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Body Composition

**A COMPARISON OF BIOELECTRICAL IMPEDANCE AND NEAR-INFRARED
INTERACTANCE TO SKINFOLD MEASURES IN DETERMINING MINIMUM
WRESTLING WEIGHT IN COLLEGIATE WRESTLERS**

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ABSTRACT

A COMPARISON OF BIOELECTRICAL IMPEDANCE AND NEAR-INFRARED INTERACTANCE TO SKINFOLD MEASURES IN DETERMINING MINIMUM WRESTLING WEIGHT IN COLLEGIATE WRESTLERS. **Donald C. Diboll and Jeffrey K. Moffit. JEPonline. 2003;6(2):26-36.** The NCAA Wrestling Weight Certification Program (WWCP) requires minimum wrestling weight (MWW) at 5% body fat (euhydrated condition) be determined for all athletes. Only hydrodensitometry and skinfold measures (SF) are accepted by the WWCP to determine MWW, although other methods are potentially less costly and/or require less technical skill to perform. The purpose of this study was to determine if whole-body bioelectrical impedance (BIA) and near-infrared interactance (NIR) methods are comparable to the SF method in estimating MWWs. Twenty-five male division I collegiate wrestlers had MWWs determined under hydrated conditions via BIA (RJL Systems) using three different equations, NIR (Futrex), and the 3-site SF method accepted by the WWCP (criterion). Pearson correlations (r) indicate significant relationships between SF and both BIA (all equations) and NIR (r ranged from 0.978 to 0.921; $p < 0.001$), and standard errors of the estimates (SEE) were small (best BIA equation $SEE = 2.1$ kg; NIR $SEE = 2.8$ kg). However, limits of agreement (Bland-Altman plots) and total error measures, considered to be more appropriate for evaluating these comparisons, suggest both BIA and NIR MWWs, utilizing the equipment and prediction equations in this study, do not compare closely enough to SF MWWs to be considered suitable methods for the WWCP.

Key Words: NCAA Wrestling Weight Certification Program, Bland-Altman plots, total error

INTRODUCTION

Body composition is frequently used as one of several indicators of overall health fitness. Body composition is also used in some sports to profile fitness for athletic performance. In 1998, body composition assessment became a requirement for collegiate wrestling under changes to the National Collegiate Athletic Association (NCAA) Wrestling Rules. These changes were in response to the deaths of three student-athletes participating in improper weight-loss practices in preparation for weight class qualifications at the beginning of the 1997-

1998 NCAA competition season (1). The result of the changes is the development and implementation of the NCAA Wrestling Weight Certification Program (WWCP). Body weight and percent body fat (%BF) data, determined under hydrated conditions, are used to establish a minimum wrestling weight (MWW) at 5.0% body fat. Wrestlers can modify their body weight over a specified preseason training period to achieve a desired weight class, but they cannot compete at a weight below the MWW nor can they lose more than 1.5% body weight per week of the preseason training period (1).

There are numerous methods for estimating %BF, and thus MWW. The NCAA currently accepts only two methods of body composition analysis for its WWCP: hydrodensitometry, with direct measurement of residual lung volume; or 3-site skinfold (SF) measurement (triceps, subscapula, abdomen), utilizing the body density (Db) prediction equation of Lohman (2). Body density is then converted to %BF via the Brozek et al. equation (3), from which the MWW is derived. The overall weight certification program is designed to be cost-effective and user friendly. However, the cost effectiveness of hydrodensitometry is questionable, and both hydrodensitometry and the SF method require a skilled technician to perform the measurements. Either of these methods may be disadvantageous for wrestling programs at smaller institutions which do not have access to a certified athletic trainer proficiently skilled in either of these methods, or to an exercise physiology or related academic program with adequate laboratory facilities and/or faculty skilled in body composition assessment.

Two other methods of body composition measurement that are relatively inexpensive (compared to hydrodensitometry) and easy to perform are bioelectrical impedance (BIA) and near-infrared interactance (NIR). Previous research supports the validity of using BIA (4, 5) and NIR (6, 7) to determine %BF in the wrestling population. Regarding the determination of MWW with respect to Thorland et al.'s (8) total error (TE) criterion of approximately 2.0 kg, other research questions the use of BIA (9, 10) and NIR (10) compared to the SF method. It should be noted that all of these studies, with the exception of one (5), utilized high school wrestlers and a slightly modified version of the Lohman SF prediction equation to derive their conclusions. The utilization of BIA and NIR should be re-evaluated with respect to collegiate wrestlers and the WWCP. Therefore, the purpose of this study was to compare the MWW estimations of two commercially available systems, one BIA and one NIR, to that of the 3-site SF method currently accepted by the WWCP.

