Agreement of bioimpedance analysis and ultrasound scanning for fat mass, fat free mass and body fat percentage evaluation in the group of adult women

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Citation: Bondareva, E., Parfenteva, O., Vasileva, A., Kulemin, N., Gadzhiakhmedova, A., Kovaleva, O., and Khromov-Borisov, N. 2023. Agreement of bioimpedance analysis and ultrasound scanning for fat mass, fat free mass and body fat percentage evaluation in the group of adult women. Bio. Comm. 68(3): 173–180. https://doi.org/10.21638/spbu03.2023.305

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Manuscript Editor: Michael Firsov, Sechenov Institute of Evolutionary Physiology and Biochemistry, Russian Academy of Sciences, Saint Petersburg, Russia

Received: March 30, 2023;

Revised: June 14, 2023;

Accepted: August 31, 2023.

Funding: The research was funded by the Russian Science Foundation grant No. 22-75-10122 "Evaluation of the influence of endogenous and exogenous factors for the development of various types of obesity".

Ethics statement: The Local Bioethics Committee of the Faculty of Bioscience of Lomonosov Moscow State University (No. 116-D of 09/08/2020) gave a positive conclusion on the data collection methodology. All volunteers who participated in the survey were aware of the objectives and methods of the survey and gave their informed consent. The Ethical committee at the Lopukhin Federal research and clinical center of physical-chemical medicine, Federal medical biological agency approved the study design and the data analysis procedures (No. 2022/12/06 dated December 6, 2022).

Competing interests: The authors have declared that no competing interests exist.

Abstract

The study aims to perform an agreement analysis of bioimpedance (BIA) results obtained using ABC-02 "Medas" (Russia) and ultrasound scanning (US) using BodyMetrix^{TM} (USA) for fat mass, fat free mass and body fat percentage in the group of females from Moscow. The study was performed with 180 female subjects 18–67 years of age. The agreement analysis conducted in the whole sample revealed a low level of agreement in estimating body fat percentage ($CCC = {}_{0.70}\,0.76\,{}_{0.81}$) and fat free mass ($CCC = {}_{0.86}\,0.89\,{}_{0.91}$), but agreement can be described as medium in estimating fat mass ($CCC = {}_{0.90}\,0.92\,{}_{0.94}$). Then we adjusted the prediction equations and the agreement analysis was conducted again. Adjusted prediction equations improved the level of agreement to medium when estimating body fat percentage and fat free mass. Thus, the proposed equations can be used for the translation of body composition results obtained by US into the BIA data.

Keywords: body composition, body fat mass, free fat mass, BodyMetrix^{TM}, ABC-02 *Medas*, agreement analysis.

Introduction

Body composition analysis is a routine practice in the medical studies. It is 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. It is also widely used in the epidemiological studies of obesity prevalence, or in the field of the biological anthropology, as well as in the sport medicine (Kasper et al., 2021). Due to the tasks listed above, methods that allow to quantify body composition are widely used for diagnosing the nutritional status in medical and anthropological studies (Price and Earthman, 2019). It is possible to distinguish extremely powerful and accurate reference methods (underwater weighing, air replacement plethysmography, neutron activation analysis, dual energy X-ray densitometry, computed tomography methods) and indirect or field methods (caliper testing, bioimpedancemetry, ultrasonic scanning, calculation by analytical formulas from simple anthropometric traits) (Tinsley, 2021). Indirect methods are less accurate but more widespread. This is because they are cheaper, less time-consuming, transportable, have no harmful effects, and have no age limits (Johnson et al., 2017; Pérez-Chirinos Buxadé et al., 2018). Since various manufactures produce bioimpedance analyzers, a direct comparison of data obtained in different studies is difficult. In the large-scale study conducted in 2014, where body composition was analyzed in the Russian population, researchers used "ABC-Medas" bioimpedance analyzer manufactured in Russia (Soboleva et al., 2014). Up to date only one study aimed to assess the agreement between body composition estimates obtained by "ABC-Medas" and those obtained by Tanita analyzers was performed (Rudnev et al., 2020). Several conditions must be met during the bioimpedance analysis procedure, such as the absence of a pacemaker and/or metal implants, fasting examination, no physical activity 24 hours 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, i. e., diseases, certain medications, drinking regimen, may also distort the results (Dehghan and Merchant, 2008). These conditions in some cases impose restrictions on the use of bioimpedancemetry. A 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 the 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.

