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Original Research

Body Mass Index Superior to Body Adiposity Index in Predicting Adiposity in Female Collegiate Athletes

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ABSTRACT

International Journal of Exercise Science 16(4): 1487-1498, 2023. Body mass index (BMI) is moderately correlated with %Fat and often used to assess obesity in athletes. Limited research assesses BMI as a surrogate for %Fat in female collegiate athletes. Body Adiposity Index (BAI) is an anthropometric measurement suggested to be superior to BMI at predicting adiposity but has not been well assessed within female athletic populations. This study aimed to determine if BAI is superior to other anthropometric indices to predict %Fat in female collegiate athletes and college-aged female non-athletes. Collegiate female athletes and female non-athletes were invited into the laboratory for anthropometrics and %Fat measurements via BOD POD. BAI was calculated as Hip Circumference/Height$^{1.5}$ – 18. Eighty-eight female non-athletes and 72 female athletes from soccer (n = 27), softball (n = 28), and basketball (n = 17) completed the study. Using BMI, 19% of non-athletes had a false positive (FP). Sensitivity of BMI in non-athletes was 85.5%, while specificity was 73%. 16% of athletes had a FP. Sensitivity of BMI within athletes was 100%, specificity was 81%. BMI outperformed BAI in athletic (BMI: r = .725, p < .001; BAI: r = .556, p < .001) and nonathletic (BMI: r = .650, p < .001; BAI: r = .499, p < .001) groups. The strongest anthropometric predictor of %Fat within the non-athlete population was BMI (r^2 = .42, p < .001). Waist circumference was the strongest predictor in the athletic population (r^2 = .62, p < .001). BMI outperformed BAI in its ability to predict %Fat.

KEY WORDS: BMI, BAI, measurement

INTRODUCTION

Accurate measurements of body composition are vital in athletic populations for many reasons. First, high and low, depending on the nature of the sport, body fat (%Fat) levels correlate with performance (3, 26, 30, 31, 39). Indeed, some sports have aesthetic or gravitational components, necessitating anthropometric characteristics that impact sports execution (5). Additionally, some sports have classifications according to %Fat (12). Body composition is also a significant component of athletes' nutritional regimens and training plans (43). Lastly, The International Olympic Committee (IOC) Medical Commission encourages regular body composition monitoring to ensure maintenance above mandatory levels (1, 27). Body composition assessments, considered the most accurate, require costly equipment, standardization, and laboratory settings, making these techniques challenging to utilize in routine testing. Consequently, often used in place of body composition techniques are anthropometric predictors of %Fat because they are a cheaper and more available method (4).

Body Mass Index (BMI), calculated as kg/m^2, is a widely accepted tool used to categorize obesity (32). Although BMI does correlate with %Fat in specific populations (r = 0.60 - 0.82) (41), the ability of BMI to predict %Fat is limited due to the inability to distinguish between fat and fat-free tissue. Thus, in athletic populations, BMI is highly criticized (34, 46). Indeed, those with higher fat-free mass relative to height, such as athletes, might have a high BMI regardless of adiposity (17, 22). Therefore, athletes may be miscategorized as obese when BMI is used (21, 37). For example, Mazic et al. assessed male body composition using bioelectrical impedance and compared the athlete's %Fat and BMI to non-athletes (25). BMI was significantly higher in the athletic group even though %Fat was lower among the athletes.

The ability of BMI to adequately predict %Fat in female athletes is not as well studied. Female athletes generally do not have as much lean body tissue as their male counterparts (4, 40), making it problematic to extrapolate data from male to female athletes. For instance, Ashtary-Larky found that BMI in female athletes (three years of training experience) and non-athletes strongly correlated with %Fat (r = 0.780 and r = 0.863, respectively) when measured by bioelectrical impedance (4). Other studies, however, provide conflicting evidence showing that BMI misclassified female athletes into the overfat category at an unacceptable rate (40). More research is needed to determine if BMI is acceptable to categorize female collegiate athletes into the normal fat and overfat categories.