METHODS

Subjects

Twenty-five Division I collegiate male wrestlers participated in this study. Subject participation was required for anthropometric measures, hydration status, and SF measures as part of team body composition and weigh-in procedures. Participation in other aspects of the study (BIA and NIR measurements) was voluntary. Additionally, subjects volunteered their respective data for this research. This study was approved by the head wrestling coach and the university's Institution Review Board/Human Subjects Review Committee.

Procedures

All testing procedures took place in the campus wrestling facility in one afternoon during September as part of the WWCP (11). Testing time for each subject was approximately 20 min. Subjects were weighed on a certified weight scale (PS-6600 Take-A-Weigh Portable Wrestling Scale, Befour Inc., Saukville, WI) and height was determined on a standard physician's scale stadiometer (Cardinal[®] Detecto, Webb City, MO). Hydration status was determined by urine specific gravity (U_{sg}) using a flint glass urinometer with a shot-weighted hydrometer float. All participating subjects were considered adequately hydrated based on the U_{sg} standard of ≤ 1.020 (11).

Skinfold measures were performed by grasping the subcutaneous adipose tissue at three sites on the right side of the body (middle triceps, subscapula, and abdomen) using Lange Skinfold Calipers (Beta Technology, Inc., Cambridge MD). Measures were repeated at each site 3 times in an alternating fashion (i.e., triceps, subscapula, abdomen), with the median score being utilized for further calculations. Body density was estimated using the Lohman equation (2): $Db = [1.0982 - (\sum \text{skinfold} \times 0.000815)] + [(\sum \text{skinfold})^2 \times 0.00000084]$, and %BF was estimated using the Brozek et al. equation (3): $\%BF = [(4.57/Db) - 4.142] \times 100$.

Bioelectrical Impedance measurements were performed using the RJL Quantum X Body Composition Analyzer (RJL Systems, Clinton Township, MI). All measures were performed supine, with the skin of the right hand and right foot exposed and cleaned with alcohol. Two electrodes placed on the dorsal surface of the right hand (detecting electrode just distal to the level of the ulnar head; signal electrode on the first phalanx of the third digit) and two on the dorsal surface of the right foot (detecting electrode just distal to the malleoli; signal electrode on the base of the second digit). The system utilizes an alternating 50 KHz current, from which it measures resistance (R) and reactance (Xc) in ohms. All calibration and measurement procedures were performed as indicated in the manufacturer's operation manual. Three different BIA equations were utilized to estimate fat free mass (FFM). In all equations, the R and Xc data, along with subject anthropometric data, were inserted into the respective equations for calculations. Equation 1 (BIA-1) is a general equation for males utilized by the RJL Cyprus Body Composition Analysis software (RJL Systems, Clinton Township, MI). This specific equation (12) is as follows: $FFM \text{ (kg)} = 0.50[Ht^{1.48}/Z^{0.55} \times 1.0/1.21] + 0.42(BM) + 0.49$, where Ht is body height (cm), Z is impedance ($Z = \sqrt{R^2 + Xc^2}$), and BM is body mass (kg). Equation 2 (BIA-2), an equation that was validated on high school wrestlers (4), is as follows: $FFM \text{ (kg)} = 1.949 + 0.701(BM) + 0.186(Ht^2/R)$. Equation 3 (BIA-3), an equation that was evaluated on male and female athletes (13), is as follows: $FFM \text{ (kg)} = 0.734(Ht^2/R) + 0.116(BM) + 0.096(Xc) - 3.152$ (this equation is modified and reduced to the form that is specific to males).

Near-infrared interactance was performed using a Futrex 5000Ai (Futrex, Inc., Gaithersburg, MD). All measures were performed with each subject seated with the right forearm supported on a table, positioning the elbow at a 90° angle. Placement of the NIR probe and light shield was on the middle of the anterior aspect of the right biceps brachii. All calibration and measurement procedures were performed as indicated in the manufacturer's operation manual. Exercise history data required for input into the Futrex system were standardized for all subjects to reflect the routine of the wrestling team conditioning program. The system measures optical density (light absorbed versus reflected) of the underlying tissue in the biceps brachii region at 938 nm and 948 nm wavelengths. The Futrex system incorporates the optical density data into a generalized adult prediction equation from which it calculates %BF and FFM.

