Evaluation of Air Displacement for Assessing Body Composition of Collegiate Wrestlers

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ABSTRACT

UTTER, A. C., F. L. GOSS, P. D. SWAN, G. S. HARRIS, R. J. ROBERTSON, and G. A. TRONE. Evaluation of Air Displacement for Assessing Body Composition of Collegiate Wrestlers. Med. Sci. Sports Exerc., Vol. 35, No. 3, pp. 500–505, 2003. Purpose: To evaluate the accuracy of air displacement plethysmography (ADP) by using the BOD POD® in comparison with hydrostatic weighing (HW) in a collegiate wrestling population in hydrated and acutely dehydrated states. Methods: Body composition was determined by ADP, HW, and three-site skinfolds (SK) in 66 NCAA Division I collegiate wrestlers before and after acute dehydration (2.6% reduction in body mass). For all methods, body density (Db) was converted to percent body fat (%BF) by using the Brozek equation for Euro-Americans and the Schutte equation for African-Americans. Results: There were no significant differences between ADP and HW for Db, %BF, and fat-free mass (FFM) in either the hydrated or dehydrated states. The standard errors of the estimate for %BF estimated from ADP with HW as the reference method were 2.12% (hydrated) and 2.16% (dehydrated); prediction errors were 2.35% (hydrated) and 2.49% (dehydrated). Bland-Altman plots of Db and %BF showed no systematic bias, and 64 out 66 subjects fell within the 95% limits of agreement (mean difference ± 2 SD) for both variables. For SK, %BF was significantly higher than HW in both the hydrated and dehydrated state. All methods (ADP, HW, and SK) showed a significant decrease in FFM from the hydrated to the dehydrated state. Conclusions: This study demonstrates that the BOD POD® air displacement method provides similar estimates of Db, %BF, and FFM when compared with HW in a heterogeneous collegiate wrestling population during hydrated and acutely dehydrated states. Pretest guidelines to ensure normal hydration status before body composition assessment using any method must be followed to minimize measurement error in %BF. Key Words: WRESTLING, BODY FAT, BOD POD, DEHYDRATION

As of the 1998–99 wrestling season, the National Collegiate Athletic Association (NCAA) has implemented a wrestling weight certification program (WCP) with the intention of minimizing unhealthy weight loss practices and increasing safe participation of student-athletes in the sport (6). The WCP mandates that each NCAA member institution have a qualified individual conduct an initial weight assessment of its wrestlers during the beginning of each wrestling season by using body weight, body composition, and specific gravity of urine (Usg). A figure consisting of the wrestler’s fat-free mass (FFM) plus 5% body fat (%BF) is then used to establish a minimum wrestling weight. Currently, the NCAA has established that either hydrostatic weighing (HW) with measured residual volume or skinfolds (SK) are the only acceptable methods for determining minimum wrestling weight. In addition, the National Federation of State High School Associations (NFHS) has made a recent recommendation that state high school athletic associations should have a wrestling WCP in place by the year 2004 that will include a body composition and hydration assessment.

Recently, questions have arisen about other permissible techniques in a wrestling WCP such as bioelectrical impedance analysis (BIA), air displacement plethysmography (ADP), and near-infrared (NIR) light interactance (18,21). Although other methods of body composition assessment may reduce the administrative burden of the WCP, a minimum wrestling weight calculated using techniques or formulas not validated within a wrestling population poses a potential health risk. Failure to identify an individual athlete whose weight loss exceeds a safe standard for minimum weight (i.e., a false high %BF reading used to calculate a minimal wrestling weight) presents a legitimate health concern. Previous research has been limited with respect to validating other body composition methods such as BIA, ADP, or NIR against criterion reference standards such as HW in a wrestling population. Additionally, wrestlers often experience acute dehydration through the loss of body water, either due to strenuous training or in an active effort to “make weight.” Consequently, the impact of dehydration on body composition measurements should be considered when evaluating the validity of any body composition method in wrestlers.