From the end of the 20th century, ultrasound scanning has been used as a quantitative method for body composition analysis (Wagner, 2013). Ultrasound scanning 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 do not affect the measurements; hence, accuracy and reliability of the estimates are improved (Wagner and Teramoto, 2020). Ultrasound 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 (Bielemann et al., 2016; 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 and Parfenteva, 2021).

The present study aims to assess the agreement of measurement of body fat percentage, fat mass and fat free mass obtained by a locally manufactured bioimpedance analyzer (ABC-02 "Medas", Russia) and an ultrasound scanner BodyMetrix™ (IntelaMetrix, USA) in the group of females from Moscow.

Material and methods

Sample characteristics

In 2020–2022, at the Research Institute and Museum of Anthropology of Lomonosov Moscow State University and Lopukhin Federal research and clinical center of physical-chemical medicine the cross-sectional, single-center, observational, anthropometric study was performed where 180 women 18–67 years of age were recruited. Their distribution according to the nutritional status based on the common BMI rating is presented in Table 1. No practically important correlation between the age and BMI was observed (the lower confidence limits for both Pearson's and Spearman's correlation coefficients were less than 0.4).

Table 1. Distribution of persons according to their nutritional status

Nutritional status	BMI, kg/m^2	n_i	f_i (%) with 95 % CLs
underweight	< 18.5	12	$_{3}7_{13}$
normal	18.5 to 24.9	114	$_{54}63_{72}$
overweight	25.0 to 29.9	32	$_{11}18_{26}$
obese	≥ 30.0	22	$_{7}12_{19}$
Total		180	100

Note: Exact confidence limits (CLs) for proportions as the parameters of multinomial distribution were calculated using StatXcat-12 software. CLs for the correlation coefficients were calculated using bootstrap algorithms with JASP software. Here CLs are presented as subscripts around the point estimates.

The examination protocol included the measurements of body height (Martin stadiometer, GPM, Switzerland) and weight (Seca, Germany), waist and hip circumferences by measuring tape, body composition by an ultrasound scanner BodyMetrix™ (IntelaMetrix, USA) and a bioimpedance analyzer (ABC-02 "Medas", Medas, Russia). During the survey, each participant was asked about their ethnicity, athletic status and their physical activity (its regularity and intensity). Professional athletes or exercised more than 3 times per week were excluded from the study.

Body composition analysis using the ultrasound scanner BodyMetrix™

During the ultrasound scanning procedure, the torso- and the limb-located skinfold thickness was measured (Bielemann et al., 2016) at sites corresponding to the traditionally measured ones (Martirosov, Nikolaev, and Rudnev, 2006). The measurement was repeated up to 5 times at each site; the mean value was calculated. An ultrasound viscous gel "Mediagel" ("Gelteck-Medica", Russia) was used as a coupling medium. All measurements were done on the right side of the body. Quantitative assessment of body composition was done according to 7-sites Jackson-

Table 2. Description of the statistical methods and programs used

Program	Version and/or date	Used procedures and methods, and their purpose
PAST	4.12b 06.2023	Comprehensive interval estimates of parameters of location, variation, shape, etc. based on bootstrap and comparisons based on Monte Carlo algorithms. Correlation ellipses
StatXact	12 2022	Exact CIs for the parameters of the polynomial distribution
JASP	0.17.1 06.03.2022	Bootstrap CIs for correlation coefficients
Estimation statistics	2017–2021	Estimation version of the paired *t*-test: the paired mean difference Gardner-Altman plot. The effect size and its bootstrap 95 % confidence interval
BA-plotteR	2021	Comprehensive Bland-Altman analysis: plots, limits of agreement with 95 % CI. Repeatability coefficient (RC) within 95 % CI
jamovi	2.3.24 15.02.2023	Lin's concordance correlation coefficient (CCC) with 95 % CI
Passing-Bablok regression	03-1	Comparison of methods or experiments via Passing-Bablok regression

