

EVALUATION OF BODY COMPOSITION ASSESSMENTS FOR A HIGH SCHOOL WRESTLING WEIGHT CERTIFICATION PROGRAM

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Abstract approved:

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Background: The Oregon Wrestling Weight Monitoring Program establishes the athlete's minimum wrestling weight (MW) for the season. This program specifies the wrestler's maximum weight loss rate and was implemented in order to reduce unhealthy weight-cutting behaviors commonly practiced by wrestlers. Aims: (1) To compare differences in percent body fat (%BF) between 3 body composition assessment methods, (2) To examine agreement between 2 hydration assessment methods, (3) To detect the presence of systematic bias in MW-prediction for 2 methods of body composition assessment, compared to a criterion, (4) To gather information pertaining to weight-cutting methods used and the frequency with which these methods were used. Methods: Participants included 55 male and female high school athletes, 18 of whom were wrestlers. Body composition assessment methods included the BODPOD while measuring thoracic gas volume (BPM) (criterion for MW prediction), BODPOD while estimating this volume (BPE), and leg-to-leg-bioelectric impedance analysis (L-BIA). The BODPOD body composition system is a densitometric method similar to hydrostatic weighing, however air displacement is

used rather than water displacement. This technique is also referred to as air displacement plethysmography. The Systematic bias of BPE and L-BIA were examined. Urine specific gravity (USG) was assessed, as an indicator of hydration level using the dipstick method and an optical refractometer. Wrestlers completed a survey. Results: The 3 methods reported similar %BF values (16.1 ± 8.3 , 15.3 ± 8.4 , 15.4 ± 7.8) for all athletes (N=51), the subgroup of wrestlers (N=16), and males (N=20), however there was a difference in %BF between L-BIA and BPE and between L-BIA and BPM for females (N=15). Hydration assessment methods did not agree when using the high school USG cutoff ($1.025 \text{ g} \cdot \text{mL}^{-1}$), and agreed weakly when using the NCAA USG cutoff ($1.020 \text{ g} \cdot \text{mL}^{-1}$). Systematic bias existed in BPE, and limits of agreement were twice as large in L-BIA compared to BPE. Most wrestlers engaged in weight-cutting behaviors. Conclusion: L-BIA is not recommended as a method for predicting MW because individual differences between L-BIA and BPM spanned multiple weight classes. Investigators recommend that program officials consider using optical refractometers and/or consider adopting the NCAA hydration cutoff ($\text{USG} < 1.020 \text{ g} \cdot \text{mL}^{-1}$) to assess hydration status.

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Evaluation of Body Composition Assessments for a High School Wrestling Weight
Certification Program

by
Kristen M. Oja

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APPROVED:

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Dean of the Graduate School

I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Kristen M. Oja, Author

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CONTRIBUTION OF AUTHORS

Dr. Anthony R. Wilcox, my major professor, oversaw this project in its entirety. Dr. Joonkoo Yun assisted with research design, statistical analyses, and writing of this paper.

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DEDICATION

This paper is dedicated to Nicholas

and

to the memory of my loved ones who are no longer with us.

Introduction

Background Information

Wrestlers often attempt to lose a large amount of their body weight (i.e., “cut weight” or “make weight”) in a short time period before competition in order to be classified within a weight category that is lower than their normal, pre-season body weight, thereby giving the athlete a perceived [1] competitive advantage during a wrestling match [2-6]. The rapid weight loss can have deleterious effects upon the athlete’s health [7, 8] and athletic performance [1], since it predisposes wrestlers to dehydration and subsequent hyperthermia [2, 3, 7, 8].

The Oregon School Activities Association (OSAA) implemented the Oregon Wrestling Weight Monitoring Program for the first time during the 2005-06 wrestling season in order to discourage unhealthy weight-cutting behaviors among high school athletes. This program assesses the body composition of hydrated athletes at the beginning of the season using leg-to-leg bioelectrical impedance analysis (L-BIA) in order to establish the athlete’s minimum wrestling weight (MW) for the season, based on his (or her) fat-free mass (FFM) and the following equations: $MW_{MALE} = FFM + 7\%FFM$; $MW_{FEMALE} = FFM + 12\%FFM$. Wrestlers may appeal the MW results by having a second body composition assessment using air displacement plethysmography (BOD POD® body composition system) [49]. The Oregon Wrestling Weight Monitoring Program [49] specifies that appeals with the BOD POD® *estimate* thoracic gas volume (BPE), rather than measure thoracic gas volume (BPM), which is the amount of air in the lungs and thorax during tidal breathing.

Research Aims

Since the OSAA is presently using L-BIA and BPE (BODPOD while *estimating* thoracic gas volume) in the Oregon Wrestling Weight Monitoring Program, the primary purpose of this study was to compare body composition estimates as obtained by L-BIA, BPE, and BPM (BODPOD while *measuring* thoracic gas volume) in hydrated high school athletes, including wrestlers, competing within the OSAA. The present study sought to clarify whether or not L-BIA and BPE are appropriate methods for predicting MW among this adolescent population, compared to the reference method of BPM, and whether or not the Oregon Wrestling Weight Monitoring Program should use BPE or BPM during the appeal process.

Though a multi-component model is commonly accepted as the “gold standard” for assessing body composition, BPM was chosen in the present investigation as the criterion method because it is theoretically the most accurate method of body composition assessment among the three methods used as an option for OSAA appeal. In addition Fields and associates reported results that support BPM as a precise and accurate method of body composition assessment that is free of systematic bias when compared to the 4-component model in children and adolescents [9].

To our knowledge, no other studies have compared these three methods of body composition assessment among hydrated high school athletes or wrestlers, and no other investigators have tested the systematic bias of L-BIA and BPE compared to BPM in this population. In addition we sought to calculate the within-day test-retest reliability of each of the body composition assessment methods for this population.

A secondary purpose of this investigation was to determine the extent of agreement that exists between two different methods of measuring urine specific gravity (USG) to assess hydration level. The methods used included assessment with a digital hand-held optical refractometer, and the more subjective dipstick method used by the OSAA.

A tertiary purpose of this investigation was to gather information about the methods high school wrestlers use to maintain or to achieve a given wrestling weight-class (i.e., make weight) during the wrestling season, after the establishment of the weight monitoring program. This was accomplished by requesting that each of the 18 wrestlers complete a validated survey that took approximately 10-15 minutes to complete [6, 10].

Methods and Procedures

Participants

Participants included 55 (16 female and 39 male) volunteers, ranging in age from 14 to 18 years, who resided in the Willamette Valley of western Oregon. The USG of four (3 male and 1 female) participants did not meet the criterion for euhydration (i.e., $USG < 1.025 \text{ g}\cdot\text{mL}^{-1}$) for both hydration assessment methods, and they were excluded from the analyses that compared body composition assessments. In order to have sufficient statistical power, the original pool of participants was expanded to include high school athletes rather than only high school wrestlers. Additionally, females were included since high school wrestling teams in Oregon may be comprised of both males

and females. Therefore, participants were comprised of athletes who competed in interscholastic sports for an Oregon high school that is a member of the Oregon School Activities Association. Eighteen (33%) of these high school athletes participated in wrestling and all wrestlers were male. Demographic information and physical characteristics for all participants are shown in Table 1.

Table 1. Demographic information and physical characteristics of participants [mean±sd (range)]

N = 55	Male (n = 39)		Female (n = 16)	N = 51
	Wrestlers (n = 18)	Non-wrestlers (n = 21)	(Non-wrestler athletes)	(Hydrated: USG < 1.025)
Age (year)	15.7±1.1 (14-17)	16.5±1.3 (14-18)	16.3±1.3 (14-18)	16.2±1.3 (14-18)
Height (cm)	171.8±7.3 (155.4-183.5)	173.1±10.1 (152.8-196.0)	165.4±7.0 (152.8-173.8)	172.8±9.5 (152.8-196.0)
Weight (kg)	68.9±15.4 (47.1-104.0)	66.6±12.6 (44.0-110.0)	58.0±8.9 (44.0-80.8)	67.6±13.9 (44.0-110.0)
BMI (kg/m ²)	23.3±4.9 (16.5-37.7)	22.1±3.2 (17.4-35.1)	21.2±3.2 (17.4-28.3)	22.6±3.9 (16.5-37.7)

Individual orientation and laboratory testing was conducted at the Human Performance Laboratory at Oregon State University (OSU) in Corvallis, Oregon in a single session. Prior to data collection, participants received a full description of the purpose and procedures of the study, and read and signed an informed consent form approved by the Internal Review Board at OSU. The signature of a parent or guardian was obtained for participants under the age of 18 years.

Apparatus and Instruments

The 18 wrestlers completed a validated survey [5, 6, 10] in order to help investigators understand the weight-cutting methods used by these athletes and the frequency with which these methods were practiced. The majority of survey items were presented using a five-point Likert scale. The original survey was developed over 25

years ago [10], however in 1990 one team of investigators [5] improved content and criterion validity by rewriting, developing, and eliminating questions after consulting with coaches and wrestlers.

Past investigators [10] have reported the one month test-retest reliability coefficient as 0.88 for survey items related to bingeing, which is defined as an uncontrolled urge to eat. For items related to demographic and competitive performance information, test-retest reliability coefficients have been reported to range from 0.94 to 1.00 [5], and for items related to body weight change, test-retest reliability coefficients have been reported to range from 0.74 to 0.99 [5]. Finally, test-retest reliability coefficients for weight loss methods and assessment of dietary behaviors have been reported as ranging from 0.77 to 1.00, and from 0.65 to 0.85, respectively [5].

Hydration level was established through urinalysis using Bayer Multistix 8 SG reagent strips (Bayer Corp., Elkhart, IN) and a hand-held digital Atago PAL-10S refractometer (Atago Co., Ltd., Tokyo, Japan). L-BIA and the BOD POD[®] body composition system (Life Measurement, Inc., Concord, CA) were used to assess the body composition of participants. The L-BIA apparatus used was a Tanita body fat analyzer; model TBF-300WA (Tanita Corporation of American, Inc., Arlington Heights, IL), with a frequency of 50 kHz.

Protocol and Tests

In accordance with body composition testing guidelines, all participants wore minimal and tightly fitting clothing. Prior to arriving at the laboratory, all participants

were encouraged to follow the standard protocol to ensure adequate hydration (i.e., USG $< 1.025 \text{ g}\cdot\text{mL}^{-1}$). Participants were instructed to avoid diuretic medications within the week prior to testing, to avoid alcohol consumption during the 48 hours preceding testing, and to avoid consuming caffeine and carbonated drinks, engaging in moderate- to intense-exercise, fasting, and water intake restriction during the 12 hours before laboratory testing.

First, each participant provided a urine sample for the purpose of assessing USG, an indicator of hydration status. Upon receipt of the sample, the temperature of the urine was assessed to ensure that it was at physiological temperature. Steps were taken to provide reasonable assurance that the urine sample was that of the participant and that it was collected immediately prior to hydration testing, however the participant did not give the sample while being observed. USG was assessed using two different methods in the following order: (1) disposable reagent test strips, which is also referred to as the dipstick method, and (2) a digital optical refractometer.

After dipping the disposable reagent strip in the urine sample and waiting one minute, the test technician compared the color of the reagent strip to a reference key comprised of graduated shades of color, each of which represented a USG range spanning $0.005 \text{ g}\cdot\text{mL}^{-1}$. The technician then chose the reference key color and USG value that best matched that of the reagent strip. Since there was an element of subjectivity involved in obtaining the USG values reported by the reagent strip, USG values reported by the digital refractometer [11] were always gathered last in order to avoid allowing the refractometer results to bias the test technician's choice of USG color shade and range. If

the USG was reported as being below $1.025 \text{ g}\cdot\text{mL}^{-1}$ by at least one of the two hydration assessment methods data collection continued; however if the USG was reported as $1.025 \text{ g}\cdot\text{mL}^{-1}$ or higher for both methods, the participant was asked to return to the laboratory after re-hydrating. The USG of 4 participants was $1.025 \text{ g}\cdot\text{mL}^{-1}$ or higher for both USG assessment methods, and since these 4 individuals chose not to re-hydrate and return to the lab at a different time, they were excluded from all body composition analyses.

Participant bare-foot height was measured with a wall-mounted stadiometer. Data was then collected using three different methods of body composition assessment. The order of body composition test administration (L-BIA, then BOD POD[®]) was not counterbalanced since there was no opportunity for results to be tainted by the effects of fatigue, practice and carry-over [12].

In accordance with the Oregon Wrestling Weight Monitoring Program, L-BIA reported percent body fat (%BF) was calculated in the “standard mode” and zero was entered for clothes. Body composition was calculated based on manufacturer-supplied prediction equations, which considered body weight, age, gender, and impedance index, defined as the ratio of body height squared to impedance (height^2/Z).

The BOD POD[®] was used to assess body composition, while *estimating* thoracic gas volume (BPE), and then while *measuring* thoracic gas volume (BPM). Lung volume measurement followed the guidelines supplied by the manufacturer of the BOD POD[®] [13]. In accordance with the Oregon Wrestling Weight Monitoring Program, all BOD POD[®] measurements used the pediatric age- and gender-specific Lohman equations to convert body density into %BF [14].

All apparatus-specific environmental conditions and quality control specifications were met throughout testing, and the same apparatus were used throughout data collection. Duplicate measurements of all body composition assessments for a subsample of participants were conducted within one hour of each other.

Statistical Analysis

In order to examine the precision of estimating body composition, two different analytical approaches were used, including repeated measures ANOVA and Bland-Altman analyses. The one-way repeated ANOVA was performed to examine body composition differences among three different body composition methods for all hydrated participants (N = 51), for hydrated female athletes (N = 15), for hydrated male wrestlers (N = 16), and for hydrated male athletes (N = 20). In order to meet the assumption of homogeneity of covariance (i.e., sphericity) Mauchly's Test of Sphericity was conducted [12, 15]. Since this test was significant (i.e., there was heterogeneity of covariance) degrees of freedom were adjusted using the Greenhouse-Geiser Test [23]. For the purpose of comparison, MW was calculated based on results reported by each of the three body composition assessment methods. Data were analyzed using SPSS for Macintosh [16].

Bland-Altman analyses [17, 18] were performed in order to evaluate systematic bias and agreement in MW prediction by the two test methods (L-BIA and BPE) compared to MW predicted by the criterion method (BPM). The mean MW of the test method (LBIA-MW or BPE-MW) and the criterion method (BPM-MW) served as the

independent variable and was plotted on the x-axis after being regressed against the dependent variable (y-axis), which was the difference between the test method and the criterion method [LBIA-MW (or BPE-MW) minus BPM-MW] [18]. MW was calculated according to the OSAA guidelines. According to Bland and Altman [18] the estimated systematic bias was computed as the mean of the difference between methods (LBIA-MW – BPM-MW). The limits of agreement were calculated as the bias (i.e., mean difference) \pm 2 standard deviations (SD) of the difference between methods [18]. Additionally, potential MW class misclassification was analyzed under the assumption that BPM-MW represented the true and correct classification.

