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## **ABSTRACT**

**STUDY OF THE PRECISION OF BODY COMPOSITION  
ASSESSMENT USING AIR DISPLACEMENT  
PLETHYSMOGRAPHY AND ULTRASONOGRAPHY: THE  
ROLE OF MULTIPLE MEASUREMENTS IN MONITORING  
PERFORMANCE ATHLETES**

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**Timișoara  
2024**

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**Key words:** air displacement plethysmography, ultrasound, body composition, body density, body volume, body fat percentage, fat mass, fat-free mass, subcutaneous adipose tissue, visceral adipose tissue

## I. BACKGROUND & RESEARCH OBJECTIVES

Assessment of body composition (BC) is crucial for the general population, as it motivates individuals to embrace a healthy lifestyle and thus, enhance public health, and more important, in the clinical arena, for overweight and obese patients, thus allowing for a refined phenotyping of these patients.

Tracking BC has been increasingly used by sports-related professionals in order to estimate the individual nutritional status and metabolic balance between lean muscle mass and fat mass. In particular, the interest in assessing the BC in athletes has increasingly flourished in the past decades with peer-reviewed publications exceeding 14,000 in the PubMed database searched after the key words “body composition” and “athletes”.

Both athletes and coaches are aware that an adequate balance between skeletal muscle mass and body fat is crucial to competitive performance. Skeletal muscle mass is a measure of functional mass that enhances force generation and strength, which in turn improves athletic performance. On the other hand, body fat is regarded as the non-functional mass; having high levels of fat has a negative impact on thermoregulation and impairs athletic performance, from both the mechanical and metabolic points of view. However, a very low fat in sport is detrimental for the individual general health.

Evaluation of BC has been essential in monitoring health, improving performance and even preventing the risk of injury in all athletes. Assessment of BC in sport research referred to the characterization of body fatness by the type of sport and gender. This is because, overall, body fatness tends to be greater in female compared to male athletes within a specific sport.

Over the past decades, numerous techniques have been developed to analyze BC using different models based on several physical principles. The simplest approach in BC assessment is the two-compartment (2C) model, which divides body mass into fat mass (FM) and fat-free mass (FFM). Although several techniques have been devised to characterize the human body in the framework of the 2C model, several measurement-related and/or assumption-related problems remain to be elucidated. Therefore, no “gold standard” methodology or generally valid technique for assessing BC in sport are available so far.

Among the various modern techniques based on the 2C model, air-displacement plethysmography (ADP) is regarded as one of the most reliable laboratory methods to assess the whole body fat percentage (%BF) in the general population, including athletes. Ultrasound (US), on the other side, is an easy-to-use field method that samples with high accuracy the subcutaneous fat deposit, yet training of the investigator is required to correctly detect the tissue layer boundaries.

For both methods there is an unmet need to minimize measurement errors and standardize protocols in order to provide an accurate assessment of the functional body composition for the health benefit in patients and performance optimization in all types of athletes.

**The aim of the PhD study** was to optimize the BC assessment in terms of reliability, validity and practicability, by means of two techniques: (i) ADP, using the BOD POD equipment (COSMED, USA), and (ii) the A-mode US (AUS), using the BodyMetrix BX2000 equipment (IntelaMetrix, USA), respectively.

The research involved in this doctoral study was carried out primary at the *Center for Modeling Biological Systems and Data Analysis* from the Department of Functional Sciences and, also at the *Research Center for Assessment of Human Motion, Functionality and Disability* from the Department of Rehabilitation, Physical Medicine and Rheumatology respectively; both centers belong to the Faculty of Medicine of "Victor Babeș" University of Medicine and Pharmacy from Timișoara, Romania. The research received the approval of the Committee for Research Ethics of "Victor Babeș" University of Medicine and Pharmacy from Timișoara.

**The research objectives** were as follows:

1. To evaluate the test-retest reliability of BC assessment with the ADP method according to well-established protocols and to propose a novel protocol of superior precision.
2. To assess the impact of learning effects on the reliability of BC assessment with the ADP method.
3. To evaluate the accuracy of several formulas implemented in the software of a portable AUS instrument for predicting %BF from subcutaneous fat layer thicknesses.
4. To assess the accuracy of %BF assessments by means of the AUS method while using anthropometric prediction formulas adapted to express the body fat content from US-derived subcutaneous fat layer thicknesses instead of skinfold thicknesses.

**II. RESULTS OF THE DOCTORAL RESEARCH** included in the Special Part of the thesis:

### **1. Implementation of a repeated trials protocol using the median for body composition evaluation using air displacement plethysmography provides an increased reliability compared to the usual protocols**