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Similar to HW, ADP is a densitometric method that relies on measurement of mass and volume to calculate body density \((D_B)\). A full description of the methodology is found elsewhere (7). The only commercial device utilizing ADP is the BOD POD® Body Composition System (Life Measurement Inc., Concord, CA). The BOD POD® was developed with the intent of possessing a faster and easier procedure to measure body volume than traditional HW. Advantages of ADP include: less technical expertise than HW, and more time efficient and comfortable because air is used as the displacement medium rather than water. A recent review of ADP (8) found that among 12 studies comparing ADP and HW in adults between 1995 and 2001, the average of the study means agreed within 1%BF. This same review paper (8) on ADP also reported that the SEE values ranged from 1.8% to 2.3%BF in adults. Previous research comparing ADP with HW have found close agreement (3,14,17,22,23), whereas others found greater discrepancies (5,10,11,16,19,24) in estimating %BF. Differences between methods may be due to a variety of factors, including variations in testing protocol, laboratory equipment, subject characteristics, and study designs (8). When investigating another collegiate athletic population, Collins et al. (5) found ADP measurement of %BF to be 1.9% higher than HW in NCAA Division I football players. No previous studies have been published evaluating ADP in a wrestling population.

Therefore, the purpose of this study was to evaluate the accuracy of ADP for measuring \(D_B\) and subsequent estimation of %BF when compared with HW in a collegiate wrestling population during a hydrated and acutely dehydrated state. HW was chosen as the criterion method because, like the BOD POD®, it also measures \(D_B\), uses a two-compartment model, and HW is currently approved by the NCAA as an acceptable measure of body composition within the wrestling population. SK were also included for comparative purposes because SK are also used to assess body composition in wrestling. We hypothesized that there would be no significant differences between ADP and HW for \(D_B\) and %BF and therefore both methods would provide similar estimates of %BF in both a hydrated and dehydrated state.

**METHODS**

**Subjects.** NCAA, Division I wrestlers \((N = 66)\) who competed on the Appalachian State University, Arizona State University, and the University of Pittsburgh wrestling teams during the 2001–02 season participated in this study. Subjects were representative of all 10 collegiate weight categories. Subjects gave written and informed consent, and the experimental procedures were approved by the Institutional Review Board for investigations at each of the respective institutions and were in compliance with the American College of Sports Medicine policies for use of human subjects.

**Testing schedule.** All body composition testing occurred in the human performance laboratories at each of the respective universities involved with the study. Body composition was assessed in every subject on two different occasions each within a 48-h period. All testing sessions took place at the same time of the day either before or after the standard afternoon wrestling practice and lasted approximately 45 min. The first measurement of body composition was made in a euhydrated state. Baseline hydration was established by obtaining a urine specimen to measure \(U_{sg}\) by using a hand-held optical refractometer. Based upon the subject’s ability to produce a \(U_{sg}\) less than or equal to 1.020 g·mL⁻¹ as a normal \(U_{sg}\) (2), and/or their ability to produce a urine sample during the test period, subjects were considered to be adequately hydrated. After the first testing session was completed, the subjects were instructed to decrease body mass by 2–3% through acute dehydration by having the subjects participate in their standard wrestling practice regime that normally occurred as part of the competitive season at each institution. Body composition measurements occurred after an approximate 30-min rest period after acute dehydration. Dehydration was confirmed by either a 2–3% reduction in body mass and/or the ability to produce a \(U_{sg}\) greater than 1.020 g·mL⁻¹. On each of the two testing sessions subject’s body composition was evaluated by three different methods in the following order: 1) SK, 2) ADP, and 3) HW. Body mass was determined using an electronic scale provided with the ADP system, and height was measured with a wall-mounted stadiometer. The total amount of time to assess body composition by the three different methods on each testing session was approximately 45 min.

