# Evaluation of Multifrequency Bioelectrical Impedance Analysis in Assessing Body Composition of Wrestlers

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**ABSTRACT**

UTTER, A. C. and P. G. LAMBETH. Evaluation of Multifrequency Bioelectrical Impedance Analysis in Assessing Body Composition of Wrestlers. *Med. Sci. Sports Exerc.*, Vol. 42, No. 2, pp. 361–367, 2010. **Purpose**: To evaluate the accuracy of multifrequency bioelectrical impedance analysis (MFBIA) in assessing fat-free mass (FFM) in comparison with hydrostatic weighing (HW) and skinfolds (SK) in high school wrestlers in a hydrated state. **Methods**: Body composition was determined by MFBIA, HW, and three-site SK in 72 high school wrestlers (mean ± SD; age = 15.3 ± 1.4 yr, height = 1.71 ± 0.08 m, body mass = 67.3 ± 13.4 kg). Hydration state was quantified by evaluating urine specific gravity. **Results**: There were no significant differences for estimated FFM between MFBIA (57.2 ± 9.5 kg) and HW (57.0 ±10.1 kg) or SK (56.4 ± 8.8 kg). The SEE for FFM with HW as the reference method were 2.73 kg for MFBIA and 2.66 kg for SK. Correlations were found for FFM between HW and MFBIA ($r = 0.96$, $P < 0.001$) and between HW and SK ($r = 0.97$, $P < 0.001$). A systematic bias was found for MFBIA because the difference between MFBIA and HW correlated with the FFM average of the two methods ($r = -0.22$, $P < 0.001$). A bias was also seen between SK and HW and correlated with the FFM average ($r = -0.47$, $P < 0.001$). **Conclusions**: This study demonstrates that MFBIA provides similar estimates of FFM when compared with HW in a heterogeneous high school wrestling population during a hydrated state. MFBIA is an attractive assessment tool, easy to use, and may be considered as an alternative field-based method of estimating the FFM of high school wrestlers.
**Key Words**: WRESTLING, FAT-FREE MASS, MINIMUM WRESTLING WEIGHT, BODY FAT, BIOELECTRICAL IMPEDANCE

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According to the National Federation of State High School Associations' annual survey, there were 259,688 wrestlers participating on more than 10,000 teams during the 2007–2008 wrestling season (www.nfhs.org). This is accompanied by a 6.8% increase in the number of teams, causing the national total of high school wrestling teams to escalate to more than 10,000 (www.nfhs.org). An increase in the growth of the sport coupled with the recent implementation of a mandatory wrestling weight certification program (WCP) intensifies the need for a practical and valid field-based method of body composition testing among the wrestling community. The WCP enforced by the National Federation of State High School Associations came about to minimize unhealthy and dangerous weight loss practices of high school wrestlers. After observing the effectiveness of the National Collegiate Athletic Association's (NCAA) implementation of a WCP (22), the goal was for every high school in the United States to have executed a WCP by the 2006–2007 wrestling season. The NCAA mandated an obligatory WCP 10 yr ago (during the 1998–1999 season) after the deaths of three collegiate-level wrestlers within a 5-wk period in 1997 (6,10).

The protocol for assessing a minimum wrestling weight (MWW) uses the athlete's body mass, body composition, and urine specific gravity. The measured fat-free mass (FFM) is then used to calculate each wrestler's MWW at 5% body fat for the collegiate level and 7% body fat for the high school level (20). Although methods of assessing hydration and body composition have been established by the NCAA, at the high school–level individual, state high school athletic associations are responsible for determining their own acceptable methods. Skinfolds (SK) have long been seen as a valid and practical method for body composition assessment in high school wrestling programs (20,27); however, this method does impart some practical limitations. These include having access to enough trained assessors within a defined geographical region, technical error that may be present because of caliper performance, within-tester and between-tester differences in SK compressibility, and the inability to palpate the fat–muscle interface (12,16,17). Variations in SK compression have been

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Submitted for publication March 2009.
Accepted for publication June 2009.

