Original Research

Comparison of Body Composition Measurements in Lean Female Athletes

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ABSTRACT

International Journal of Exercise Science 11(4): 417-424, 2018. This study compared body composition measurements in lean female athletes. The primary objective was to compare the accuracy of percent body fat (%BF) determined by bioelectrical impedance analysis (BIA), air-displacement plethysmography (ADP), and underwater weighing (UWW) in female Division I cheerleaders (*n* = 10 bases, 6 back-spots, and 12 flyers) from two universities. The secondary objective was to compare health risk predicted by %BF to body mass index (BMI) categorizations. UWW was considered the gold standard for assessing %BF. Pearson correlation coefficients were used to determine associations between methods. Repeated measures analysis of variance was used to identify differences in %BF by method. BIA, ADP, and UWW were highly correlated (*r* ≥ .828, *p* < .001 for all). However, %BF by BIA (20.0 ± 5.2%) and ADP (19.3 ± 6.0%) was higher than %BF by UWW (15.9 ± 4.1%, *p* < .001). Health risk was predicted less often when classified based on very lean (risky low) %BF levels by BIA and ADP than UWW (7.1%, 3.6%, and 21.4%, respectively). This finding suggests that, similar to female track-and-field athletes who also exhibit lean muscular physiques, %BF is overestimated by BIA and ADP in female cheerleaders and health risk associated with low %BF is underestimated when compared to UWW. In contrast, BMI was not associated with %BF by any method and no participants were classified as underweight by this measure. Thus, BMI should not be used to predict health risk in lean female athletes, such as collegiate cheerleaders.

KEY WORDS: Athletic performance, BOD POD, college, hydrodensitometry, hydrostatic weighing, predictive accuracy, sports nutrition

INTRODUCTION

The use of body composition measurement is an important aspect of assessing athletic performance and health risk (15). There is a subset of lean athletes who have an aesthetic aspect of the sport that may result in low body weight (e.g., gymnasts and cheerleaders). Considerable attention has been paid to comparing methods of body composition measurement in various collegiate athlete populations (e.g., wrestlers (15), track-and-field athletes (3), and football players (4)).

It is important to understand the limitations of body composition measurement when applied to lean athletes with low body weight so that these athletes can be assessed and advised based on accurate methodology. For example, as part of a nutrition knowledge survey, coaches and athletic trainers at a National Collegiate Athletic Association (NCAA) Division I university rated body weight as more important to athletic performance than body composition (12). Determining health status based on body composition measurement in cheerleaders, as opposed to focusing on appearance or body weight, may be beneficial in promoting the well-being and performance of these athletes. In this study, NCAA Division I collegiate cheerleaders were used as a population of lean female athletes, and three body composition measurement techniques (i.e., bioelectrical impedance analysis (BIA), air-displacement plethysmography (ADP), and underwater weighing (UWW)) were utilized, along with body mass index (BMI).

A cheerleading squad includes the following positions: back-spots, bases, and flyers. Flyers, the necessarily smaller females who participate in air stunts, are thought to be at greater health risk than their back-spot and base counterparts. Placing an emphasis on low body weight may predispose these cheerleaders to disordered eating patterns with downstream complications of amenorrhea, accelerated bone loss, and an increased risk of musculoskeletal injury (14).

Previous studies comparing methods for assessing body composition in other collegiate athlete populations have yielded disparate results. In male collegiate wrestlers, the "gold standard" method of UWW provided similar estimates for percent body fat (%BF) when compared to ADP (15). Among lean female track-and-field athletes with physiques similar to flyers, UWW yielded significantly lower %BF than either BIA or ADP (3). However, a comparison of the accuracy of these methods specifically for lean female athletes competing in an aesthetic sport has not been conducted.

Thus, the primary objective of this study was to compare methods for assessing body composition in female collegiate cheerleaders. The primary hypotheses were that compared to the gold standard method of UWW, %BF by BIA and ADP would be overestimated in flyers and similar for back-spots and bases. A secondary objective was to compare health risk predicted by %BF to BMI categorizations. The secondary hypotheses were that very lean %BF would be demonstrated in all cheerleaders, and BMI would not be associated with any of the body composition assessment methods.