**Skinfold analysis.** Double thickness subcutaneous adipose measures were recorded with Lange skinfold calipers at three sites: triceps, subscapular, and abdomen. Skinfolds were measured three times at each site to the nearest 0.5 mm with the mean value recorded. All skinfold measurements were taken on the right side of the body. Different skinfold assessors were used at each institution, but all were highly trained and experienced in measuring skinfolds of wrestlers. \(D_B\) was determined from the three skinfold measures by using the prediction equation \((D_B = [1.0982 - (\text{sum skinfolds}) 	imes 0.000815]) + [(\text{sum skinfolds})^2 	imes 0.00000084]\) validated by Lohman et al. (13). The Lohman equation has been adopted by the NCAA as the official equation to be used when calculating \(D_B\) from skinfolds (6). %BF was determined from \(D_B\) by using the Brozek equation (4) for Euro-American subjects and Schutte equation for African-American subjects (20). These %BF equations were also used with the \(D_B\) determined from HW and ADP.

**Hydrostatic weighing.** \(D_B\) was also determined by HW. At two of the three universities, HW was performed in a custom-built, stainless steel tank, with three load cells interfaced to a computer (Exertech Fitness Equipment, Dresbach, MN). At the third institution, HW was accomplished in a 640-gallon capacity water tank containing a rectangular chair of PVC pipe suspended from a cable that was attached to a load cell connected to a computer. 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.
Residual volume (RV) was measured by the nitrogen washout procedure using procedures previously described by Wilmore et al. (25). A minimum of two trials were completed with the two closest reading within 10% being averaged for the RV. At two of the three universities, RV was determined by an automated oxygen dilution gas calibration system (Nitralyzer, Nitrogen Gas Meter, Model 505, Med-Science, St. Louis, MO) and (Cosmed Quark Pulmonary Function System, Cosmed, Rome, Italy). At the third institution, RV was determined using the techniques described by Wilmore et al. (25) employing anesthesia bags and a standard metabolic system (Applied Electrochemistry, Pittsburgh, PA). The same RV measurement used in the hydrated state was also used in the dehydrated condition.

Air displacement plethysmography. The BOD POD® measures body volume by using air displacement plethysmography as previously described (7). The system is composed of a fiberglass structure that is divided into two chambers, i.e., a front test chamber and a rear reference chamber. These two chambers are separated by a seat. In between the chambers, a volume-perturbing element is present that oscillates under computer control, yielding complementary volume perturbations between the two chambers. By using basic gas laws (Boyle’s law and Poisson’s law), the pressure fluctuations that occur as a result of the volume perturbations are used to determine the chamber air volume. Chamber air volume is determined both with and without the subject seated in the test chamber, with the difference between the two measures yielding body volume (7). All subjects were tested wearing minimal, tight-fitting clothing (Lycra swim suit and cap) to compress the hair (7). A correction was made on all subjects for the average air volume contained in the lungs and thorax during normal respiration, which is measured by the BOD POD® using standard pulmonary plethysmographic technique (7). The same thoracic gas volume was used for both the hydrated and dehydrated conditions. Db was calculated by dividing body mass by body volume.

Hydration assessment. At each testing session, the hydration state of every subject was quantified by measuring Usg. Usg was determined by employing an optical hand-held refractometer (NSG Precision Cells Inc., Farmindale, NY). All Usg samples were evaluated in duplicate. Each urine specimen was collected in an inert polypropylene container. All Usg measurements were performed within 10 min of collection.

Statistical analysis. Data were analyzed using SPSS 10.0 for Windows (SPSS Inc., Chicago, IL) and SAS 8e for Windows (SAS Institute Inc., Cary, NC). Values are expressed as means ± SD. Normal probability plots and Kolmogorov-Smirnov tests were used to determine whether variables followed a normal distribution. A repeated-measures one-way ANOVA was performed to detect significant differences in body composition variables (Db, %BF, and FFM) by using the three methods (SK, HW, and ADP) in hydrated and dehydrated states. The Dunnett multiple comparison procedure was further used to compare body composition variables by ADP and SK against the reference method HW. Multiple paired-sample t tests with Bonferroni’s adjustment were performed to examine body composition variables during hydrated versus dehydrated states. To assess the agreement in Db and %BF measured by ADP versus HW, linear regression and Bland-Altman analyses were conducted. Linear regression analyses were performed with Db or %BF 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 ± 2 SD of the differences between methods (1).

