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ESTIMATION OF BODY FAT IN FEMALE COLLEGIATE DANCERS VIA BMI-BASED EQUATIONS AND AIR DISPLACEMENT PLETHYSMOGRAPHY

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ABSTRACT
This study was conducted to evaluate the efficacy of three body mass index (BMI) based equations (BEQ) used to estimate body-fat percentage (BF%) in female-collegiate dancers in relation to air-displacement plethysmography (AP). **Methods:** Data from 28 collegiate dancers were assessed for this study. Body mass and height were measured to calculate BMI. Three BEQ to estimate BF% [Jackson et al. (J_{BMI}), Deurenberg et al. (D_{BMI}), and Womersley & Durnin (W_{BMI})] were compared to BF% estimated via AP. **Results:** The following estimates of BF% were produced: AP = 24.6 ± 4.7%; J_{BMI} = 21.9 ± 4.0%; D_{BMI} = 23.8 ± 2.2%; and W_{BMI} = 24.7 ± 2.5%. There were no differences ($p > 0.05$) for the BF% estimations between AP, D_{BMI}, or W_{BMI}. However, BF% estimated via J_{BMI} was lower than AP ($p = 0.04$), D_{BMI} ($p < 0.001$), and W_{BMI} ($p < 0.001$). Only moderate correlations were found between AP and BEQ (J_{BMI}, r = 0.43; D_{BMI}, r = 0.44; W_{BMI}, r = 0.43). The limits of agreement (constant error ± 1.96 SD) for each BEQ compared to AP were: J_{BMI} = -2.6 ± 9.1%; D_{BMI} = -0.8 ± 8.1%; and W_{BMI} = 0.2 ± 8.2%. **Conclusions:** Two BEQ produced similar group means to AP. However, all BEQ had a wide range of individual differences when compared to AP. An accurate, inexpensive, and practically feasible method of assessing body composition is valuable for sport practitioners. The results of this study demonstrate that D_{BMI} and W_{BMI} may be acceptable in a field setting for estimating BF% for a large group of female collegiate dancers. However, due to the large range of differences, none of the BMI-based equations should be utilized to predict BF% for individuals. It is suggested that other field methods of predicting BF% be used in female collegiate dancers due to individual error of BEQs and potential harm in providing misinformation.

Keywords: air-displacement, body mass index, percent fat, dancers

INTRODUCTION

Sport practitioners and coaches assess a multitude of performance- and fitness-related outcomes in athletes. The assessment of body composition is an important component of physical fitness to monitor as it has been shown to influence both athletic performance and health (1-5). Excessively-low body fat percentage (BF%) in women is associated with many detrimental health conditions including disordered eating, low bone mineral density, and amenorrhea, known collectively as the female athlete triad (6, 7). More recently, the term relative energy deficiency in sport (RED-S) is often used to represent a low-energy status model within which physically active women and men experience similar symptoms (8). These issues are more common in sports like dance and gymnastics, where aesthetics are traditionally an aspect of the culture (7, 9, 10). It has been noted that dancers' sense of body image may be distorted (9, 11) despite a low BF% (11). Furthermore, in an attempt to aesthetically conform, some female dancers are known to achieve these physical goals by engaging in behaviors that could negatively impact ones' health (12). Thus, regular BF% monitoring in female dancers is of value, to assure that adequate BF% is being maintained for both performance goals and overall health of the athlete. However, particular focus should be placed on accurate means of BF% assessment, as misclassifying individuals in sensitive populations could negatively impact the psychological well-being of the individual.