Because of inconclusive evidence that BMI can adequately predict/categorize a female athlete's %Fat, additional anthropometric measures have been proposed. The Body Adiposity Index (BAI) was developed as a surrogate measure of adiposity and can be calculated as BAI = hip circumference / $height^{1.5}$ – 18 (7). BAI has been validated against DXA (35) and underwater weighing (9). BAI has been tested as a surrogate for body composition in athletes in a few studies. These studies, however, utilize small samples of female athletes and provide conflicting results (9, 40).

Thus, the purposes of this study were two-fold. First, to determine if BMI is acceptable to categorize female collegiate athletes and college-aged female non-athletes into the normal fat and overfat categories. Second, to determine if BAI is superior to other anthropometric indices to predict %Fat in collegiate athletes and college-aged non-athletes.

METHODS

Participants

The methodology for the study was quantitative, and the research design was cross-sectional. An apriori sample size was estimated using G*power 3.1. The sample size was estimated using Linear regression as the statistical test, α error probability set at 0.05, power at 0.80, effect size

(f^2) at 0.15, and one predictor. The estimated sample size was estimated to be n = 55. Because both athletes and non-athletes will be analyzed separately, the total sample size estimate was doubled to n = 110.
Division I female collegiate athletes from the basketball, softball, and soccer teams were asked to come to the laboratory for one visit before the start of their respective seasons. To be included in the study, the female athletes had to be active members of a collegiate team and be willing to participate in a single laboratory visit. Participants were excluded if they had an injury that forced them to not participate in their sport. All female athletes on the three teams were invited to participate in the study by their respective strength and conditioning coaches. Non-athlete female students were also invited to participate. The non-athletes were included if they were 18 - 25 years old and could come to the laboratory for a single visit. There were no exclusion criteria for the female non-athletes. The non-athlete students responded to an advertisement posted around campus about the study.

To prepare for the laboratory visit, participants were asked to fast for five hours and refrain from physical activity for 12 hours before the visit. All participants then underwent anthropometric and body composition testing. All participants were provided informed consent prior to testing. All procedures were approved by the IRB at Grand Canyon University (IRB-2022-4842) and were conducted following the declaration of Helsinki for human studies of the World Medical Association (45). In addition, this research was carried out following the ethical standards of the International Journal of Exercise Science (33).

Protocol
Body mass to the nearest 0.01 kg and stature to the nearest 0.1 cm were measured as described in the Anthropometric Standardization Reference Manual (23). Height was measured with the participant standing barefoot using a stadiometer (Tree LS-PS 500). Body weight was measured with minimal clothing using the digital scale attached to the stadiometer. Waist and hip circumference were determined while the participant was standing with a Gulick II 150 cm anthropometric tape (model 67020) and reported to the nearest 0.1 cm. Waist circumference (WC) was measured with the anthropometric tape parallel to the floor and immediately above the iliac crest, with readings taken at the end of a normal exhalation (32). Hip circumference was assessed at the level of the most substantial protrusion of the buttocks (23). The formula for BAI is described in Equation 1. Hip circumference is in cm, while height was measured in meters.

$$\text{Equation 1: BAI} = \text{Hip circumference} / \text{height}^{1.5} - 18.$$

Body composition was determined via whole-body air displacement plethysmography (BOD POD, COSMED). BOD POD has been shown to be valid when compared to underwater weighing (10). Participants were asked to wear a bathing suit or tight-fitting shorts and remove their shirt and jewelry to test. Participants were weighed again using the scale associated with the BOD POD device. Participants were then asked to place a silicone swim cap (Aegend) on their heads to cover their hair and sat in the BOD POD for two to three measurements of 50 seconds each.

Statistical Analysis
Data analysis was performed using SPSS version 28 (IBM, Chicago, IL, USA). Data are expressed as means ± SD. *P* value < .05 were considered statistically significant. All participants with missing data were removed from the analysis. An independent t-test was used to determine group differences between athletes and non-athletes. One-way ANOVA was used to determine group differences between the athletes of the three sports (soccer, softball, and basketball). Tukey post hoc test was used to determine where differences may lie.