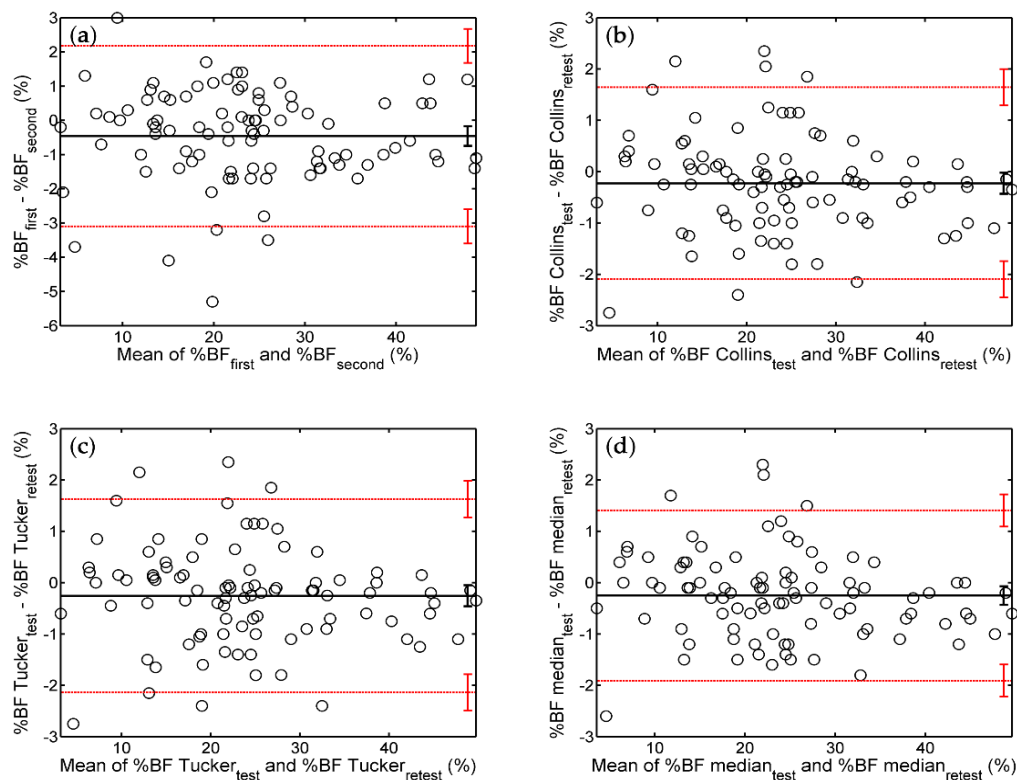
In the first study the fiability of the ADP method was assessed in a gender-balanced group of 92 (46 M, 46 F), healthy adults athlets performing mainly mixed endurance sports (cyclists and soccer players). Three ADP protocols involving repeated trials were compared: (i) the Collins protocol (proposed by Collins and McCarthy in their study on the precision of ADP), (ii) the Tucker protocol (devised by Tucker et al.), and (iii) the protocol proposed in this study, which involves taking the median of triplicate trials.

Figure 1 displays Bland-Altman (BA) plots acquired for a single pair of trials (a), the Collins protocol (b), the Tucker protocol (c), and the median protocol proposed in this study (d). In Figure 1a, concerning single ADP trials (the protocol recommended by the instrument's manufacturer), the bias in the BA plots is slightly negative, and the value of zero is slightly outside of the associated 95% confidence interval. Therefore, when comparing the test and retest, the retest offers a greater estimation of the subject's adiposity, by about 0.3% body fat.

A comparison of all 4 panels of Figure 1 indicates that, the 95% interval of agreement is largest for single measurements, suggesting that methods including repeated trials are more reliable than individual ADP testing. Despite being more time-consuming, the Collins protocol was not superior to the Tucker one in terms of reliability (panels b and c). The median protocol provided the narrowest interval of agreement, as depicted in Figure 1d.

Individual FFM measurements showed a bias of around 0.2 kg, indicating that, on average, the retest generated greater FFM values compared to the initial test. The 95% interval of agreement was widest for individual tests, followed by the Collins and Tucker protocols, and the median protocol. Repeated trials led to a reduced bias compared to single measurements. Furthermore, in the majority of cases, the 95% confidence interval included zero. The level of bias was greater for women compared to males, particularly for assessments of body volume (BV) and %BF.

The width of the 95% interval of agreement for the median protocol was 3.36 %BF for women and 3.3 %BF for men, suggesting a somewhat higher precision in males compared to women. In regard to the variables FFM, BV, and resting metabolic rate (RMR), the 95% interval of agreement was narrower for women when considering both single measurements and multiple trials protocols.