Multiple methods of body composition exist, including: dual energy x-ray absorptiometry (DXA), hydrostatic weighing (HW), air-displacement plethysmography (AP), bioelectrical impedance analysis (BIA), and skinfold assessment (SKF), among others (1). Each of these noted techniques have unique advantages and disadvantages. DXA, HW, and AP are valid with high levels of reliability; however, laboratory measures are expensive, require trained technicians, can be difficult to access, require extensive time per test, and are not portable (13, 14). Typically, field-based methods (BIA and SKF) are more cost-effective, user-friendly, and practical for coaches and sport practitioners. However, field-based methods have several limitations. For example, the most inexpensive and portable variations of BIA tools have been shown to underestimate BF% and overestimate fat-free mass (FFM) in college female athletes (15). Further, body composition estimates via BIA can be influenced by small changes in hydration status and fluid balance. As a result, controlling for hydration is a necessity with BIA, but is often ignored in practical settings (15, 16). SKF has produced accurate results relative to laboratory methods (14). However, SKF requires a technician to be trained and have considerable experience to obtain the most valid result (1, 17). Furthermore, previous research has demonstrated potential issues with inter-tester reliability of the SKF (18). This potential issue could result in validity and reliability issues if an unskilled, or more than one, technician performs the assessment.

BMI is a common and readily available metric that is related to body composition. BMI is inexpensive, time efficient, and easy to conduct as the method only requires the measurement of height and weight. BMI is highly correlated to BF% in the general population (19) and a poor BMI (i.e., underweight, overweight, or obese) is associated with many negative health outcomes (1). However, BMI does not differentiate between fat mass and fat-free mass (FFM). Athletes and physically-active individuals typically have a lower BF% and more FFM when compared to the general population. As a result, BMI alone often misclassifies athletic body types as overweight or obese when the BF% is actually of an appropriate range (20, 21). Due to the limitations of BMI, multiple regression equations have been developed to utilize BMI to estimate BF% (22-24). Recent research has demonstrated that these BMI-based equations (BEQ) produce similar group mean estimations of BF% when compared to laboratory methods in both the general population and some athletic populations (25-27). However, many of the studies evaluating BEQ have noted large variations in individual BF% estimation when compared to more advanced body composition techniques (25, 27, 28). Currently, no research has been published evaluating any BEQ in female-collegiate dancers. Therefore, the purpose of this study was to assess the value of using BEQ to estimate BF% against AP in female-collegiate dancers.

METHODS

Participants

This study utilized data from 28 female collegiate dancers (age = 20 ± 1 yr, height = 164.6 ± 2.4 cm, body mass = 55.7 ± 5.2 kg, BMI = 20.6 ± 1.8 $kg \cdot m^{-2}$). This study was approved by the Institutional Review Board.

Procedures

The comparison of the three previously developed BEQ [Jackson et al. (J_{BMI}) (23), Deurenberg et al. (D_{BMI}) (22), and Womersley & Durnin (W_{BMI}) (24)] with AP was accomplished via data from a de-identified database. For the purposes of this study, height, body mass, BF% via AP, and age were the only obtained data from this database. BMI was subsequently calculated and BF% estimates were derived using the BMI in each BEQ. See Table 1 for the equations. BF% estimates determined from each BEQ were then compared to the BF% estimates assessed via AP.

Table 1. BMI-based BF% regression equations.

Abbreviation	Equation
J_{BMI}	$(4.35 \times BMI) - (0.05 \times BMI^2) - 46.24$
D_{BMI}	$(1.20 \times BMI) + (0.23 \times age) - 5.4$
W_{BMI}	$(1.37 \times BMI) - 3.47$

Participants were instructed to abstain from exercise for at least 3 hours and refrain from eating or drinking for at least 2 hours prior to testing, in accordance with standard AP protocols. A stadiometer (Detecto, Webb City, MO) was used to assess barefoot height to the nearest 0.1 cm. The BOD POD (Model 2000A; Life Measurement Instruments, Concord, CA) electronic scale was used to assess body mass to the nearest 0.02 kg. The scale was calibrated to manufacturer guidelines prior to testing. Participants' body mass was assessed using BOD POD manufacturer directions (barefoot, wearing tight-fitting spandex clothing). BMI was calculated as mass (kg) divided by height-squared (m^2). All BMI values were rounded to the nearest 0.1 $kg \cdot m^{-2}$.