0195-9131/10/4202-0361/0
MEDICINE & SCIENCE IN SPORTS & EXERCISE®

DOI: 10.1249/MSS.0b013e3181b2c8b4

attributed to factors such as subcutaneous fat thickness, state of hydration, and the distribution of fibrous tissue and blood vessels (12). State high school athletic associations are receptive to methods that are equivalent to the SK measurements in ease of use, accessibility, cost, validity, and reliability. Other methods to estimate body composition include dual x-ray absorptiometry (DXA), hydrostatic weighing (HW), single-frequency leg-to-leg bioelectrical impedance analysis (SFBIA), ultrasound, air displacement plethysmography (ADP), and near-infrared light interaction (1,8,12,18,19,26,28,29,31,32). Access to and cost of both DXA and HW pose practical limitations for state high school athletic associations in using these methods when assessing body composition of high school wrestlers. Multifrequency bioelectrical impedance analysis (MFBIA) has also been demonstrated to be an alternate method to measure body composition (7,15,23–25).

Whereas SFBIA uses only one frequency (50 kHz) to measure impedance via surface electrodes on the hand and foot, a leg-to-leg MFBIA incorporates multiple frequencies, measuring impedance at 0, 1, 5, 50, 100, and 200 to 500 kHz (15). By introducing different frequencies, FFM, total body water (TBW), intracellular water, and extracellular water can be estimated (15). MFBIA is based on the theory that lower frequencies (<50 kHz) are conducted within the extracellular compartment and that higher frequencies, defined as greater than 200 kHz, can measure intracellular space by passing through the cell membrane. Intracellular and extracellular water can be measured separately because of the changing direction of electrical impulses when the frequency of the signal is changed (24). Previous research on the validation of MFBIA to estimate TBW and acute changes in TBW have demonstrated positive results (11,14,33). The estimated amount of total body water is based on the constant relationship that there is 73.2% water in lean body mass(34). Therefore, an accurate estimate of TBW will improve the validity of FFM measurements and subsequent body fat values.

Multifrequency bioelectrical impedance analysis is relatively new with its introduction in the late 1980s; an earlier study done in 1989 determined that MFBIA failed to estimate TBW accurately in the trunk, where impedance is relatively low (4). Pietrobelli et al. (23) conducted a study that demonstrated that MFBIA was superior to SFBIA in estimating FFM when compared with the DXA. That investigation evaluated 49 healthy, nonexercising males and females without serious medical conditions. Results demonstrated significant correlations between DXA and MFBIA of arm skeletal muscle $R^2$ = 0.91, SEE = 0.57 (kilograms of FFM), $P$ < 0.01. Previous research has also demonstrated that arm-to-leg SFBIA (21) and leg-to-leg SFBIA (31) are acceptable methods for establishing minimal weight in interscholastic wrestlers.

In another more recent investigation, 40 male subjects from a subpopulation of a weight loss/maintenance study underwent HW, DXA, and segmental MFBIA (5, 50, 250, and 500 kHz) for comparison of FFM, body fat percentage (%BF), and fat mass (24). The results from that study demonstrated a high correlation between MFBIA with DXA ($r$ = 0.94, $P$ < 0.01) and HW ($r$ = 0.94, $P$ < 0.01), suggesting that MFBIA is an acceptable method for assessing segmental distribution of FFM (24).

To our knowledge, no previous studies have investigated the validity of MFBIA in determining body composition in high school wrestlers. Therefore, the purpose of this study was to evaluate the accuracy of MFBIA (5, 50, and 500 kHz) method for measuring FFM when compared with HW and SK in high school wrestlers. SK measures were included for comparative purposes because SK measures are commonly used to assess body composition in high school wrestlers. We hypothesized that there would be no significant differences between MFBIA or SK and HW for the estimation of FFM.

## METHODS

**Subjects.** Subjects were male interscholastic wrestlers from three North Carolina high schools ($N$ = 72). The athletes ranged in age from 12 to 18 yr, height from 1.4 to 1.9 m, and body mass from 39.6 to 99.8 kg. Please refer to Table 1, which includes the mean (±SD) values for age, height, and body mass in addition to the range values mentioned. Subjects were representative of all the high school weight categories with the exception of heavyweight. The heavyweight wrestlers were excluded because they typically do not have weight loss concerns. Subjects and parents gave written and informed consent, and the experimental procedures were approved by the institutional review board for investigations at Appalachian State University (ASU) and were in compliance with the American College of Sports Medicine policies for use of human subjects.