Although there is no consensus on using %Fat criteria to define obesity or excess body fat levels (18), a widely accepted cut-off is 33% for African American and Caucasian female (2, 14). A BMI between 25-29.9 kg/m² will be considered overweight (32). Using the above BMI and %Fat cut points, participants were classified into one of four categories: 1) Overweight and overfat (a true positive (TP)), 2) overweight and normal fat (false positive (FP)), 3) normal weight and overfat (false negative (FN)), and 4) normal weight and normal fat (true negative (TN)). The percentage of each group falsely categorized as overfat (FP) was calculated. Sensitivity analysis was calculated as the proportion of overfat individuals who were identified as overweight by BMI. Specificity was calculated as the proportion of normal fat individuals who were identified as normal weight by BMI.

Pearson correlation coefficients (*r*) were used to determine the relationship between the different anthropometric variables and %Fat. Linear regression was then used to determine the percentage of variance explained by the predictor variable (anthropometric measurements) on the criterion variable (%Fat).

RESULTS

In all, 160 (*n* = 88 non-athletes, *n* = 72 collegiate athletes) female participants completed the study. Sports that were represented were soccer (*n* = 27), softball (*n* = 28), and basketball (*n* = 17). Table 1 compares participant anthropometrics, body composition, and demographic information for athletes and non-athletes. On average, the athletes were taller (168.1 ± 7.8 cm vs. 165.5 ± 7.6 cm, *p* = .037), slightly younger (19.6 ± 1.4 yr vs. 20.4 ± 1.7 yr, *p* = .002), had lower %Fat (23.6 ± 6.9 % vs. 28.0 ± 8.2 %, *p* < .001), lower BAI (26.4 ± 4.7 vs. 28.3 ± 5.0, *p* = .014) and increased lean body mass (51.2 ± 7.0 kg vs. 48.6 ± 7.2 kg, *p* = .023) compared to non-athletes.

Table 1. Descriptive data for all participants.

	Non-Athlete (*n* = 88)	Athlete (*n* = 72)	Sig.
Age (yr.)	20.4 ± 1.7	19.6 ± 1.4	0.002*
Height (cm)	165.5 ± 7.6	168.1 ± 7.8	0.037*
Weight (kg)	68.0 ± 10.6	67.8 ± 12.6	0.874
BMI (kg/m²)	24.8 ± 3.5	23.9 ± 3.3	0.096
Body fat (%)	28.0 ± 8.2	23.6 ± 6.9	< 0.001*
Waist (cm)	79.1 ± 8.8	78.3 ± 9.7	0.593
Hip (cm)	98.3 ± 8.9	96.9 ± 10.6	0.349
Waist/Hip ratio	.80 ± .07	.81 ± .06	0.693

BAI	28.3 ± 5.0	26.4 ± 4.7	0.014*
Lean mass (kg)	48.6 ± 7.2	51.2 ± 7.0	0.023*

Descriptives between groups are presented as means ± standard deviation. *Statistically significant at $p < 0.05$

Table 2 shows the three sports' anthropometric, body composition, and demographic comparisons. On average, the softball players had an increased %Fat ($p = 0.003$), increased WC ($p = 0.002$), hip circumference ($p = 0.032$), and an increased BAI ($p < 0.001$) compared to the soccer and basketball participants.

Table 2. Descriptive differences between sports.

	Soccer ($n = 27$)	Softball ($n = 28$)	Basketball ($n = 17$)	P-Value
Age (yr)	19.5 ± 1.1	19.3 ± 1.0	20.2 ± 2.0	0.126
Height (cm)	167.9 ± 5.7	166.0 ± 5.7	171.4 ± 8.1	0.078
Weight (kg)	64.4 ± 9.6	69.0 ± 14.7	70.6 ± 12.9	0.221
BMI (kg/m^2)	22.7 ± 2.3	24.9 ± 4.0	24.1 ± 3.4	0.058
Body fat (%)	22.6 ± 5.0^a	26.9 ± 7.0^b	19.9 ± 7.7^a	0.003
Waist (cm)	74.2 ± 6.3^a	83.3 ± 11.3^b	76.9 ± 8.2^{ab}	0.002
Hip (cm)	94.4 ± 8.6^a	101.2 ± 10.4^b	93.8 ± 12.2^a	0.032
Waist/Hip ratio	.79 ± .07	.82 ± .05	.81 ± .07	0.14
BAI	25.4 ± 4.5^a	29.2 ± 3.7^b	23.8 ± 4.6^a	<.001
Lean mass (kg)	49.6 ± 6.5^a	49.7 ± 6.4^a	55.9 ± 6.8^b	0.004