A calibrated BOD POD was used to assess body composition via AP. Prior to each testing session, all BOD POD calibration procedures were completed according to the manufacturer guidelines by measuring an empty chamber and a calibrating cylinder of a standard volume (49.55 L). Researchers only proceeded with body composition assessment after successful calibration. Per BOD POD instructions, participants wore a tight-fitting spandex sports bra, spandex shorts, removed all jewelry, and were provided a swim cap to wear over their head to minimize the effect of hair on body volume assessment. A trained technician performed all BOD POD assessments.

For body volume assessment, participants sat erect in the BOD POD with hands folded in their laps. Two tests were performed to ensure reliability of the assessment, as directed by the manufacturer. Each of the two original tests were required to be within 150 mL of each other. If the two original tests were not within the stated range, two additional tests were performed to achieve reliable data. This method of assessment is recommended by the manufacturer. These methods have been shown to have a high test to test reliability for assessment of body mass (r = 1.0), BF% (r = 0.997), and FFM (r = 1.0) via the BOD POD (29). The BOD POD software predicted the following in all participants: thoracic gas volume, FFM, fat mass, and BF%.

Data Analyses

All data were analyzed using SPSS version 25.0 (IBM, Somers, NY, USA). Group mean BF% differences between AP and the three BEQ were determined via a repeated measures analysis of variance (ANOVA) using an alpha level of 0.05. A Bonferonni post-hoc analysis was used as a follow-up procedure to further evaluate group mean BF% differences by accounting for significant interactions. The 95% limits of agreement were calculated between AP and the three BEQ via the Bland-Altman method (30). Additionally, Pearson product-moment correlation coefficients and constant error were determined to evaluate the relationship between AP and each of the three BEQ.

RESULTS

BF%, r-values, constant error, and 95% limits of agreement comparative statistics between AP and the BEQ can be seen in Table 2. The repeated measures ANOVA and follow-up post hoc analysis demonstrated that the only BF% value that differed from AP was J_{BMI} (p = 0.04). Further, J_{BMI} was lower than both D_{BMI} and W_{BMI} (p < 0.001). Moderate, positive correlations (identified as an r = 0.4-0.69) (31) were determined between AP and each BEQ (J_{BMI}, r = 0.43; D_{BMI}, r = 0.44; W_{BMI}, r = 0.43). AP also had a moderate, positive correlation with BMI (r = 0.43). Figures 1-3 depict Bland-Altman plots assessing the individual differences between AP and each BEQ.

Table 2. BMI-based equations compared to AP (n = 28) (mean ± SD).

Method	Body Fat %	r	CE ± 1.96 SD
AP	24.6 ± 4.6	-	-
J_{BMI}	21.9 ± 4.0*	0.43	-2.6 ± 9.1%
D_{BMI}	23.8 ± 2.2	0.44	-0.8 ± 8.1%
W_{BMI}	24.7 ± 2.5	0.43	0.2 ± 8.2%

r = Pearson product-moment correlation coefficient with AP.
*Different from AP, (p = 0.04).

Figure 1. Bland-Altman plot demonstrating the comparison of the BF% estimated by J_{BMI} and AP. The solid middle line indicates mean difference (-2.6%) between BF% estimated by J_{BMI} and BF% determined by AP. The outer dashed lines denotes ± 1.96 SD of the mean difference [upper (6.4%) and lower limits (-11.7%) of agreement]. The dashed middle line represents the trend between the difference of the BF% methods and their mean.