Once %BF and FFM estimates were obtained, MWWs, based on 5% BF, were calculated from the following equations: $MWW = FFM/0.95$ (11); $FFM = BM - (BM \times \%BF \times 0.01)$.

Statistical Analyses

All of the following statistical procedures were applied to the MWW estimations. A one-way analysis of variance (ANOVA) was performed to detect significant differences between MWW estimations from the various measurement methods. In the remaining statistical procedures, skinfold served as the criterion method, while BIA-1, BIA-2, BIA-3 or NIR served as the prediction method. Pearson product moment correlation coefficients (r), coefficients of determination (r²), and standard errors of the estimates (SEE) were calculated to determine the strength of relationship between estimations from these methods. Statistical significance for

ANOVA and correlation procedures was established at the alpha level of $p < .05$. Other variables used to describe the comparison of methods include difference in means ($\bar{D}\bar{X}$), where $\bar{D}\bar{X} = \bar{X}$ criterion MWW - \bar{X} predicted MWW, difference in standard deviations (DSD), where $DSD = SD$ criterion MWW - SD predicted MWW, and total error (TE), where $TE = \sqrt{\sum (\text{criterion MWW} - \text{predicted MWW})^2 / N}$ (14). Finally, differences between MWWs for each subject (i.e., individual criterion MWW - individual predicted MWW) were plotted against each subject's \bar{X} MWW of the same two methods [i.e., \bar{X} (individual criterion MWW + individual predicted MWW)] to explore any difference in agreement between measurement methods, as described by Bland and Altman (15). The solid line on each plot represents the mean of the differences (\bar{X} diff), where \bar{X} diff = $\bar{X}(\text{criterion MWW} - \text{predicted MWW})$ and is numerically equivalent to the $\bar{D}\bar{X}$. The dashed lines represent the upper and lower limits of agreement, where the limits = \bar{X} diff \pm 2 SD diff, with SD diff being the standard deviation of the differences [SD diff = $SD(\text{criterion MWW} - \text{predicted MWW})$]. Standard deviation of the difference is fundamentally and numerically different from DSD.

RESULTS

The physical characteristics of the subjects are presented in Table 1. Estimated MWWs ($\bar{X} \pm SE$) for SF, BIA (equations 1-3), and NIR are indicated in Figure 1. Based on ANOVA results, no statistical differences ($p=0.250$) were detected between MWW estimations. The results of the statistical analyses comparing the prediction methods (BIA-1, BIA-2, BIA-3, NIR) to the criterion method (SF) are summarized in Table 2. Pearson product moment correlation coefficients reveal a significant relationship ($p<0.001$) between SF and all three of the BIA equations as well as NIR, with BIA-1 having the strongest correlation ($r=0.978$) and BIA-3 with the weakest ($r=0.921$). These results are depicted in Figure 2 (A-D). The strength of relationship, as indicated by the r^2 (% of variability explained between measures) ranged from 95.6% (SF and BIA-1) to 84.8% (SF and BIA-3). As indicated by the $\bar{D}\bar{X}$, BIA-3 overestimated MWW by the greatest amount (3.9 kg) and BIA-2 underestimated MWW by almost as much (-3.1 kg), whereas NIR was the closest to the \bar{X} of SF MWW. The DSD for BIA-3 (0.2 kg) was the smallest compared to BIA-2 (-5.1 kg), which was the largest. The SEE ranged from 2.1 kg for BIA-1 to 3.9 kg for BIA-3. Total error ranged from 3.4 kg for BIA-1 to 6.4 kg for BIA-2. Finally, the Bland-Altman plots [Figure 3 (A-D)] indicate BIA-1 had the best agreement with SF (narrowest margins between limits of agreement), whereas BIA-2 had the worst agreement with SF (widest margins).