**Testing schedule.** All body composition assessments occurred in the Human Performance Laboratory at the ASU. All measurements were made early in the preseason (October–November) and during the morning hours (8:00 a.m. to 12:00 p.m.) of Saturday. Height was determined using a stadiometer, and body mass was determined using a calibrated digital scale. All body composition measurements were performed in a hydrated state. Baseline hydration was established by obtaining a urine sample for

TABLE 1. Subject characteristics ($N$ = 72).

| Characteristics | Mean ± SD |
|---|---|
| Age (yr) | 15.3 ± 1.4 |
| Height (m) | 1.71 ± 0.08 |
| Body mass (kg) | 67.3 ± 13.4 |
| Wrestling experience (yr) | 3.3 ± 2.5 |
| Urine specific gravity | 1.01 ± 0.01 |
| Residual lung volume (L) | 1.45 ± 0.4 |
| % body fat (HW) | 14.7 ± 7.0 |

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measurement of urine specific gravity ($U_{sg}$) using a handheld optical refractometer (Atago; National Microscope Exchange, Redmond, WA). All subjects were considered to be adequately hydrated based on an $U_{sg} \leq 1.025$ g·mL$^{-1}$ (3). During each testing session, the subject's body composition was evaluated by three different methods in the following succession: 1) SF analysis, 2) MFBIA, and 3) HW.

**SK testing.** SK measures were done with Lange SK calipers at three sites: triceps, subscapular, and abdomen. The SK calipers were calibrated to 10 g·mm$^{-2}$ by the manufacturer. SK were measured three times at each site to the nearest 0.5 mm with the mean value recorded. All SK measurements were taken on the right side of the body. The triceps SK was measured vertically in the midline of the posterior aspect of the upper arm, midway between the lateral acromion process of the scapula and the inferior margin of the olecranon process of the ulna. The subscapular SK was measured as a diagonal fold just below the inferior angle of the scapular toward the right side of the body. The abdomen SK was raised vertically on the right side of abdomen 3 cm from the midpoint of the umbilicus (16). There was only one SK assessor who is highly trained and experienced in measuring SK of wrestlers with a test–retest reliability of consistently $r > 0.90$. Body density ($D_b$) was determined from the three SK measures using the prediction equation $D_b$ = [1.0982 − (sum SK) × 0.000815] + [(sum SK)$^2$ × 0.00000084] validated by Lohman (16). %BF was determined from $D_b$ using the equation of Brozek et al. (5). This %BF equation was also used with the $D_b$ determined from HW.

**HW.** $D_b$ was also determined by HW. HW was performed in a custom-built stainless steel tank, with three load cells interfaced to a computer (Exertech Fitness Equipment, Dresbach, MN). During HW, the subject was asked to expel as much air as possible from his lungs during complete submersion. After 5–10 trials, the highest underwater weight that could be repeated within 100 g by the subject was averaged and recorded. After completion of the HW trials, residual volume was measured (outside the tank) by the oxygen dilution method using the procedures described by Wilmore et al. (35). A minimum of two trials were completed with the two closest readings within 10% being averaged to calculate residual volume.

**MFBIA.** MFBIA measurements were determined using the InBody 520 (Biospace Co., Beverly Hills, CA). Subjects were measured for MFBIA standing erect and fully hydrated. The InBody 520 body fat analyzer measures impedance across both legs, arms, and the trunk via multiple frequencies of 5, 50, and 500 kHz. The system's eight electrodes are in the form of footpads mounted on the surface of a platform scale and in handheld pads in handles extending out from the machine's body. Each footpad is divided in half so that the anterior and posterior portions form two separate electrodes. Each handle of the machine has two separate electrodes as well, one in contact with the thumb and the other in contact with the palm. These electrodes are connected to the current and voltage supply of the device. Impedance and body mass are automatically measured, and the subject's height and age are manually entered into the system. The device is regulated by an internal microprocessor that measures impedance from each body segment in a particular order and regulates the varying frequencies. Segmental impedance, TBW, extracellular water, intracellular water, and body mass are all measured simultaneously as the subject's bare feet and palm and thumbs make pressure contact with the electrodes and digital scale. FFM was calculated using the equations supplied by the manufacturer.

**Statistical analysis.** Multiple paired-sample $t$-tests with Bonferroni adjustment ($P < 0.025$) were performed to examine body composition differences. Values are expressed as means ± SD. To assess the agreement in FFM measured by MFBIA and SK versus HW, linear regression and Bland–Altman analyses were conducted. Linear regression analyses were performed with FFM by HW as the dependent variable to determine whether the regression line differed significantly from the line of identity (slope = 1, intercept = 0). In the Bland–Altman plots, bias was calculated as the mean difference between methods, and the 95% limits of agreement were calculated as the bias ± 2SD of the differences between methods (2).