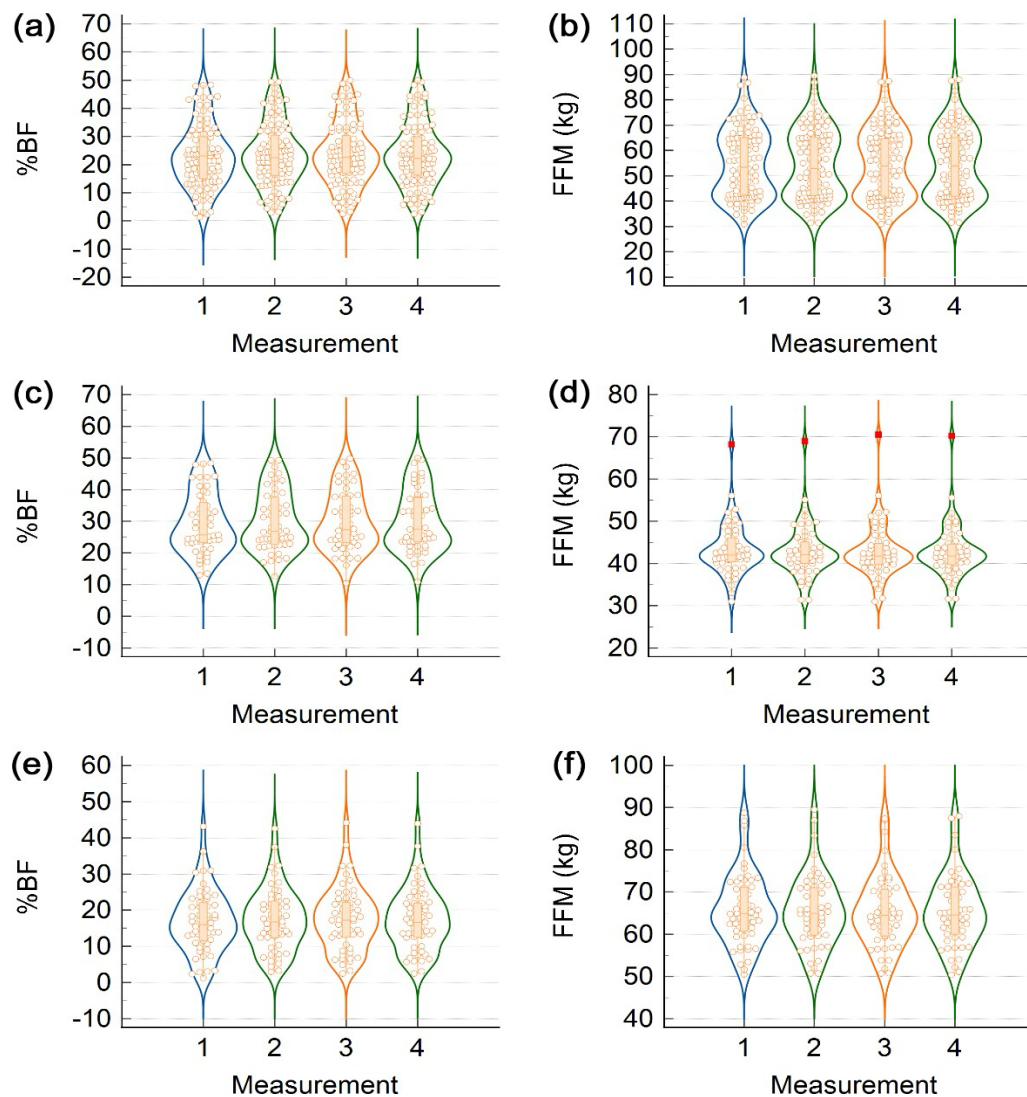
**Figure 1. Bland-Altman (BA) analysis of the agreement between test - retest results of single ADP trials and 3 repeated trials protocols. The plots of differences vs. means of two %BF are showed as determined by: (a) individual trials, (b) Collins protocol, (c) Tucker protocol, and (d) median protocol. In each panel, the thick, solid, horizontal line depicts the bias (the mean value of the differences), whereas the thin, red dotted, horizontal lines represent the 95% limits of agreement (bias  $\pm$  standard deviation of the differences). Vertical error bars represent the 95% confidence intervals (95% CI) of the corresponding quantities.**

The absolute and relative test-retest measures of reliability validate the conclusion derived from the BA analysis, indicating that methods including repeated trials offer superior reliability

compared to single measurements. Out of all the protocols, the median procedure had the highest level of reliability, whereas the protocol developed by Collins and McCarthy was only slightly superior to the one developed by Tucker et al., although it involved more triplicate trials.

## 2. Learning effects can have a substantial impact on body composition measurements using air-displacement plethysmography

The second study was purported to assess the impact of the learning effects on the reliability of the BC assessment using the ADP technique in a group of 105 adults (54 M, 51 F).