To determine the (within-day) test-retest reliability of each body composition method, we conducted an analysis for 2-way random effects intraclass correlation coefficient with absolute agreement [$ICC_{(2,2)}$], where $N = 29$ for BPM, $N = 31$ for BPE, and $N = 34$ for LBIA.

Since the two urine assessment methods dichotomized hydration status (USG < 1.025 $\text{g}\cdot\text{mL}^{-1}$ when hydrated) Cohen's Kappa was used to determine the extent of agreement between these two measures. Secondly, Cohen's Kappa was performed using a USG cutoff of 1.020 $\text{g}\cdot\text{mL}^{-1}$, which complies with the National Collegiate Athletics Association (NCAA) definition of euhydration (i.e., USG < 1.020 $\text{g}\cdot\text{mL}^{-1}$).

Survey data was collected in order to describe behaviors of competitive high school wrestlers. Survey data was divided into three categories: demographic information, information pertaining to weight loss, and information regarding weight-cutting behaviors. A frequency distribution was generated for survey items in each

category. For example, proportions were computed and weight loss methods were ranked from the most frequently used to the least frequently used techniques. For all tests, statistical significance was accepted at $P < 0.05$.

Results

Survey

Survey results are descriptive in nature, and are divided into three categories: demographic information, information pertaining to weight loss, and information regarding weight-cutting behaviors. All wrestlers completed the survey with respect to their present wrestling season, *after* the implementation of the Oregon weight-monitoring program. Descriptive information regarding demographics is discussed below.

Often light- and mid-weight wrestlers tend to engage in weight-cutting more frequently than heavyweight wrestlers. Of the fourteen weight classes, two (112-pound and 171-pound weight classes) were not represented by this survey. One wrestler had been in the 112-pound weight class the previous year, but moved to the 119-pound weight class during the season in which he completed the survey. Four wrestlers were categorized in weight classes ranging from the 189-pound to the 285-pound weight classes, and the remaining 14 wrestlers were in weight classes ranging from the 103-pound to the 160-pound weight classes.

At the time the survey was completed, wrestlers ranged in age from 14 to 17 years, with the mean (\pm SD) age being 15.7 (\pm 1.1) years, and most wrestlers competed for large schools. High schools in Oregon range in size from 1A, which is the smallest, to 6A, which is the largest. One wrestler who participated in this investigation, competed

within the 3A district, one competed within the 6A district, and 16 wrestlers competed within the 5A district. These wrestlers appeared to represent a wide range of skill levels. Individual success was demonstrated through percentage of wins during a season. The win percentage ranged from 14.0 to 90.0, with the mean (\pm SD) being 55.1 (\pm 26.3). Most wrestlers began competitive wrestling at the mean (\pm SD) age of 13.1 (\pm 3.6) years; however the beginning age ranged from 6 to 16 years.

Descriptive information regarding specific weight-cutting behaviors is presented in Table 2; descriptive information pertaining to weight loss is discussed below. Fifteen (83%) out of 18 wrestlers reported that they did engage in weight-cutting behaviors during the wrestling season, and 3 wrestlers reported that they did not. Of the three wrestlers who claimed that they did not engage in weight-cutting, the body weight of two individuals fluctuated by an average of 4.6% and 6.6% per week. The one other wrestler who reported that he did not engage in weight-cutting behaviors was classified in the 189-pound weight class and his weight fluctuated approximately 0.9% of total body weight each week. The average (\pm SD) fluctuation of percent body weight per week among all wrestlers was 4.0% (\pm 2.3) and ranged from 0.9 to 8.1 % of total body weight.

The survey used a 5-point Likert scale to assess self-perception of body weight, and results indicated that most wrestlers considered themselves to be at a weight that was (a score of “3”) “about right” (\pm 5 lbs) during the wrestling season, however self-perception ranged from feeling “underweight by 6-10 pounds” to feeling “overweight by 6-10 pounds”. When asked to reveal the person who most influenced their weight loss behaviors, wrestlers indicated most frequently ($f = 11$) that their wrestling coach was the

most influential, closely followed by their fellow wrestlers ($f = 10$). Other individuals who were named with considerably less frequency included the technicians who assess MW ($f = 3$), parents ($f = 2$), athletic trainers ($f = 1$), and physicians ($f = 1$). According to the survey, of those who did engage in weight-cutting behaviors, the highest percentage of body weight cut before a competition averaged 4.2% ($\pm 2.7\%$), with the range spanning 1.3 to 9.5 % body weight. Finally, ten wrestlers practiced gradual dieting throughout the season, and 11 wrestlers consciously restricted food intake to control body weight. On a 5-point Likert scale, the average (\pm SD) frequency of food restriction was a score of “3.0” (± 1.0), where “3” represented a food restriction frequency of 4 to 7 times per season and was described as “occasional”. The frequency of food restriction among these 11 wrestlers varied from “2”, or “rarely” (1-3 times per season) to “5”, or daily. Four wrestlers engaged in binge eating, and of these 4 participants, the average (\pm SD) frequency of binge eating was a score of “3.5” (± 1.0), where “3” represented a frequency of once per week, and “4” represented a frequency of three to four times per week (on a 5-point Likert scale). Binge eating was defined as eating much more than most people would eat, under the same circumstances, where one feels as though he may not be able to stop eating [4].

Table 2. Results: Survey information pertaining to weight-cutting behaviors

[0=Never; 1=once/month; 2=twice/month, 3=once/week, 4=3-4 times/week, 5=daily]						
Weight cutting of those who engaged in these behaviors during the season	Mean ^{&}	± SD ^{&}	Range		Number who engaged in behavior	% who engaged in behavior
			Min	Max		
**Exercising vigorously	4.0	1.4	1	5	14	77.8
Skipping 1-2 meals/day	3.0	1.3	1	5	12	66.7
Restricting fluid intake	2.6	0.9	1	3	9	50.0
Practicing in a heated wrestling room	2.7	1.2	1	5	9	50.0
Spitting	3.1	1.5	1	5	8	44.4
*Fasting	1.7	1.3	1	4	7	38.9
Taking saunas	3.4	1.6	1	3	5	27.8
Wearing a plastic or rubber suit	2.0	1.0	1	3	3	16.7
***Sleeping with extra clothes					1	5.6
Taking laxatives, diet pills or diuretics					0	0.0
Using enemas					0	0.0
Self-imposed vomiting					0	0.0
* Fasting was defined as not eating all day.						
** Exercising vigorously was for the sole purpose of losing weight.						
*** Information volunteered by one participant (not included in survey).						
^{&} Means and standard deviations for the 5-point scale are calculated based on the number of participants who did engage in the weight cutting behavior.						

Body Composition Method Comparison

There was no significant main effect for the one-way repeated measures ANOVA [F (19.58, 1.30) = 0.96, p = 0.35] that compared body composition results between three assessment methods for all hydrated participants, for hydrated male wrestlers, or for hydrated male athletes; however there were significant differences in body composition between L-BIA and BPE and between L-BIA and BPM among hydrated female athletes. The mean %BF, SD, standard errors of measurement (SEM), and 95% confidence interval for each method are shown in Tables 3 and 4.

Table 3. Results: Body composition & USG of wrestlers & male athletes

	⁴ Hydrated male wrestlers				⁴ Hydrated male non-wrestler athletes			
	(n = 16) (mean±sd)	SEM	95% CI		(n = 20) (mean±sd)	SEM	95% CI	
			Lower Limit	Upper Limit			Lower Limit	Upper Limit
BIA (% body fat)	13.9±8.5	2.12	9.3	18.4	12.4±5.2	1.16	10.0	14.9
BPE (% body fat)	14.1±8.5	2.13	9.6	18.6	13.0±8.0	1.80	9.3	16.8
BPM (% body fat)	13.7±7.9	1.98	9.2	17.6	13.6±6.8	1.53	10.4	16.8
¹ StripUSG (g•mL ⁻¹)	1.019±0.008	0.002	1.014	1.023	1.016±0.006	0	1.013	1.019
² DigitalUSG (g•mL ⁻¹)	1.017±0.007	0.002	1.013	1.020	1.018±0.007	0	1.015	1.021
³ FFM (kg)	58.5±8.7	2.17	54.2	62.7	55.2±11.4	1.52	61.0	67.0
¹ USG assessed by dipstick method (hydrated: USG < 1.025 g•mL ⁻¹)								
² USG assessed by digital refractometer (hydrated: USG < 1.025g•mL ⁻¹)								
³ BIA-reported fat-free mass								
⁴ Hydrated: USG < 1.02 g•mL ⁻¹ for both the dipstick and digital methods								
⁵ All participants, n=51 (male and female)								

Table 4. Results: Body composition and USG of females and all participants

	⁴ Hydrated female non-wrestler athlete				⁵ All ⁴ hydrated participants			
	(n = 15) (mean±sd)	SEM	95% CI		(n = 51) (mean±sd)	SEM	95% CI	
			Lower Limit	Upper Limit			Lower Limit	Upper Limit
BIA (% body fat)	23.4±7.0	1.80	19.5	27.2	16.1±8.3	1.16	13.8	18.4
BPE (% body fat)	*19.7±7.7	1.99	15.4	23.9	15.3±8.4	1.18	12.9	17.7
BPM (% body fat)	*19.9±7.4	1.91	15.9	24.0	15.4±7.8	1.09	13.2	17.6
¹ StripUSG (g•mL ⁻¹)	1.015±0.008	0.002	1.011	1.020	1.017±0.007	0.001	1.014	1.019
² DigitalUSG (g•mL ⁻¹)	1.015±0.008	0.002	1.010	1.019	1.016±0.007	0.001	1.014	1.019
³ FFM (kg)	43.9±3.8	0.98	42.0	45.8	56.4±10.8	1.51	53.4	59.3

¹USG assessed by dipstick method (hydrated: USG < 1.025g•mL⁻¹)
²USG assessed by digital refractometer (hydrated: USG < 1.025g•mL⁻¹)
³BIA-reported fat-free mass
⁴Hydrated: USG < 1.025 g•mL⁻¹ for both the dipstick and digital methods
⁵All participants, n=51 (male and female)
*Significantly different from BIA % body fat (p < 0.05)

BPE-MW and LBIA-MW were compared to the criterion method of predicting minimum wrestling weight (BPM-MW) in order to determine if the weight classes calculated using a test method (BPE-MW and LBIA-MW) would differ from the minimum weight class predicted with the criterion (BPM-MW) and, if a difference were present, the number of weight classes the predicted weight class would differ from BPM-MW, which is denoted as (BPM ± the number of weight classes different). This analysis was conducted for wrestlers (N=17) and for all hydrated participants (N=49) with complete data.

BPE-MW results were consistent with BPM-MW and BPE-MW (potentially) misclassified one wrestler into the weight class directly below (BPM – 1) the weight-

class designated by BPM-MW. Throughout this paper, the term misclassification should be considered a “potential” misclassification because this term requires the assumption that the BPM-MW is the correct classification.

With respect to all participants (N=49), BPE-MW misclassified 12 individual participants (24 %) into weight classes that differed from BPM-MW. Of the 12 misclassified athletes, five individuals were misclassified into the weight class directly above (BPM + 1) the weight-class designated by BPM-MW and seven participants were misclassified into the weight class directly below (BPM – 1) the weight-class designated by BPM-MW.

In contrast, LBIA-MW misclassified 12 wrestlers (N=17) compared to the MW class designated by BPM-MW. Specifically, LBIA-MW misclassified two wrestlers into weight classes that were two weight classes below (BPM – 2) the weight classes designated by BPM-MW. Six wrestlers were misclassified into weight classes directly below (BPM – 1) those classes designated by BPM-MW, and four wrestlers were misclassified into the weight class directly above (BPM + 1) those designated by BPM-MW.

With respect to all athletes (N=49), LBIA-MW misclassified 30 individual participants (61 %). Specifically, LBIA-MW misclassified one individual into a weight class that was three weight classes above (BPM + 3) the weight class designated by BPM-MW and misclassified one individual into a weight class that was two weight classes above (BPM + 2) the weight class designated by BPM-MW. Eight participants were misclassified into weight classes that were two weight classes below (BPM – 2) that

designated by BPM-MW. Twelve participants were misclassified into the weight class directly above (BPM + 1) that designated by BPM-MW, and eight participants were misclassified into weight classes directly below (BPM – 1) the weight class designated by BPM-MW.

The Bland-Altman plots that examined the systematic bias of LBIA-MW and BPE-MW compared to BPM-MW among hydrated athletes are shown in Figures 1 and 2 [18]. For both Bland-Altman plots, the black, centerline represents the mean of the difference (i.e., bias) in predicted MW between methods, whereas the upper- and lower-most longer dashed lines represent the limits of agreement for this population (bias \pm 2SD). (The middle, shorter-dashed lines represent the bias \pm 1 SD.) All Bland-Altman plots report the association (r) between the difference between the test method-predicted MW and the criterion-predicted MW (BPM-MW) and the mean of that difference for all hydrated participants, whereby the correlation coefficient (r) indicates whether or not the variances are equal [18]. Different variances demonstrate systematic bias or that a trend in the difference between methods exists as the magnitude of the measurement increases [18]. The correlation coefficient was calculated using the following formula:

$$r(T - S, \bar{x}) = \frac{\rho\sigma_T^2 - \sigma_S^2}{\sqrt{\sigma_T^2 + \sigma_S^2 - 2\rho\sigma_T\sigma_S}}, \text{ where T refers to test method, S refers to criterion}$$

method, \bar{x} refers to bias, ρ refers to correlation, and variances are represented by σ_T^2 and σ_S^2 . Additionally, each plot reports the bias \pm SD, the regression equation, the range of residuals, and the limits of agreement.