The SEE obtained from the linear regression model and the prediction error (PE) representing the average deviation of individual variables from the line of identity ($y = x$) were also used to compare FFM measurement by MFBIA and HW (13). For all tests, statistical significance was accepted at $P < 0.05$.

## RESULTS

The characteristics of the study subjects are presented in Table 1. The sample consisted of 72 high school wrestlers who were moderately experienced, with an average of 3.29 yr of wrestling experience. Table 2 presents the FFM data (mean ± SD) and the relation between MFBIA and SK to HW for the sample. There was a strong correlation ($r = 0.96$ and $r = 0.97$) and no significant differences in mean FFM predicted by MFBIA (57.2 ± 9.5) or SK (56.4 ± 8.8) and the criterion HW (57.0 ± 10.1).

Figures 1 and 2 illustrate the regression analysis when HW is the dependent variable ($y$-axis) and the prediction method is the independent variable ($x$-axis). Normal distribution of the data was confirmed by evaluating the skewness and kurtosis. A good SEE and high adjusted $R^2$

TABLE 2. Comparison of FFM between MFBIA and SK with HW ($N$ = 72).

| Method | FFM (kg) | $R$ | MD (kg) | SEE (kg) | PE (kg) |
|---|---|---|---|---|---|
| HW | 57.0 ± 10.1 | | | | |
| SK | 56.4 ± 8.8 | 0.97 | −0.6 ± 2.8 | 2.66 | 2.89 |
| MFBIA | 57.2 ± 9.5 | 0.96 | 0.2 ± 2.7 | 2.73 | 2.73 |

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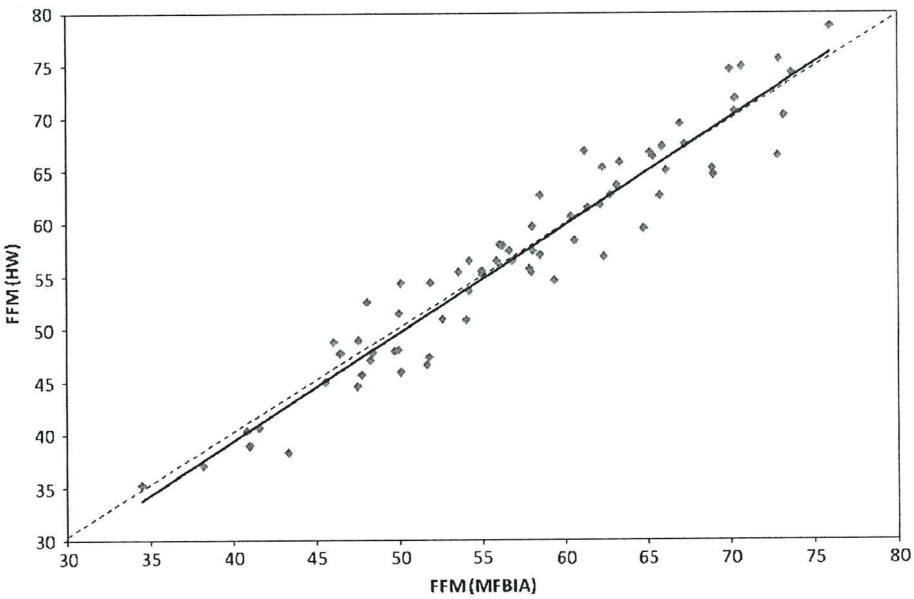


**FIGURE 1—Comparison of FFM determined by HW and MFBIA in high school wrestlers. Linear regression ($y = 1.0245x - 1.6124$, adjusted $R^2 = 0.93$, SEE = 2.73 kg, $P < 0.001$). *Solid line* indicates line of best fit. *Dashed line* indicates line of identity.**



resulted from both MFBIA and SK compared with the criterion HW. Small nonsignificant mean differences were found between the methods in estimating FFM: (MFBIA − HW = 0.2 ± 2.7 kg) and (SK − HW = −0.6 ± 2.8 kg).