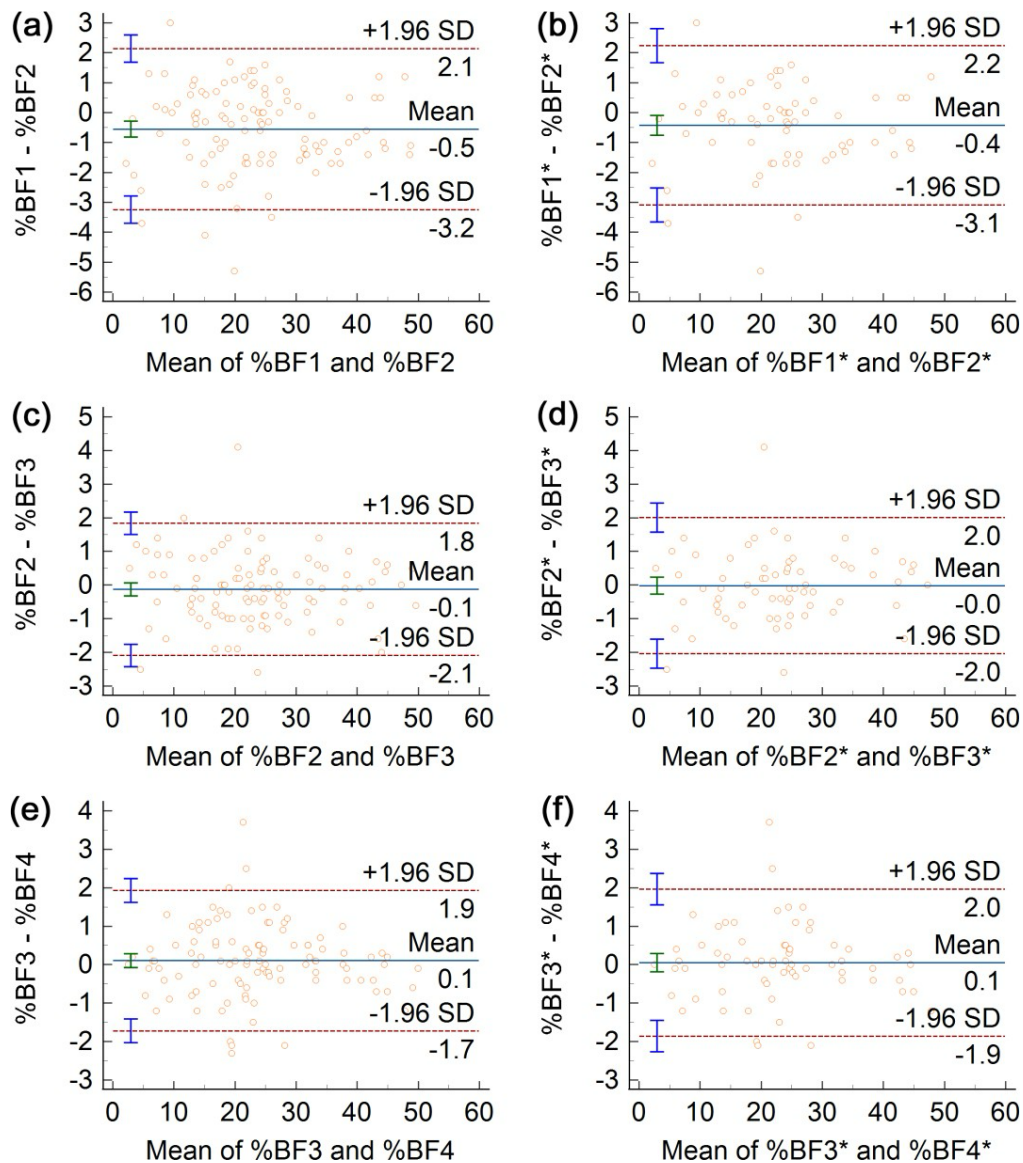


**Figure 2. Violin plots of data recorded in four successive ADP tests. Individual panels represent: (a) %BF of all subjects, (b) FFM of all subjects, (c) %BF of women, (d) FFM of women, (e) %BF of men, and (f) FFM of men.**

The BC data obtained from four consecutive ADP measurements are represented by the violin plots displayed in Figure 2. Upon analyzing the complete dataset, it was noticed that the

%BF exhibited a single peak (unimodal) distribution (Figure 2a), whereas the FFM showed a bimodal distribution (Figure 2b).

Both the %BF and FFM exhibited distributions that were characterized by a single peak for each sex, as shown in Figure 2c-f. However, the modes of the probability density functions were found to be displaced in women compared to males. Notably, there were outliers (data points that fell outside the whiskers) for both %BF and FFM in each sex individually (Figure 2d-f), but not in the full dataset as a whole (Figure 2a,b).



**Figure 3.** BA plots of differences vs. means of %BF obtained in pairs of consecutive trials. The outcomes of the first two trials are compared in (a) and (b), trials 2 and 3 are compared in (c) and (d), and trials 3 and 4 are compared in (e) and (f). Panels (a), (c), and (e) refer to the entire data set, whereas (b), (d), and (f) do not include participants evaluated at the beginning of the day of measurements (an asterisk, \*, labels body composition variables of subjects who did not start off the testing day).

Although there were no statistically significant differences between the results of consecutive trials, the BA plots in Figure 3 show that the first trial differs from the following ones by 0.4 %BF to 0.6 %BF, resulting in a slight underestimation of the subject's adiposity.

The horizontal line labeled "Mean" in Figure 3a represents a bias of -0.5 %BF. This means that, on average, the second trial generated body fat values that were 0.5 %BF higher compared to the first trial. Furthermore, this bias is statistically significant since, unlike in Figure 3c and 3e, the value of zero is not included within the 95% CI of the bias, which is visually depicted as a green error bar in Figure 3a.

In Figure 3, panels b, d, and f, individuals who were the first to arrive (21 women and 17 males) were eliminated. The resemblance between panels (a,b), (c,d), and (e,f) indicates that the notable prejudice detected between the initial two trials cannot be attributed to warm-up concerns of the BOD POD during the initial quality check.

The study of FFM assessments using the BA method reveals a substantial bias of 0.4 kg between the first and second trial, with trial 1 overestimating FFM compared to trial 2. However, there is a minor bias for pairings (2,3) and (3,4). In addition, the difference in BV measures was most pronounced for pair (1,2), -70 mL, whereas it was negligible for the other pairs.

Test-retest reliability indices of single ADP tests indicate that, once the subject becomes familiar with the test process, the reliability of individual trials is similar to that of multiple measurement protocols (e.g. Tucker or median). Regardless of gender, successive tests showed greater agreement, likely due to the individuals being familiar with the test procedure and subsequently stabilizing their breathing pattern.

The reliability indices, both absolute and relative, became leveled off after the second pair of trials and reached a level similar to that of multiple-assessment methods. As such, the present research proposes that, particularly for inexperienced participants, the initial attempt should be regarded as a practice examination. Subsequently, the outcome of the second trial may be deemed acceptable if it deviates by no more than 3 %BF from the initial trial. If the deviation exceeds this limit, a third test is required, and the subject's body composition variables can be determined using a repeated trials protocol.