Pollock equation (Jackson, Pollock, and Ward, 1980). Namely, for females: Body density = 1.097 – (0.00046971 × sum of all of skinfolds) + (0.00000056 × sum of all of skinfolds squared) — (0.00012828 × age). Body Fat Percentage (%) = [(495 / Body Density) — 450] × 100. All calculations were performed using BodyViewProFit software (IntelaMetrix, Inc., Livermore, CA). Correspondingly, the absolute body fat mass and fat free mass were calculated.

Body composition analysis using the bioimpedance analyzer (ABC-02 "Medas")

Bioimpedance 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 (Nikolaev, Smirnov, Bobrinskaya, and Rudnev, 2009). Throughout the period of data collection, the same examiner performed the measurements. The time between the ultrasound scanning and the impedance measurement did not exceed 15 minutes. At the beginning of the examination day and before the first impedance measurements, the resistance (Rc) and reactance (Xc) were calibrated by a special calibrator with which all analyzers ABC-02 "Medas" are equipped. The resistance (Rc) and reactance (Xc) values did not vary by more than 1 %. The absolute content of body fat mass and fat free mass as well as the body fat percentage were calculated using ABC01–0362 software.

Table 3. Sample characteristics

Characteristic	Parameters				
	Location		Variation		
	M	*Me*	*Min*	*Max*	*SD*
Age (yrs)	$_{32}34_{35}$	$_{33}34_{37}$	18	67	$_{10.6}11.7_{12.8}$
Body height (cm)	$_{166}167_{169}$	$_{164}165_{167}$	153	194	$_{8.1}9.3_{10.3}$
Body weight (kg)	$_{65}67_{69}$	$_{62}64_{68}$	42	99.7	$_{12.0}14.1_{16.2}$
Body fat percentage BodyMetrix^{TM} (%)	$_{29}30_{31}$	$_{28}30_{32}$	15	41	$_{5.4}5.8_{6.3}$
Body fat percentage ABC-02 "Medas" (%)	$_{29}30_{31}$	$_{28}30_{31}$	13	52	$_{7.1}7.8_{8.4}$
Fat mass BodyMetrix^{TM} (kg)	$_{19}21_{22}$	$_{17}19_{21}$	8	53	$_{6.7}7.6_{8.6}$
Fat mass ABC-02 "Medas" (kg)	$_{20}21_{v22}$	$_{17}19_{21}$	6	72	$_{8.1}9.7_{11.2}$
Fat free mass BodyMetrix^{TM} (kg)	$_{45}47_{48}$	$_{44}45_{47}$	32	85	$_{6.8}7.8_{8.9}$
Fat free mass ABC-02 "Medas" (kg)	$_{45}46_{47}$	$_{44}45_{46}$	34	66	$_{5.0}5.5_{6.1}$
Waist circumference (cm)	$_{74}76_{78}$	$_{72}74_{75}$	55	132	$_{10.4}12.3_{14.0}$
Hip circumference (cm)	$_{98}99_{100}$	$_{96}98_{100}$	79	148	$_{7.9}9.5_{10.9}$
BMI (kg/m^2)	$_{23}24_{25}$	$_{23}23_{24}$	16	48	$_{4.0}4.9_{5.6}$

Notes: *M* — mean, *Me* — median, *SD* — standard deviation.