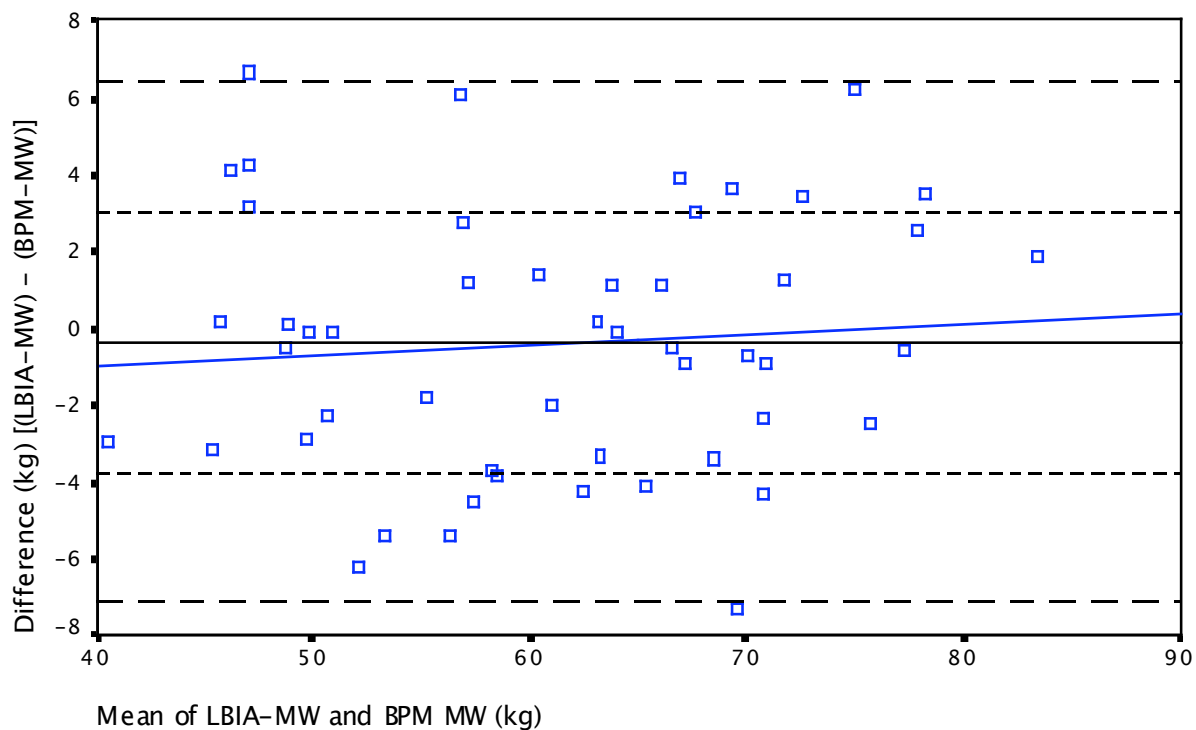


Figure 1. Bland-Altman plot [17, 18] to examine systematic bias in the L-BIA method for male and female athletes.

No significant systematic differences in predicting LBIA-MW (kg), as compared to BPM-MW (kg) were revealed [$r = 0.088$, $p > 0.05$; mean \pm SD = -0.37 ± 3.38 kg]. The limits of agreement (bias \pm 2SD) for MW ranged from -7.13 kg (-15.72 lb) to 6.39 kg (14.09 lb). MW residuals ranged from -7.17 kg (-15.81 lb) to 7.37 kg (16.25 lb). Line of best fit: $y = 0.03x - 2.09$. (N = 51).

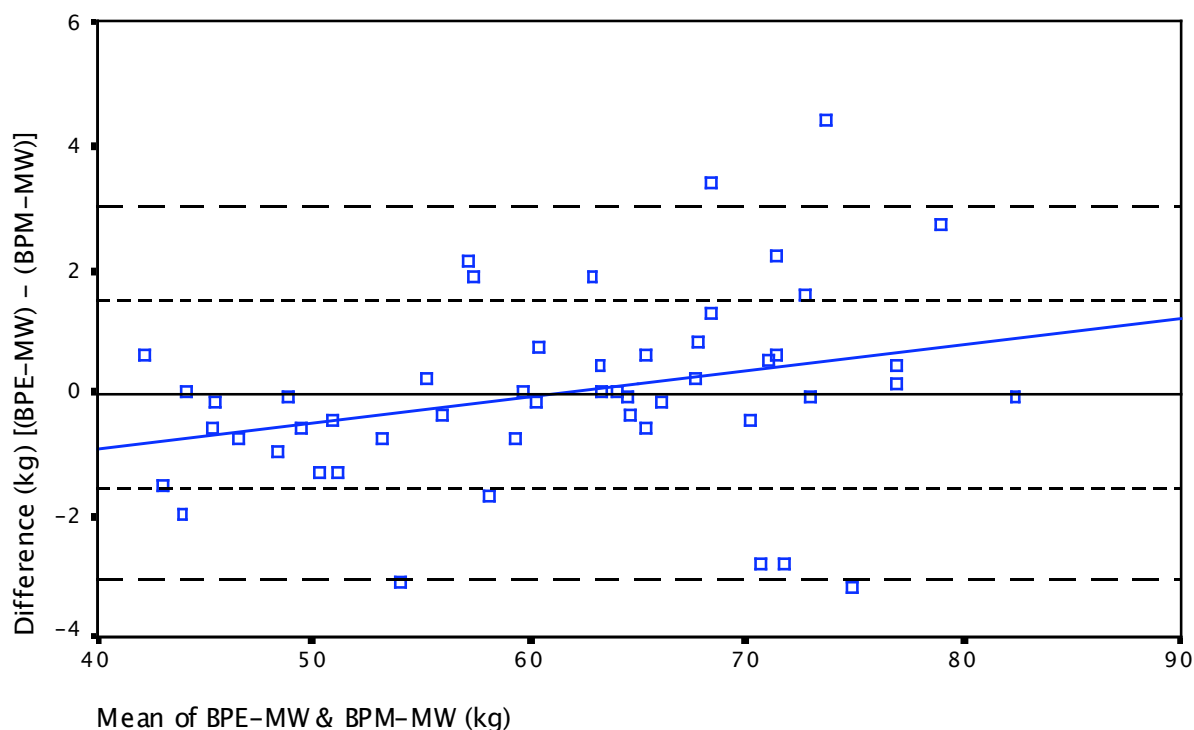


Figure 2. Bland-Altman plot [17, 18] to examine systematic bias in the BPE method for male and female athletes. Significant systematic differences were demonstrated when predicting BPE-MW (kg), as compared to BPM-MW [$r = 0.302$, $p < 0.05$; mean \pm SD = -0.02 ± 1.52 kg]. (There was a significant difference in variability between participants for the 2 methods.) The limits of agreement (bias \pm 2SD) for MW ranged from -3.05 kg (-6.72 lb) to 3.01 kg (6.64 lb). MW residuals ranged from -3.76 kg (-8.29 lb) to 3.90 kg (8.60 lb). Line of best fit: $y = 0.04 - 2.65$. ($N = 51$).

All body composition methods were highly reliable throughout testing. The two-way random effects test-retest (within-day) intraclass correlation coefficients [$ICC_{(2,2)}$] were 1.00 for L-BIA, 0.99 for BPE, and 1.00 for BPM. The ICC may more accurately reflect consistency than the Pearson product-moment correlation because, unlike the product-moment, the ICC detects absolute changes in values [19].)

Hydration Assessment Comparisons

Agreement between hydration assessment methods depended on the USG limit used. On one hand, when the Oregon Scholastic Activities Association USG limit of $1.025 \text{ g}\cdot\text{mL}^{-1}$ was used, the Cohen's kappa statistics was 0.2, which indicated a lack of agreement between hydration assessment methods. On the other hand, when the NCAA USG limit of $1.020 \text{ g}\cdot\text{mL}^{-1}$ was used, the Cohen's kappa statistic was 0.4, which indicated agreement between methods, though not to a high degree.

Discussion

Though the aims of this investigation were multiple, the primary purpose was to compare differences in body composition among hydrated high school athletes (and wrestlers) using the BOD POD[®] while measuring thoracic gas volume (BPM) and, while estimating this lung volume (BPE), and while using L-BIA. Additionally, the present investigation sought to report the reliability and measurement error.

The present investigation revealed high (0.99) test-retest (within-day) intraclass correlation coefficients, indicating that all methods were highly reliable throughout the course of testing. Results of the present study were consistent with other investigators who reported that L-BIA [20] and the BOD POD[®] were highly reliable [21], and that duplicate BOD POD[®] measurements were within $\pm 0.2\%$ body fat of one another [22].

Though the investigators of the present study did not intend to establish BPM as a criterion method of body composition assessment, BPM was assumed to be the criterion of the three methods used in the present investigation. This assumption was based on the

work of other investigators [9], who reported strong evidence supporting BPM as a valid tool for assessing body composition among adolescents [9]. Additionally if one considers theory alone, intuitively it seems as though one could argue that BPM should be the most accurate method of the three used.

Results of the present investigation indicated no statistically significant or practically meaningful mean differences in %BF between L-BIA, BPE, or BPM (N = 51). Despite the small number of female participants (N = 16), L-BIA reported significantly higher %BF values than both BPE and BPM among this subgroup. Again, since females do wrestle for high school wrestling teams in Oregon, they were included in this investigation.

Others reported similar results for L-BIA compared to underwater weighing (measuring residual volume) among high school wrestlers [23], and compared to the 4-component model [24] among collegiate wrestlers. In contrast, some investigators [25] reported that L-BIA significantly underestimated (- 2.2 % and -1.9 %BF) %BF compared to hydrostatic weighing (measuring residual volume) and the skinfold method, respectively; however one could argue that these statistically significant differences may be considered within measurement error, thereby eliminating the practical meaningfulness of these results. It is interesting to note that mean differences of 1.9 %BF reported by a different team of researchers were statistically equivalent [24].

One group of investigators reported no difference in %BF between BPM and BPE among 50 adult males and females [22]. Until now, no investigators have made this comparison among adolescent high school athletes (and wrestlers), and our results were

consistent with the previous study [22], in that we reported no difference (± 0.06) in %BF between BPM and BPE. If the OSAA were to base their decision to use BPE, rather than BPM, solely on the results of the repeated-measures ANOVA, they appear to have made a sound choice that is supported by the results of the present study of adolescents and a previous study of adults [22]. Since the BPE procedure does not require the participant to perform the breathing maneuver described earlier, this method is more time-efficient than the BPM method.

However, if the analyses include an examination of scatter plots using the methods of Bland and Altman [17, 18], greater scrutiny may reveal systematic bias associated with the BPE method. One other purpose of the present investigation was to determine whether or not there was a presence of systematic bias in L-BIA-MW and BPE-MW, compared to BPM-MW, as well as to determine the appropriateness of L-BIA and BPE to predict MW among high school wrestlers. The present investigation demonstrated an increase in the difference between BPE-MW and BPM-MW (i.e., variability) as the magnitude of MW increased (i.e., individuals in heavier weight-classifications); however, it revealed no significant systematic bias for LBIA-MW. Others have reported similar results after comparing L-BIA- to skinfold-predicted %BF among NCAA wrestlers [26] and after comparing L-BIA-predicted FFM to hydrostatic weighing (HW) among men ranging in age from 18 to 72 years [27]. Dixon and colleagues [25] reported no systematic bias for BPM, skinfolds, and L-BIA. To our knowledge, no other investigators have reported the presence or absence of systematic bias for BPE.

Despite the lack of systematic bias for LBIA-MW in the present investigation, data still did not support the use of L-BIA as an effective method for predicting MW among a heterogeneous group of male and female high school athletes because the results of the present study indicated wide limits of agreement for MW prediction [-7.13 kg (-15.71 lb) to 6.39 kg (14.08 lb)]. Limits of agreement are defined as bias (i.e., mean of LBIA-MW and BPM-MW) \pm 2 SD, and they serve as estimates of values that apply to the entire population [17]. Wide limits of agreement may reflect large variation in differences and/or a small sample size [17]. According to Heyward and Stolarczyk [28], statisticians recommend at least 20 participants per predictor variable. The sample size of the present investigation (N = 51) was sufficiently large [29], particularly given that only one predictor variable (i.e., MW) [28] was used to generate the prediction equation, thus the primary cause of the wide limits of agreement may be attributed to large variability in differences between LBIA-MW and BPM-MW.

Although, in the present investigation, BPE-MW demonstrated systematic bias, it had limits of agreement (-3.17 to 3.05 kg) that were half that of LBIA-MW (-7.13 to 6.39 kg). The implications of these results are that BPE-MW classifications were within -1.6 to 1.5 kg of the BPM-MW for more than 70% of participants, while LBIA-MW values were within -3.75 to 3.01 kg of BPM-MW for approximately 60% of participants. Therefore, LBIA-MW values were within -7.13 kg (-15.71 lb) to 6.39 kg (14.08 lb) of BPM-MW for approximately 40% of participants assessed by L-BIA. In contrast, BPE-MW was within -3.17 kg (-7.00 lb) to 3.05 kg (6.71 lb) of BPM-MW for about 23% of participants. For these participants, differences were half as large as for LBIA-MW.

Similar results were reported by other investigators who compared Bland-Altman limits of agreement for L-BIA to underwater weighing (measuring residual volume) [20], skinfolds [27], and the 4-component model [23].

Despite the fact that there were no significant or meaningful differences between methods, variability of individual differences between LBIA-MW and the criterion was twice as large as variability of individual differences between BPE-MW and BPM-MW. For example, BPE-MW resulted in the potential misclassification of one high school wrestler into a weight class that was directly below (BPM -1) the weight class designated by BPM-MW, whereas LBIA-MW resulted in the potential misclassification of 12 wrestlers by one (BPM \pm 1 or BPM -2) or more weight classes. When this analysis was applied to all participants, 12 of 49 participants were classified by BPE-MW into weight classes that differed from the weight classes assigned by BPM, and 30 of 49 participants were classified by LBIA-MW into weight classes that differed from the weight classes assigned by BPM. To reiterate, the term “misclassification” is based upon the assumption that the criterion method predicts the true weight class of the athlete. These results raise legitimate concerns about the use of L-BIA to assess %BF and MW among wrestlers. The authors do acknowledge that this participant sample included non-wrestling athletes in order to achieve sufficient statistical power and that the characteristics of this sample present a study limitation.

Within the OSAA, wrestling weight classes are separated by as little as 2.26 kg (5 lb), so the differences in magnitude between LBIA-MW and BPM-MW reflected in this investigation surpass the range of multiple wrestling weight classes. Given that MW

represents the lowest possible wrestling weight for an individual during the season, his or her lightest possible weight class may be incorrectly determined (either too high or too low) if L-BIA is the method used to establish MW. If an inaccurate MW was established, his (or her) well being may be compromised. On one hand, if a higher than appropriate MW class was established, he (or she) may be forced to compete against opponents who are larger and perhaps stronger, conceivably increasing the chance of injury. If, on the other hand, a lower than appropriate weight-class was established and the athlete attempted to maintain the lower than appropriate weight, there could conceivably be negative consequences for the health of the athlete.