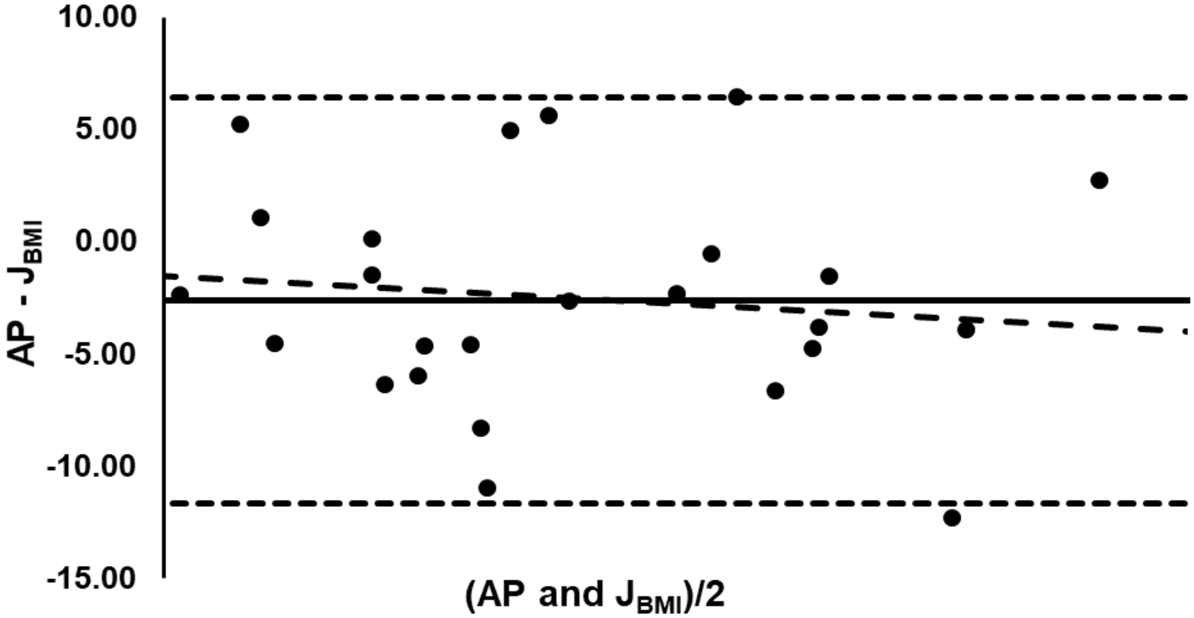


Figure 2. Bland-Altman plot demonstrating the comparison of the BF% estimated by D_{BMI} and AP. The solid middle line indicates mean difference (-0.8%) between BF% estimated by D_{BMI} and BF% determined by AP. The outer dashed lines denotes ± 1.96 SD of the mean difference [upper (7.3%) and lower limits (-8.9%) of agreement]. The dashed middle line represents the trend between the difference of the BF% methods and their mean.