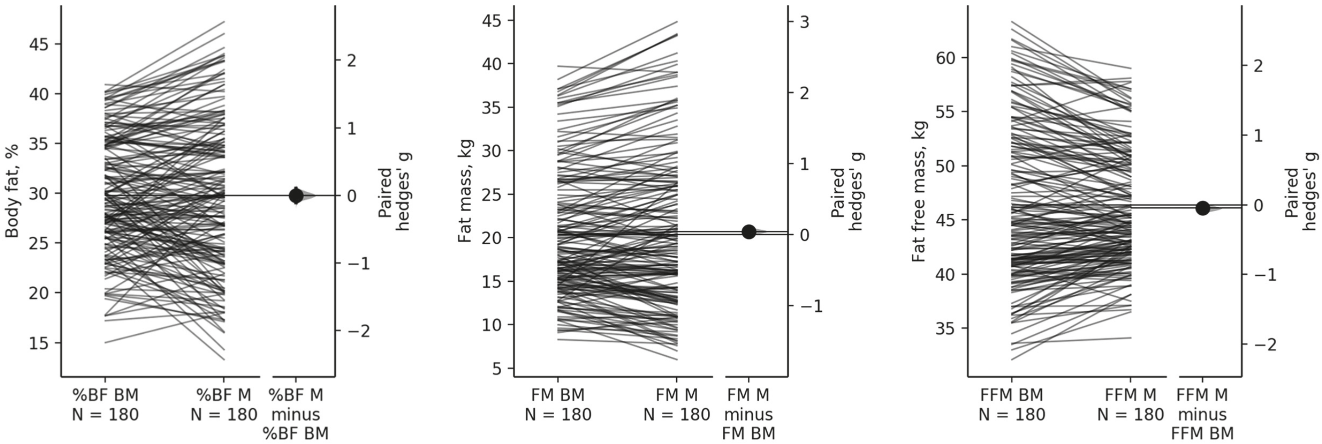


Fig. 1. Gardner-Altman plots for body composition characteristics in the studied sample. FM — fat mass, kg; %BF — body fat, %; FFM — fat free mass, kg; BM — BodyMetrix™, M — Medas.

Statistical analysis. The description of the statistical methods and programs used is presented in Table 2 as suggested in (Khromov-Borisov, 2022). For the multiple comparisons Bonferroni adjustment for the p-values was used.

Results

Anthropometric characteristics of the sample

The main statistical descriptions of the obtained data are presented in Table 3. At the group level, no significant differences were found between the two methods when estimating body fat mass (FM), fat free mass (FFM), and body fat percentage (BF). Effect sizes (Hedges' g) for paired samples were close to zero ($g_{BF} = {}_{-0.1}0.0_{0.1}$, $g_{FM} = {}_{-0.06}0.0_{0.06}$ and $g_{FFM} = {}_{0.07}0.15_{0.22}$).

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 a small systematic bias by 0.1 % in body fat percentage, 0.5 kg in fat mass and 0.4 kg in fat free mass estimating, which confirms an insignificant effect size.

Reproducibility coefficients obtained for fat mass and fat free mass were lower than for body fat percentage, which indicates a low reproducibility of ultrasound and BIA in body fat percentage estimations. However, Bland-Altman analysis revealed that at the low body fat mass values, the ultrasound scanning overestimated it compared to the bioimpedance analysis. For fat free mass estimates in the range of low values, ABC-02 "Medas" overestimates this parameter compared to the ultrasound scanner BodyMetrix™.

Agreement analysis conducted for the whole studied sample revealed a low level of agreement between two methods in estimating body fat percentage ($CCC = {}_{0.70}0.76_{0.81}$) and fat free mass ($CCC = {}_{0.86}0.89_{0.91}$). For fat mass estimated the agreement can be described as medium ($CCC = {}_{0.90}0.92_{0.94}$).