Table 1. Physical characteristics of subjects (N = 25)

Variable	$\bar{X} \pm SD$	Range
Age (yr)	20 \pm 2	17 - 23
Height (cm)	169.5 \pm 8.0	148.6 - 185.4
Weight (kg)	75.2 \pm 17.7	54.5 - 121.6

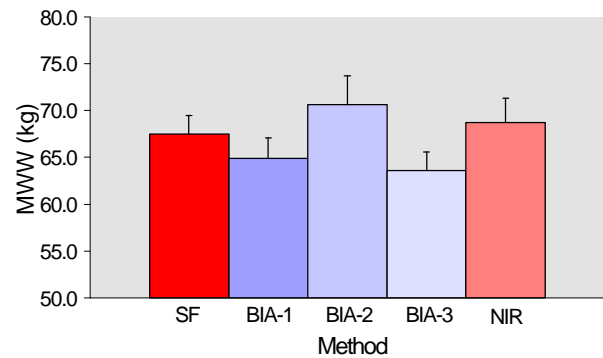


Figure 1. Estimated minimum wrestling weights (MWW) from each measurement method. Bars represent mean \pm SE. No significant differences ($p=0.250$) were detected between MWWs.

Table 2. Statistical analysis data comparing BIA and NIR methods to the SF method

Method	r	r^2 (%)	SEE (kg)	$\bar{D}\bar{X}$ (kg)	DSD (kg)	TE (kg)
BIA-1	0.978*	95.6	2.1	2.6	-0.8	3.4
BIA-2	0.973*	94.7	2.3	-3.1	-5.1	6.4
BIA-3	0.921*	84.8	3.9	3.9	0.2	5.4
NIR	0.960*	92.2	2.8	-1.2	-2.8	4.3

All comparison data are based on MWW determined from each method. * denotes a significant correlation ($p<0.001$) between SF and the respective method.

Additionally, it can be noted that BIA-2 (Figure 3B) and NIR (Figure 3D) overestimated MWW with increases in average MWW (x-axis of plots).