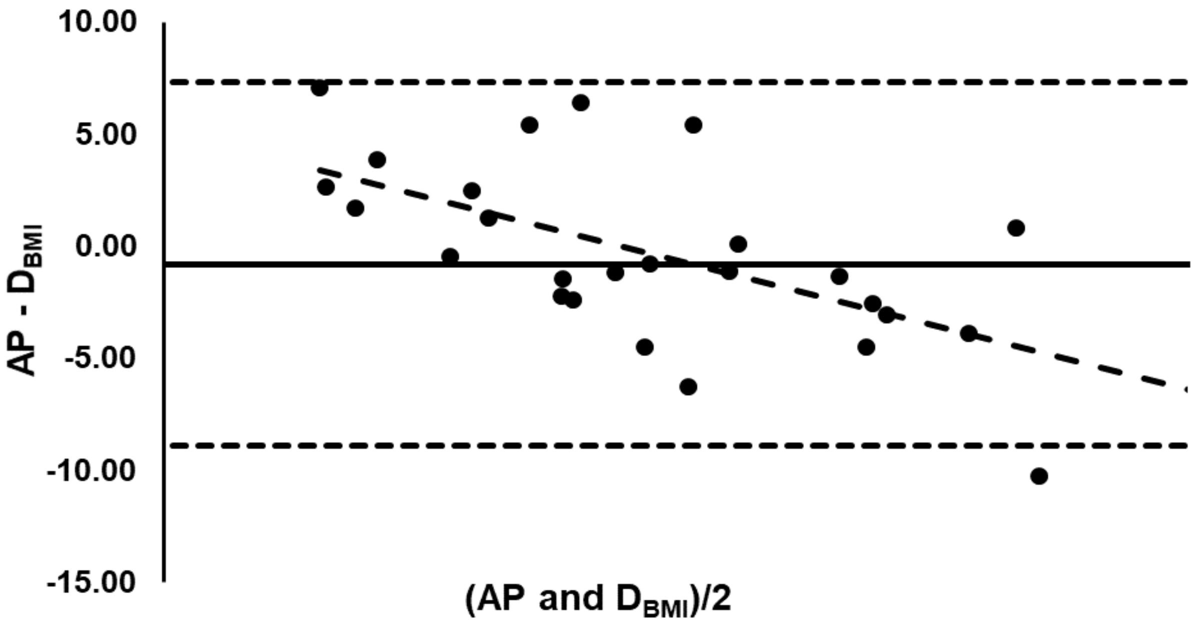
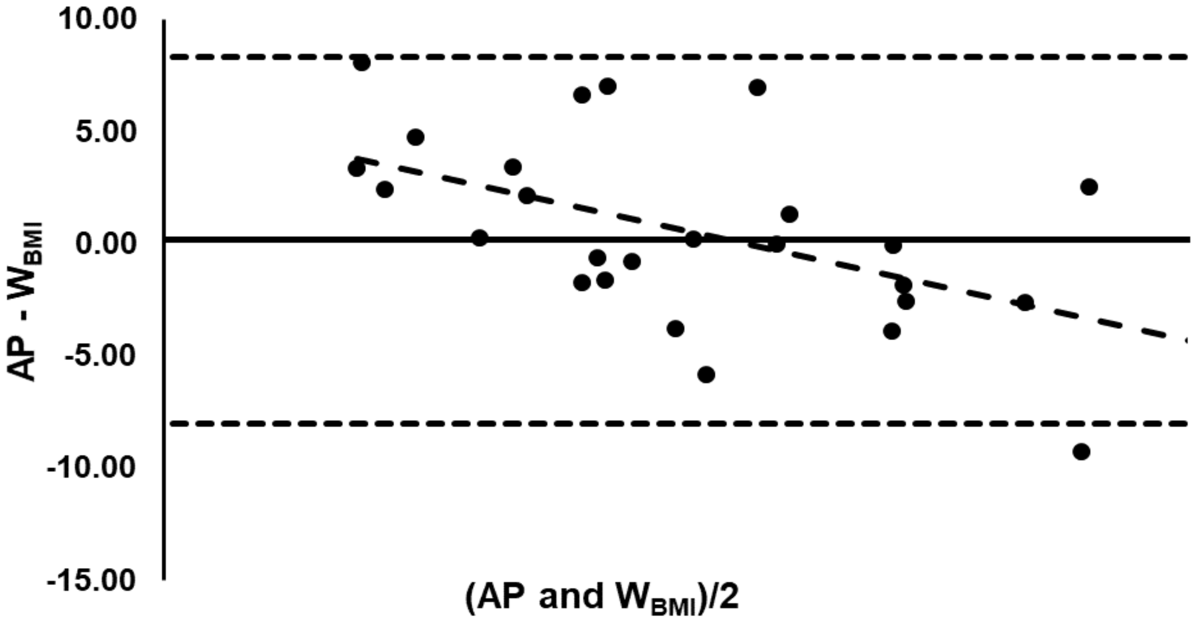


Figure 3. Bland-Altman plot demonstrating the comparison of the BF% estimated by W_{BMI} and AP. The solid middle line indicates mean difference (0.2%) between BF% estimated by W_{BMI} and BF% determined by AP. The outer dashed lines denotes ± 1.96 SD of the mean difference [upper (8.3%) and lower limits (-8.0%) of agreement]. The dashed middle line represents the trend between the difference of the BF% methods and their mean.