To evaluate systematic bias, Figures 3 and 4 illustrate the Bland–Altman plot of the difference between FFM measured by MFBIA or SK and HW versus the average FFM by the two methods. The regression lines of the Bland–Altman plots indicated a significant negative correlation for both MFBIA ($r = -0.22$, $P < 0.001$) and SK ($r = -0.47$, $P < 0.001$).

## DISCUSSION

Results from this investigation demonstrated that the MFBIA (InBody 520) system estimates FFM within an

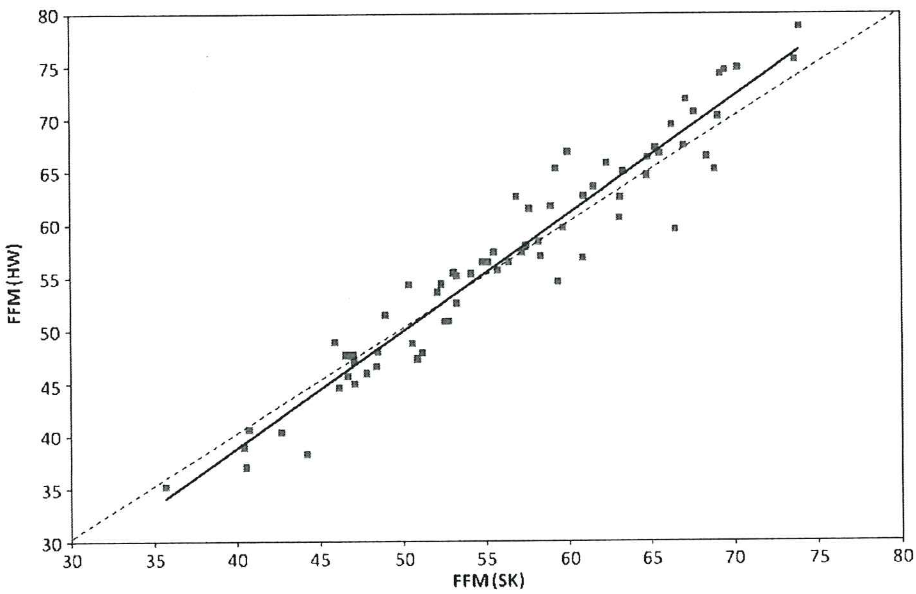


**FIGURE 2—Comparison of FFM determined by HW and SK analysis in high school wrestlers. Linear regression ($y = 1.11x - 5.5883$, adjusted $R^2 = 0.94$, SEE = 2.66 kg, $P < 0.001$). *Solid line* indicates line of best fit. *Dashed line* indicates line of identity.**

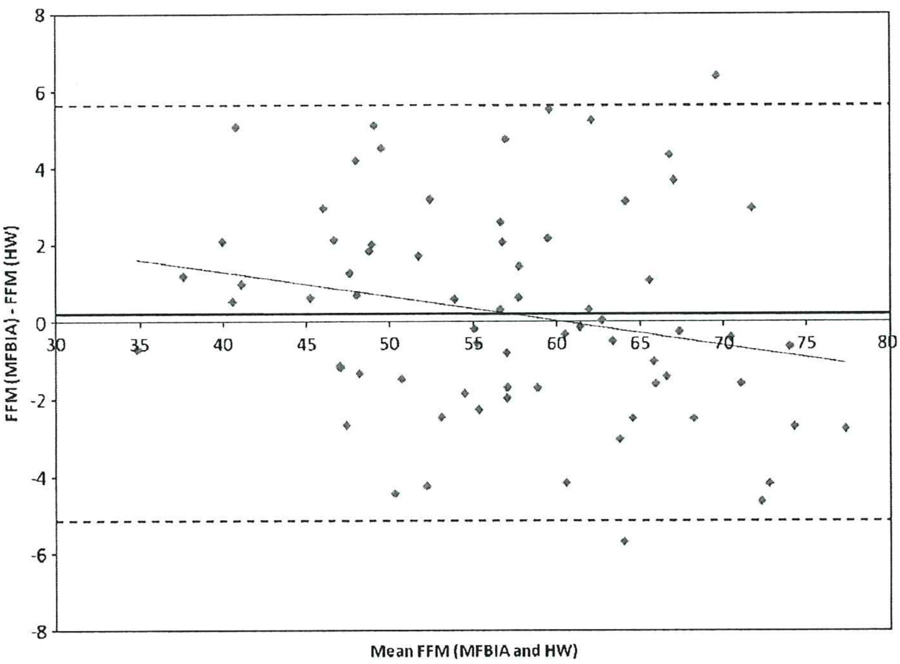


**FIGURE 3**—**Bland–Altman plot of the difference between FFM measured by HW and MFBIA. The** ***light solid line*** **indicates line of best fit, the** ***heavy solid line*** **indicates the mean difference, and the** ***dotted lines*** **(mean difference ± 2SD) indicate upper and lower 95% limits of agreement.**