Hydration level is a consideration for prediction of MW because a dehydrated state produces an artificially lower body mass than normal. Bartok and associates [30] compared the precision of HW, skinfold, L-BIA, and bioelectrical impedance spectroscopy (BIS) to the 4-component model among 22 male collegiate wrestlers in both a dehydrated and a euhydrated state [30]. Results indicated that all three methods of body composition assessment reported inaccurate and imprecise predictions of MW for the dehydrated participants ($USG \leq 1.020 \text{ g}\cdot\text{mL}^{-1}$) [30]. In addition, it is well established within the literature [30] that hydration level has a significant impact on the validity of body composition assessment using any form of bioelectrical impedance analysis (BIA) [31]. A dehydrated state results in an underestimation of FFM and an overestimation of %BF by BIA [31], which may potentially result in the misclassification of a wrestler into a lower weight class.

Some investigators [32] have questioned whether using disposable reagent strips to assess USG to establish hydration level among wrestlers is acceptable. This method is also referred to as the dipstick method because the test technician dips a disposable reagent strip into a urine sample. According to Oppliger and colleagues [32], the “gold standard” for assessing hydration level is plasma osmolality, however this laboratory method is not feasible for use in a high school wrestling program, thus USG or urine osmolality are plausible alternatives. Presently the NCAA and most high school wrestling programs use USG, largely due to the low cost and ease of administration [32]. Given the affordability of USG assessment, this method would likely be attractive for high schools in other states as well.

Most organizations accept using either disposable reagent strips or an optical refractometer for measuring USG, however there are two main reasons why the authors of the present investigation recommend that schools consider using the digital optical refractometer. The Oregon School Activities Association uses only disposable reagent strips, which as previously mentioned, involves an element of subjectivity. Though the dipstick method may be slightly more affordable than an optical refractometer for a single season, reagent strips are disposable and amortization of the refractometer over multiple seasons would not be cost prohibitive. Consideration of the more objective method is recommended, particularly since the long-term cost of both methods is comparable.

Given that most states, including Oregon, presently use the dipstick method for assessing hydration state at the time of MW determination, there may be reason to

scrutinize the high school definition of euhydration. High schools define MW and euhydration slightly differently than colleges, where the high school MW is defined as a male wrestler's $\text{FFM} + 7\% \text{BF}$, and euhydration is defined as having a USG below $1.025 \text{ g}\cdot\text{mL}^{-1}$. However, at the collegiate level (NCAA), the MW for a male athlete is defined by a lower $\% \text{BF}$ ($\text{FFM} + 5\% \text{BF}$) and euhydration is defined by a lower USG ($\text{USG} \leq 1.020 \text{ g}\cdot\text{mL}^{-1}$). There is evidence [33] to suggest that a USG below $1.020 \text{ g}\cdot\text{mL}^{-1}$ may be a more appropriate cutoff than $1.025 \text{ g}\cdot\text{mL}^{-1}$, when using reagent strips, due to a higher sensitivity (true positive rate) [33].

Though Bartok and colleagues [33] used a smaller sample size ($N = 25$) than is recommended ($50 < N < 100$) for hydration test studies, these investigators concluded that most hydration tests are useful screening tools for assessing hydration status when establishing MW; however, these investigators recommended that when using the dipstick method, a $\text{USG} \leq 1.020 \text{ g}\cdot\text{mL}^{-1}$ should be used to establish that an athlete is sufficiently hydrated. The lower limit ($1.020 \text{ g}\cdot\text{mL}^{-1}$) is recommended primarily because the sensitivity (true positive rate) and specificity (true negative rate) of this value are superior to that reported for the USG cutoff of $1.025 \text{ g}\cdot\text{mL}^{-1}$. For example, the sensitivity was 87% and the specificity was 91% when the limit for dipstick USG was $1.020 \text{ g}\cdot\text{mL}^{-1}$, however the sensitivity was lower (83%) and the specificity was higher (100%) when the limit for dipstick USG was $1.025 \text{ g}\cdot\text{mL}^{-1}$ [33]. According to the authors [33], it is more important to have high sensitivity than it is to have high specificity because the risk of poor sensitivity is predicting an artificially low MW for an individual, whereas poor

specificity only results in requiring the athlete to return for testing at a later time, when he (or she) is properly hydrated.

In the present investigation, USG was assessed using two methods: (1) the dipstick method and (2) a digital optical refractometer, which eliminates all subjectivity of the test technician. Results of the Cohen's Kappa analysis indicated that there were discrepancies in agreement of the test strip and the digital refractometer in classifying participants as hydrated or dehydrated when euhydration was defined as a USG less than $1.025 \text{ g}\cdot\text{mL}^{-1}$ (Kappa = 0.2). Therefore, with a USG limit of $1.025 \text{ g}\cdot\text{mL}^{-1}$, the agreement between assessment methods was no better than if left to chance. However, agreement improved (Kappa = 0.4), and was marginally acceptable, when euhydration was defined as a USG less than $1.020 \text{ g}\cdot\text{mL}^{-1}$.

The lack of agreement between the two methods that were used to assess USG for hydration status, in combination with the results of other investigators [32, 33], again raise the question as to whether or not high school wrestling programs should implement the same USG limits ($1.020 \text{ g}\cdot\text{mL}^{-1}$) adopted by (NCAA) collegiate programs, particularly if the dipstick method is used. Additionally, the lack of agreement reflected by the present investigation raises the question of whether or not the Oregon School Activities Association should eliminate the element of technician subjectivity by requiring schools to assess hydration state with a digital optical refractometer.

The survey completed by the 18 male wrestlers in the present investigation was completed after the implementation of the Oregon Wrestling Weight Monitoring Program and was in reference to the participants' present season at the time of survey completion.

Results do indicate that participants were still engaging in weight-cutting behaviors commonly used by competitive wrestlers at the time the survey was completed. At least 50% of the participants implemented the following weight-cutting behaviors: exercising vigorously solely for the purpose of losing weight, skipping meals, restricting fluid, and practicing in a heated wrestling room. Weekly fluctuations in body weight (0.9 to 9.5%) also support the conclusion that participants engaged in weight-cutting behaviors.

Validity of these results is based upon the assumption that each participant answered all survey questions honestly and accurately, and a limitation of this investigation is that the survey is based upon self-report and recall. Since no comparisons could be made prior to the implementation of this program, there is no way to determine if this program has significantly reduced these behaviors. Considering that weight-cutting behaviors have been so prevalent and embedded within the wrestling culture for over 50 years [5], it is not surprising that most high school wrestlers in the present investigation engaged in some type of weight-cutting behavior, even after the implementation of the Oregon Wrestling Weight Monitoring Program.

Since the participants reported most frequently that their coach and fellow wrestlers influenced their weight-cutting behaviors most, it stands to reason that education regarding the health risks associated with weight-cutting should be emphasized among this group of individuals. Given that the National Wrestling Coaches Association is largely responsible for the implementation of wrestling weight-monitoring programs at the high school and collegiate levels, the sport of wrestling appears to be making strides in attempting to protect the health of athletes.

Strengths of this study include the fact that it was a repeated measures design, which removed bias, in that participants were compared to themselves during the investigation. To our knowledge, no other investigators have compared these three methods of body composition assessment, nor have any others examined the systematic bias of BPE among this adolescent population.

A limitation of this investigation was that, in order to achieve sufficient statistical power, the participant pool was expanded to include any high school athlete, rather than solely interscholastic wrestlers. Since females are allowed to participate in high school wrestling programs, they were not excluded from this investigation. Also, there were an insufficient number of female participants to divide the group by sex. In addition, the limitations and experimental error of data collection are acknowledged.

The findings of this study must be delimited to healthy male and female adolescents who participate in interscholastic athletics in western Oregon under the supervision of the Oregon Scholastic Activities Association. In addition, results are delimited to the specific instruments and apparatus used for data collection, and adolescents with a hydration status defined as a $USG \leq 1.025 \text{ g}\cdot\text{mL}^{-1}$ at the time of body composition assessment.

Given the significant differences in %BF (between L-BIA and both BODPOD methods) for the 16 female participants, future investigations may consider examining differences between these methods among females only. With respect to the sport of wrestling, future studies should limit participants to the status of high school wrestler and further examine the appropriateness of the present definition of euhydration and the

method of hydration assessment for high school wrestlers. Future investigators may consider comparing the BODPOD and commonly used field methods of body composition assessment to a multi-component model among high school athletes. Finally, future investigators may consider developing an equation for predicting MW using a large sample size and multiple field-type predictor variables that would be cross validated against a separate group of participants.

Praise should be given to the American College of Sports Medicine, the NCAA, the National Wrestling Coaches Association, the National Federation of State High School Associations, and the many states (e.g., Oregon, Wisconsin [34]) that have implemented wrestling weight monitoring programs within their high schools, and for the proactive role that these governing bodies have adopted in the effort to protect the health and well-being of young athletes.

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Appendix A: Review of Literature

Introduction

In 1979, the Journal of the American Medical Association [8] published a report of a 16-year old high school wrestler who lost 12% of his body weight and suffered a massive pulmonary embolism after undergoing two consecutive bouts of rapid dehydration within one week in order to “make weight” before wrestling competitions. The term “making weight” or “weight-cutting” refers to the practice of rapidly losing a large proportion of one’s body mass in order to be assigned to a low wrestling weight-class before competition [2-6]. Typically these athletes re-gain the lost weight in the 24- to 48-hours following the competition [35], however the rapid weight loss can have negative effects upon the athlete’s health [7, 8] and athletic performance [1].

These weight-cutting behaviors include a variety of methods, ranging from engaging in activities that cause excessive sweating to food and fluid restriction, and these behaviors predispose wrestlers to dehydration and subsequent hyperthermia [2, 3, 7, 8]. Some examples of weight-cutting methods, besides fasting and fluid restriction, include: spitting, vomiting, consuming laxatives, diuretics, and/or diet pills, using enemas, and increasing sweat production by exercising vigorously in an artificially heated environment, sleeping while wearing many layers of clothing, using saunas while clothed, and wearing suits that are impermeable to water vapor [2-4, 35, 36].

The American College of Sports Medicine (ACSM) published position statements, recommending ways in which wrestling-related organizations and coaches could assist in eliminating these unsafe behaviors among athletes [2]. Tragically, in

1997, three collegiate wrestlers died within a period of one month due to dehydration-related hyperthermia attributable to weight-cutting behaviors [7]. The following wrestling season, the National Collegiate Athletics Association (NCAA) modified the wrestling rule book by adding weight to each weight class, by weighing athletes for weight-class categorization within 1-2 hours of competition, rather than one day prior, and by implementing a weight monitoring program where athletes are limited to losing a maximum of 1.5% of FFM per week during the wrestling season [37-39]. After measuring body composition and body weight of a hydrated NCAA wrestler, his minimum wrestling weight for the season is calculated as follows:

$NCAAMW_{MALE} = FFM + 5\%FFM$. The NCAA weight-monitoring program defines a state of euhydration as a USG below $1.020 \text{ g}\cdot\text{mL}^{-1}$ [37-39].

In conjunction with the NCAA and the National Wrestling Coaches Association (NWCA), the National Federation of State High School Associations (NFHS) developed a weight certification program modeled after the collegiate plan and specific rules designed to discourage high school athletes from weight-cutting prior to a wrestling match [40]. Presently, the high school weight certification program requires that a trained individual assess the euhydrated athlete's body weight and body composition at the onset of the wrestling season, whereby the state of euhydration is defined as having a USG that does not exceed $1.025 \text{ g}\cdot\text{mL}^{-1}$ [40]. An individual's MW for that season is calculated as follows: $MW_{MALE} = FFM + 7\%FFM$; $MW_{FEMALE} = FFM + 12\%FFM$ [40].

The Oregon Scholastic Activities Association (OSAA) implemented the Oregon Wrestling Weight Monitoring Program during the 2005-2006 wrestling season, and

required that the body composition of its euhydrated athletes be assessed by a trained technician using L-BIA between the first practice and the first wrestling competition [11]. The Oregon School Activities Association established the MW according to the guidelines outlined by the National Federation of State High School Associations; however defined a hydrated state as a USG below $1.025 \text{ g}\cdot\text{mL}^{-1}$, rather than *at or below* $1.025 \text{ g}\cdot\text{mL}^{-1}$.

Oregon high school wrestlers have the right to appeal the L-BIA results within a 14-day period following the initial body composition assessment by having a second body composition assessment of better precision whereby a qualified individual at a pre-approved site conducts one of two methods of densitometry: hydrostatic weighing (HW) or air displacement plethysmography using the BOD POD[®] body composition system [49]. To reiterate, air displacement plethysmography will be referred to as the BOD POD[®]. The Oregon Wrestling Weight Monitoring Program [49] states that appeals with the BOD POD[®] estimate thoracic gas volume (BPE), rather than measure thoracic gas volume (BPM). Again, thoracic gas volume (V_{TG}) is the amount of air in the lungs and thorax during tidal breathing.

The Oregon Wrestling Weight Monitoring Program selected the less time-consuming of the two BOD POD[®] methods, BPE rather than BPM, and this choice *may potentially be* supported by research reporting that there is no difference in body composition results when comparing the use of BPE and BPM among male and female adults, ranging in age from 18 to 56 years [22]. To our knowledge, there has been no investigation comparing the differences between BPE and BPM among adolescents, or

have there been any research studies comparing the differences between the BOD POD[®] and L-BIA among high school wrestlers and/or athletes.

Again, the main purpose of this investigation was to evaluate the OSAA's newly implemented weight monitoring program that uses L-BIA to assess an athlete's body composition at the beginning of the wrestling season in order to predict the MW for the season. Since high school wrestlers may appeal the results of the original assessment using BPE, the present investigation compared the prediction of %BF among L-BIA, BPE, and BPM. Therefore, this portion of the paper will discuss the theory, assumptions, and methodology of the body composition techniques involved in this investigation, as well as some relevant studies that have compared the precision of these methods among different samples of the population.

Bioelectrical Impedance Analysis (BIA)

Bioelectrical impedance analysis (BIA) is a safe, fast, portable, relatively inexpensive, and noninvasive method of indirectly estimating total body water (TBW) and FFM that minimizes technician error through a simple protocol. Once FFM is reported, fat mass (FM) may be calculated as the difference between body mass and FFM. The Siri or Brozek equation may then be used to calculate %BF. BIA is based on the ability of bodily tissues to conduct (or impede) the flow of electricity, which follows the path of least resistance. A small (500 μ A to 800 μ A) alternating current is applied to a person's body at one or two sites and the body's impedance (Z) to the flow of electrical current is measured with the bioelectrical impedance analyzer. Highly conductive tissues

comprised of large amounts of water and electrolytes include muscle, blood, and cerebrospinal fluid, whereas highly resistive tissues include fat, bone, and tissues with air-filled spaces [29, 41, 42]. Therefore, individuals with large amounts of an anhydrous tissue, such as fat, will consequently have less TBW and higher impedance to electrical flow than lean individuals.