### **3. The A-mode ultrasound prediction formulas Jackson-Pollock-3 (JP3) and Jackson-Pollock-7 (JP7) have the same level of accuracy in measuring the body fat percentage of male athletes, while Parillo-9 (P9) and Biceps-1 (B1) overestimate their level of body fat**

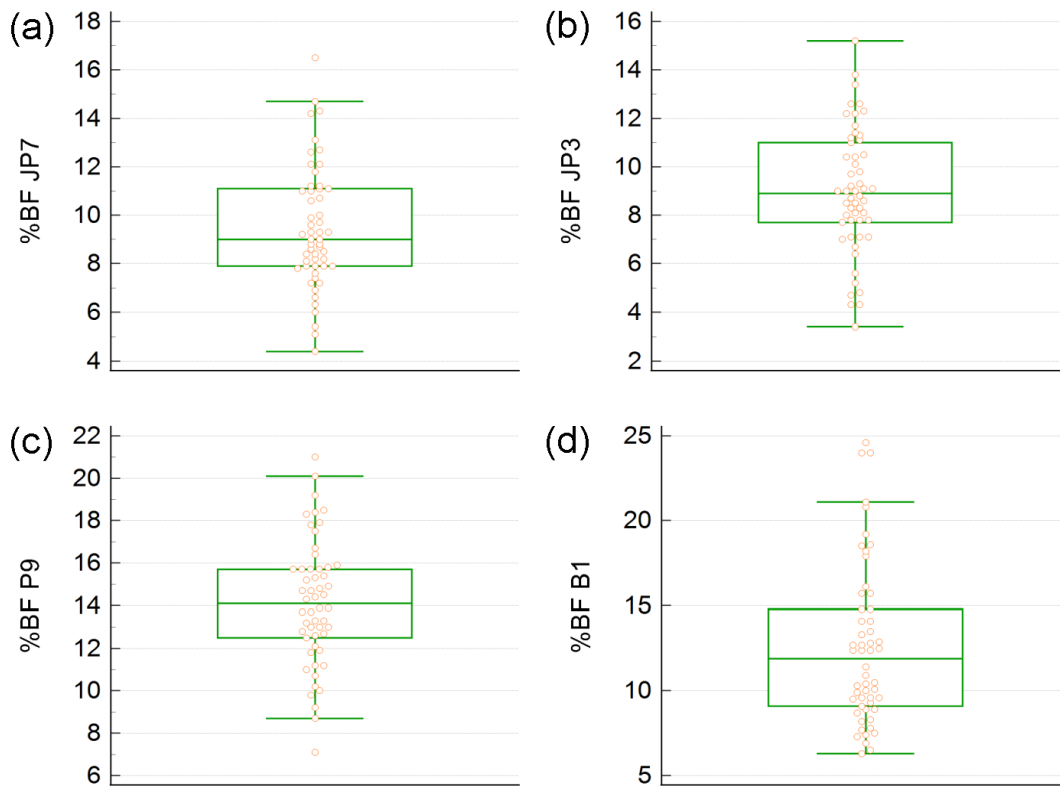
The third study was designed to assess the accuracy of several formulas implemented in the software of a portable A-mode ultrasonography instrument for the calculation of %BF based on subcutaneous fat layer thickness in a group of 54 adult male elite soccer players.

The results of the third study average %BF provided by JP7 and JP3 show a significant level of consistency and are distinct from those produced by P9 and B1.

Figure 4 displays the box plots of %BF values provided by the JP7 (a), JP3 (b), P9 (c), and B1 (d) formulas. The medians, indicated by the horizontal lines dividing the boxes, reveal similarity between JP7 and JP3. Notably, JP3 had the fewest outliers (Figure 4b), despite a prior investigation on a sample of the general population that found it to be less reliable than JP7. Among the formulas tested, B1 was the least reliable, as it produced the highest number of outliers

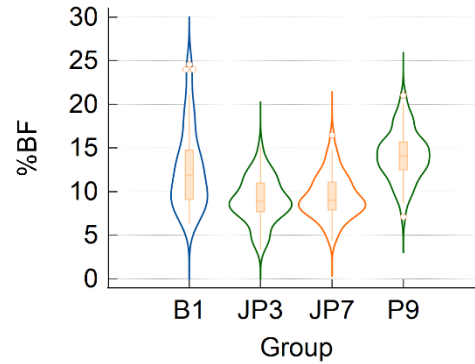


and the widest interquartile interval (defined as the difference between the third and first quartiles) (Figure 4d).



**Figure 4. Box plots of %BF assessed by A-mode ultrasound using four different prediction formulas implemented in the BodyView ProFit software shipped with the BodyMetrix instrument.**

The violin plots in Figure 5 represent the probability density functions of the four datasets. Figure 5 displays the distributions of the %BF values obtained from the JP3 and JP7 formulas. The distributions of %BF values obtained from the JP3 and JP7 formulas are remarkably similar to each other, but distinct from the distributions obtained from the other two formulas. Figure 5 displays deviations from the typical bell-shaped pattern of the probability density function of the normal distribution.



**Figure 5. Violin plots of %BF values of the investigated group of 54 soccer players, obtained using A-mode ultrasound measurements of the subcutaneous fat thickness at certain anatomical sites and the B1, JP3, JP7, and P9 formulas.**

The conclusions derived from the analysis of variance are supported also by Lin's concordance correlation coefficient (CCC), a metric ranging from 0-1 (with larger values indicating better agreement) that encompasses both precision and accuracy. The CCC between B1 and JP7 was 0.464, with a corresponding 95% CI of [0.328, 0.581]. The CCC between P9 and JP7 was 0.341, with a 95% CI of [0.238, 0.437]. Lastly, the CCC between JP3 and JP7 was 0.909, with a 95% CI of [0.850, 0.946].