acceptable range when compared with HW in high school wrestlers. There were no significant differences in mean FFM predicted by MFBIA and the criterion HW. The SEE and PE values of FFM were in the "very good" range (2.73 kg) (13). Please refer to Table 2 for the SEE and PE values. When examining systematic bias using the Bland–Altman plot, a significant correlation was found between the difference of FFM measured by MFBIA and HW versus the average FFM by the two methods. Therefore, across the body mass range, there was a systematic bias to overestimate FFM of wrestlers in the lighter weight classes when using MFBIA and to underestimate FFM of those in the

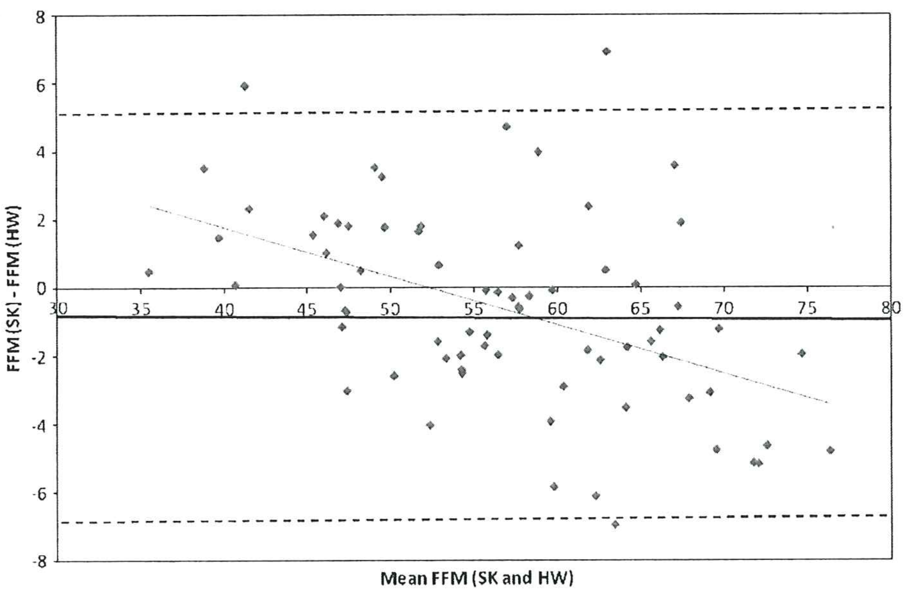


**FIGURE 4**—**Bland–Altman plot of the difference between FFM measured by HW and SK. The** ***light solid line*** **indicates line of best fit, the** ***heavy solid line*** **indicates the mean difference, and the** ***dotted lines*** **(mean difference ± 2SD) indicate upper and lower 95% limits of agreement.**

upper weight classes when using MFBIA (Fig. 3). Interestingly, a similar significant negative correlation and subsequent systematic bias was also found for SK when compared with HW within this cohort (Fig. 4).