Impedance (Z) is the opposition of a conductor to an electrical current and is comprised of two components: resistance (R), which is the pure opposition to the conductor, and reactance (X_C), which is the reciprocal of capacitance [28, 29, 41, 42]. Cell membranes act as condensers (or capacitors) since they consist of two conducting surfaces separated by a nonconductor, and they accumulate, hold, and store electrical charges [28, 29, 41]. Reactance is the dielectric component of impedance so it transmits electric effects through induction, where an electric current appears due to the presence of another electric current nearby [28, 29]. Impedance is determined according to the following relationship between these two components: $Z^2 = R^2 + X_C^2$. The capacitance of cell membranes varies according to the signal frequency used [29]. At low frequencies, impedance is equal to resistance and reactance is zero. BIA is based on several assumptions. Though the theory of bioelectric impedance assumes that the human body is a uniform conductor with one current pathway, it is not [28, 29, 41]. As frequency increases, reactance increases due to multiple current pathways that impede the current at different rates [29, 41]. At a given high frequency reactance is maximal, which then decreases as frequency continues to increase [29, 41]. The phase angle is the angle between the impedance vector and the resistance vector [29, 41]. Though multi-

frequency bioelectrical impedance analyzers do exist, most bioelectrical impedance use the frequency of 50 kHz, and since X_C is generally small at 50 kHz, Z and R are often used interchangeably [28, 29, 41]. The maximum reactance of muscle tissue occurs at a frequency of 50 kHz [29, 41], and multi-frequency bioelectrical impedance analyzers do not estimate body composition any more precisely or accurately than single-frequency analyzers [29, 41].

Two additional assumptions of the BIA method are that FFM has a density of 1.1 g/cm³ [31], and that FFM may be estimated from TBW because the fat-free proportion of the human body is comprised of 73% water [28, 31]. However both the density of FFM, which is largely comprised of muscle and bone, and the proportion of water vary between and within individuals. The within-range changes in the density of bone may vary by as much as 1.068 to 1.123 g/cm³ and the within-range changes in density of muscle may vary by as much as 1.09 to 1.11 [28]. Between individuals, the proportion of muscle as part of FFM may range from 40 to 60% and the proportion of bone as part of FFM may range from 12.5 to 18.7% [28].

One other assumption is defined by a geometrical relationship between the conductor's volume (V) and its resistance (R) [28, 29, 41]. First, the human body is assumed to be a perfect cylinder with a uniform length and cross-sectional area. According to Ohm's law, for a cylindrical conductor, such as a wire, resistance (R) is directly proportional to its length (L) in centimeters (cm) and inversely proportional to its cross-sectional area, (A) in cm², thus $R = \frac{\rho L}{A}$, where ρ (ohm • cm) is the reciprocal of conductivity and is a constant known as the specific resistivity constant. Since volume

(V) is $V = L \cdot A$, then $V = \frac{\rho L^2}{R}$, or the volume of FFM, can be calculated if length squared (L^2) and resistance (R) are two known quantities.

One limitation of this assumption is that the human body is not a perfect cylinder with a uniform length and cross-section. Rather, the human body is more closely represented as five cylinders connected in series including both upper extremities, both lower extremities, and the torso. In addition, the cross-sections of the cylinders differ, particularly when comparing the torso with the extremities. The torso is different than the extremities because it is comprised of several organs and muscles with a different architecture than is commonly found in the extremities. The extremities consist of a higher proportion of muscles whose fibers run parallel to the longitudinal axis of the bone [29, 41] than the torso. Since the lengths and cross-sectional areas of these five cylinders differ, resistance to the flow of the current will also differ. Also, since the human body is not a perfect cylinder, the specific resistivity constant (ρ) is not truly constant. The ρ of the trunk is greater than that of the extremities, and ρ varies across age groups and level of adiposity [29, 41].

The precision and accuracy of BIA are influenced by instrumentation; the prediction equations used, subject factors, environmental factors, and are minimally influenced by technician skill. According to Stolarczyk and colleagues [43], the standard error of estimate (SEE) is ≤ 3.5 kg for males and ≤ 2.8 kg for females and these values translate to ± 3.5 %BF when appropriate prediction equations are applied [28]. A variety of factors influence resistance and a change in resistance of approximately 15Ω results in a 1.5 kg change in FFM.

The traditional BIA method requires the subject to lie on a nonconductive surface in the supine position and uses either 2 or 4 electrodes, however the tetrapolar method is the more common of the two. In this case, an excitation current is injected into the two most distal electrodes attached at the hand and foot and the voltage decrease is measured at the proximal electrodes attached at the wrist and ankle. Technician skill level is a small source of measurement error, since subject positioning and electrode placement are simple procedures and have been standardized [28].

It is important to use the same BIA instrument for all tests when comparisons will be made since the impedance values reported vary between brands and models of BIA instruments [28]. Additionally instrumentation precision tends to decrease at the extreme ends of the frequency spectrum (< 10 kHz and > 500 kHz) [29]. The type of analyzer may account for a 1.0 to 1.3 kg change in FFM [28].

Prediction equations should be used for subjects whose individual characteristics closely match the homogenous sample of population used to develop the equation. Different prediction equations consider a variety of subject variables, such as the resistance index (Ht^2/R), or height (Ht) and resistance (R) alone, sex, race, physical activity level, level of fatness, and body weight. Also, since age influences the amount of FFM, most prediction equations require this value as well [28, 29, 41, 42].

Both subject and environmental factors influence hydration level, thereby affecting the resistance (R) and FFM reported by BIA. The BIA apparatus reports a lower resistance (R) after a reduction in TBW, thereby overestimating FFM and underestimating %BF; and variations in within-subject TBW account for between 3 and

4% of the variability of resistance (R) [28, 44]. Eating, drinking, engaging in moderate- to high-intensity aerobic exercise, and dehydrating oneself through any other means decreases resistance (R) and TBW; and elevated skin and core body temperature, from exercise or a fever, reduces resistance (R) as well [28, 44]. Eating or drinking within 4 hours of the test, purposefully dehydrating oneself, and engaging in moderate- to high-intensity aerobic exercise prior to the test may cause changes in FFM of 1.5 kg [44], 5.0 kg, and 12.0 kg, respectively [28].

Since ambient temperature influences body temperature, BIA technicians should avoid testing in extreme temperatures or in conditions where ambient temperature fluctuates more than $\pm 2^{\circ}\text{C}$ [42]. A 20°C change in ambient temperature results in a 2.2 kg change in FFM [28].

Stage of menstrual cycle influences TBW, and it is recommended that subjects be tested when they are not experiencing a large, menstrual cycle-related weight gain due to an increase in TBW [28, 44]. The distribution of body water is influenced by body position [42] thus protocol should be standardized such that subjects remain in the same position for the same amount of time prior to each measurement. It is also important that subjects breathe normally since inflated tidal volume influences trunk impedance (Z). Due to within-individual changes in these factors, BIA is better for estimating FFM at one point in time, than for assessing changes in body composition [42].

Standard protocol for traditional BIA excludes eating and drinking for 4 hours preceding the test, exercising within 12 hours of the test, drinking alcohol 48 hours before the test and taking diuretic medications during the 7 days preceding the test, and testing

female subjects during the portion of the menstrual cycle that causes water retention [28, 42]. In addition, subjects should void their bladders (urinate completely) [28, 42] within 30 minutes of the test.

The accuracy of this method has been questioned when assessing obese individuals since the FFM of these individuals is comprised of a higher proportion of water and since the ratio of extracellular water (ECW) to intracellular water (ICW) is higher in this subpopulation [28, 41, 42].

Since BIA is relatively inexpensive and involves little technical skill, it may be more commonly used in middle schools, junior high schools, and high schools, particularly if school personnel do not have access to professionals trained in the skinfold (SF) technique, and since other more sophisticated methods commonly available in laboratories [e.g. HW and dual-energy x-ray absorptiometry, (DXA)] are cost prohibitive.

Luttermoser and associates [45] examined the precision and accuracy of determining MW using two SF methods, that use different calipers, and conventional tetrapolar BIA among 104 junior high and high school boys interested in wrestling. The calipers used were the metal Lange caliper and the Adipometer, which is a small, plastic, and inexpensive caliper [45]. Measurements from three sites were used to estimate body composition and the results of both the Adipometer and BIA were compared to those of the Lange caliper [45]. Following the guidelines of the National Federation of State High School Associations, MW was calculated as $FFM + 7\%BF$ [45].

The investigators did not assess hydration status nor adhere to standard pre-BIA protocol prior to data collection, since all measurements were announced on the day of

testing [45]. All SF measurements were taken twice and were repeated if they varied more than 0.5 mm [45]. The two measurements taken with the Adipometer disagreed by more than 1 mm 15.4% of the time, whereas the two measurements taken with the Lange disagreed more than 1mm 3.3% of the time [45].

Despite the significant intra-rater error among the Adipometer, correlations were 0.992 between the two calipers, and 0.979 between the Lange caliper and the BIA methods [45]. The authors reported the largest error values (total or pure error of 2.46 kg and SEE of 1.166) between BIA and the Lange SF method, and they reported the smallest error values (total error of 1.71 kg and SEE of 0.498) between the two caliper methods [45]. Compared to the Lange calipers, BIA underestimated MW by a mean of 2.49 kg (5.5 lb.), whereas the Adipometer calipers overestimated MW by a mean of 0.59 kg (1.31 lb.) [45]. Underestimating MW may contribute to a wrestler losing more body weight than he/she can safely lose.

Leg-to-Leg Bioelectrical Impedance Analysis (L-BIA) and Wrestling

In the past, the traditional BIA method of body composition assessment has been used to assess MW in competitive wrestlers [45]; however more recently L-BIA has become more popular and is presently being used by the OSAA to establish MW in the euhydrated athlete [20, 23-26].

The L-BIA apparatus (Tanita Corporation of American, Inc., Arlington Heights, IL) differs from the traditional method of BIA in subject position, electrode type, and electrical path. The L-BIA method assesses lower extremity impedance of a single

frequency (50 kHz) electrical current using two stainless-steel footpads that are each divided into an anterior and posterior pressure-contact electrode. After the participant steps onto the scale and places his (or her) bare feet on the electrodes, the instrument simultaneously measures body weight and impedance, which is converted to FFM and %BF. The current is applied to the anterior electrodes and the voltage decrease is measured at the posterior electrodes [27].

Conventional BIA has required that the injection electrode and the detection electrodes be at least 4-5 cm apart in order to avoid electrical interference, however it would appear that the L-BIA apparatus might approach this minimum distance [28, 43]. Since L-BIA is a segmental method limited to the lower extremities, this method eliminates the need to factor the complex cross-section of the trunk [28, 43]. Traditional tetrapolar BIA is conducted on an individual in the supine position, thereby standardizing the effect of the gravitational redistribution of body water [28, 43]. L-BIA estimates the FFM of the subject while standing, thus, depending on the duration of the measurement, one might expect body water to pool in the lower extremities [28, 43]. An increase in segmental body water would decrease resistance (R) resulting in an overestimation of FFM and an underestimation of %BF. Despite these methodological differences, some investigators [28, 43] have reported a similar predictive accuracy (%BF) when comparing L-BIA to the conventional arm-to-leg BIA.

The L-BIA apparatus has simplified the method of BIA because electrodes do not need to be replaced and the potential technician-related error has been eliminated since needle or gel electrodes need not be applied to specific anatomical landmarks [28, 43]. In

addition, Nunez and colleagues [46] reported that the mean of pressure-contact electrode measured impedance was significantly (about 15 Ω) higher than that measured by gel-electrodes, however similar predictions of body composition are possible when variables such as age and gender are factored into the prediction equation used to report %BF. In addition these investigators [46] reported similar coefficients of variation (CV) for within- and between-day variability among pressure-contact and gel electrodes. Others [28] have reported similar predictive accuracies (%BF) when comparing conventional BIA with L-BIA.

Since 1998, HW and SF have been the NCAA-approved methods of establishing MW [47], and some investigators [20, 26] have compared L-BIA to the SF technique and HW for estimating FFM. Utter and colleagues [26] compared L-BIA and the 3-site SF technique to predict body composition among (N ranging from 90 to 274) NCAA Division I and III collegiate wrestlers across a wide range of weight classes at five different times during the 1998-1999 wrestling season.

These investigators [26] complied with the recommendations of Heyward and Stolarczyk [28], in that they evaluated the precision of the regression equation by computing the standard error of estimate (SEE), which provides a measure of the standard distance between the regression line and the actual data points,

$$SEE = \frac{\sqrt{\sum (Observed - Predicted)^2}}{N - 2} \quad [48].$$

Results indicated that the precision of the SF-generated regression equation was similar to the L-BIA-generated regression equation [26]. (In other words, each method had similar standard errors of estimate). The SEE values between L-BIA and the 3-site skinfold ranged from 2.1 %BF to 3.5 %BF, and this

team of investigators [26] reported significant ($p < 0.001$) correlations between the two methods ranging from 0.68 to 0.83. Though the SEE of %BF between the two methods is similar to that reported elsewhere [28], a low correlation of 0.68 may have been statistically significant due to the large sample size ($N = 274$). Hydration level was not measured at three (out of five) assessment sessions, however the authors [26] reported the highest SEE (2.1%, 2.2%, and 2.3%) values at these L-BIA sessions.

In a separate investigation, Utter and associates [20] compared the precision of L-BIA and the SF technique to HW in predicting FFM among 129 hydrated high school wrestlers, where euhydration was defined as $USG \leq 1.020 \text{ g}\cdot\text{mL}^{-1}$. There were no significant differences in FFM, correlation coefficients, and SEE between methods [20]. Using HW as the reference method, the SEE of the SF method was 1.97 kg of FFM (or 3.0 %BF), whereas the SEE of L-BIA was 3.64 kg of FFM (or 5.5 %BF) [20]. The FFM (kg) for all three methods was reported as 56.2 ± 9.9 , 56.9 ± 8.4 , and 56.1 ± 8.9 for HW, L-BIA, and SF, respectively [20]. When using the mean body weight of the sample, these FFM values translate to 14.3 %BF, 13.3 %BF, and 14.5 %BF for HW, L-BIA, and SF, respectively [20]. The authors [20] recommended that the 3-site SF be used, rather than L-BIA, to assess body composition among high school wrestlers based on the differences in the resulting SEE values. The largest SEE (3.88 kg) was observed for L-BIA and the authors [20] reported that L-BIA consistently underestimated %BF. The authors [20] only recommended the use of L-BIA to determine MW when trained personnel are not available to conduct SF assessments.