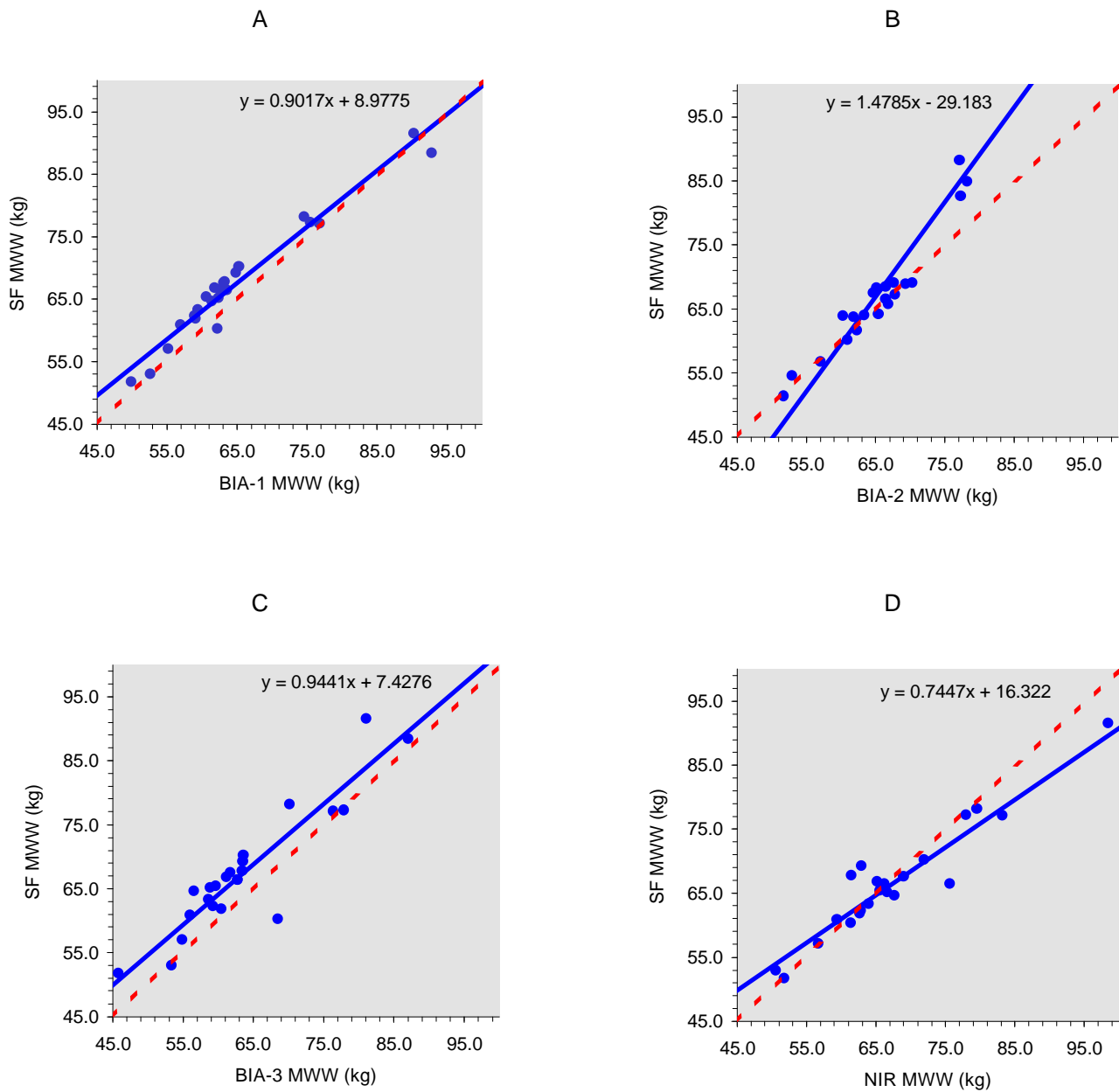


Figure 2. Scatterplots of SF MWW to BIA-1 (A), BIA-2 (B), BIA-3 (C), and NIR (D). The solid line is the regression line (line equation also displayed); the dashed line is the line of identity.