METHODS

Participants
Participants were recruited from two NCAA Division I universities in the Mid-American Conference. Coaches were contacted and provided written permission to allow recruitment announcements at practice. Forms listing inclusion criteria were individually distributed to cheerleaders, who then self-determined their eligibility. Criteria required for participation included: (a) at least 18 years of age, (b) weight less than 500 pounds (scale capacity), (c) not

pregnant, (d) no implanted medical devices (contraindication to BIA testing), (e) non-claustrophobic (contraindication to ADP and UWW testing), and (f) no chronic lung or pulmonary disorders (contraindication to UWW testing). Written informed consent, approved by the university's institutional review board, was obtained from each participant prior to testing. Participants were asked to schedule an individual test visit via the SignUpGenius online scheduling system (Charlotte, NC) and reschedule if they had a cold or the flu (due to illness-related difficulties in expelling air from lungs). Visit times were blinded to other participants. Coaches were not aware of which squad members participated.

This study was part of a larger investigation aimed at exploring body composition in both female and male cheerleaders. Based on data from this investigation, which included 28 females (of all positions) and 12 males (bases only), a power analysis was performed using R, the smallest difference in means for %BF (between ADP and UWW), and the maximum standard deviation. For females, using a difference of 4.1%BF and a maximum standard deviation of 4.0%BF, the required sample size for 90% power is 13. For males, using a difference of 1.6%BF and a maximum standard deviation of 8.7%BF, the required sample size for 90% power is 313. Thus, the results for males have less than 90% power and are not presented herein.

The sample population consisted of 28 female collegiate cheerleaders who were aged 20.1 ± 1.1 years (range 18 to 23 years). Most participants were Caucasian ($n = 24$, 85.7%), with the remainder African American ($n = 1$, 3.6%), Hispanic ($n = 1$, 3.6%), and other ($n = 2$, 7.1%). Positions were divided between bases ($n = 10$, 35.7%), back-spots ($n = 6$, 21.4%), and flyers ($n = 12$, 42.9%). Participant characteristics including height, weight, BMI, and %BF by BIA, ADP, and UWW are shown in Table 1.

Protocol
Anthropometric and body composition measurements were conducted according to manufacturer instructions. All assessments were completed at a single test visit in order to minimize bias. Participants were instructed to refrain from exercising and eating or drinking anything (other than water) for 3 hours prior to testing and void their bladder upon arrival to the laboratory (8). This was to ensure that test results were not influenced by body temperature, breathing rate, and/or presence of food/beverages in the gastrointestinal tract (6). Participants received a printed copy of their body composition results. As an incentive, participants who completed the experimental protocol were entered into a drawing to win one of six $25 gift cards. The participants learned of the incentive at an informational recruiting session.

Anthropometric Measurements: Anthropometric measurements collected included height and weight. Height was measured to the nearest .1 cm using a stadiometer (Hopkins Road Rod Portable Stadiometer, Hopkins Medical Products, Baltimore, MD). The participant was required to stand upright with heels together, head straight, and back touching, but not leaning against, the measuring device. Weight was obtained using an electronic scale, which

was coupled with ADP (BOD POD, COSMED, Concord, CA), measuring to the nearest .1 kg. Height and weight measurements were used to calculate BMI (kg/m²).

Body Composition Measurements For ADP, body fat was assessed via BOD POD (COSMED, Concord, CA) using standard procedures to measure body volume (9). Calibration of the BOD POD was performed daily. Once a participant was seated inside the chamber, two body volume measurements were taken. Using weight and volume measurements, body density was calculated and converted to %BF using the Siri equation (13).

For BIA, body composition was assessed by means of a direct segmental multi-frequency method using hand and foot electrodes (InBody 230; Biospace, Seoul, Korea) (4). The participant was required to stand barefoot on the footplates, while holding the hand electrodes during testing. Empirically-derived formulas supplied by the manufacturer were used to calculate %BF.

For UWW, body composition was assessed when the participant entered a stainless steel weighing tank. The participant was instructed to sit on an underwater swing attached to a scale and expel all of the air from their lungs while underwater. Measurements lasted 3-5 seconds. The test was repeated several times (≤ 5 depending on the participant) in order to obtain an accurate net underwater weight (UWW$_{net}$), i.e., the highest stable weight, with the participant fully submerged in the weighing tank. Body density was calculated by dividing body mass (BM) by body volume (BV), i.e., body density = BM / BV. BV was calculated as UWW$_{net}$ divided by water density following a correction for estimated residual volume (RV), i.e., BV = UWW$_{net}$ /density of water - RV. Body density was then converted to %BF using the Siri equation (13).