Cable and colleagues [27] investigated the difference in FFM between L-BIA and HW among a heterogeneous group of adult males ($N = 192$). The authors [27] reported no significant difference between the FFM of these two methods, and they reported a SEE of 3.5 kg (7.7 lbs) FFM for L-BIA.

Though measurement error exists for all methods that estimate %BF in living human beings, when cross-validating the accuracy and precision of a given method (L-BIA) to a criterion method, investigators should select the most precise and accurate criterion model, the four-component model [49]. The four-component model may be anatomical or chemical, whereby the former divides the human body into the following four compartments: adipose tissue, non-skeletal muscle, skeletal muscle, and bone, and the latter divides the body into the following chemical compartments: fat, water, protein, and mineral [49].

Recently, Clark and colleagues [23, 24] evaluated L-BIA against a 4-component model among 53-57 NCAA Division I wrestlers, who were euhydrated, according to the NCAA standards ($USG \leq 1.020 \text{ g}\cdot\text{mL}^{-1}$). These investigators [23, 24] measured body density (D_B) by HW, bone mineral content (BMC) by DXA and TBW by deuterium dilution [23, 24]. In addition, body composition was assessed using the 3-site SF method [23, 24]. A MW prediction error of 2 kg was considered acceptable, and L-BIA successfully predicted MW within an error of 3.5 kg 68% of the time [23, 24]. There was no significant difference in %BF, MW, or correlation coefficients (R) between the criterion method and HW, or the criterion method and SF [23, 24]. Compared to the criterion method, the correlation coefficients were reported as 0.98, 0.97, 0.96, and 0.92

for HW, SF, DXA, and L-BIA, respectively [23, 24]. In addition, the SEE values were reported as 1.31 %BF, 1.72 %BF, 2.19 %BF, and 2.98 %BF for HW, SF, DXA, and L-BIA, respectively [23, 24]. The SEE for L-BIA translated to ± 3.98 kg (8.8 lb) FFM [23, 24].

Clark and colleagues [23, 24] generated Bland-Altman plots and reported no systematic bias. The authors [23, 24] concluded that since the L-BIA prediction of MW spanned several wrestling weight classes, the technique should not be used to predict MW in collegiate wrestlers. The best precision was observed in the SF and HW methods [23, 24], which are two accepted methods of MW determination for the NCAA.

According to Bland and Altman [18], since the true value of MW is unknown, the mean of the test and criterion method values is the best estimate of the true value [18]. Therefore, it is inappropriate to plot the difference (between methods) against the criterion value, because the difference would be related to the criterion value, resulting in statistical artifact [17]. Plotting the difference against the criterion will be more likely to demonstrate a significant relationship (systematic bias) even when there is no association between the difference between methods and the magnitude of the measurement [17, 18].

Despite the fact that Clark and colleagues [24] conducted Bland-Altman analyses by plotting differences between methods as a function of the *criterion method* (rather than the mean of both methods), they reported no systematic bias among hydrostatic weighing, skinfold, DXA, and L-BIA compared to the 4-component model. One year later, the same team of investigators [23] reported the effectiveness of L-BIA for predicting MW by comparing the difference between LBIA-MW and the 4-component

model-predicted minimum weight (LBIA-MW minus 4C-MW) as a function of the criterion (4C-MW) among collegiate wrestlers. Contrary to their earlier investigation [24], these investigators did report significant systematic bias of L-BIA [23], however these (and the previous) results should be interpreted with caution, due to the potential introduction of statistical artifact [17, 18].

Leg-to-Leg Bioelectric Impedance Analysis in the Present Investigation

In the present investigation, L-BIA was conducted with a Tanita Body Fat Analyzer (Tanita Corporation of American, Inc., Arlington Heights, IL), which has stainless steel footpad electrodes that are each divided into an anterior and a posterior portion. Body composition (%BF) was estimated by having the subject stand barefooted on a platform scale while a small and imperceptible alternating current (500 μ A, 50 kHz) was passed through the lower body. The apparatus delivered the current through the anterior footpad and measured the change in voltage at the posterior foot-pad. The L-BIA apparatus simultaneously measured body weight and leg-to-leg impedance. FFM was calculated in the “standard mode” and used the manufacturer-supplied prediction equations that consider body weight, age, gender, and impedance index, which is the ratio of body height squared to impedance (height^2/Z).

Air Displacement Plethysmography (ADP) Using the BOD POD[®]

Though the NCAA has accepted both SF and HW as appropriate methods for predicting MW for some time, more recently (2003-2004) air displacement

plethysmography (ADP) has been accepted as an additional method of predicting MW in collegiate (NCAA) and high school wrestlers. Within the last decade, ADP has become a more commonly used method of body composition assessment that operates under the theory of densitometry. The apparatus discussed is the BOD POD[®] body composition system, manufactured by Life Measurement Instruments (Concord, CA). This apparatus is insulated and is divided into 450 L anterior “test” and 300 L posterior “reference” chambers that are separated by a diaphragm [50]. The diaphragm may be moved (or “perturbed”) to cause equal and opposite changes in the volume of the chambers by a computer-controlled electronic servo system [50]. The instrumentation is housed in the posterior chamber, and a fiberglass seat is housed in the anterior chamber [50].

The BOD POD[®] is calibrated by measuring the volume of the empty chamber, followed by the volume of the chamber containing a cylinder with a known volume (of 50 L) [50]. After being calibrated, the BOD POD[®] calculates the volume of a human being by subtracting the volume of the closed and empty chamber from the volume of the closed chamber containing a person [50]. Once the volume (V_B) and mass (M_B) of a human are known, his/her body density (D_B) can be calculated. %BF can then be calculated from D_B using the Siri equation: $\%BF = \frac{495}{D_B} - 450$, or the Brozek equation [28, 41, 42, 49].

Past attempts at assessing body composition with ADP were abandoned because the %BF error was significantly greater compared to other body composition assessment methods [50]. The source of error was related to the fact that ambient chamber air is adiabatic (there is no evolution or absorption of heat by the system) whereas air in the

clothing, in the hair, over the skin and within the thorax is isothermal (has a constant temperature) at physiological temperature [50].

Air under isothermal conditions behaves differently than air under adiabatic conditions [50]. The temperature (or average kinetic energy of a gas) of air under adiabatic conditions increases as it is compressed (or as the volume of air decreases) since, by definition, the system may not absorb energy. Boyle's Law $\left[\frac{P_1}{P_2} = \frac{V_2}{V_1} \right]$ states that under isothermal conditions, pressure increases in proportion to the decrease in volume of a gas. In order for temperature to remain constant (isothermal), the increasing energy from the decrease in volume must be removed from the system. In this way, isothermal air is more easily compressed than adiabatic air [50].

Consider the analogy where a flawless coiled spring represents a volume of air. Under adiabatic conditions, if one expended energy (did work on) compressing the spring, the kinetic energy put into the system would be converted to an equal amount of elastic energy and the spring would rebound. However, under isothermal conditions, a portion of the kinetic energy that compressed the spring would be absorbed by the spring's surroundings, thereby robbing the spring of some of its elastic energy, resulting in a less powerful rebound. Therefore, the spring (or volume of air) under adiabatic conditions is more easily compressed.

Poisson's Law $\left(\frac{P_1}{P_2} \right) = \left(\frac{V_2}{V_1} \right)^\gamma$ where γ is 1.4 for air, describes the relationship

between the pressure and volume of a gas under adiabatic conditions [50]. Since the ratio of gas volumes is mathematically raised to the 1.4th power, the compressed volume of air

under isothermal conditions will change its volume 40% less than air under adiabatic conditions [50]. The BOD POD[®] reports a smaller (or negative) volume for objects under isothermal conditions [50]. Although the majority of the air in the BOD POD[®] exists under adiabatic conditions, the volume of isothermal air in the hair and clothing, over the skin, and within the thorax must be corrected for in order to avoid underestimating body volume (V_B), overestimating body density (D_B), and underestimating %BF [50]. In order to account for the external isothermal air, body surface area (BSA), reported in units of cm^2 , is estimated using the Dubois formula: $BSA = 71.84 \cdot M_B^{0.425} \cdot H_B^{0.725}$ where body mass (M_B) is reported in units of kg and height (H_B) is reported in units of cm [50]. Surface area artifact (SAA), expressed in units of L, is calculated as: $SAA = k \cdot BSA$ where k, the constant, is expressed in units of (L/cm^2) [50]. Throughout testing, the subject is required to wear a tightly fitting swimsuit, and a swim cap in order to minimize the effects of clothing and to compress the hair [50].

Since air in the lungs and thorax is under isothermal conditions, the average thoracic gas volume (V_{TG}) during tidal breathing may be measured during the test or estimated using prediction equations programmed into the apparatus' computer [50]. If V_{TG} is to be measured, a subject connects to a breathing circuit (mouthpiece attached to a breathing tube) and breathes air external to the chamber while wearing a nose clip [50]. After the apparatus records a few cycles (inhalation and exhalation) of tidal breathing, the airway is occluded for a few seconds at mid-exhalation so that there is minimal difference between alveolar and airway pressures [50]. While the airway is occluded the subject puffs against the closed airway in order to measure simultaneous pressure changes in the

lungs [50]. $V_{TG} (L) = (m/1.4) - \text{dead space of breathing circuit}$, and m will have been determined during calibration [50]. As was discussed earlier, “40% of the measured V_{TG} is added to the measured V_B ” [50] in order to account for the fact that isothermal “lung air appears 40% larger” [50] than adiabatic chamber air [50]. Finally, the BOD POD[®] reports whether or not the V_{TG} test is acceptable by producing a Figure of Merit (M) [50]. The Figure of Merit (M) is based upon how well the pressure curves of the airway and chamber superimpose [50]. The test results may be accepted if $0 < M < 1.0$ [13]. The final V_B measurement is then calculated as: $\text{Final } V_B = \text{Uncorrected } V_B (L) - \text{SAA} (L) + 40\% V_{TG} (L)$ [50]. Most research studies discussed throughout this paper measured V_{TG} . To reiterate, BPM refers to the BOD POD[®] while measuring V_{TG} , and BPE refers to the BOD POD[®] assessment while estimating V_{TG} using prediction equations.

The advantages of this method are that it is fast, easy, accurate, and minimizes tester bias and error [13, 50]. BPM is appropriate for a wider variety of human subjects compared to HW, another densitometric method. People varying in age from infancy to their elder years may be comfortably tested, and individuals who are ill or who have a disability may be more easily tested using BPM, as compared to HW [13, 50]. The BOD POD[®] chamber is also large enough to accommodate large individuals such as professional athletes [13, 50].

It has been reported [50] that the BOD POD[®] accurately measures the volume of an inanimate repeatedly object over time. Over a period of two days, the system measured the calibration cylinder (of a known volume) 40 times with a coefficient of variation (CV) of 0.025% on the first day and 0.027% on the second day [50]. The

minimal variation of volume translates to 0.1%BF [50]. The system was able to test a series of objects ranging in volume from 25 L to 150 L [50].

Other investigators [21, 51, 52] have reported the validity and reliability of BPM (BOD POD[®]) using human beings, rather than inanimate objects. As may be expected, BPM is less reliable when assessing human beings, rather than cylinders of a known volume. Ballard and associates [51] reported the validity and reliability of BPM compared to DXA in 47 female collegiate athletes and 24 female controls. The validity of BPM was reported as SEE of 2.14 %BF ($R^2 = 0.85$) and SEE of 2.83 %BF ($R^2 = 0.83$) for athletes and controls, respectively [51]. The reliability was reported as an SEE of 2.11 %BF ($R^2 = 0.94$) among ten athletes, and an SEE of 1.98 %BF ($R^2 = 0.93$) among 12 controls [51].

Compared to the previous study by Ballard associates [51], Collins and colleagues [52] reported superior reliability among NCAA Division I collegiate football players. Reliability of BPM was established using 15 subjects, where the SEE across trials was 0.7 %BF [52]. In the larger validation study, conducted by Ballard and colleagues [51], %BF of 69 collegiate football players was assessed using two methods of densitometry, HW and BPM, which are based upon a two-component model. Among these subjects, 20 subjects were assessed using DXA, so that 20 athletes were assessed using a three-component model, where DXA measured bone mineral content (BMC) [51]. Results indicated no significant difference between %BF estimated by DXA (12.9 ± 1.2 %BF) and the 3-component model (12.7 ± 0.8 %BF) however %BF estimated by BPE (10.9 ± 1.0 %BF) was significantly different from both of these methods [51]. The SEE for BPM

was 2.4 %BF, compared to the 3-component model (and to DXA), and 1.9 %BF compared to HW [51].

McCrorry and associates [21] also investigated the reliability of BPM using the BOD POD[®], and validity of BPM compared to HW among 68 adult males and females who varied in age and body mass. Both methods were found to be reliable, as there was no significant difference in %BF between the first and second trials for BPM or HW [21]. The coefficient of variation (CV) for BPM was reported as 1.7 ± 1.1 %BF and the CV for HW was 2.3 ± 1.9 %BF [21]. In addition, %BF predicted by BPM was not different than that predicted by HW [21]. Percent body fat reported by BPM was 27.4 ± 1.4 %BF, 23.7 ± 1.0 %BF, and 25.2 ± 0.8 %BF for women (N = 26), men (N = 42), and for all subjects (N = 68), respectively, where as %BF reported by HW was 27.1 ± 1.3 %BF, 24.4 ± 1.0 %BF, and 25.4 ± 0.8 %BF, respectively [21].

In 1998, these same investigators [22] compared the difference in precision between BPM (ADP while measuring V_{TG}) and BPE (ADP while predicting V_{TG} with manufacturer-supplied prediction equations), and between HWE (HW, while estimating V_R), and HWM (HW while measuring V_R) among 50 adult males (N = 14) and females (N = 36) ranging in age from 18 to 56 years [22]. The SEE of BPE was ± 1.36 %BF, compared to the reference BPM, whereas the SEE of HWE was ± 1.67 %BF, compared to HWM [22]. There was no difference in %BF between BPM (23.8 ± 1.3 %BF) and BPE (23.6 ± 1.3 %BF), however there was a significant difference between the two methodological variations of HW (estimating verses measuring V_R) [22]. When comparing BPE to HW, the authors [22] attributed the fact that there was no difference

between BPE and BPM to the fact that the error term associated with the prediction of V_{TG} would have only 40% of the effect on the measurement of %BF, whereas the error term associated with the estimation of V_R would have 100% of the effect on the measurement of %BF by HW [22].