While applying the Passing-Bablok regression analysis, when comparing JP3 to JP7, the intercept is -0.722 with a 95% CI of [-1.882, 0.316]. Given that this interval contains the value of 0, we can deduce that there are no systematic differences between the two approaches. When comparing P9 to JP7, the intercept is 2.784 with a 95% CI of [0.592, 4.254], which does not include 0. The slope is 1.227 with a 95% CI of [1.049, 1.462], which does not include 1. Therefore, the Passing-Bablok regression analysis shows both consistent and proportional differences between the %BF estimates provided by P9 and JP7. In the regression analysis comparing B1 and JP7, the intercept is -6.717 with a 95% CI of [-10.90, -3.007]. The slope is 2.056 with a 95% CI of [1.618, 2.500]. This interval is the widest among all three.

Based on the BA analysis, JP3 barely underestimates the overall body adiposity of soccer players compared to JP7. On the other hand, P9 greatly overestimates the %BF, particularly in individuals with higher than usual %BF. The B1 formula shows good agreement with JP7 for extremely lean athletes, but increasingly diverges from JP7 for participants with higher levels of adiposity. The width of the 95% interval of agreement, the difference between the upper limit of agreement (ULA) and the lower limit of agreement (LLA) (ULA-LLA) is the narrowest for JP3 in comparison to JP7 (3.9 %BF), moderate for P9 in comparison to JP7 (5.8 %BF), and the widest for B1 in comparison to JP7 (12.8 %BF).

JP3 is preferable when considering the comfort of the subject and the duration of the test. On the other hand, JP7 is recommended when the most essential aspect is precision and the ultrasound equipment is being used in automatic mode. Surprisingly, the formula proposed by Parrillo for tracking body fat in bodybuilders, involving 9 anatomical sites, and, therefore, expected to provide high precision and a thorough mapping of subcutaneous fat deposits, it turned out to be inaccurate when it comes to predict global body fat percentage in male soccer players.

**4. Modifying skinfold equations by substituting each skinfold thickness (SKF) with the subcutaneous fat thickness (SF) measured by ultrasound at the same location, multiplied by the average value of the corresponding SKF/SF ratio demonstrated superior performance compared to the proprietary equations given in the BodyView Pro software, particularly for overweight and obese persons**

The fourth study aimed to evaluate the accuracy of %BF measurements with the USA technique using anthropometric prediction formulas adapted to estimate the amount of body fat from ultrasonographically measured subcutaneous fat layer thicknesses instead of skinfold thickness. The study was performed on a mixed group of 201 adults (107 M, 94 F).

We modified 33 anthropometric equations (15 for women and 18 for men, respectively) to calculate body density (D) or %BF using A-mode ultrasound-measured SFs instead of SKFs.

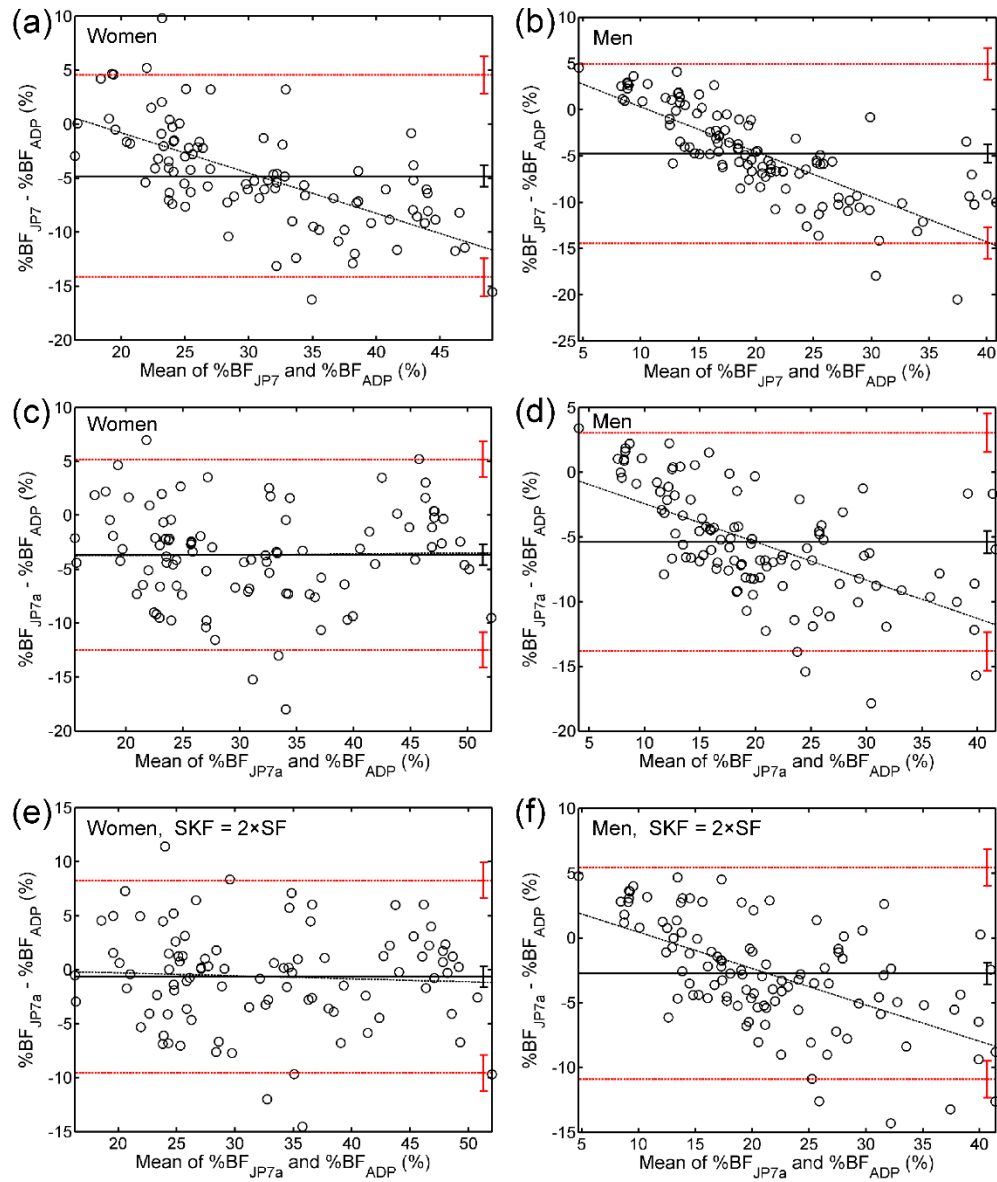
In order to represent D or %BF in terms of uncompressed subcutaneous adipose tissue thicknesses determined by A-mode US, we modified anthropometric formulas. This modification was based on the published values of the SKF/SF ratio at the specific sites that were studied. These values were derived by taking the average of the SKF and SF measurements taken by two investigators for both women and men. The ratios were then calculated separately for women and men, and the mean value was determined for each location. The modified formulas are referred to as, for example JP7a, with the last character representing "adapted".