Fat risk classifications were based on American College of Sports Medicine "Fitness Categories" for adult females ages 20-29 years, very lean (< 15.0%BF), excellent (15.1-16.7%BF), good (16.8-20.5%BF), fair (20.6-24.1%BF), poor (24.2-30.4%BF), and very poor (≥ 30.5%BF) (1). BMI classifications were based on National Institutes of Health (NIH) standards for adults 18 years and older: underweight (< 18.5 kg/m²), normal weight (18.5-24.9 kg/m²), overweight (25.0-29.9 kg/m²), obese (≥ 30.0 kg/m²) (10). With respect to these risk classifications, very lean and underweight were considered as having health risks due to low %BF. In this study, none of the participants were classified as overweight/obese by BMI or very poor (risky high) by %BF; thus, the health risk discussed in this study is for underweight or risky low %BF only.

Statistical Analysis
Statistical analyses were completed using IBM SPSS Statistics Version 25 (Armonk, NY). Pearson correlation coefficients were calculated to determine associations between techniques. Repeated-measures analysis of variance was performed to identify differences in %BF determined by BIA, ADP, and UWW. The Bonferroni adjustment was used to correct for multiple comparisons. Cheerleading position (i.e., base, back-spot, and flyer) was a between participant variable; differences between races/ethnicities were not analyzed. Data are

presented as mean ± standard deviation. Power analysis and linear regression were performed using R version 3.4.0 (2017-04-21), 64-bit. The alpha level for significance was set at $p < .05$.

RESULTS

Anthropometric and Body Composition Measurements: Compared to the gold standard method of UWW, %BF was significantly higher when assessed using BIA and ADP ($p < .001$ for both, see Table 1). Strong correlations were seen between %BF by BIA, ADP, and UWW ($r \geq .828$, $p < .001$ for all). BMI was not correlated with %BF by any method for assessing body composition (see Table 2).

Table 1. Anthropometric measures and body composition measures by cheerleading position.

	Anthropometric Measures			Body Composition Measures		
	Weight (kg)	Height (cm)	BMI (kg/m²)	BIA (%BF)	ADP (%BF)	UWW (%BF)
Base (n = 10)	58.7 ± 3.5	159.8 ± 3.2	23.0 ± .9	21.9 ± 2.7	21.0 ± 3.5	16.1 ± 3.3
Back-Spot (n = 6)	62.4 ± 4.3	167.3 ± 3.2	22.3 ± 1.3	18.6 ± 4.3	18.3 ± 6.5	14.3 ± 5.0
Flyer (n = 12)	52.1 ± 3.8	155.6 ± 5.4	21.5 ± 1.2	21.6 ± 3.4	20.9 ± 2.6	17.3 ± 2.0
All (n = 28)	56.7 ± 5.6	159.6 ± 6.1	22.2 ± 1.3	21.1 ± 3.5*	20.4 ± 4.0*	16.3 ± 3.3

BMI = body mass index, %BF = percent body fat, BIA = bioelectrical impedance analysis, ADP = air-displacement plethysmography, UWW = underwater weighing, * $p < .001$ compared to UWW.

Table 2. Associations between BMI and body composition measures.

	BMI	BIA	ADP	UWW
Body mass index (BMI)	---			
Bioelectrical impedance analysis (BIA)	.188	---		
Air-displacement plethysmography (ADP)	.174	.852*	---	
Underwater weighing (UWW)	.277	.831*	.828*	---

Comparisons are based on Pearson correlation coefficients. *$p < .001$ level (2-tailed).

Linear Regression: Linear regression can be performed on approximately 15 to 25 subjects per variable, and analyses have shown that less than 10 subjects per variable can be used with good results (2). After BMI, teams are most likely to have access to BIA to determine body composition. Since many teams are unlikely to have access to ADP or UWW, a linear regression was performed using BIA %BF to predict %BF using UWW.

$$UWW \ \%BF = 1.0892 + .7203 * BIA \ \%BF$$

Where $p < .001$ for the factor BIA%BF, and $R^2 = .5742$.

Health Risk: Very lean (risky low) %BF was indicated in 7.1% (n = 2), 3.6% (n = 1), and 21.4% (n = 6) of cheerleaders by BIA, ADP, and UWW, respectively. No cheerleaders were classified as underweight based on BMI. Complete breakdowns by %BF and BMI (n = 28), as well as frequency of very lean (risky low) %BF and underweight BMI by position are shown in Table 3.

DISCUSSION

This study was the first to compare %BF assessment techniques in collegiate cheerleaders, representing lean female athletes in an aesthetic sport. Although BIA, ADP, and UWW were strongly correlated, %BF was overestimated by the BIA and ADP methods, and very lean (risky low) %BF was under-predicted, when compared to UWW. This means that BIA and ADP underestimate, or fail to identify, health risk due to low %BF when a risky low %BF is present. To correct for this in settings where UWW is unavailable, a linear regression was performed to predict %BF by UWW using %BF by BIA. BMI was not associated with %BF and should not be used to predict health risk in lean female cheerleaders.