P-value represents overall group difference. $p < 0.05$ is considered statistically significant. Different letters denote significant group differences.

Figure 1 shows that within the non-athlete population, roughly 19% ($n = 17$) were within the FP category. Approximately 4.5% ($n = 4$) were categorized into the FN category. All non-athlete participants with a BMI > 30 kg/m^2 were found to be overfat (body fat > 33%). The sensitivity of BMI in the non-athletes was 85.5%, while specificity was 73%.

Figure 2 shows that 16% ($n = 12$) of the athletes were categorized as an FP. None of the athletes were categorized as an FN. Roughly 3% ($n = 2$) of the female athletes had a BMI > 30 kg/m^2 but were found to be normal fat (body fat % < 33). The sensitivity of BMI within the athletes was 100%, while specificity was 81%. Four soccer, three softball, and five basketball participants were categorized into the FP category.

Table 3 details correlations between the different anthropometric predictors and %Fat. The anthropometric measure that was the strongest predictor of %Fat within the non-athlete population was BMI ($r^2 = 0.42$, $p < 0.001$). While WC was the strongest predictor in the athletic population ($r^2 = 0.62$, $p < 0.001$). WC was the strongest predictor of %Fat within the soccer ($r^2 = 0.699$, $p < 0.001$) and softball ($r^2 = 0.889$, $p < 0.001$) participants, while weight was the strongest predictor in the basketball participants ($r^2 = 0.692$, $p < 0.001$).