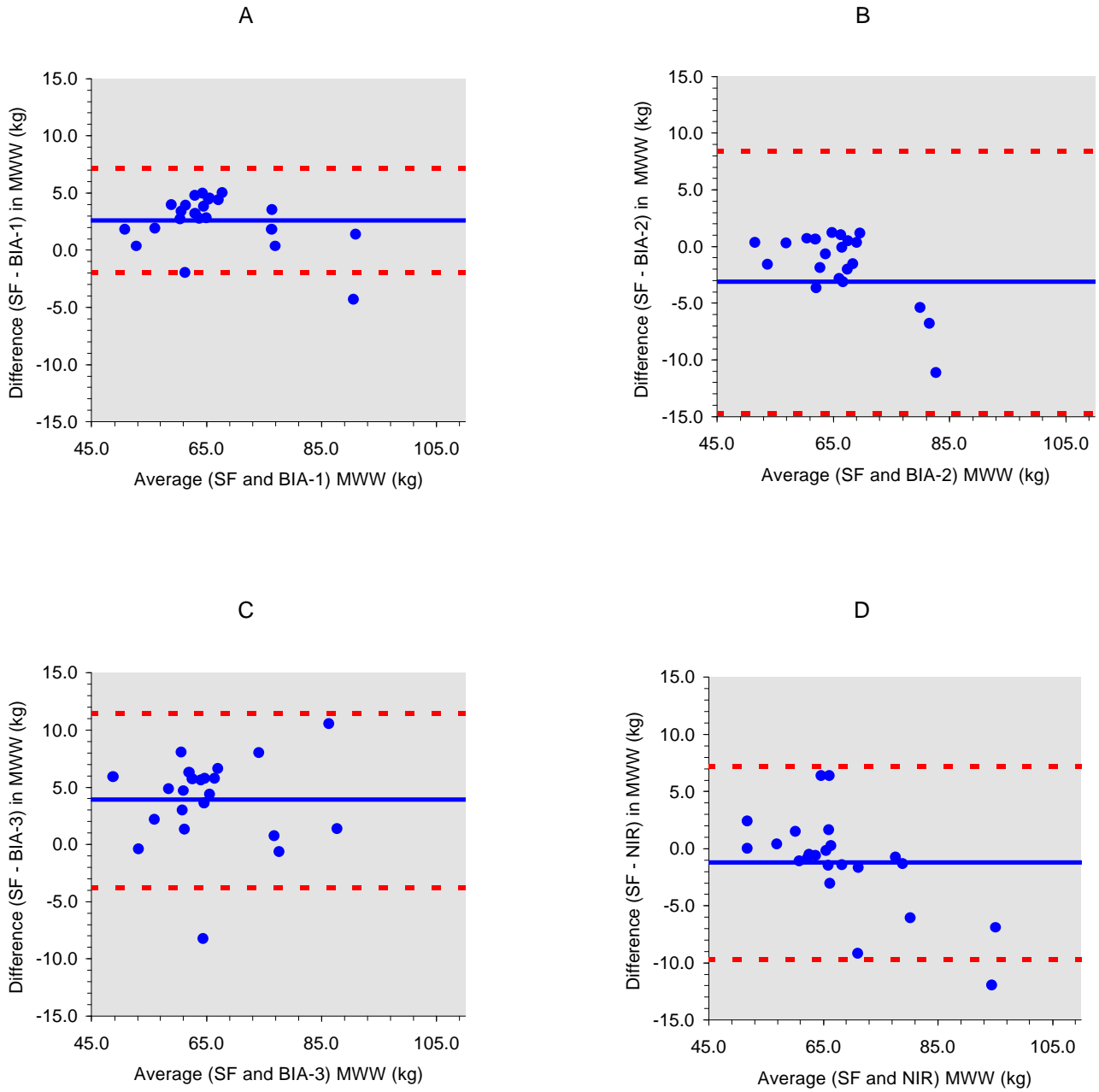


Figure 3. Bland-Altman plots comparing SF MWW against BIA-1 (A), BIA-2 (B), BIA-3 (C), and NIR (D). The x-axis represents the mean of both SF MWW and the prediction method’s MWW for each subject; the y-axis represents the difference between SF MWW and the prediction method’s MWW for each subject. Solid lines represent the mean of the differences; dashed lines represent the upper and lower limits of agreement (mean diff ± 2 SD diff). See text for further explanation.

DISCUSSION

Several statistical procedures were utilized to compare the SF method approved by the WWCP to commercially available BIA and NIR technologies (RJL and Futrex, respectively). The r and r^2 results suggest that there is a strong relationship between the SF method and both BIA (all three equations) and NIR, with the BIA method using equation BIA-1 being slightly better. However, it is generally recommended to consider the SEE along with the r and r^2 in determining whether one method of body composition estimation is a suitable substitute for a criterion method (17). By determining the SEE for FFM, which is used in the direct calculation of MWW ($MWW = FFM/0.95$), these values can then be evaluated against standards for body composition estimation SEE values. According to these established standards (18), the FFM SEE for BIA-1 (2.0 kg) and BIA-2 (2.2 kg) are considered ideal, the SEE for NIR (2.7 kg) is considered excellent to very good, and the SEE for BIA-3 (3.7 kg) is considered good to fairly good. These results suggest that both BIA and NIR are potentially suitable in determining MWW criteria for collegiate wrestlers.

Other results are not as supportive of BIA and NIR use in the WWCP. Ideally, the $\overline{D\bar{X}}$ between the predicted and criterion MWW would be 0.0 kg, indicating no difference in the average predicted versus criterion MWW. The best BIA equation (BIA-1) overestimated MWW by 2.6 kg, while the other two equations overestimated or underestimated by an additional 0.5 to 1.3 kg. However, NIR underestimated by only 1.2 kg. With respect to DSD, this value would also be 0.0 kg in an ideal comparison, as this would indicate the variability of the predicted values is the same as the variability of the criterion values (14). The DSD was best for BIA-3 (0.2 kg), with the other DSD values ranging from -0.8 kg (BIA-1) to -5.1 kg (BIA-2). Note that the DSD value for BIA-3 is a positive value, indicating that this equation generated a smaller variability (compared to SF) than did the other two BIA equations and NIR. Based on variability (DSD), BIA, using equations 1 or 3, provided the best results, but adjustments in MWW values to compensate for the large $\overline{D\bar{X}}$ would be required to make the values comparable to SF. This assumes that repeated comparisons on different subjects from the same population would result in similar $\overline{D\bar{X}}$ and DSD values for BIA-1 and BIA-3.