For this investigation, A-mode ultrasound (US) and ADP tests were performed three times each, and then calculated the median of the three assessments for further analysis. Initially, we conducted a comparison between the JP7 formula used in BodyView and the 7-site Jackson and Pollock formula modified for A-mode US-derived data (JP7a). The BA plots depicted in Figure 6 illustrate the disparities between the %BF estimated using prediction formulae and the %BF measured through ADP.

Figure 6 demonstrates that the proprietary JP7 formula is not only a modified version of the comparable anthropometric formula. The JP7 formula exhibits a proportional bias toward females, as seen in Figure 6a. However, the JP7a formula does not exhibit this bias, independent of the proportional constants between SKFs and SFs, as depicted in Figure 6c and e. In males, the proportional bias was observed in both JP7 and JP7a, but the range of agreement was greater for JP7 (Figure 6b, d and f). Surprisingly, the bias was the least significant for JP7a while assuming that  $SKF = 2 \times SF$ .

Both men and women experienced the smallest standard error of estimate (SEE) when using the exclusive JP7 formula. The total error (TE), however, was the highest primarily due to the gradual underestimating of %BF in individuals with high levels of adiposity. A similar pattern was also noted for JP7a among men. Conversely, the JP7a method consistently underestimated body fat for women, with an average underestimation of 3.7 %BF (Figure 6c). This was due to the regression line having a slope close to 1. When SKF was equal to 2 times SF, there was a significant decrease in TE and a minimal change in SEE, regardless of gender.

Among the formulas tested, JP3 and JP7 outperformed all others in terms of SEE for women. However, some of the other formulas did provide a lower TE. Amongst men, the majority of optimized formulas exhibited a greater SEE compared to JP7. However, a few of these formulas shown superior TE in comparison to JP7. Significantly, B7a and L3a were comparable to JP7 in terms of the SEE and superior to JP7 in terms of the TE.



**Figure 6. BA analysis of %BF given by various forms of the 7-site Jackson and Pollock formula compared to ADP.**

While calculating Lin's concordance-correlation coefficient (CCC), among the females in our diverse sample, the majority of the adjusted formulae achieved a superior equilibrium between accuracy and precision compared to the widely-used proprietary formulas. Within our group of male participants, we observed that numerous modified equations exhibited a higher CCC compared to the JP3 and JP7 equations. Specifically, B7a and L3a outperformed JP3 and JP7 in this regard.

It should be noted that only J3a would gain an advantage by approximating the SKF as double the corresponding SF.

While generating the BA analysis of the most favorable formulas identified for men, it was found that the overall bias was rather low for L3a and L4a. However, all of the prediction formulas, except for JP3a, exhibited proportional bias, indicating that the accuracy of %BF provided by these formulas may be confined to specific ranges of body adiposity. Specifically, B7a and L4a were accurate for 15-20 %BF, L3a for 22-28 %BF, H2a for 10-15 %BF, and B1a for 25-35 %BF. To verify this, it is necessary to examine a larger sample and categorize the results based on %BF intervals.

The consistent bias indicated by JP3a suggests that increasing the %BF reported by JP3a by 4.2% would yield an accurate measurement of body fat content across a wide variety of body compositions. This aligns with the agreement interval of  $\pm 9.6$  %BF with ADP.

The proposed technique was applied on 33 anthropometric equations and assessed their precision in comparison to the ADP. While none of the derived formulae were considered valid alternatives to the ADP method, some of them demonstrated superior performance compared to the proprietary equations given in the BodyView Pro software, particularly for overweight and obese persons.

### III. CONCLUSIONS

1. Implementing repeated trials for body composition evaluation via the ADP method provided more reliability compared to the usual measurement procedure. Out of all the protocols, the median procedure demonstrated the highest level of reliability. Both genders were found to validate this result based on Bland-Altman analysis and several statistical measures of test-retest reliability. Consequently, by conducting multiple measurements, one can achieve a better precision in assessing body volume, body fat percentage, fat-free mass, and resting metabolic rate.