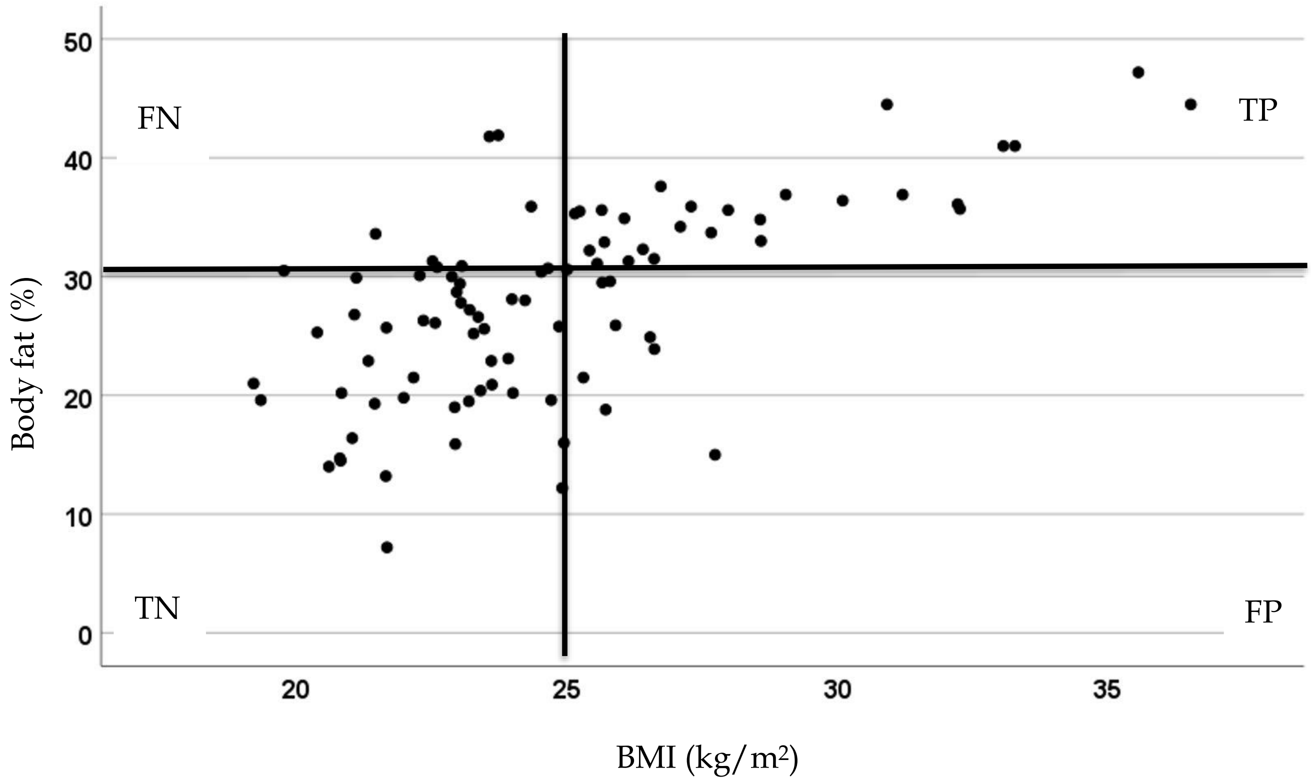

Figure 1. Scatterplot of BMI and %Fat for non-athlete females. The four quadrants are labeled FN (false negative), TP (true positive), TN (true negative), and FP (false positive).