The Bland-Altman plots (Figure 3) describe the agreement (how close one measure compares to another) in MWW estimates between body composition methods. This is suggested to be a more useful indication compared to r , r^2 , and SEE as to whether one method can be a valid substitution for another (15, 16). Correlation data are misleading in that a large r value indicates a strong relationship, but measures can be related without having close agreement (15). Graphically, this would look like a regression line that does not coincide with the line of identity. Also, small SEE values are misleading in that the scatter of predicted vs. criterion values can be tight around the regression line, but again, the regression line may not coincide with the line of identity (14, 15). Finally, the numerical nature of MWW values makes them somewhat homogeneous compared to, for example, %BF values, therefore improving the r value (10). As described previously in this paper, the solid line on the Bland-Altman plots represents the \overline{X} diff in MWWs for SF and either BIA-1, BIA-2, BIA-3 or NIR, and the dashed lines represent the limits of agreement (± 2 SD diff). The limits of agreement represent the magnitude of variability in which 95% of naturally occurring differences fall. Once determined, the limits can be evaluated as to whether they are too large to be acceptable for practical application of the prediction method, in this case BIA (using one of three equations) or NIR. Perfect agreement would have a SD diff of 0.0 kg, indicating that, for each subject measured, the prediction and criterion methods generated the same MWW. For the purposes of evaluating BIA and NIR against SF with respect to MWW, a reasonable guide for the maximum acceptable limits of agreement would be the range of body weights within the NCAA

wrestling competition weight classes (i.e., the difference between the lowest and highest body weight within each weight class). The overall purpose of the WWCP is to accurately place wrestlers in appropriate weight classes for competition. The smallest, and most common, range of body weights within the various weight classes is 3.6 kg (1). Although the plots in Figure 3 indicate considerably better agreement between SF and BIA-1 compared to SF and either of the other BIA equations or NIR, the limits of agreement for BIA-1 are ± 4.6 kg, or a range of 9.2 kg between limits. This is 2.6 times greater than the 3.6-kg range within many of the weight classes. This would suggest that neither BIA (utilizing any of the equations) nor NIR is an acceptable substitution for SF in determining MWW for collegiate wrestlers. It should be noted that the weakness of the Bland-Altman plot is using the average of the criterion and prediction measure to represent the true measure for each MWW. Since the true value of each MWW is not known, the average MWW from the criterion and prediction method is considered the best estimate of the true value (15).

Previous research refers to TE as the best variable to determine the accuracy of a prediction method compared to a criterion method (2, 10, 14). This is due to the fact that TE reflects the dispersion of measures around the line of identity (14). Thorland et al. (8) determined that an accuracy of lean body mass measurement approximating 2.0 kg is a good expectation of SF equations. This standard has been applied to other body composition techniques to determine accuracy of prediction in high school wrestlers (9, 10). In the present study, the smallest TE values resulted from BIA-1 (3.4 kg), while the TE for the other BIA equations and NIR ranged from 4.3 kg (NIR) to 6.4 kg (BIA-2). Neither technique is close to the TE recommendation of 2.0 kg, once again indicating a concern for substituting BIA and NIR for SF in determining MWW.

Choices in whole-body BIA systems are currently available (e.g., RJL; Biodynamics Corporation, Seattle, WA). This may seem advantageous with respect to accessibility to BIA systems, however different systems will produce different measurement results, thus serving as a source of measurement error (17). Obviously, this complicates the issue of comparing BIA methods to other accepted methods of body composition assessment. Recently, various models of a lower body BIA system that uses leg-to-leg impedance measures have become available commercially (Tanita.bz, a division of Itin Scale Company, Inc.). One of these models was evaluated in collegiate wrestlers (5). This study suggests agreement between SF and leg-to-leg BIA methods based on Bland-Altman plots. However, the comparisons were made on %BF measures and not MWWs. Therefore, the reported results cannot be evaluated on the criteria discussed in this paper. Arm-to-arm impedance systems are also available (Omron Healthcare, Inc., Vernon Hills, IL; American Weights and Measures, Rancho Santa Fe, CA), but little research exists with these systems, and we are not aware of any on the wrestling population. These segmental BIA systems, some of which include an "athlete mode" for measurement, are appealing due to their even simpler operation compared to whole-body systems. However site-specific lean tissue development observed in athletes is problematic for BIA in general (19), and it would seem that this is even more problematic for segmental BIA systems given that the distribution of lean mass differs between types of athletes. This makes the possibility of developing generalized athlete equations seem questionable for segmental BIA systems.