2. The learning effects can have a substantial impact on body composition measurements using the ADP method. No matter the gender, successive tests showed progressively greater agreement, likely due to the subjects being more and more familiar with the test procedure and subsequently stabilizing their breathing pattern. The reliability indices, both absolute and relative, stabilized after the second pair of trials and reached a level similar to that of multiple-assessment methods. This study suggests that, particularly for inexperienced participants, the initial ADP trial should be regarded as a practice examination. Subsequently, the outcome of the second trial may be deemed acceptable if it deviates by no more than 3% BF from the initial trial. If the deviation exceeds this limit, a third test is required, and the subject's body composition variables can be determined via a repeated trials protocol.

3. Analysis of 4 prediction formulas utilized in the BodyViewProFit software provided with the BodyMetrix A-mode ultrasound instrument showed that JP3 and JP7 have the same level of accuracy in measuring the body fat percentage of male soccer players. In contrast, P9 and B1 formulas overestimate their level of body fat in these athletes. JP3 is preferable when considering the comfort of the subject and the duration of the test. On the other hand, JP7 is recommended when the most essential aspect is precision and the ultrasound equipment is being used in automatic mode.

4. A technique was developed to convert an anthropometric formula that calculates %BF based on skinfold thicknesses into a model that estimates %BF using measurement of

subcutaneous fat thickness obtained by ultrasound. The skinfold equations were modified by substituting each SKF with the SF measured by ultrasound at the same location, multiplied by the average value of the corresponding SKF/SF ratio. The proposed approach was used on 33 anthropometric equations and their accuracy was assessed in comparison to the ADP method. While none of the derived formulae could be deemed valid alternative to the ADP method, some of them demonstrated superior performance compared to the proprietary equations given in the BodyView software, particularly for overweight and obese persons.

#### **IV. ORIGINAL CONTRIBUTIONS**

- Evaluation for the first time, of the ADP reliability in assessing body composition in the context of two multiple trials protocols proposed in the literature.
- Development of a new multiple trials ADP protocol, which provided a better reliability than the existing protocols.
- Demonstration of the fact that the results of ADP measurements are influenced by the learning effects. As such, it was shown that, at least in the case of a novice subject, the standard error of ADP measurements levels off starting with the second measurement; therefore, the first measurement should be regarded as a practice test.
- It was uncovered that, once the practice test is discarded, the precision of individual ADP tests is similar to that of multiple trials protocols.
- In A-mode US assessment of body fat percentage of male soccer players, it was shown that the 3-sites and the 7-sites Jackson and Pollock formula are equally accurate, but the 7-sites formula ensures a better precision;
- Identification of the fact that two popular formulas implemented in the software of the A-mode US instrument, Parillo-9 (P9) and Biceps-1 (B1), were found less accurate than the Jackson and Pollock formulas, since they overestimated the global body fat percentage in professional male soccer players.
- Proposal of a new method has been proposed to convert an anthropometric formula of body fat percentage computed from skinfold thicknesses into a formula that predicts body fat percentage from ultrasound-derived thicknesses of the uncompressed subcutaneous adipose tissue measured at the same anatomical locations.

#### **V. FUTURE RESEARCH DIRECTIONS**

- Further improvement of the accuracy of body composition assessment by combining several techniques and apply the multicompartiment models. The multi-frequency bioelectrical impedance analysis, or bioelectrical impedance spectroscopy could be used to determine the amount of water (total body water, TBW). Then, using ADP at its highest precision, body volume will be measured. Based on these results, the body composition of the subject will be described by Siri's 3C model.
- Further investigation of the accuracy of AUS relying on the 3C model as the reference technique.

- Besides substituting skinfolds with subcutaneous adipose tissue thicknesses multiplied by experimental values of their ratio, the constants involved in anthropometric formulas could also be modified to increase the accuracy of the formulas. To this end, global optimization algorithms will be used.
- Subcutaneous body fat estimates in elite athletes can be performed also by high-resolution B-mode ultrasound, as recommended by the Medical Commission of the International Olympic Committee. It involves a semi-automatic analysis of ultrasound images taken at 8 standard locations (different from the typical skinfold sites), which are known to provide clearly stratified ultrasound images. An interesting, still unsolved problem is to predict the total body fat content of the subject starting from US-derived subcutaneous fat thicknesses obtained at these standard sites.

## VI. SCIENTIFIC PUBLICATIONS

1. **Muntean P.**, Micloș-Balica M., Popa A., Neagu A., Neagu M. *Reliability of Repeated Trials Protocols for Body Composition Assessment by Air Displacement Plethysmography*, **International Journal of Environmental Research and Public Health**, 2021:18(20), 10693; **ISI Journal (IF – 3.390)**
2. **Muntean P.**, Popa A., Micloș-Balica M., Schick F., Munteanu O., Pupăzan V., Neagu A., Neagu M. *Learning Effects in Air Displacement Plethysmography*, **Life** 2023, 13, 1315. **ISI Journal (IF – 3.253)**
3. **Muntean P.**, Neagu M., Amăricăi E., Hărăguș H.G., Onofrei R.R., Neagu A. *Using A-Mode Ultrasound to Assess the Body Composition of Soccer Players: A Comparative Study of Prediction Formulas*, **Diagnostics** 2023, 13(4), 690. **ISI Journal (IF – 3.992)**
4. **Muntean P.**, Miclos-Balica M., Macavei G.A., Munteanu O., Neagu A., Neagu M. *Anthropometric formulas repurposed to predict body fat content from ultrasound measurements of subcutaneous fat thickness*, **Symmetry** 2024, 16(8), 962. **ISI journal (IF – 2.2)**