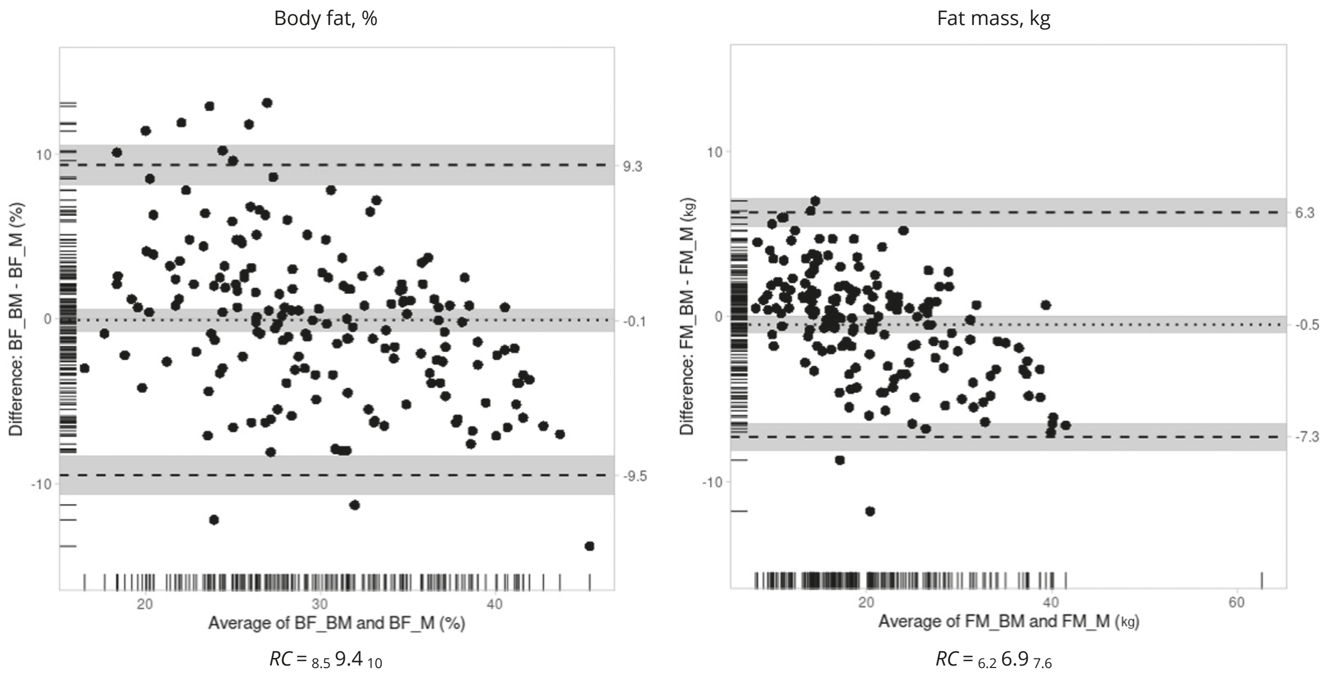
Since a low level of agreement between the ultrasound scanning and BIA did not allow a direct comparison of these two techniques in body composition evaluation at the individual level, new regression equations for predicting body composition from the ultrasound scanning and BIA (Fig. 3, panel A) were recalculated.

After recalibrations of the body composition according to the new prediction regression equations (Fig. 3), a new agreement analysis was performed. Use of the new prediction regression equations to estimate fat mass and fat free mass resulted in medium agreement between US and BIA. Thus, according to the proposed equations body composition estimated by US can be transformed to BIA data.

Initially the agreement analysis was performed with the sample of 181 women. The agreement was substantially lower ($CCC_{BF} = {}_{0.69}0.76_{0.81}$, $CCC_{FM} = {}_{0.55}0.61_{66}$ and $CCC_{FFM} = {}_{0.85}0.88_{0.90}$). Due to this, a person with BMI equal to 47.8 kg/m^2 was excluded from the dataset before the performed data analysis. This means that additional analysis and generation of new prediction equations in the group of people with morbid obesity would be required.

Discussion

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 (Soboleva et al., 2014). 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



