BIA's fat mass reached a high level. However, direct comparison of fat and fat-free mass by AUS and other methods should be done carefully in the group of obese individuals. Smith-Ryan et al revealed that Jackson-Pollock seven sites using AUS underestimated fat mass and overestimated fat-free mass compared to three-component models of body composition (Smith-Ryan et al., 2014). All of the above allows us to conclude that in the group of people with morbid obesity, additional agreement analysis is needed because including subjects with severe obesity decreases the level of agreement.

The present study has limitations such as a small number of underweight (BMI < 18.5 kg/m^2) and elderly female subjects (>59 year old): 6% and 5% of sample size, respectfully. Size of the groups divided in accordance to their nutritional status is not enough for agreement analysis. Each group should include more than 96 individuals to achieve 80% statistical power. Level of agreement between two methods in fat and fat-free mass evaluation may differ in the group of professional female athletes and depend of sports. Since we used Jackson-Pollock seven sites equation for fat and fat-free mass evaluation, an additional agreement analysis should be done in case of alternative selected equations using BodyMetrix™ system.

5 | CONCLUSION

We found negligible differences between ABC-02 Medas and BodyMetrix™ suggesting potential interchangeability of these devices at the group level. Thus, direct comparison of fat and fat-free mass estimates by AUS and BIA from different studies seems feasible and significantly expands the possibilities of using body composition data (obtained by ABC-02 Medas). A low (%BF and FFM) and moderate (FM) level of agreement at the individual level do not allow to conduct direct comparison. High agreement between fat mass estimates by AUS and corrected BIA's fat mass estimates was achieved by using the introduced regression equations. The equations may be used for recalculation of BIA's fat mass estimates obtained by ABC-02 Medas and future pooling with the data obtained by AUS. Due to high within-instrument reliability we assume that the results obtained when comparing ABC-02 Medas and BodyMetrix™ may be relevant for bioimpedance analyzers from other manufacturers. Searching of indirect method for body composition analysis, suitable for the group of people with a high range of values in morphological traits, and with accuracy similar to laboratory methods, resulted in a development of equations that combine bioimpedance and skinfold thickness data for body composition estimation based on three-compartment model. Combining bioimpedance and ultrasound scanning data can significantly improve accuracy of body composition prediction based on the three-compartment model. In the future, the regression equations developed here should be evaluated in terms of accuracy for both men and women.

AUTHOR CONTRIBUTIONS

Elvira A. Bondareva: Conception and design; acquisition of data; analysis and interpretation of data; writing (draft and review/editing). **Olga I. Parfenteva**: Acquisition of data; writing (draft and review/editing). **Ekaterina A. Troshina**: Revising the manuscript critically for important intellectual content. **Ekaterina V. Ershova**: Acquisition of data; interpretation of data. **Natalya V. Mazurina**: Acquisition of data; analysis and interpretation of data. **Kseniya A. Komshilova**: Acquisition of data; interpretation of data. **Nikolay A. Kulemin**: Analysis and interpretation of data. **Ildus I. Ahmetov**: Analysis and interpretation of data; writing (review/editing). All authors have read and agreed to the published version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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