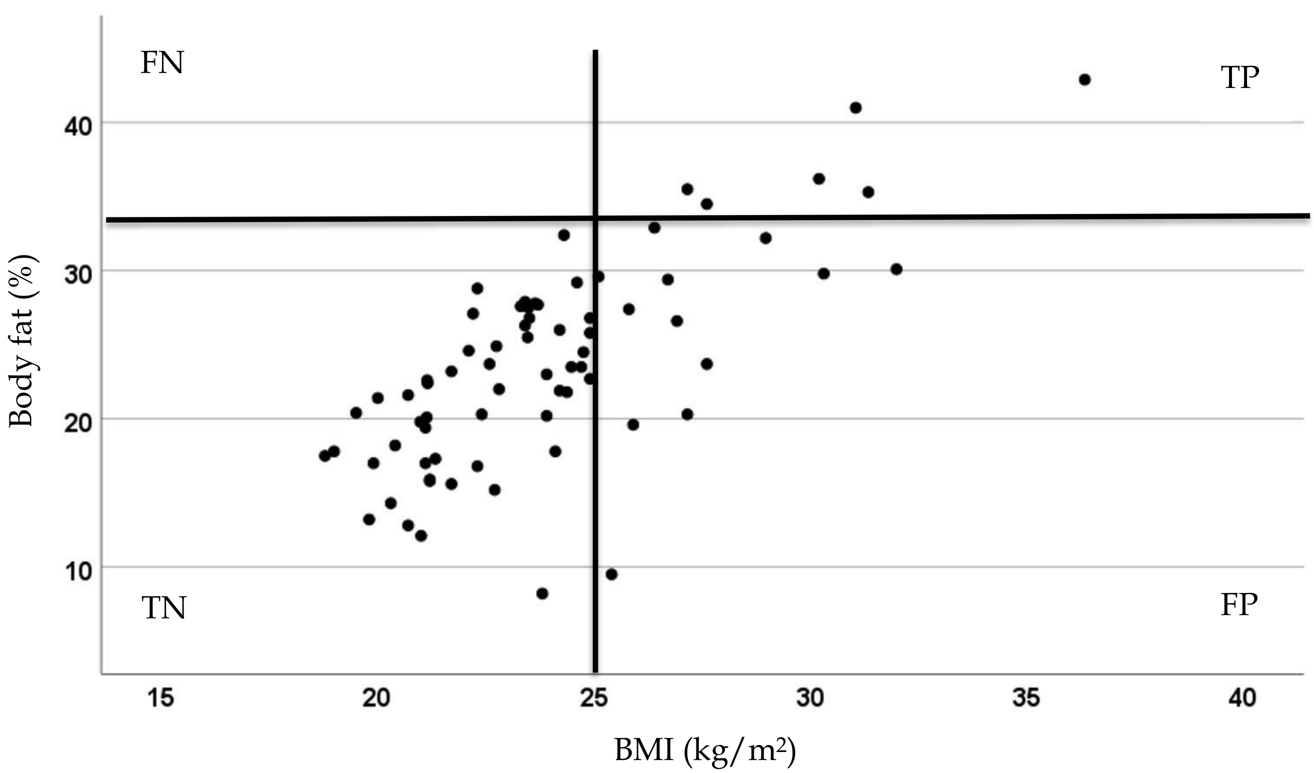

Figure 2. Scatterplot of BMI and %Fat for female athletes. The four quadrants are labeled FN (false negative), TP (true positive), TN (true negative), and FP (false positive).

Table 3. Correlations between anthropometric measures and %fat.

	Non-athlete (n = 88)	Athletes (n = 72)	Soccer (n = 27)	Softball (n = 28)	Basketball (n =17)
Height (cm)	0.257*	0.063	0.030	0.321	0.339
Weight (kg)	0.434**	0.616**	0.461*	0.797**	0.692**
Waist (cm)	0.589**	0.788**	0.699**	0.889**	0.683**
Hip (cm)	0.408**	0.614**	0.432*	0.848**	0.323
Waist/Hip ratio	0.295**	0.404**	0.241	0.587*	0.417
BMI (kg/m²)	0.650**	0.725**	0.677**	0.869**	0.633**
BAI	0.499**	0.556**	0.369	0.836**	0.141
Lean body mass (kg)	0.368**	0.086	0.049	0.464*	0.132

*statistically significant at $p < 0.05$. **statistically significant at $p < 0.001$.

DISCUSSION

The present study analyzed female collegiate athletes and non-athletes to determine if BMI is acceptable to categorize into the normal fat and overfat categories and to determine if BAI is superior to other anthropometric indices to predict %Fat. The first main finding of the study was that BMI accurately categorized female athletes more than female non-athletes. Indeed, the FP of athletes was 16%, while the FP of the non-athletes was 19%. Additionally, the current study showed that BMI had a higher sensitivity and specificity within the athletic group than the non-athletic females. Ode et al. (37) looked at the ability of BMI to categorize female athletes as overfat and found the FP rate to be much higher than the current study (31%). They also reported a sensitivity of 100% and specificity of 66% in their female athletes. The decreased number of FP's and higher specificity in the current study may be due to the different sports included in the analysis. Although Ode et al. also included a sample from basketball and softball, most female athletes were from crew teams, while the current study included a soccer sample.

The current study found no statistical group differences (athletes vs. non-athletes) in BMI but a significant difference in %Fat of about 4.4%. This finding of a similar BMI between groups differs from past literature that has found athletes have higher BMIs than their non-athlete counterparts. For example, Kruschitz et al. (22) compared a small group of female athletes and non-athletes and found statistically higher BMIs in the athletes despite lower body fat percentages. It is worth noting that the sample size in that study was much smaller than the current study (n = 21 for athletes, n = 21 for non-athletes), and the athletes were only from swimming and triathlon. Our larger sample size and the different sports included in the analysis may be the reason for divergent findings.

Past research has found that increased muscle mass's influence on athletes' BMI misclassifies these individuals as overweight or obese (38). Our study suggests this also holds when looking at specific sports within the athletic population. For instance, the average lean mass in the basketball athletes was roughly 6.6 kg more than in the other two sports, and the number of FP was also the highest in this group.