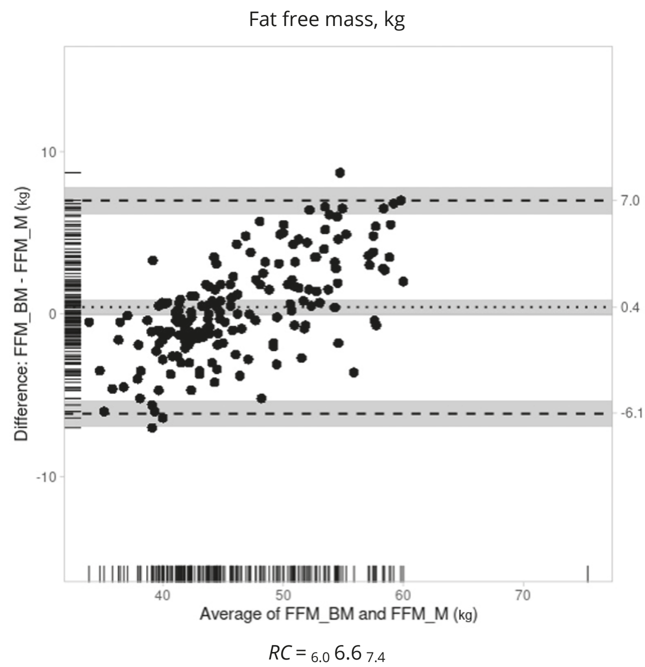


Fig. 2. Bland-Altman plots for body fat percentage, fat mass and fat free mass. Dotted line — group bias; dashed lines — limits of agreement (*LoA*); grey zones — 95 % confidence intervals for them. Average value (US+BIA)/2 is shown on the X axis; difference between ultrasound and BIA results is shown on the Y axis; *RC* — reproducibility coefficient.

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). An agreement analysis between body composition measurements obtained by various indirect methods is still needed (Kogure et al., 2020; Nickerson, McLester, McLester, and Kliszczewicz, 2020). Previously, we conducted the study in the group of women and men where we checked the agreement between body composition estimates obtained by the equipment mentioned above (Bondareva and Parfenteva, 2021). In the present study, the agreement analysis was performed in the group of female subjects with high variation in morphological traits. Mostly the results obtained in the present study are similar to previous results (Bondareva and Parfenteva, 2021) — at the population level both techniques are interchangeable (Fig. 1). Differences in body fat mass estimates obtained by two techniques were increasingly more pronounced with the increase in BMI and body fat percentage (Fig. 2). With a decrease in BMI and, as a result, body fat mass, estimates obtained using BIA are getting lower than in US. New prediction equations of body fat mass

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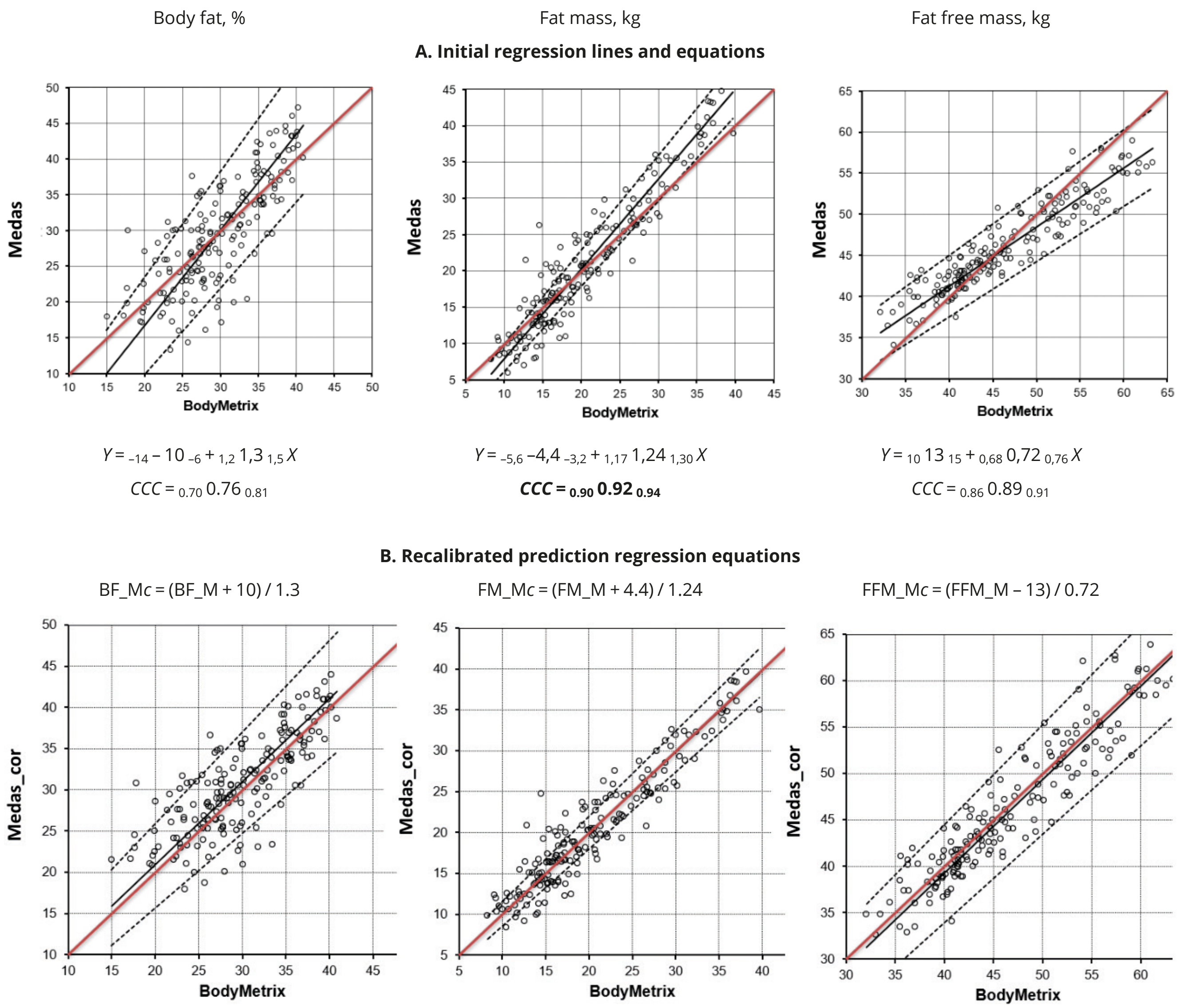