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 %BF measurements by ADP and HW (9). For all tests, statistical significance was accepted at P < 0.05.

RESULTS

Table 1. Subject characteristics (N = 66).

| Age (yr) | 20.2 ± 2.0 |
| Height (m) | 1.73 ± 0.08 |
| Weight (kg) | 77.1 ± 13.2 |
| Wrestling experience (yr) | 9.0 ± 1.1 |

Values are expressed as mean ± SD.

Table 2. Comparison of body composition measurements by methods and hydration status (N = 66).

<table>
<thead>
<tr>
<th></th>
<th>Hydrated</th>
<th>Dehydrated</th>
</tr>
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<tbody>
<tr>
<td>Weight (kg)</td>
<td>76.7 ± 13.1</td>
<td>74.7 ± 12.9*</td>
</tr>
<tr>
<td>Urine specific gravity-refractometer (g/mL)</td>
<td>1.019 ± 0.009</td>
<td>1.027 ± 0.007*</td>
</tr>
<tr>
<td>DbHW (g·cc⁻¹)</td>
<td>1.0749 ± 0.013</td>
<td>1.0755 ± 0.012</td>
</tr>
<tr>
<td>DbADP (g·cc⁻¹)</td>
<td>1.0758 ± 0.014</td>
<td>1.0780 ± 0.013*</td>
</tr>
<tr>
<td>DbSK (g·cc⁻¹)</td>
<td>1.0722 ± 0.012†</td>
<td>1.0727 ± 0.011‡</td>
</tr>
<tr>
<td>%BFHW</td>
<td>11.3 ± 4.8</td>
<td>11.1 ± 4.7</td>
</tr>
<tr>
<td>%BFADP</td>
<td>11.0 ± 5.3</td>
<td>10.1 ± 5.1*</td>
</tr>
<tr>
<td>%BFSK</td>
<td>12.4 ± 4.6†</td>
<td>12.2 ± 4.5‡</td>
</tr>
<tr>
<td>FFMHW (kg)</td>
<td>67.7 ± 10.1</td>
<td>66.1 ± 10.0*</td>
</tr>
<tr>
<td>FFMADP (kg)</td>
<td>67.9 ± 9.7</td>
<td>66.8 ± 9.7*</td>
</tr>
<tr>
<td>FFMSK (kg)</td>
<td>66.9 ± 10.5</td>
<td>65.4 ± 10.3*</td>
</tr>
</tbody>
</table>

Values are expressed as mean ± SD. * Significantly different from the hydrated state (P < 0.001) (multiple paired-sample t-tests with Bonferroni’s adjustment). † Significantly different from the corresponding body composition variables by HW within the hydrated state (P < 0.05) (repeated-measures one-way ANOVA, with Dunnett multiple comparison procedure). ‡ Significantly different from the corresponding body composition variables by HW within the dehydrated state (P < 0.05) (repeated-measures one-way ANOVA, with Dunnett multiple comparison procedure). Db, body density; %BF, percent body fat; FFM, fat-free mass; HW, hydrostatic weighing; ADP, air displacement plethysmography; SK, skinfolds.
hydration was confirmed by a significant reduction in weight (2.0 kg, or 2.6% of body weight) accompanied by a significant increase in $U_{\text{sk}}$ ($P < 0.001$). Cross-sectional comparisons of body composition variables determined by the three methods (HW, ADP, and SK) during both the hydrated and dehydrated states are also summarized in Table 2.