Our second main finding was that BMI was the strongest anthropometric predictor of body fat percentage in the non-athletic group, explaining 42% of the variance. While BMI had a higher predictive value in the athletes (r^2 = .525) than the non-athletes, waist circumference was the strongest anthropometric predictor in the athletes explaining 62% of the variance. Our finding that WC was a better predictor of %Fat in female athletes seems to disagree with past literature that suggests BMI may be one of the more accurate anthropometric predictors of %Fat in non-athletic and athletic females (4, 15, 28, 37). For example, in a sample of male and female (n = 341, 40% female), it was found that BMI was a stronger predictor of %Fat, measured via magnetic resonance imaging (MRI), than WC (19). NHANES 1999-2004 data found that WC had a higher correlation with %Fat than BMI in men but not female (11). Lastly, in a sample of athletic and non-athletic female, BMI was shown to be superior to weight, waist-to-hip ratio, waist-to-height ratio, and body surface area in predicting %Fat (4). Because the correlation between BMI and %Fat in our study (r = .650 in the non-athletes, r = .725 in the athletes) is comparable to prior research (37, 41), these conflicting results are more than likely due to the specific sports selected to be analyzed in each study.

The current study included BAI, which most prior research did not. BAI was inferior to BMI in predicting %Fat in athletes and non-athletes. Using a four-compartment model to determine %Fat, Fedewa et al. (9) looked at BAI as a surrogate for %Fat in *non-athletic* young adults and found that BAI was a stronger predictor than BMI in the entire set. However, when looking at young female, BAI was no better than BMI. Previous literature looking at non-athletic populations has also found that when both sexes are included, BAI is superior to BMI at predicting %Fat (13, 20, 42). When stratifying by sex, however, BAI is not as accurate a predictor of %Fat as BMI. Additionally, the current study corroborates past findings that BAI does not do as well as BMI in athletic populations (8, 40). The current study builds upon these past studies by analyzing a larger sample size and including additional sports in the analysis.

The current study does have limitations. Divergent cut-points for categorizing overweight and overfat have been used. For example, Wellens et al. (44) analyzed the accuracy of BMI as a measure of %Fat in a large sample of Caucasian non-athlete female. They used 33% as the cut-off to determine overfat, similar to our study, but a BMI of 26 kg/m^2 to categorize as overweight. They reported a sensitivity of 52% and perfect specificity. These sensitivity and specificity values differ from our non-athlete females and could be due to the different BMI cut points selected. Additionally, there is no consensus on what %Fat level should be used to define overfat in females. For example, Heo et al. suggested that 35-37% should be considered overfat in female (16). An additional limitation in the current study was using a two-compartment model to measure %Fat. Nevertheless, previous research has shown that BOD POD is a valid measure of %Fat compared to DEXA (36). Within female athletes specifically, the BOD POD only has shown a 0.5% difference between DEXA (6). Also, the %Fat values for basketball (~20%) (37), softball (~27%) (37), and soccer (~22%) (29) players in the current study are similar to what has been reported in prior literature. Lastly, the non-athletes physical activity and fitness levels were not measured, making it hard to determine if our non-athletes represent a sedentary or active population.

Due to different methodological approaches, it is challenging to compare the current study adequately to past research. For example, prior studies in this area have used skinfold measurements (22), bioelectrical impedance (3, 25), DEXA (9), and underwater weighing (40) to determine %Fat. Additionally, different sports have been included in the various analyses, such as basketball, crew, and softball (37), swimmers and triathletes (22), handball, judo, karate, taekwondo, swimming, basketball, tennis (40), and "identified as having three years of training" (3). Divergent findings undoubtedly may come when measuring athletes in different sports, as fatness is strongly influenced by sport (24).

In conclusion, BMI more accurately classified female athletes than non-athletes in the correct %Fat categories. BMI was also superior to BAI in predicting %Fat in both athletes and non-athletes. Although WC was a superior predictor of %Fat in athletes, BMI was still a better predictor of %fat in the athletes than in non-athletes. Even though BMI did reasonably well in predicting %Fat in both groups, roughly 48-58% of the variance is left unexplained by BMI. Depending on the level of athletics, this may be unacceptable. Whether or not anthropometrics should be used as a surrogate for %Fat comes down to the error a coach, trainer, or dietitian is willing to accept. If a coach determines that body composition is crucial to athletic success, %Fat should be measured instead of using anthropometrics as a surrogate.

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