Currently, Futrex, Inc. is the only manufacturer of commercial systems that perform %BF estimates using NIR. The Futrex 5000 series has a newer model (5000A/WL), which has a high school wrestler mode that utilizes multiple measurement sites and population specific prediction equations. This removes the necessity for exercise history data as part of the body composition prediction, unlike the older 5000Ai model used in the present study. The manufacturer claims this newer model improves its %BF prediction in high school wrestlers.

This is supported by a recent study (7) in which multiple measurement site NIR equations were validated to hydrodensitometry in a population of high school wrestlers. Cross validation results, based on measures of predictive error for MWW (the equivalent of TE), were very good compared to hydrodensitometry (~ 2.2 kg) and were slightly better than SF using the Lohman equation modified for high school wrestlers. The newer Futrex model utilizes similar prediction equations and may result in improved accuracy of MWW estimations in collegiate wrestlers. This NIR system should be evaluated in the collegiate wrestler population.

Several factors need to be considered in evaluating the application of BIA and NIR technologies to the estimation of MWWs. Hydration status is a major factor that affects the accuracy of BIA (17). In the present study, all subjects were determined to be euhydrated based on U_{sg} measures. However, the use of U_{sg} as a measure of hydration status has been questioned (20), along with the standard of ≤ 1.020 (21). The degree to which changes in hydration status, especially small changes, affect BIA accuracy, and the best methods to accurately measure hydration status need to be determined. Also, strict guidelines regarding food and fluid intake, exercise, urination, and diuretic use prior to BIA measurement must be followed in order to insure measurement accuracy (22). This is a potential source of error in the present study as it was not possible to specifically determine that these guidelines were observed. The monitoring of these pre-measurement guidelines presents a potential problem with BIA use in any collegiate wrestling population, thus introducing another factor to consider when evaluating the possible application of BIA technology in the WWCP. It should be noted that the RJL system measurement guidelines do not mention requirements regarding urination and fluid/food intake prior to measurement. If these are truly not an issue for the RJL system, then the accuracy of the BIA measures in the present study is likely good given that the other criteria were unlikely violated. The potential for error associated with subject compliance to pre-testing procedures may be less of an issue for NIR compared to BIA, a point that Futrex, Inc. emphasizes for its system. However, it is suggested that hydration status and skin color are potential sources of measurement error using NIR technology (17). These factors' affect on NIR body composition assessment should be further evaluated.

The use of a so-called "gold standard" reference method, such as hydrodensitometry, in the present study would have been desirable as this would better match the research protocols of other studies cited in this paper, thus allowing a better comparison of results. Unfortunately, this was not possible due to equipment and time limitations. However, given that the SF method is accepted by the WWCP and is likely the preferred method to determine MWWs by many wrestling programs, the comparison of BIA and NIR methods to SF has merit. It is also important to keep in mind that there will be some measurement error with all present body composition reference methods, which can result in as much as 50% of the prediction error of other methods compared to the respective reference method (22). Thus there is no true "gold standard," and it is theoretically possible that body composition techniques that have been compared to accepted standards such as hydrodensitometry might actually be more accurate in assessing body composition than has been documented. Given the purpose of this study, it is more appropriate to indicate that we were testing the agreement between BIA and NIR methods to the SF method (15).

SUMMARY

The present study compared a commercial BIA system (RJL Quantum X Body Composition Analyzer), using three different BIA equations, and a commercial NIR system (Futrex 5000Ai) to the 3-site skinfold technique accepted by the WWCP in the estimation of MWWs of collegiate wrestlers. Pearson correlations suggest

significant relationships between SF and both BIA and NIR methods, and SEEs for BIA using two of the equations are considered ideal, while the SEE for NIR is considered excellent to very good. However, other statistical methods such as Bland-Altman plots and measures of TE, which are considered to be more useful in comparing body composition assessment methods, suggest that BIA and NIR, utilizing the equipment and prediction equations in the present study, are not suitable methods of MWW estimation in the WWCP. Given the overall ease (minimal technical skill required) and speed of operation with BIA and NIR technologies, they would be useful and desirable alternatives in the WWCP, provided valid MWW measures could be obtained. Therefore, further study of these methods should be performed to evaluate newer BIA and NIR technologies, including comparing these measures to those from the most accurate body composition measurement methods available. Additionally, factors such as subject pre-measurement criteria adherence should be carefully evaluated to determine their impact on MWW estimations.

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