This is the first investigation to compare estimations of FFM from the MFBIA (InBody 520; Biospace Co.) system to HW in heterogeneous high school wrestling population. The size of the sample studied and its physical characteristics make it a representative sample of high school wrestlers (22,31). Therefore, results from the present investigation may be of value concerning wrestling WCP established by state high school athletic associations who are considering other methods to assess body composition and MWW. The SEE value for MFBIA (2.73 kg) found in the present study is comparable to other field-based measures of body composition in wrestlers: 1.72–1.97 kg for SK (8,31), 2.3 kg for ultrasound (30), and less than for SFBIA (3.5 kg) (9,31). In practical terms, the results of this study demonstrated that MFBIA predicted FFM within 2.73 kg (6.0 lb) 68% of the time and within 5.48 kg (12.0 lb) 95% of the time. The average amount of weight between high school weight classes varies from 2.27 to 11.79 kg (5–26 lb) excluding heavyweight. MFBIA compares slightly better than SFBIA, another field-based measure that predicts FFM within 3.64 kg (8.0 lb) 68% of the time and within 7.3 kg (16.0 lb) 95% of the time in a sample of 129 high school wrestlers (31). In addition, a newer technology, ultrasound, predicted FFM within 2.31 kg (5.0 lb) 68% of the time and within 4.5 kg (10 lb) 95% of the time in a sample of 70 high school wrestlers (30). In the present study, when examining the MWW as determined by the criterion HW results demonstrated that 40% and 39% of the subjects were correctly classified when using MFBIA and SK, respectively. Although HW, ADP, and DXA have been considered the criterion standard for minimal wrestling weight assessment, these are clearly not practical for use when testing a large cohort of wrestlers. Because wrestling is the only sport in the United States that mandates body composition measurement before competition coupled with an increase in participation, assessment and validation of new technologies are clearly warranted. Choosing an appropriate method to assess body composition becomes an important objective of the health care provider and the state high school athletic associations. When state high school athletic associations determine which body composition method(s) to use when implementing a wrestling WCP, the following factors should be evaluated: 1) accuracy and precision (validity), 2) cost, 3) competitive equity, 4) practicality, 5) ease of use and administration, and 6) safety.

Results of the present investigation are consistent with previous research evaluating MFBIA in other populations. Salmi (24) investigated 40 male subjects from a subpopulation of participants in a weight loss maintenance study, ranging in body mass index from 24.9 to 40.7 kg·m$^{-2}$ and age from 36 to 53 yr. In that study, a significant correlation of FM ($r$ = 0.94), FFM ($r$ = 0.88), and %BF ($r$ = 0.88) between DXA and MFBIA was found. Pietrobelli et al. (23) compared the segmental skeletal muscle from MFBIA, in which a skeletal muscle prediction equation was developed, with that of DXA in 49 healthy Caucasian subjects older 20 yr. The results demonstrated that the correlation ($R^2$ = 0.88) was greater at higher frequency (>300 Hz) for the leg muscle versus any frequency <300 Hz in which variance was significantly lower ($R^2 \leq 0.84$). In a study of 15 healthy, active men (%BF = 15.6 ± 5.1%) aged 19–25 yr, Stahn et al. (25) measured the muscle volume of the arm and leg using magnetic resonance imaging and MFBIA. Their findings demonstrated that MFBIA was beneficial in estimating lower limb muscle volume of healthy, active adult men producing a mean nonsignificant underestimation of less than 0.5% at both 50 and 500 Hz when comparing magnetic resonance imaging and MFBIA. Considering that previous research with MFBIA has been completed on nonathletic samples, future validation research is clearly warranted in both other wrestling populations (i.e., collegiate or international) and/or other sport populations in which body composition assessment is deemed important.

When evaluating the Bland–Altman plots for FFM with MFBIA and SK, a systematic bias was found for both methods. The systematic bias found for MFBIA and SK in the present study and previous investigations (30,31) suggests that "bias" should be included and evaluated as an outcome variable in future validation studies concerning body composition assessment techniques in wrestlers.

This study demonstrated that FFM values measured by the MFBIA (InBody 520) system were not statistically different when compared with values obtained by HW in a representative high school wrestling population during a hydrated state, and therefore, this method should be considered as an alternative field-based method for determining the minimum weight for wrestlers. As newer technologies to assess body composition are carefully evaluated, one must consider that any field-based method to assess body composition may introduce biological and technical error that will affect the precision of FFM estimation at the individual level. Therefore, caution and careful interpretation of results (including an option for an appeal process) should be a vital component of a wrestling WCP. MFBIA has several advantages: it does not require a high degree of technical skill, making it easy to use; it is safe; it provides simultaneous measures of body mass, body composition, and TBW in a short period; results are instantaneous; and the device is portable. These advantages may make MFBIA attractive to educational institutions that may not have access to trained anthropometrists, HW, ADP, and DXA and to address concerns that have been expressed by coaches, officials, and athletic trainers who question the results of SK testing performed by someone who may not be completely objective or impartial. Pretest guidelines to ensure normal hydration status must be followed to minimize measurement error when using the MFBIA method.

This work was funded by Biospace Co., Beverly Hills, CA. The results of the present study do not constitute endorsement of any product by the authors, ASU, or the American College of Sports Medicine.

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