In the hydrated state, $D_b$, %BF, and FFM determined by ADP ($D_b-\text{ADP}$, %BF$_{\text{ADP}}$, and FFM$_{\text{ADP}}$, respectively) did not differ significantly from the corresponding body composition variables determined by HW ($D_b-\text{HW}$, %BF$_{\text{HW}}$, and FFM$_{\text{HW}}$, respectively). The mean difference for $D_b$, %BF, and FFM for ADP-HW in the hydrated state were as follows: (mean $\pm$ SD) 0.0008 $\pm$ 0.0059 g·cc$^{-1}$, $-0.33 \pm 2.34\%$, and 0.17 $\pm$ 1.81 kg, respectively. In contrast, $D_b$ estimated from SK ($D_b-\text{SK}$) was significantly lower than that from HW ($D_b-\text{HW}$) ($P = 0.037$) (mean difference: $-0.0027 \pm 0.0010$), which accounted for a significant overestimation of percent body fat by SK (%BF$_{\text{SK}}$) when compared with %BF$_{\text{HW}}$ ($P = 0.041$).

In the dehydrated state, there were no significant differences in $D_b$, %BF, and FFM determinations by ADP versus HW. However, comparison of body composition measurements by SK and HW demonstrated that $D_b-\text{SK}$ was significantly lower ($P = 0.027$) and %BF$_{\text{SK}}$ was significantly higher ($P = 0.030$) when compared with HW.

Assessment of the potential effects of acute dehydration on body composition methods demonstrated that mean values for FFM determined by the three methods, FFM$_{\text{HW}}$, FFM$_{\text{ADP}}$, and FFM$_{\text{SK}}$, respectively, were significantly lower in the dehydrated state as compared with the hydrated state ($P < 0.001$). In addition, $D_b-\text{ADP}$ and %BF$_{\text{ADP}}$ were significantly different ($P < 0.001$) during the hydrated versus the dehydrated state.

Linear regression and Bland-Altman analyses of $D_b$ and %BF determined by ADP versus HW during the hydrated and the dehydrated states indicated a high degree of agreement (Fig. 1). However, the slope of the regression lines differed significantly from 1.0, and the intercept differed significantly from 0 in both (Fig. 1). As shown in Figure 1 (A and C), the regression equations resulted in a very low SEE and high adjusted $R^2$ in both the hydrated and dehydrated states, indicating good agreement between $D_b-\text{ADP}$ and $D_b-\text{HW}$. Furthermore, the 95% limits of agreement from Bland-Altman analyses (panels B and D) were relatively narrow, and none of the individual differences was a function of $D_b$.

There was a similar good agreement between %BF$_{\text{ADP}}$ and %BF$_{\text{HW}}$ as indicated by the low SEE and high adjusted $R^2$ from regression analysis: hydrated state ($y = 0.806x + 2.469$, adjusted $R^2 = 0.803$, SEE = 2.121, $P < 0.001$) and in the dehydrated state ($y = 0.830x + 2.702$, adjusted $R^2 = 0.790$, SEE = 2.159, $P < 0.001$). Small mean differences were found between methods (%BF$_{\text{ADP}}$ - %BF$_{\text{HW}}$ = $-0.33\%$ and $-0.98\%$ for hydrated and dehydrated state, respectively), as well as random distribution of individual differences from Bland-Altman analyses. The PE values for %BF when comparing ADP with the reference method HW were 2.4% and 2.5% in the hydrated and dehydrated conditions, respectively.
DISCUSSION

This study found no significant differences between ADP and HW for $D_b$, %BF, and FFM in either hydrated or dehydrated states for Division I collegiate wrestlers. Furthermore, Bland-Altman plots indicated no systematic under- or over-estimation of $D_b$ and %BF despite a wide range of $D_b$ in the wrestlers. The SEE associated with %BF estimated from ADP with HW as the reference method were 2.12% (hydrated) and 2.16% (dehydrated). These SEE values are in the “excellent to ideal” range (=2.5%BF) according to Lohman (12).