Despite the fact that BPM is the more theoretically sound method of the two, according to McCrory and colleagues [22], there appears to be no difference in %BF between BPM and BPE. These results support the method used by organizations such as the OSAA, who allow high school wrestlers to appeal their original L-BIA results one time with BPE. Using BPE, rather than BPM, to establish MW is further supported by the results of a study conducted by Collins and associates [52], who investigated the precision of BPE among 69 NCAA Division I collegiate football players. Besides comparing BPE to HW, DXA, and a three-component model, as was discussed earlier, Collins and associates [52] compared BPE to the reference, BPM, and reported that BPE had a SEE of ± 1.2 %BF ($R^2 = 0.97$). As was stated earlier, when compared to the reference of HW, the SEE of BPM was 2.2 %BF, however the SEE of BPE was only slightly larger (2.4 %BF) than if V_{TG} was measured [52].

According to one group of investigators [53], BPM underestimated %BF in adult women, when compared to the criterion of a 4-component model. Fields and associates [53] compared the precision of HW and BPM to predict D_B and the precision of BPM compared to a 4-component model among 42 adult women [53]. There was no significant difference in D_B between BPM and HW, however there was a significant difference in %BF between BPM (28.8 %BF) and the 4-component model (30.6 %BF),

due to the aqueous fraction of FFM [53]. Compared to the 4-component model, the SEE of BPM was 2.68 %BF [53].

In contrast to the study by Fields and associates [53], BPM overestimated %BF in 30 African-American men ranging in age from 19 to 45 years, when compared to HW and the reference, DXA [54]. D_B values reported by BPM and HW were compared [54]. With respect to HW, V_R was measured and D_B was converted to %BF using race-specific equations [54]. The %BF for DXA, HW, and BPM were significantly different [54, 55], despite the fact the difference between BPM and DXA was only 1.6 %BF [56].

In a group of collegiate wrestlers, L-BIA consistently underestimated %BF, whereas SF and BPM did not [25]. To the author's knowledge, there has been only one other study to compare the precision of BPM to L-BIA. Dixon and colleagues [25] compared four NCAA-approved methods to determine MW in 25 NCAA Division III collegiate wrestlers spanning 10 weight classes. The NCAA-approved methods included HW, 3-site SF, BPM (measuring V_{TG}), and L-BIA where euhydration was defined as $U_{SG} \leq 1.020 \text{ g}\cdot\text{mL}^{-1}$. Body composition estimates (%BF and D_B) for BPM and SF were not significantly different than the reference method, HW, however %BF for L-BIA was systematically and significantly less than it was for HW and SF [25].

After conducting regression analysis, The SEE between the reference method (HW) and the other methods was 1.87 %BF, 1.68 %BF, and 3.60 %BF for SF, ADP-M, and L-BIA, respectively [25]. Despite the fact that the lowest SEE (1.68%) was observed in BPM and the highest SEE (3.60%) was observed for L-BIA, %BF estimated by L-BIA was similar to that estimated by BPM, with a difference of only 1.92 %BF [25]. Percent

body fat (mean \pm SD) was 14.5 ± 6.0 , 13.8 ± 6.3 , 14.2 ± 5.3 , and 12.3 ± 4.6 for HW, BPM, SF, and L-BIA, respectively [25]. When compared to the reference of HW, all correlations were strong, however the BPM (0.96) and SF (0.95) correlations were the highest and the L-BIA (0.80) correlation was the lowest [25]. The authors supported the use of hydrostatic weighing, ADP, and the skinfold technique, however did not support the use of L-BIA in establishing MW in collegiate wrestlers [25].

BOD POD (BPE) in the Present Investigation

In the present investigation, the participant wore his/her swimsuit, and a swim cap during all data collection with the BOD POD. Once the BOD POD[®] body composition system (Life Measurement Inc., Concord, CA) was calibrated using the manufacturer-supplied 50 L cylinder, the subject's body volume was measured by causing small changes in the BOD POD[®] chamber air pressure (± 1 cm H₂O, compared to the ambient pressure, which is 1000 cm H₂O). The subject, who was able to look through the BOD POD[®] chamber window throughout testing, was asked to sit and to breathe normally in the closed chamber while his/her D_B was measured. Approximately 2 or 3 body volume measurements were required and each measurement took approximately 45 seconds. The computer calculated and reported the FFM and %BF according to the computer's prediction equations. Percent body fat was calculated using the pediatric Lohman equation [14].

BOD POD (BPM) in the Present Investigation

During the present investigation, the calibration of the BOD POD[®] and V_B measurements was repeated, however FFM and %BF was not reported until V_{TG} was measured, which was accomplished by connecting the subject to a breathing circuit (i.e., a mouthpiece attached to a tube) while he/she breathed for a minute. Specifically, the subject breathed into a breathing circuit while wearing a nose clip. With the chamber door closed, the subject breathed normally (i.e., tidal breathing) for approximately 2-3 cycles, where each cycle was comprised of both inhalation and exhalation. After 2-3 cycles of tidal breathing, the subject's airway was momentarily occluded (breathing circuit valve closed) while the subject gently puffed (i.e., contracted and then relaxed his diaphragm) into the breathing circuit. Once the V_{TG} was successfully measured, the apparatus reported the %BF using the Lohman equation. Body composition (%BF) comparisons were then made. Body composition testing lasted approximately 25-30 minutes.

Conclusion

Methods of body composition used to establish MW among wrestlers include L-BIA, the 3-site SF, and densitometric methods, such as HW and the BODPOD. When comparing densitometric methods, BPM is the simpler, faster of the two methods. However since BPM and HW require expensive equipment typically available in a laboratory setting, other field tests are being used to determine MW, particularly at the high school level.

High school wrestling programs aim to adopt a non-laboratory method of body composition assessment that is affordable, yet reliable and precise. Presently, high schools regularly use L-BIA and the skinfold method, which are both affordable and portable methods that may easily be used by high school wrestling programs. The advantages of using L-BIA include the fact that tester bias is minimized since electrode placement is unnecessary, and L-BIA requires little training and/or skill, compared to the SF method, however the latter of the two may prove to be superior [47].

The OSAA is primarily using L-BIA to determine MW among high school wrestlers in Oregon. Each wrestler may appeal the original L-BIA results one time using either HW or BPE. Although previous investigators [22, 52] reported no significant difference in %BF between BPM and BPE, there is evidence [9] to suggest that BPM and the 4-component model predict body composition equally well among adolescents. Based on this evidence, and the fact that BPM seems to be more theoretically sound than BPE and L-BIA, BPM was used as the reference method in the present investigation. In

addition, measurement of V_{TG} is a relatively simple process and only adds a couple minutes to each test.

The primary aim of this investigation was to evaluate the OSAA weight monitoring program by making comparisons among three different methods of body composition assessment: L-BIA, BPE, and BPM. Of specific interest was whether or not there was a difference between BPE and BPM among high school wrestlers, and if a difference was reported, what was the magnitude of differences between methods.

Though the 4-component model is a superior reference method, few studies mentioned in this review of literature used this time-consuming method when validating different body composition methods. Based on this review of literature, BPE appears to have an acceptable level of reliability, and both BPE and BPM appear to be more precise than L-BIA. Since only one other study has compared BPM to L-BIA and the difference in %BF was small (1.6 %BF), it would seem premature to draw any conclusions about specific comparisons between BPM and L-BIA.

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Appendix B: Survey Instrument**ANONYMOUS Survey of High School Wrestlers**

Subject ID: _____ (to be completed by researcher) Sex: Male Female

Directions: Please answer all questions as honestly and accurately as possible. Some questions will ask you about the time before the 2004-2005 wrestling season, so just answer to the best of your ability (memory). Please ask the OSU researcher if you do not understand the question. All responses to these questions will remain anonymous.

Date: _____ Time: _____ AM

SECTION 1: GENERAL PARTICIPANT INFORMATION

1) Circle the response that represents your current grade in school.

FR. **SO.** **JR.** **SR.**

2) Circle the response that represents your current age (years).

13 **14** **15** **16** **17** **18** **19**

3) Circle the response that describes your school's district sports classification (based on number of students enrolled).

6A **5A** **4A** **3A** **2A** **1A**

4) Circle the response that describes your current wrestling weight division (lbs.).

103	135	171
112	140	189
119	145	215
125	152	285
130	160	

5) Have you ever placed in the top 3 at district championships? Yes No

- 6) Have you ever qualified, individually, for the state competition? Yes No
- 7) Have you ever placed in the top 6 at the state meet? Yes No
- 8) Has your wrestling team ever qualified for the state competition? Yes No
-
-

SECTION 2: GENERAL - BODY WEIGHT

- 9) At what age did you begin competitive wrestling? Circle the appropriate age (years).

5	10	15
6	11	16
7	12	17
8	13	18
9	14	

- 10) Have you ever “cut weight” before a wrestling competition? (The term “cutting weight” means that you try to lose body weight before a wrestling meet in order to achieve a certain weight division.)

Yes No (If you answer No, skip the next question.)

- 11) If you answered yes to the preceding question, at what age did you begin “cutting weight” for wrestling? Circle the appropriate age (years).

5	10	15
6	11	16
7	12	17
8	13	18
9	14	

12) Rate the amount of influence **fellow wrestlers** have had on your weight loss practices throughout your life as a wrestler.

1	2	3	4
Not influential	somewhat influential	fairly influential	very influential

13) Rate the amount of influence **your team athletic trainer** has had on your weight loss practices throughout your life as a wrestler.

1	2	3	4
Not influential	somewhat influential	fairly influential	very influential

14) Rate the amount of influence **coaches** have had on your weight loss practices throughout your life as a wrestler.

1	2	3	4
Not influential	somewhat influential	fairly influential	very influential

15) Rate the amount of influence **any BIA assessor (or % body fat assessor)** has had on your weight loss practices throughout your life as a wrestler.

1	2	3	4
Not influential	somewhat influential	fairly influential	very influential

16) Rate the amount of influence **schoolteachers** have had on your weight loss practices throughout your life as a wrestler.

1	2	3	4
Not influential	somewhat influential	fairly influential	very influential

17) Rate the amount of influence **parents** have had on your weight loss practices throughout your life as a wrestler.

1	2	3	4
Not influential	somewhat influential	fairly influential	very influential

18) Rate the amount of influence **medical personnel (i.e., doctors, nurses, etc.)** have had on your weight loss practices throughout your life as a wrestler.

1	2	3	4
Not influential	somewhat influential	fairly influential	very influential

BEFORE THE 2004-2005 WRESTLING SEASON

The OSAA wrestling weight monitoring program began during the 2004-2005 season. The following questions refer to all the time *before the beginning of the 2004-2005 wrestling season.* Please answer to the best of your memory, and keep in mind that your responses are approximations. NA means not applicable. (The term “cutting weight” means that you try to lose body weight before a wrestling meet in order to achieve a certain weight division.)

SECTION 3: BODY WEIGHT - *BEFORE THE 2004-2005 WRESTLING SEASON*

19) To the best of your memory, how often in a season (*on average*) did you cut weight before a wrestling competition *before the beginning of the 2004-2005 wrestling season?* Circle the appropriate response. (NA means not applicable.)

1	2	3	4	5
NA	Rarely	Occasionally	Frequently	Always
or never cut	(1–3 times/season)	(4-7 times/season)	(8-12 times)	(every meet)

20) To the best of your memory, what was the *average* weight (lb.) that you cut before a wrestling competition *before the beginning of the 2004-2005 wrestling season?*

NA or 0	5	10
1	6	11
2	7	12
3	8	13
4	9	14-15

21) To the best of your memory, what was the *most* weight (lb.) that you *ever* cut before a wrestling competition **before the beginning of the 2004-2005 wrestling season?**

NA or 0	5	10
1	6	11
2	7	12
3	8	13
4	9	14-15

22) Circle the response that best describes how *you* considered yourself during the wrestling season(s) **before the beginning of the 2004-2005 wrestling season.**

1	2	3	4	5
Very overweight (11+ lb over)	Overweight (5–10 lb over)	About right (± 5 lb)	Underweight (5–10 lb under)	Very underweight (11+ lb under)

23) Circle the response that best describes (*on average*) how much your weight (lb.) fluctuated during the wrestling season(s) **before the beginning of the 2004-2005 wrestling season.**

NA or 0	5	10
1	6	11
2	7	12
3	8	13
4	9	14-15

24) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* have to consciously restrict your food intake in order to control your weight during a wrestling season?

Yes

No

25) If you answered Yes to the preceding question, how often (*on average*) did you consciously restrict your food intake **before the beginning of the 2004-2005 wrestling season?**

1	2	3	4	5
NA	Rarely	Occasionally	Frequently	Always
or never cut	(1–3 times/season)	(4-7 times/season)	(8-12 times)	(every meet)

26) **Before the beginning of the 2004-2005 wrestling season,** what response best described you? Circle the appropriate response (1, 2, or 3).

- 1 – “I was heavier during the wrestling season than I was during the off-season.”
- 2 – “I was about the same weight during the wrestling season as I was during the off-season.”
- 3 – “I was lighter during the wrestling season than I was during the off-season.”
-

SECTION 4: WEIGHT LOSS METHODS *BEFORE THE 2004-2005 WRESTLING SEASON*

27) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* binge eat during a given season? (The term binge eating is eating much more than most people would eat, under the same circumstances, where you feel you may not be able to stop.)

Yes No (If you answered No, skip the next question.)

28) If you answered Yes to the preceding question, how often (*on average*) did you binge eat to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

29) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* try to make yourself, or make yourself vomit to lose weight?

Yes No (If you answered No, skip the next question.)

30) If you answered Yes to the preceding question, how often (*on average*) did you try to make yourself, or make yourself vomit to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

31) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* use laxatives to lose weight?

Yes No (If you answered No, skip the next question.)

32) If you answered Yes to the preceding question, how often (*on average*) did you use laxatives to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

33) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* use diuretics (water pills) to lose weight?

Yes No (If you answered No, skip the next question.)

34) If you answered Yes to the preceding question, how often (*on average*) did you use diuretics (water pills) to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

35) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* use diet pills to lose weight?

Yes No

36) If you answered Yes to the preceding question, how often (*on average*) did you use diet pills to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

37) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* use enemas to lose weight?

Yes No (If you answered No, skip the next question.)

38) If you answered Yes to the preceding question, how often (*on average*) did you use enemas to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

39) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* exercise vigorously or increase exercise to lose weight?

Yes No (If you answered No, skip the next question.)

40) If you answered Yes to the preceding question, how often (*on average*) did you exercise vigorously or increase exercise to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

41) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* diet gradually to lose weight?

Yes No (If you answered No, skip the next question.)

42) If you answered Yes to the preceding question, how often (*on average*) did you diet gradually to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

43) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* skip 1-2 meals to lose weight?

Yes No (If you answered No, skip the next question.)