Table 3. Health risk categorizations by cheerleading position.

	Health Risk (based on low BMI or %BF)			
	Low BMI[a]	BIA Risk[b]	ADP Risk[b]	UWW Risk[b]
Base (n = 10)	0% (n = 0)	0% (n = 0)	0% (n = 0)	30.0% (n = 3)
Back-Spot (n = 6)	0% (n = 0)	16.7% (n = 1)	16.7% (n = 1)	33.3% (n = 2)
Flyer (n = 12)	0% (n = 0)	8.3% (n = 1)	0% (n = 0)	8.3% (n = 1)
All (n = 28)	0% (n = 0)	7.1% (n = 2)	3.6% (n = 1)	21.4% (n = 6)

BMI = body mass index, %BF = percent body fat, BIA = bioelectrical impedance analysis, ADP = air-displacement plethysmography, UWW = underwater weighing, * p < .001 compared to UWW. [a] Classification of health risk based on low BMI is based on National Institutes of Health standards (i.e., underweight = BMI < 18.5 kg/m²) (10). [b] Classification of health risk based on low %BF is based on American College of Sports Medicine standards (i.e., very lean = %BF < 15.0% in females) (1).

The primary hypotheses were related to comparison of methods for assessing body composition. The hypothesis that BIA and ADP would overestimate %BF in flyers compared to UWW was confirmed. In addition to this, %BF by BIA and ADP was significantly higher than UWW overall, not just in flyers. This varied from the hypothesis that %BF by BIA and ADP would be similar for back-spots and bases when compared to UWW. These outcomes align with a previous study that found BIA and ADP may overestimate %BF in lean female track-and-field athletes compared to UWW (3). This appears consistent since female cheerleaders exhibit lean, muscular physiques similar to those of female track-and-field athletes.

The secondary hypotheses were related to health risks of cheerleaders, related to low %BF. The hypothesis that BMI would not be related to %BF by any of the body composition methods was accurate. Interestingly, no participants were classified as underweight based on BMI, whereas 3.6-21.4% of all participants and 0-30.0%, 16.7-33.3%, 0-8.3% of bases, back-spots, and flyers, respectively, were classified as possessing very lean (risky low) levels of body fat based on %BF by BIA, ADP, and UWW (despite being in the "normal weight" range of BMI classifications, see Table 3). No cheerleaders of any position were categorized as overweight/obese by BMI. This suggests that BMI should not be used to assess weight status in female cheerleaders. Further, advising an athlete in the very lean (risky low) %BF category to lose weight is unlikely to improve performance and could possibly lead to disordered eating with increased risk of complications, such as amenorrhea (14). This may be particularly

relevant for the back-spots, who were deceptively lean in this investigation (i.e., classified as normal weight by BMI with up to one-third identified as having very lean %BF).

The lack of statistical power to conduct analyses in male cheerleaders was a limitation. While the sample size of 28 female cheerleaders, is small, this study was adequately powered and is consistent in size with body composition studies in other collegiate athletic populations (e.g., 30 female track-and-field athletes (3), 66 male wrestlers (15), 69 male football players (5)). Another limitation is the potential influence of hydration status on BIA results (7). Although participants were provided instructions to abstain from exercise, eating, and drinking anything (other than water) for the 3 hours prior to testing and void their bladder upon arrival to the laboratory, hydration assessments did not occur prior to measurements.

This is the first investigation comparing methods for assessing body composition in collegiate cheerleaders. Results suggest that BIA and ADP overestimate %BF in lean female cheerleaders when compared to %BF by UWW, which may cause athletes to partake in unnecessary weight loss practices. Also, BMI did not correlate with %BF in this group, aligning with previous investigations recommending that although BMI may be an appropriate assessment tool for the general population, it should not be used to predict adiposity in lean athletes (11). In addition, BMI should not be used as an indicator for health risk, as cheerleaders with very lean (risky low) %BF were not identified as at risk due to low weight.

The findings of this study add to the growing body of evidence concerning body composition testing and its importance in the assessment of athletes. This work indicates that BIA and ADP are comparable to UWW (the "gold standard" of assessing body composition), since all methods were highly correlated. However, caution is warranted when interpreting BIA and ADP results in individuals with very low %BF, as measurements could overestimate %BF and underestimate health risk. Further, BMI is not a valid tool in this population of lean female athletes due to under-classification of health risk.

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