A. Initial regression lines and equations:

Body fat, %: $Y = {}_{-14}-10_{-6} + {}_{1,2}1{,}3_{1,5}X$; $CCC = {}_{0.70}0.76_{0.81}$

Fat mass, kg: $Y = {}_{-5,6}-4{,}4_{-3,2} + {}_{1,17}1{,}24_{1,30}X$; $\boldsymbol{CCC = {}_{0.90}0.92_{0.94}}$

Fat free mass, kg: $Y = {}_{10}13_{15} + {}_{0,68}0{,}72_{0,76}X$; $CCC = {}_{0.86}0.89_{0.91}$

B. Recalibrated prediction regression equations:

BF_Mc: $Y = {}_{0,98}1{,}0_{1,11} + {}_{-2,5}0{,}90_{3,6}X$; $CCC = {}_{0.71}0.78_{0.83}$; $RCcor = {}_{6.9}7.6_{8.5}$

FM_Mc: $Y = {}_{0,94}0{,}99_{1,0} + {}_{-0,85}0{,}08_{1,1}X$; $\boldsymbol{CCC = {}_{0.92}0.94_{0.96}}$; $RCcor = {}_{4.3}4.8_{5.3}$

FFM_Mc: $Y = {}_{-4,1}-1{,}14_{1,46} + {}_{0,95}1{,}0_{1,1}X$; $\boldsymbol{CCC = {}_{0.90}0.93_{0.95}}$; $RCcor = {}_{4.9}5.5_{6.1}$

Fig. 3. Black solid lines — Passing-Bablok regression lines; black dashed lines — prediction intervals; red lines — identity line; FM — fat mass in kg; BF — body fat percentage; FFM — fat free mass in kg; M — ABC-02 “Medas”; BM — BodyMetrix^{TM}, cor — corrected.

and fat free mass based on the data obtained by an ultrasound scanner BodyMetrix^{TM} (IntelaMetrix, Inc., USA) and a bioimpedance analyzer ABC-02 “Medas” (Medas, Russia) are reported for the first time. The use of the following equations: (BF_Medas_cor = (BF_Medas + 10) / 1.3, FM_Medas_cor = (FM_Medas + 4.4) / 1.24 and FFM_Medas_cor = (FFM_Medas – 13) / 0.72) allows to achieve the medium level of agreement between the body composition estimates (fat and fat free mass).