44) If you answered Yes to the preceding question, how often (*on average*) did you skip 1-2 meals to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

45) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* fast (not eat all day) to lose weight?

Yes No (If you answered No, skip the next question.)

46) If you answered Yes to the preceding question, how often (*on average*) did you fast (not eat all day) to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

47) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* restrict fluids (not drink) to lose weight?

Yes No (If you answered No, skip the next question.)

48) If you answered Yes to the preceding question, how often (*on average*) did you restrict fluids (not drink) to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

49) **Before the beginning of the 2004-2005 wrestling season,** did you *ever* practice in a heated wrestling room to lose weight?

Yes No (If you answered No, skip the next question.)

50) If you answered Yes to the preceding question, how often (*on average*) did you practice in a heated wrestling room to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

51) **Before the beginning of the 2004-2005 wrestling season**, did you *ever* use a sauna to lose weight?

Yes No (If you answered No, skip the next question.)

52) If you answered Yes to the preceding question, how often (*on average*) did you use a sauna to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

53) **Before the beginning of the 2004-2005 wrestling season**, did you *ever* wear a rubber or plastic suit to lose weight?

Yes No (If you answered No, skip the next question.)

54) If you answered Yes to the preceding question, how often (*on average*) did you wear a rubber or plastic suit to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

55) **Before the beginning of the 2004-2005 wrestling season**, did you *ever* spit to lose weight?

Yes No (If you answered No, skip the next question.)

56) If you answered Yes to the preceding question, how often (*on average*) did you spit to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

AFTER THE 2004-2005 WRESTLING SEASON

The OSAA wrestling weight monitoring program began during the 2004-2005 season. The remaining questions in this survey refer to all the time *AFTER* the beginning of the 2004-2005 wrestling season. NA means not applicable.

SECTION 5: BODY WEIGHT *AFTER THE 2004-2005 WRESTLING SEASON*

57) To the best of your memory, how often in a season (*on average*) did you cut weight before a wrestling competition *AFTER* the beginning of the 2004-2005 wrestling season? Circle the appropriate response. (NA means not applicable.)

1	2	3	4	5
NA	Rarely	Occasionally	Frequently	Always
or never cut	(1-3 times/season)	(4-7 times/season)	(8-12 times)	(every meet)

58) To the best of your memory, what was the *average* weight (lb.) that you cut before a wrestling competition *AFTER* the beginning of the 2004-2005 wrestling season?

NA or 0	5	10
1	6	11
2	7	12
3	8	13
4	9	14-15

59) To the best of your memory, what was the *most* weight (lb.) that you *ever* cut before a wrestling competition **AFTER the beginning of the 2004-2005 wrestling season?**

NA or 0	5	10
1	6	11
2	7	12
3	8	13
4	9	14-15

60) Circle the response that best describes how *you* considered yourself during the wrestling season(s) **AFTER the beginning of the 2004-2005 wrestling season.**

1	2	3	4	5
Very overweight (11+ lb over)	Overweight (5–10 lb over)	About right (± 5 lb)	Underweight (5–10 lb under)	Very underweight (11+ lb under)

61) Circle the response that best describes (*on average*) how much your weight (lb.) fluctuated during the wrestling season(s) **AFTER the beginning of the 2004-2005 wrestling season.**

NA or 0	5	10
1	6	11
2	7	12
3	8	13
4	9	14-15

62) **AFTER the beginning of the 2004-2005 wrestling season,** did you *ever* have to consciously restrict your food intake in order to control your weight during a wrestling season?

Yes

No

63) If you answered Yes to the preceding question, how often (*on average*) did you consciously restrict your food intake **AFTER the beginning of the 2004-2005 wrestling season?**

1	2	3	4	5
NA	Rarely	Occasionally	Frequently	Always
or never cut	(1–3 times/season)	(4-7 times/season)	(8-12 times)	(every meet)

64) **AFTER the beginning of the 2004-2005 wrestling season,** what response best described you? Circle the appropriate response (1, 2, or 3).

- 1 – “I was heavier during the wrestling season than I was during the off-season.”
- 2 – “I was about the same weight during the wrestling season as I was during the off-season.”
- 3 – “I was lighter during the wrestling season than I was during the off-season.”

SECTION 6: WEIGHT LOSS METHODS *AFTER THE 2004-2005 WRESTLING SEASON*

65) **AFTER the beginning of the 2004-2005 wrestling season,** did you *ever* binge eat during a given season? (The term binge eating is eating much more than most people would eat, under the same circumstances, where you feel you may not be able to stop.)

Yes No (If you answered No, skip the next question.)

66) If you answered Yes to the preceding question, how often (*on average*) did you binge eat to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

67) **AFTER the beginning of the 2004-2005 wrestling season,** did you *ever* try to make yourself, or make yourself vomit to lose weight?

Yes No (If you answered No, skip the next question.)

68) If you answered Yes to the preceding question, how often (*on average*) did you try to make yourself, or make yourself vomit to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

69) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* use laxatives to lose weight?

Yes No (If you answered No, skip the next question.)

70) If you answered Yes to the preceding question, how often (*on average*) did you use laxatives to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

71) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* use diuretics (water pills) to lose weight?

Yes No (If you answered No, skip the next question.)

72) If you answered Yes to the preceding question, how often (*on average*) did you use diuretics (water pills) to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

73) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* use diet pills to lose weight?

Yes No

74) If you answered Yes to the preceding question, how often (*on average*) did you use diet pills to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

75) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* use enemas to lose weight?

Yes No (If you answered No, skip the next question.)

76) If you answered Yes to the preceding question, how often (*on average*) did you use enemas to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

77) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* exercise vigorously or increase exercise to lose weight?

Yes No (If you answered No, skip the next question.)

78) If you answered Yes to the preceding question, how often (*on average*) did you exercise vigorously or increase exercise to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

79) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* diet gradually to lose weight?

Yes No (If you answered No, skip the next question.)

80) If you answered Yes to the preceding question, how often (*on average*) did you diet gradually to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

81) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* skip 1-2 meals to lose weight?

Yes No (If you answered No, skip the next question.)

82) If you answered Yes to the preceding question, how often (*on average*) did you skip 1-2 meals to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

83) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* fast (not eat all day) to lose weight?

Yes No (If you answered No, skip the next question.)

84) If you answered Yes to the preceding question, how often (*on average*) did you fast (not eat all day) to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

85) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* restrict fluids (not drink) to lose weight?

Yes No (If you answered No, skip the next question.)

86) If you answered Yes to the preceding question, how often (*on average*) did you restrict fluids (not drink) to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

87) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* practice in a heated wrestling room to lose weight?

Yes No (If you answered No, skip the next question.)

88) If you answered Yes to the preceding question, how often (*on average*) did you practice in a heated wrestling room to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1	2	3	4	5
Once/month	Twice/month	Once/week	3-4 times/week	Daily

89) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* use a sauna to lose weight?

Yes No (If you answered No, skip the next question.)

90) If you answered Yes to the preceding question, how often (*on average*) did you use a sauna to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

91) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* wear a rubber or plastic suit to lose weight?

Yes No (If you answered No, skip the next question.)

92) If you answered Yes to the preceding question, how often (*on average*) did you wear a rubber or plastic suit to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

93) **AFTER the beginning of the 2004-2005 wrestling season**, did you *ever* spit to lose weight?

Yes No (If you answered No, skip the next question.)

94) If you answered Yes to the preceding question, how often (*on average*) did you spit to lose weight? Circle the appropriate response. (Answer to the best of your memory.)

1 **2** **3** **4** **5**
Once/month Twice/month Once/week 3-4 times/week Daily

Thank you for your cooperation in completing this survey.

Appendix C: Figure 3

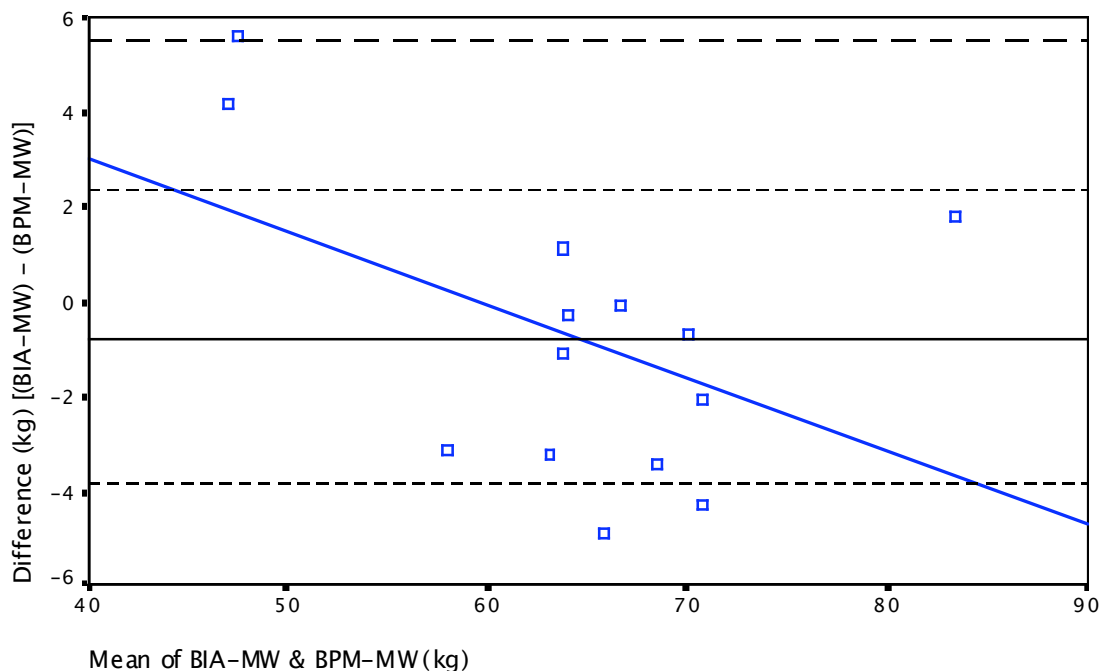


Figure 3: Bland-Altman Plot to examine systematic bias in the L-BIA method for male wrestlers.

Weakly significant systematic differences were demonstrated when predicting LBIA-MW (kg) [$r = -0.462$, $p < 0.05$, $\text{mean} \pm \text{SD} = -0.75 \pm 3.11$ kg]. (There was a significant, but weak, difference in variability between participants for the two methods.) The limits of agreement ($\text{bias} \pm 2\text{SD}$) for MW ranged from -6.97 kg (-15.37 lb) to 5.47 kg (12.06 lb). Minimum weight residuals ranged from -3.95 kg (-8.71 lb) to 5.46 kg (12.04 lb). Line of best fit: $y = -0.15x + 9.19$. Note: The lower limit of agreement is not shown. ($N = 14$).

Appendix D: Figure 4

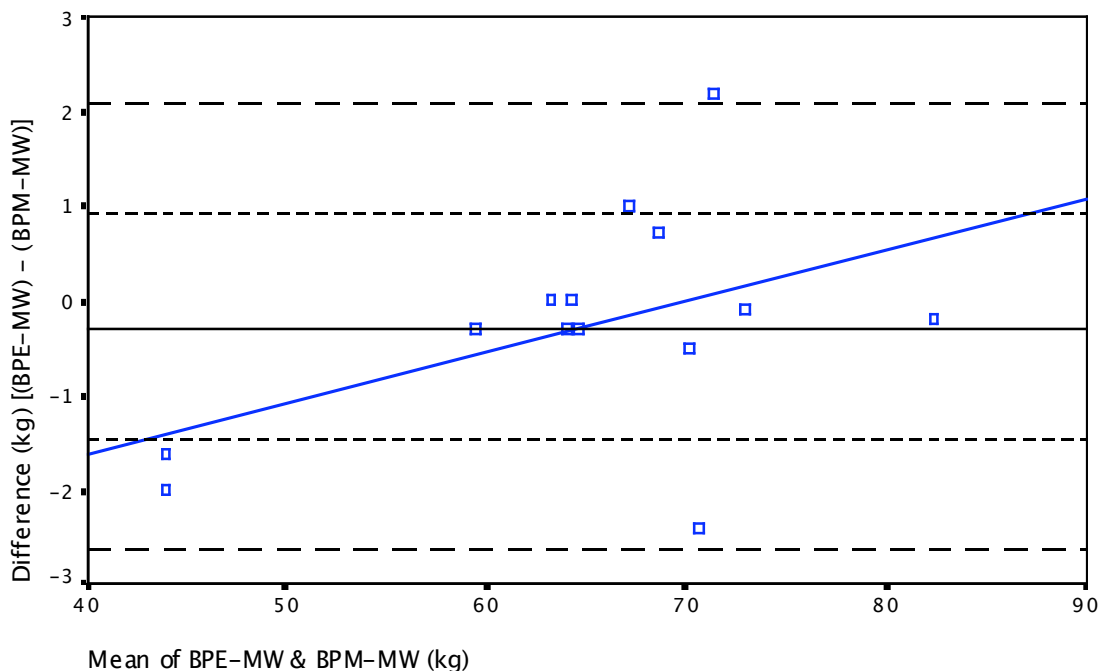


Figure 4: Bland-Altman Plot to examine systematic bias in the BPE method for wrestlers. Weakly significant systematic differences were demonstrated when predicting BPE-MW (kg) [$r = 0.472$, $p < 0.05$, $\text{mean} \pm \text{SD} = -0.27 \pm 1.18$ kg]. (There was a significant, but weak, difference in variability between participants for the two methods.) The limits of agreement ($\text{bias} \pm 2\text{SD}$) for MW ranged from -2.64 kg (-5.82 lb) to 2.10 kg (4.63 lb). Minimum weight residuals ranged from -2.44 kg (-5.38 lb) to 2.12 kg (4.67 lb). Line of best fit: $y = 0.05x - 3.75$. ($N = 14$).

Appendix E: Glossary of Manuscript Abbreviations

1. BIA: Bioelectric impedance analysis
2. L-BIA: Leg-to-leg bioelectric impedance analysis
3. BPE: BODPOD while estimating thoracic gas volume
4. BPM: BODPOD while measuring thoracic gas volume
5. BPE-MW: BPE-predicted minimum wrestling weight
6. BPM-MW: BPM-predicted minimum wrestling weight
7. LBIA-MW: LBIA-predicted minimum wrestling weight
8. MW: Minimum wrestling weight
9. FFM: Fat free mass
10. NCAA: National Collegiate Athletics Association
11. %BF: Percent body fat
12. HW: Hydrostatic weighing or underwater weighing
13. SD: Standard deviation
14. V_{TG} : Thoracic gas volume: The amount of air in the lungs and thorax during tidal breathing.