For SK, %BF was significantly higher than HW in both hydrated (12.4 ± 4.8% vs 11.3 ± 4.8%) and dehydrated (12.2 ± 4.5% vs 11.1 ± 4.7%) states. These differences were statistically significant but relatively small at 1.1%BF under both conditions. A concern exists that any body composition technique applied to wrestlers not give falsely high readings and thus fail to identify an individual athlete whose weight loss exceeds a safe standard. Because the determination of an ideal competition weight for a wrestler is dependent upon many variables (i.e., initial weight of wrestler, amount of weight separating weight classes, and how motivated the wrestler is to lose weight if weight loss is desired), it is highly likely that a 1% overestimation of %BF will have very little if any practical significance in the determination of a minimal wrestling weight.

To our knowledge, this is the first investigation to compare $D_b$, %BF, and FFM from ADP and HW in both hydrated and acutely dehydrated conditions in a wrestling population. The size of the sample studied and its physical characteristics make it a representative sample of NCAA Division I wrestlers. Therefore, results from this investigation may be important with regard to the wrestling weight certification program previously established by the NCAA. Currently as part of the wrestling WCP, the NCAA has determined that each wrestler must present a $U_{sg}$ value of 1.020 or less as a limit for hydration status before undergoing a body composition assessment. In this study, dehydration was confirmed by a significant increase in $U_{sg}$ (1.019 ± 0.009 g·mL$^{-1}$ vs 1.027 ± 0.007 g·mL$^{-1}$, $P < 0.001$) and a significant decrease in body mass (77.1 ± 13.2 kg vs 75.0 ± 13.0 kg, $P < 0.001$). The wrestlers in this study lost an average of 2.0 kg, the equivalent of 2.6% of body weight. Decreasing the hydration of the FFM increases its density, leading to an underestimation of %BF due to the assumptions inherent in the 2-compartment model. This was seen in all methods, although it reached significance only in ADP. Considering that the mean differences were very small during dehydration ($<0.005$ g·cc$^{-1}$ for $D_b$$_{ADP}$ and $<1$% body fat for %BF$_{ADP}$), it is likely that they may be clinically negligible. It is also possible that the increase in $D_b$-HW during dehydration did not reach statistical significance due to the fact it may have been confounded by using the RV value that was determined during a hydrated state. Because the dehydrated HW procedures were completed after a vigorous training session, the subjects may have been less efficient in maximally expiring air from their lungs resulting in an overestimation of %BF. All methods (ADP, HW, and SK) showed a significant decrease in FFM between hydrated to dehydrated states, as would be expected.

The findings of this study add to the growing body of evidence concerning the validity of measuring $D_b$ in ADP when compared with HW (14,15,17,22,23). Although previous research has indicated that the validity of ADP may be less accurate when using lean individuals (5,22), this was not the case in the present study where the average %BF from HW (11.3 ± 4.8%) for the wrestlers was even lower than that of previous research: 17.0 ± 0.8% for football players (5) and 14.1 ± 0.6% for lean male and female adults (22). Other studies found significant differences in $D_b$ when comparing ADP with HW as the reference standard (5,10,16,24). Whether the discrepancies found between studies are the result of using study populations of one race (African-Americans), mixed genders, HW procedures, or differences in ADP systems has yet to be elucidated. For comparative purposes, the lack of a control group of wrestlers that were not dehydrated should also be considered as a limitation within the context of the present study design.

This study demonstrated that $D_b$, %BF, and FFM values measured by ADP using the BOD POD® are not statistically different when compared with values obtained by HW in a heterogeneous collegiate wrestling population in a hydrated and dehydrated state, and therefore should be considered as a suitable alternative to HW and SK for determining the minimum weight for wrestlers. The BOD POD® air displacement method has several advantages: 1) it requires less technical expertise than HW; 2) is more comfortable than HW due to its use of air rather than water; 3) is fast (<5 min); and 4) for most individuals does not overestimate %BF, which could lead to a minimal wrestling weight that is potentially unhealthy to the wrestler. Pretest guidelines to ensure normal hydration status before any body composition assessment using any method (ADP, HW, or SK) must be followed to minimize error in the determination of a minimal wrestling weight.

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