Using the new prediction equations did not improve the level of agreement between two methods in estimating body fat percentage. 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. Previously we showed that in the group of subjects with morbid obesity the difference in measurements of fat mass can reach 30 kg (Bondareva and Parfenteva, 2021). In the present study, the difference reached 20 kg. Reproducibility coefficient calculated in the whole sample was ${}_{6.2}6.9_{7.6}$ kg for fat mass, ${}_{6.0}6.6_{7.4}$ kg for fat free mass and ${}_{8.5}9.4_{10}$ for body fat percentage, that is with probability of 95 % the difference between the measurements by BodyMetrix^{TM} and ABC-02 “Medas” is in this range. Using the generated prediction equations allowed to reduce the reproducibility coefficient to ${}_{4.3}4.8_{5.3}$ kg for fat mass, ${}_{4.9}5.5_{6.1}$ kg for fat free mass and ${}_{6.9}7.6_{8.5}$ for body fat percentage (Figs 2 and 3). The agreement analysis between the ultrasound testing by BodyMetrix^{TM} and an air displacement plethysmography showed a sufficient level of agreement in estimating fat and fat free mass (Johnson et al., 2017). Moreover, the skinfold thickness and thickness of the muscles data can be used for generating new prediction equations other than those implemented in the software (Bielemann et al., 2016). Large databases of bioimpedance analysis results obtained by various analyzers are accumulated in Russia and other countries (Rudnev et al., 2020; Franssen et al., 2014; Pedrera-Zamorano et al., 2015).

Statistical analysis has revealed that the ultrasound scanning and the bioimpedance analysis had a high level of correlation in body fat mass ($r = 0.95$), fat free mass ($r = 0.93$) and body fat percentage ($r = 0.79$) estimations. Previously it was shown that the ultrasound scanner BodyMetrix^{TM} had a high level of accuracy in the assessment of body composition components not only in the group of healthy young adults, but also in the group of overweight and obese subjects (Johnson et al., 2017). However, the ultrasound scanner compared to the air displacement plethysmography underestimated body fat mass and overestimated fat free mass (Johnson et al., 2017). For instance, in the group of Brazilian women, it was shown that BIA and caliperometry underestimated body fat percentage compared to DEXA; yet, these indirect methods are interchangeable (Baranauskas et al., 2017). High correlation was found between the ultrasound scanning and BIA ($r = 0.86$), and the ultrasound scanning and air displacement plethysmography ($r = 0.87$) when comparing the ultrasound scanning, bioimpedance analysis and air displacement plethysmography results (Nickerson, McLester, McLester, and Kliszczewicz, 2020). A comparison of ultrasound scanning with the three-compartment model of body composition revealed that ultrasound scanning 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 the ultrasound scanning and air displacement plethysmography, nor systematic discrepancy (Miclos-Balica et al., 2021). A comparison analysis of bioimpedance spectroscopy, BIA, DEXA, air displacement plethysmography with "reference" five-component model of body composition revealed that at the group level bioimpedance spectroscopy and BIA had a sufficient level of accuracy. However, at the individual level they had a high level of inaccuracy (Price and Earthman, 2019). Based on our knowledge, the analysis of accuracy and reliability of body composition measurements by locally produced bioimpedance analyzer "Medas" ("Medas" Russia) has not been performed. The situation is further complicated by the fact that manufacturers producing bioimpedance analyzers do not publicly disclose regression equations implemented in the software.

Body composition analysis is commonly used for risk assessment of diseases associated with obesity, for monitoring the changes in body composition of professional athletes and subjects with some diseases, as well as for the assessment of nutritional status in adult and children's populations. Ultrasound scanning has several advantages apart from common use and low cost. It can be used both in hospital settings and in field studies. An ultrasound scanner is able to collect data of skinfold thickness, so it can replace calipers. Moreover, ultrasound scanning 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.

The present study has limitations such as a small number of underweight, overweight and obese subjects.

Conclusion

A search of an 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 a three-compartment model. Combining bioimpedance and ultrasound scanning data can significantly improve the accuracy of body composition prediction based on the three-compartment model. In the future, the generated prediction regression equations should be verified using the new data obtained in the females and males to assess the accuracy of the prediction equations and a necessity to generate new equations for each sex.

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