DISCUSSION

Coaches and sport-related practitioners need quality body composition assessment methods that are inexpensive and easy to administer. There are data that demonstrate the prevalence of normal-weight obesity could be much higher in this population analysis based on BMI alone (5). BEQs may be an attractive means of body composition assessment in the sport setting as they are non-invasive procedures, only requiring height and weight to calculate BMI. Previous evidence suggests that BEQs provide a reasonable estimation of BF% in the general population (22-24). However, recent publications in female athletic populations have demonstrated that, while BEQ may provide acceptable group mean BF% estimations, they often present large limits of agreement when compared to more advanced body composition techniques (27, 28).

The results of the current study demonstrated that D_{BMI} and W_{BMI} provided group mean BF% estimates that did not statistically differ from that of AP (Table 2). However, J_{BMI} did produce statistically lower BF% estimates than AP (Table 2). These results are similar to those found by Esco et al. (2011), whom determined that W_{BMI} and J_{BMI} demonstrated no statistically significant different mean BF% values when compared to DXA in a sample of female collegiate athletes from various sports (27). However, the findings do differ from previous research by Casey et al. (2019) whom showed that J_{BMI}, D_{BMI}, and W_{BMI} all produced statistically greater group mean BF% estimations when compared to AP in a sample of female collegiate gymnasts (28).

Furthermore, the current study found that all BEQs showed large limits of agreement relative to AP, which can be seen in Figures 1-3. The Bland-Altman plots depict J_{BMI} may provide BF% estimates of 11.7% below to 6.4% above AP, D_{BMI} may provide BF% estimates of 8.9% below to 7.3% above AP, and W_{BMI} may provide BF% estimates of 8.0% below to 8.3% above AP. Additionally, each plot depicts a trend that the BEQ overpredict BF% in those with lower BF% measured by AP and under-predict BF% in those with higher BF% measured by AP (seen in Figures 1-3). Further, only moderate correlation coefficients were shown between each BEQ and AP (Table 2). Lastly, AP had only a moderate correlation with BMI alone ($r = 0.43$). This further supports previous literature that suggests BMI may not be appropriate to determine body composition in athletic populations. As noted, the use of BEQ to assess individual BF% may result in gross estimation errors that can lead to individual misclassification. Therefore, it is recommended that practitioners avoid the exclusive use of BEQ in the female-collegiate dance population.

Two primary limitations to this study were that the phase of the menstrual cycle was not taken into consideration and hydration status was not measured in the participants. It is of note that all measurements were taken during a single session and, as a result, any influence of total body water or menstraul stage would have influenced body weight for all measurements. This would result in minimal impact on results. Another potential limitation is that residual volume was estimated via AP standard process as opposed to directly measuring. However, this method has been used to establish body composition descriptive values for a large sample of female-collegiate athletes (29).

CONCLUSIONS

Collegiate dance is an athletic endeavor that often includes an aesthetic focus in addition to physical performance. While body composition assessment can be valuable for both health and performance of the participants, inaccurate estimations of BF% may promote unhealthy body-image perceptions. Thus, there is a need for continued research to provide sport practioners with a quick and accurate method of assessing BF% that also has a high inter-tester reliability. While BEQs meet the desires for ease of adminstration and a high inter-tester reliability, the current study demonstrated there was a wide range of individual differences when comparing the results of each BEQ to AP. As a result, it appears that body composition methods should not heavily rely on BMI as the primary means of predicting BF% in the female-collegiate dance population. The authors discourage the use of BEQs by coaches and sport practitioners when working with this population.

Conflict of interest declaration

The authors have no conflict of interests.

Ethics

Institutional Ethics Research Committee approval was obtained for the study procedure. The study conformed to the provisions of the Declaration of Helsinki.

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